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Faris et al.

(54) METAL-AIR FUEL CELL BATTERY SYSTEMS HAVING A METAL-FUEL CARD STORAGE CASSETTE, INSERTABLE WITHIN A PORT IN A SYSTEM HOUSING, CONTAINING A SUPPLY OF SUBSTANTIALLY PLANAR DISCRETE METAL-FUEL CARDS, AND FUEL CARD TRANSPORT MECHANISMS THEREIN

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Elmsford, NY 10523 (US)

(21) Appl. No.: **10/281,910**

(22) Filed: **Oct. 28, 2002**

Related U.S. Application Data

(60) Division of application No. 09/074,337, filed on May 7, 1998, now Pat. No. 6,472,093, which is a continuation-in-part of application No. 08/944,507, filed on Oct. 6, 1997, now Pat. No. 6,296,960.

Publication Classification

(51) Int. Cl.[7] **H01M 8/04**; H01M 12/06; H01M 4/00

(52) U.S. Cl. **429/22**; 429/27; 429/61; 429/68

(57) **ABSTRACT**

Disclosed are various types of metal-air FCB-based systems comprising a Metal-Fuel Transport Subsystem, a Metal-Fuel Discharging Subsystem, and a Metal-Fuel Recharging Subsystem. The function of the Metal-Fuel Transport Subsystem is to transport metal-fuel material, in the form of tape, cards, sheets, cylinders and the like, to the Metal-Fuel Discharge Subsystem, or the Metal-Fuel Recharge Subsystem, depending on the mode of the system selected. When transported to or through the Metal-Fuel Discharge Subsystem, the metal-fuel is discharged by (i.e. electro-chemically reaction with) one or more discharging heads in order produce electrical power across an electrical load connected to the subsystem while H_2O and O_2 are consumed at the cathode-electrolyte interface during the electrochemical reaction. When transported to or through the Metal-Fuel Recharging Subsystem, discharged metal-fuel is recharged by one or more recharging heads in order to convert the oxidized metal-fuel material into its source metal material suitable for reuse in power discharging operations, while O_2 is released at the cathode-electrolyte interface during the electrochemical reaction. In the illustrative embodiments, various forms of metal fuel can be discharged and recharged in an efficient manner to satisfy a broad range of electrical loading conditions.

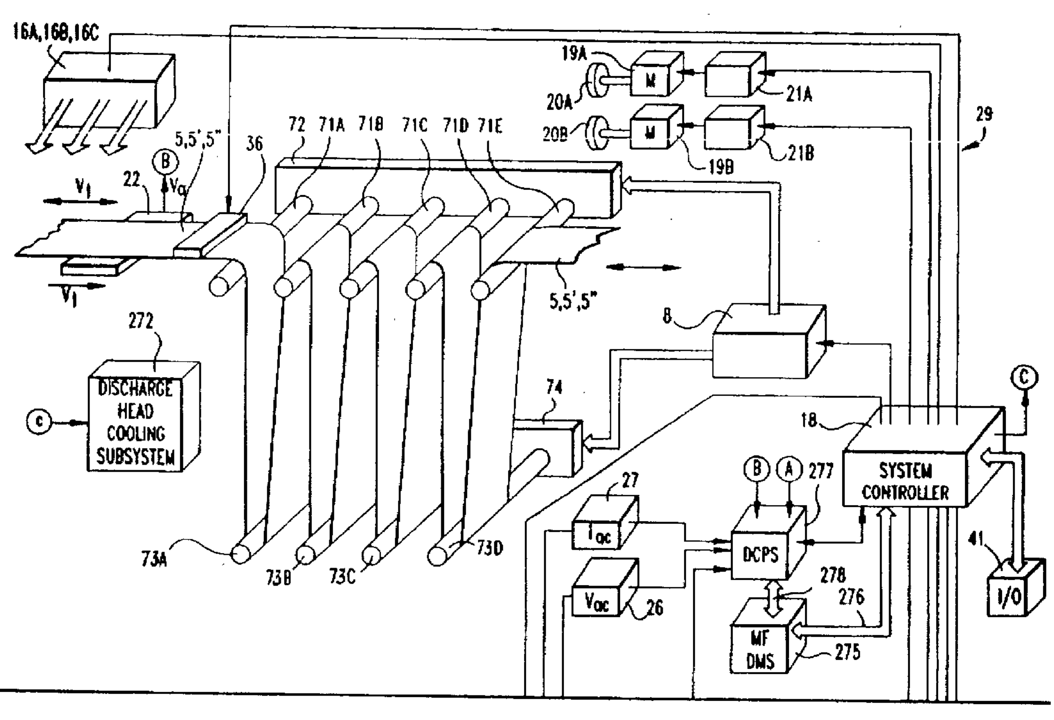


FIG.1

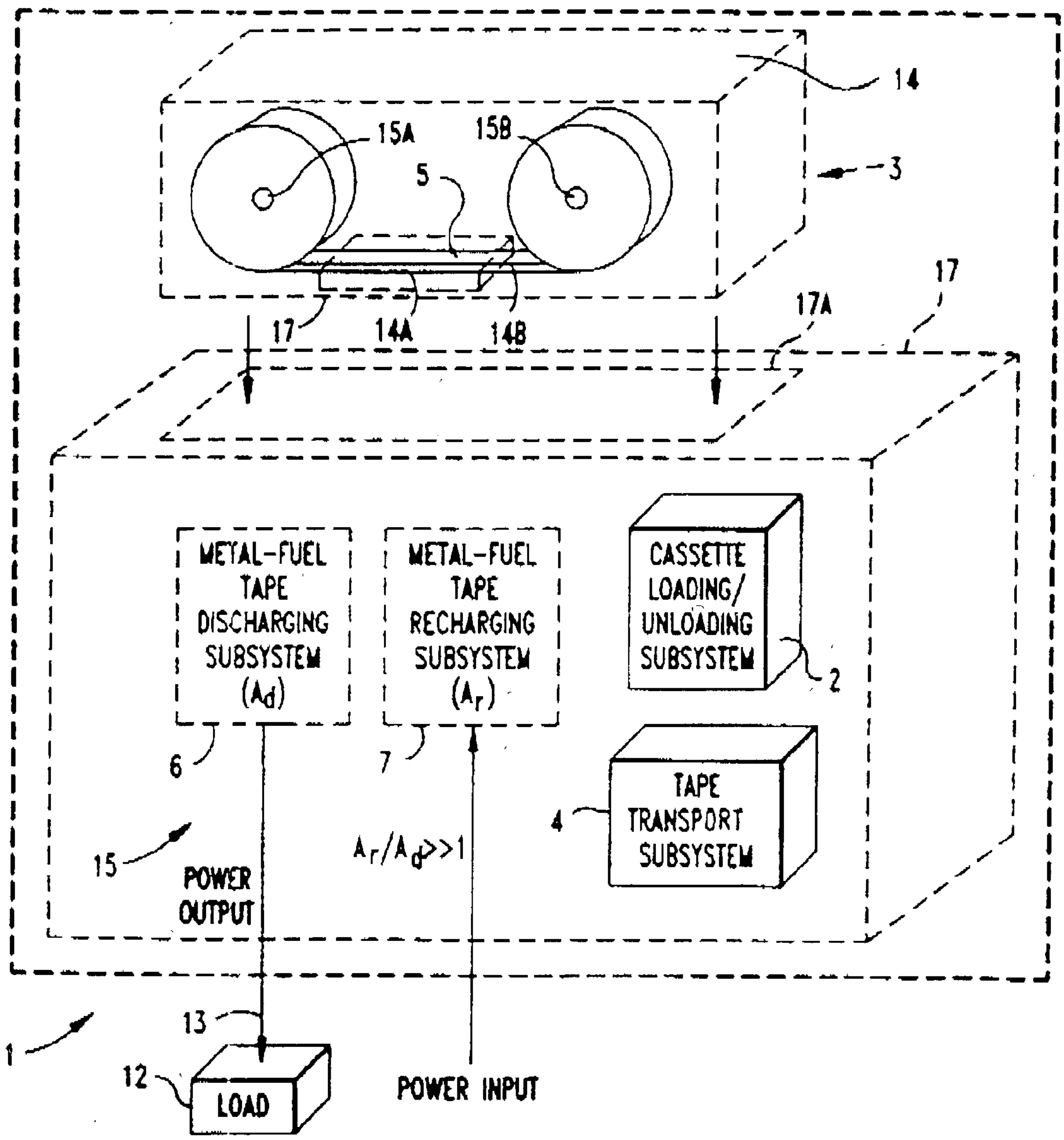

14
15A
15B
5
3
17
17A
17
14A
14B
METAL-FUEL TAPE DISCHARGING SUBSYSTEM (A_d)
METAL-FUEL TAPE RECHARGING SUBSYSTEM (A_r)
CASSETTE LOADING/ UNLOADING SUBSYSTEM
2
6
7
TAPE TRANSPORT SUBSYSTEM
4
15
POWER OUTPUT
$A_r/A_d >> 1$
13
1
12
LOAD
POWER INPUT

FIG.2A1

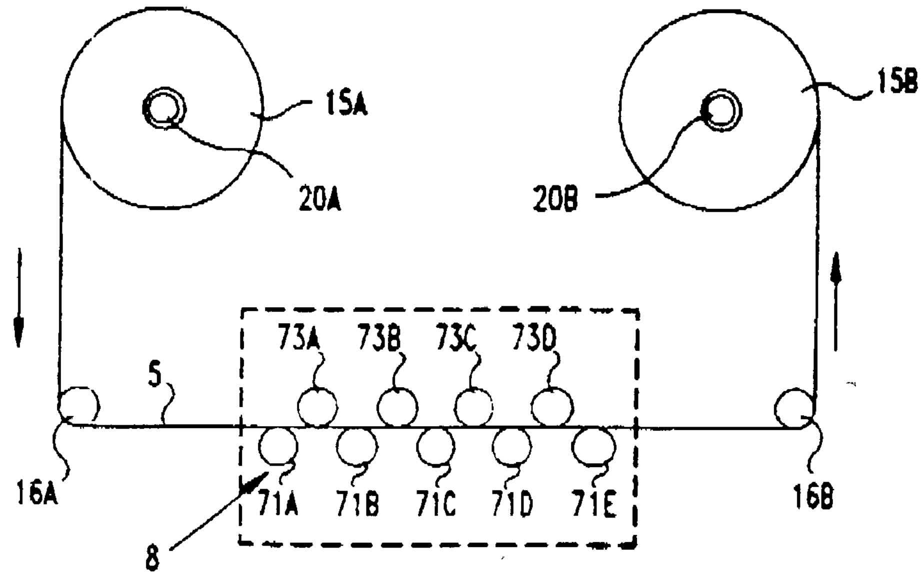
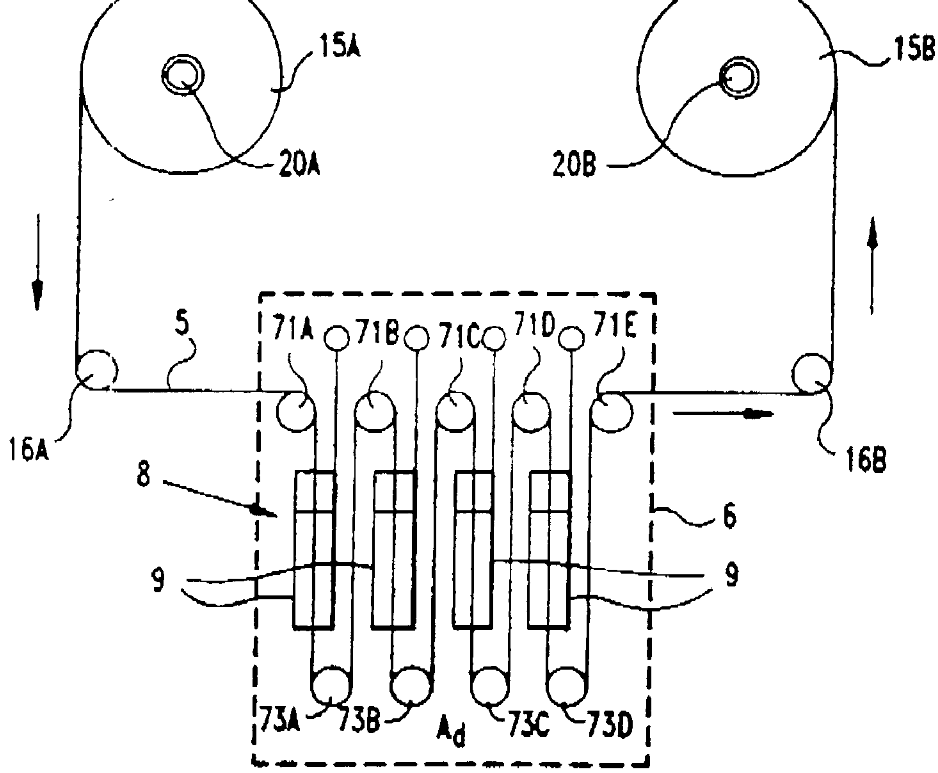


FIG.2A2



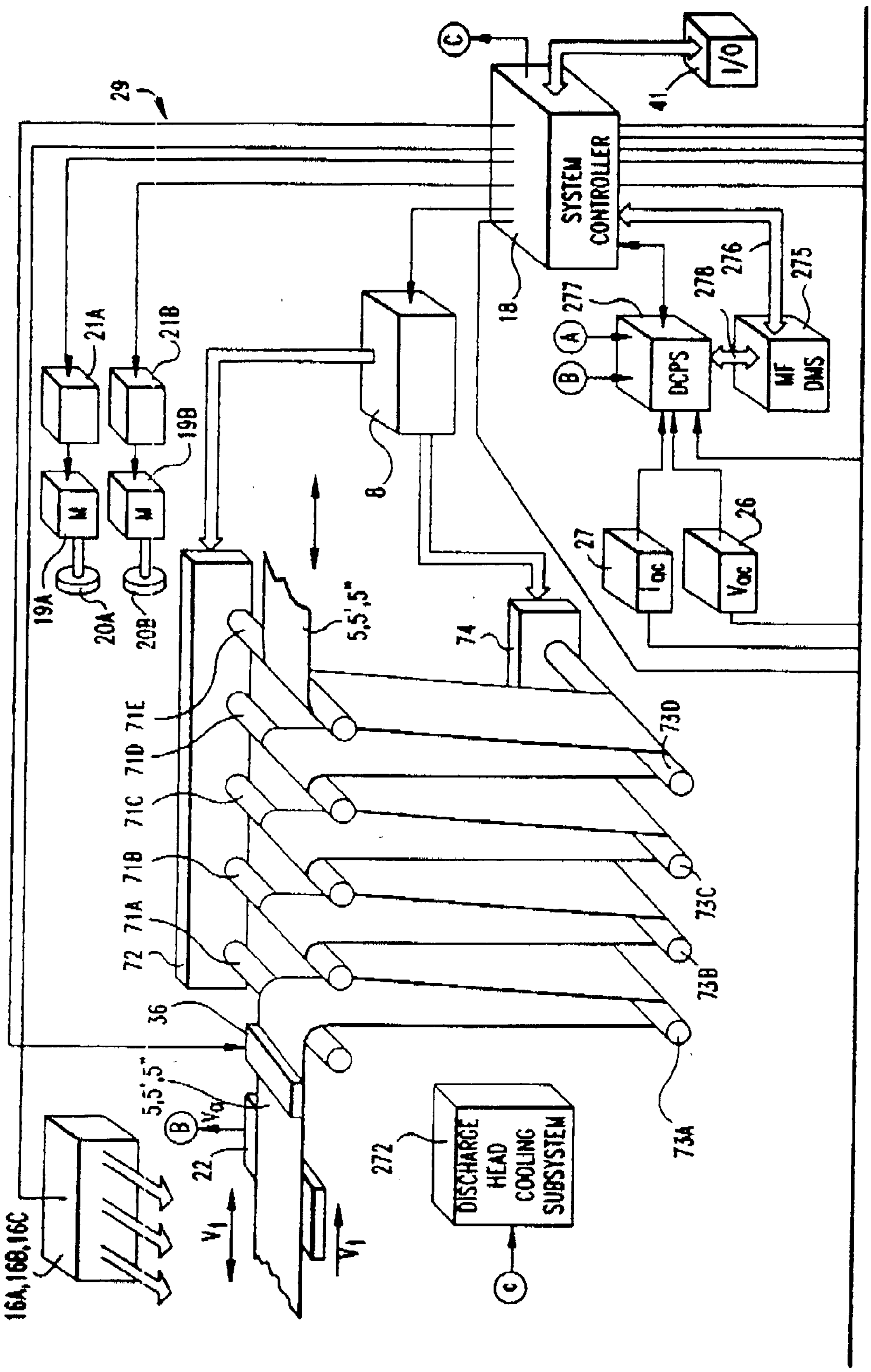
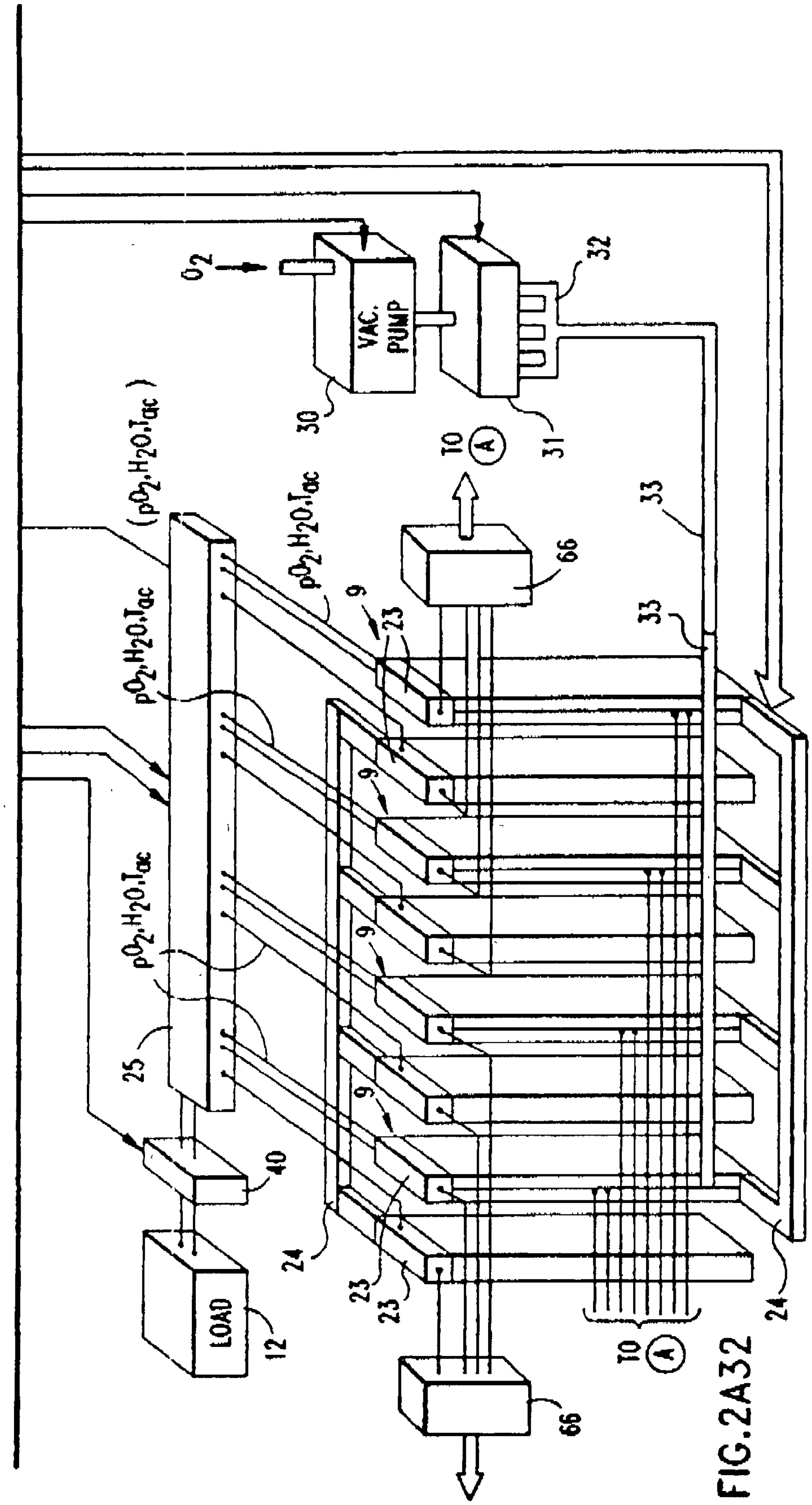

SYSTEM CONTROLLER
I/O
DCPS
MF DMS
DISCHARGE HEAD COOLING SUBSYSTEM
M
M
29
41
18
277
278
276
275
21A
21B
19A
19B
20A
20B
8
27
26
74
5,5',5"
71A
71B
71C
71D
71E
72
73A
73B
73C
73D
36
22
272
16A,16B,16C
V1
A
B
C

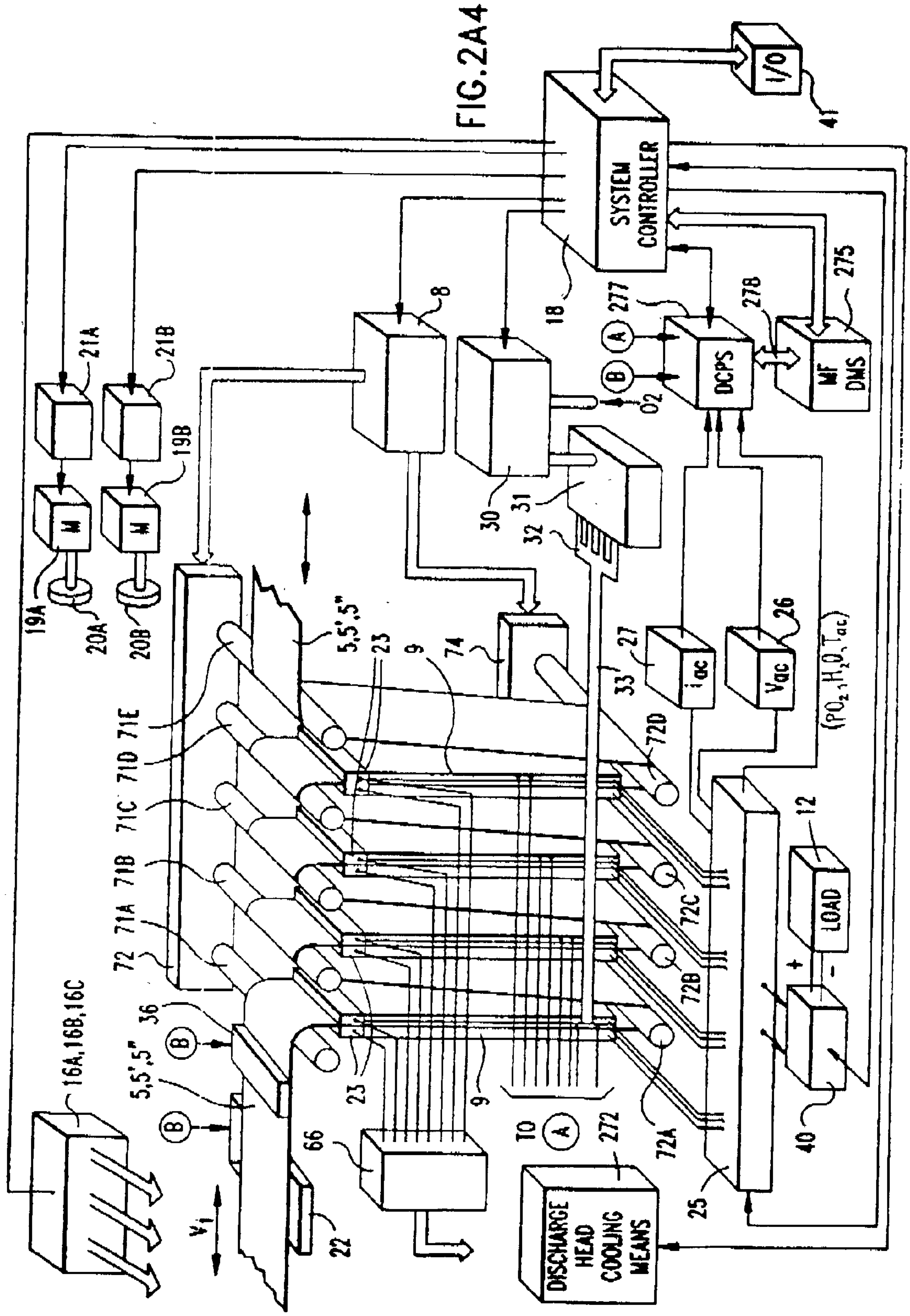
FIG.2A31



O_2
VAC. PUMP
30
31
32
33
33
(pO_2, H_2O, T_{ac})
pO_2, H_2O, T_{ac}
pO_2, H_2O, T_{ac}
pO_2, H_2O, T_{ac}
TO (A)
66
9
23
23
9
9
9
25
40
LOAD
12
24
23
23
24
TO (A)
66

FIG.2A32

FIG.2A4


SYSTEM CONTROLLER
I/O
41
18
8
30
31
32
277
278
275
DCPS
MF DMS
A
B
O_2
i_{ac}
V_{ac}
27
26
(PO_2, H_2O, T_{ac})
74
33'
72D
72C
72B
72A
25
12
LOAD
40
M
19A
19B
20A
20B
21A
21B
72
71A
71B
71C
71D
71E
5,5',5"
23
9
36
16A,16B,16C
V_1
22
66
TO A
272
DISCHARGE HEAD COOLING MEANS

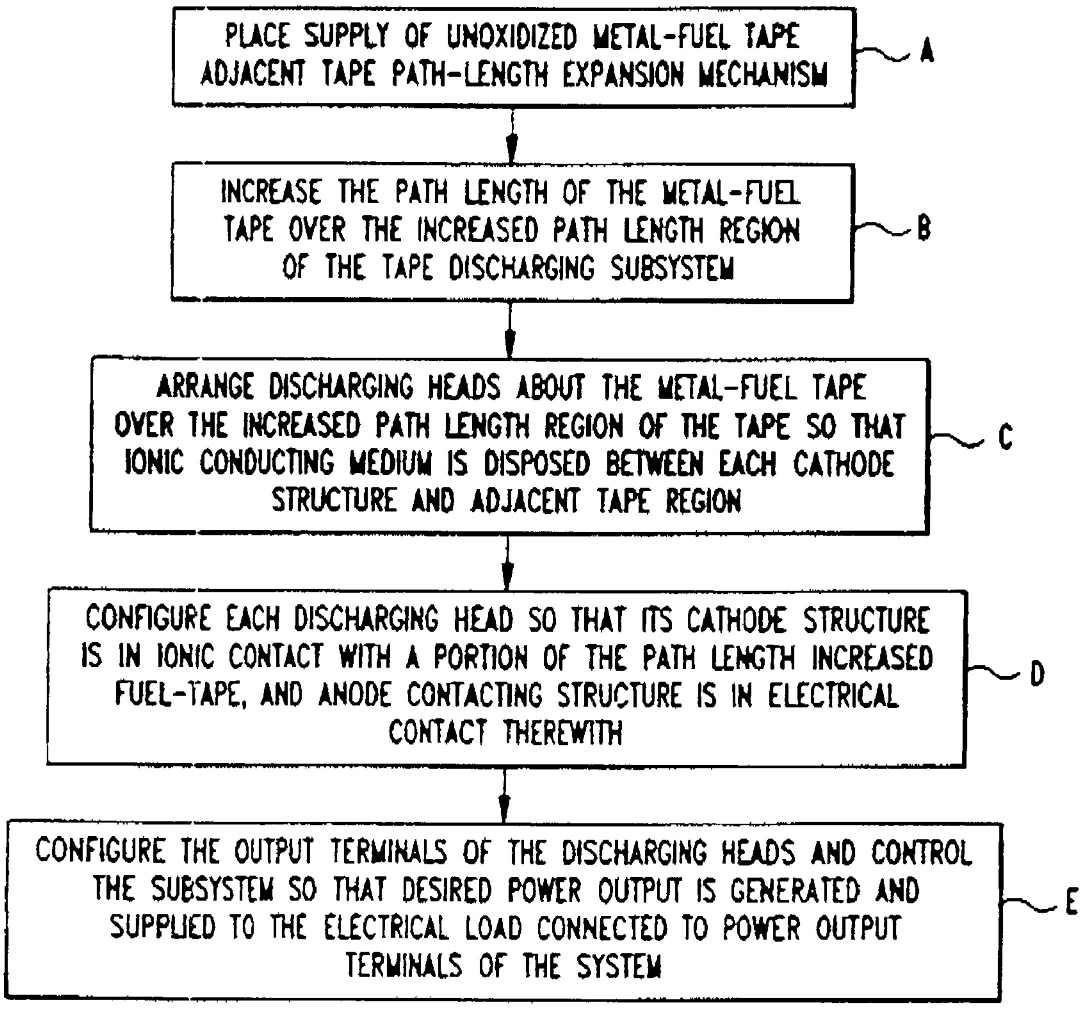

PLACE SUPPLY OF UNOXIDIZED METAL-FUEL TAPE ADJACENT TAPE PATH-LENGTH EXPANSION MECHANISM
A
INCREASE THE PATH LENGTH OF THE METAL-FUEL TAPE OVER THE INCREASED PATH LENGTH REGION OF THE TAPE DISCHARGING SUBSYSTEM
B
ARRANGE DISCHARGING HEADS ABOUT THE METAL-FUEL TAPE OVER THE INCREASED PATH LENGTH REGION OF THE TAPE SO THAT IONIC CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND ADJACENT TAPE REGION
C
CONFIGURE EACH DISCHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A PORTION OF THE PATH LENGTH INCREASED FUEL-TAPE, AND ANODE CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
D
CONFIGURE THE OUTPUT TERMINALS OF THE DISCHARGING HEADS AND CONTROL THE SUBSYSTEM SO THAT DESIRED POWER OUTPUT IS GENERATED AND SUPPLIED TO THE ELECTRICAL LOAD CONNECTED TO POWER OUTPUT TERMINALS OF THE SYSTEM
E

FIG.2A5

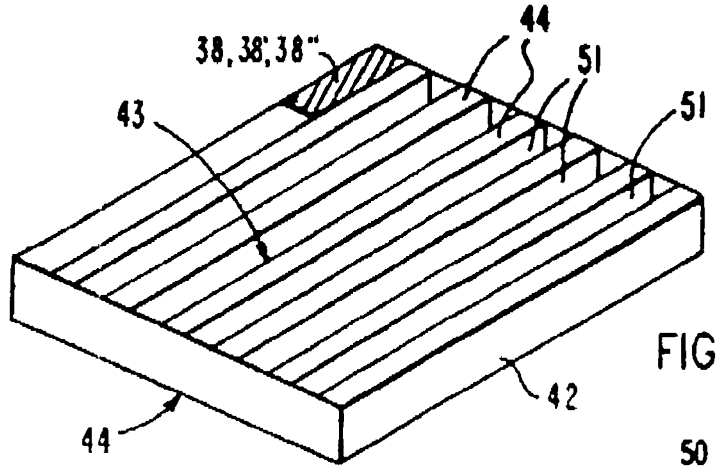


FIG.2A6

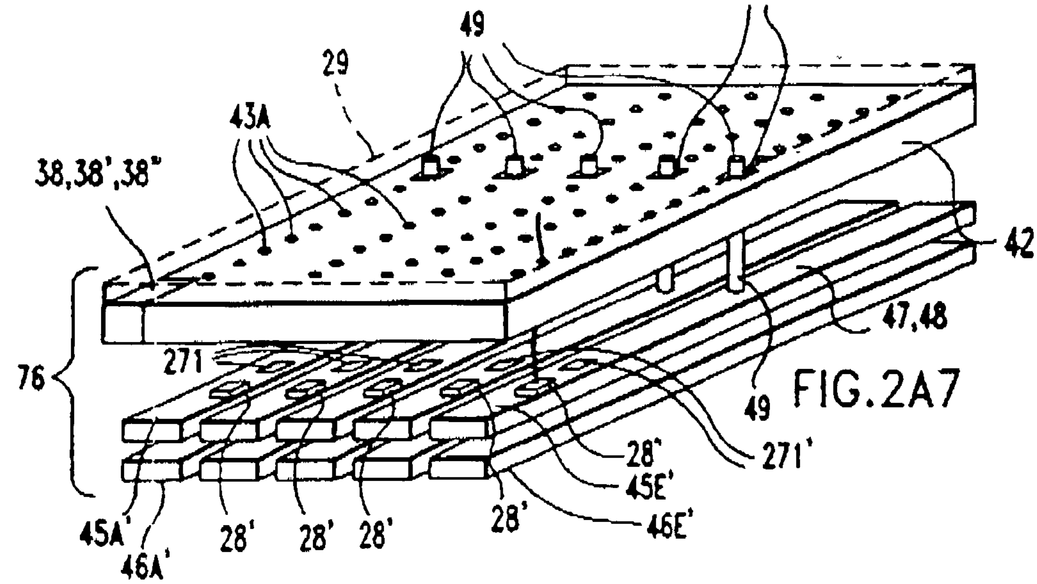


FIG.2A7

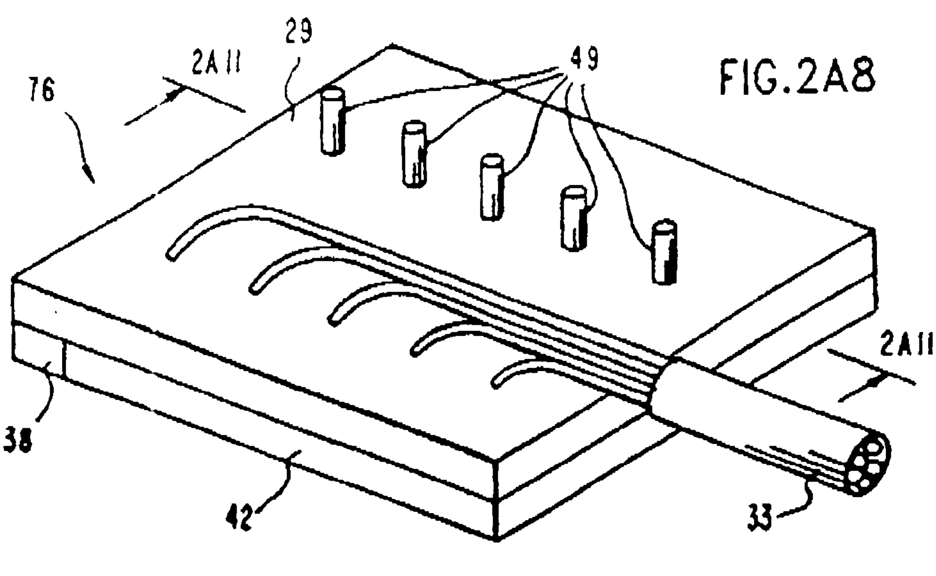


FIG.2A8

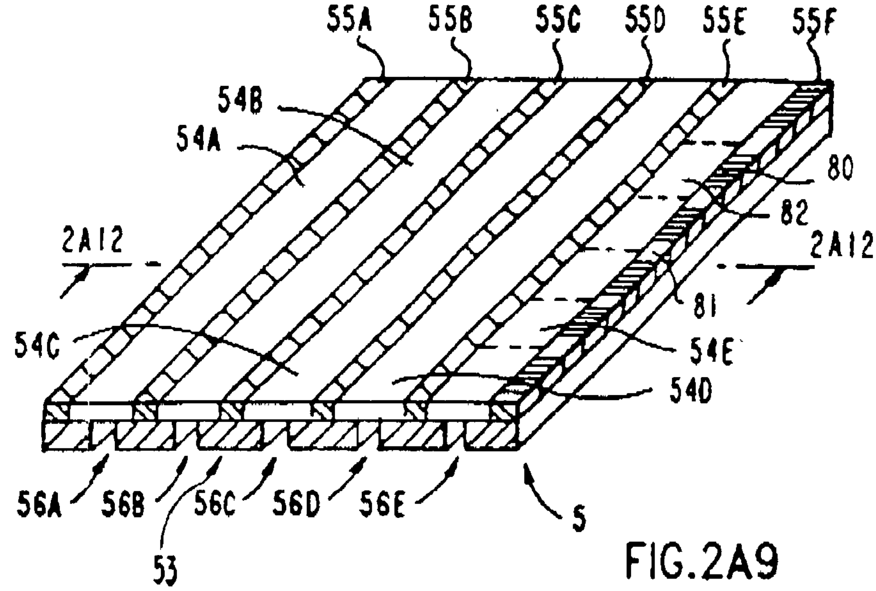


FIG.2A9

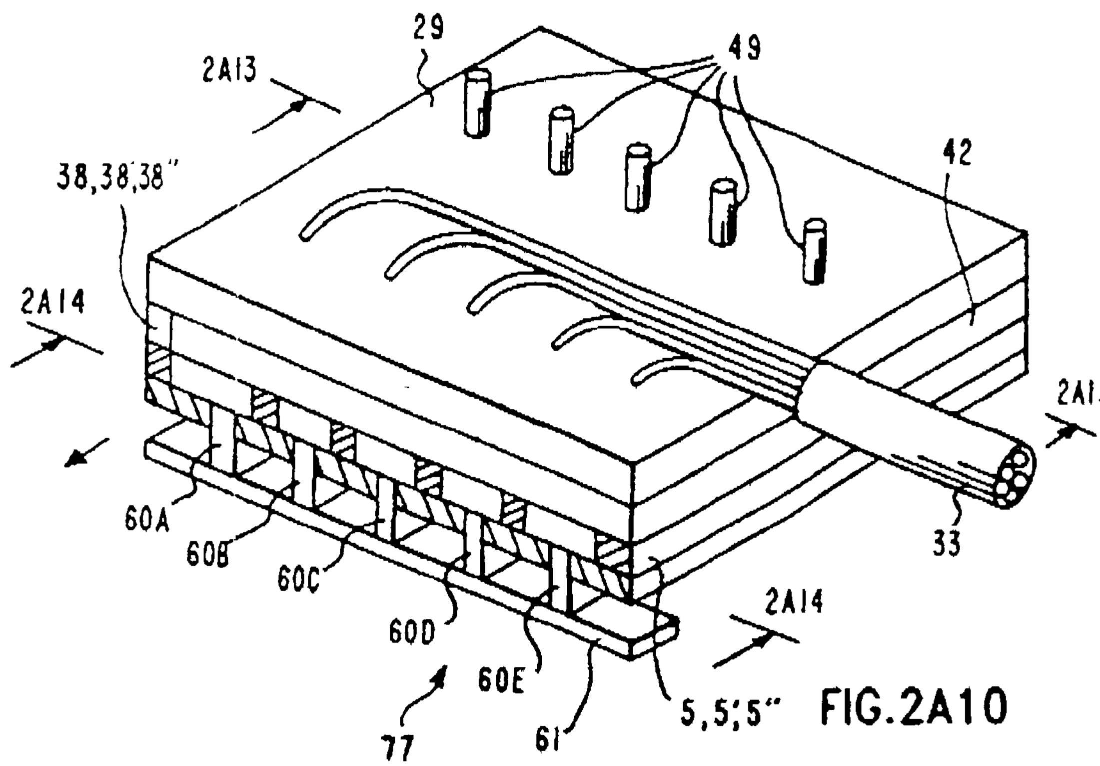


FIG.2A10

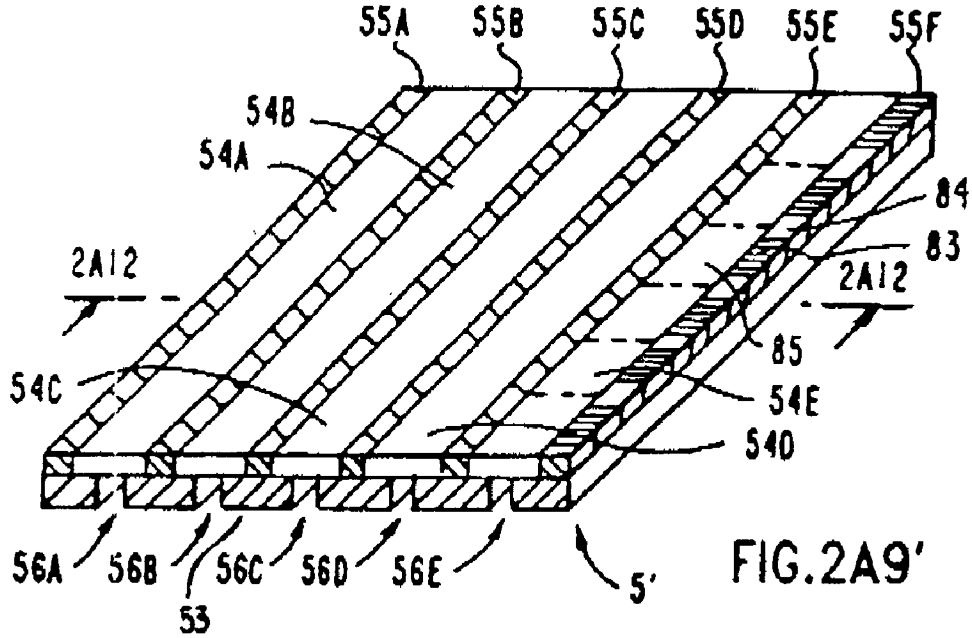


FIG.2A9'

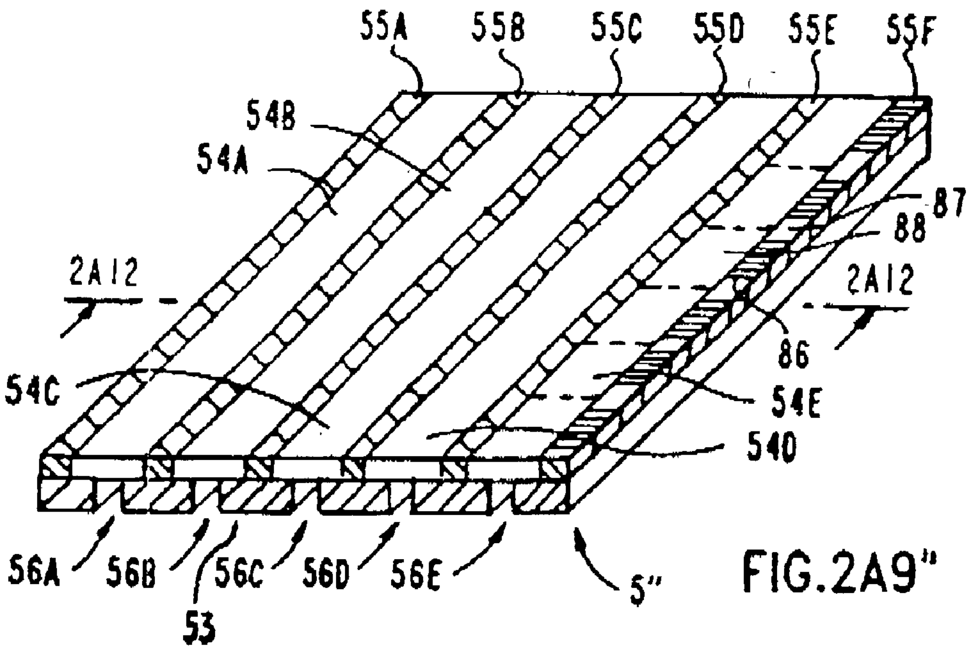


FIG.2A9"

FIG.2A11

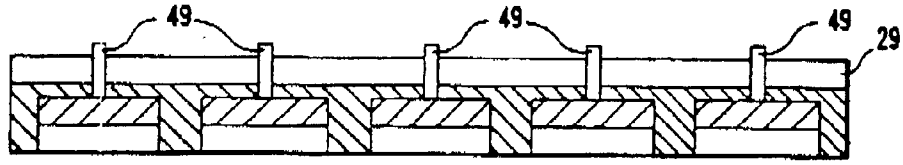


FIG.2A12

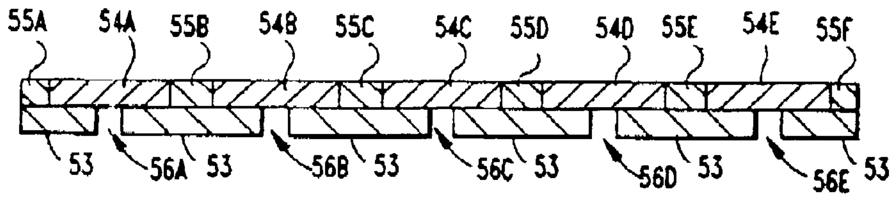


FIG.2A13

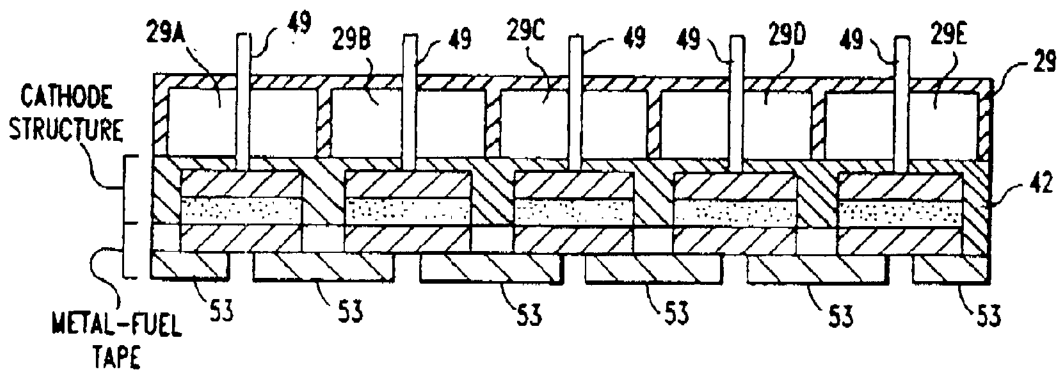
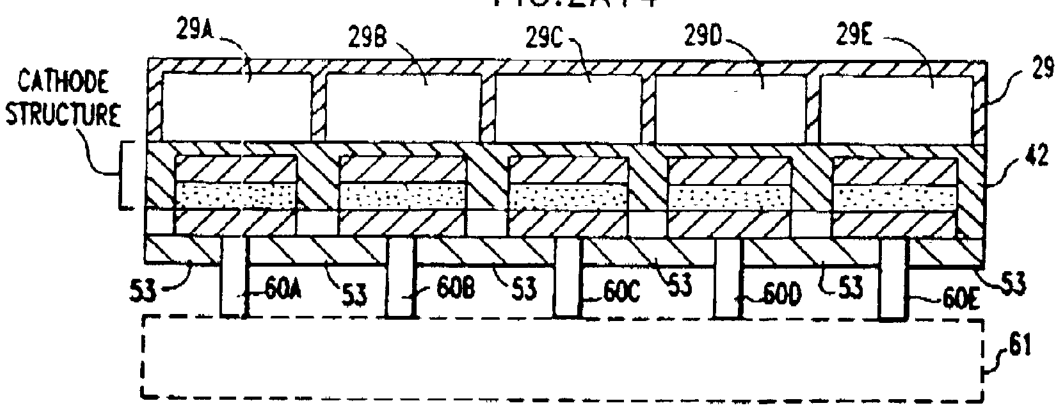


FIG.2A14



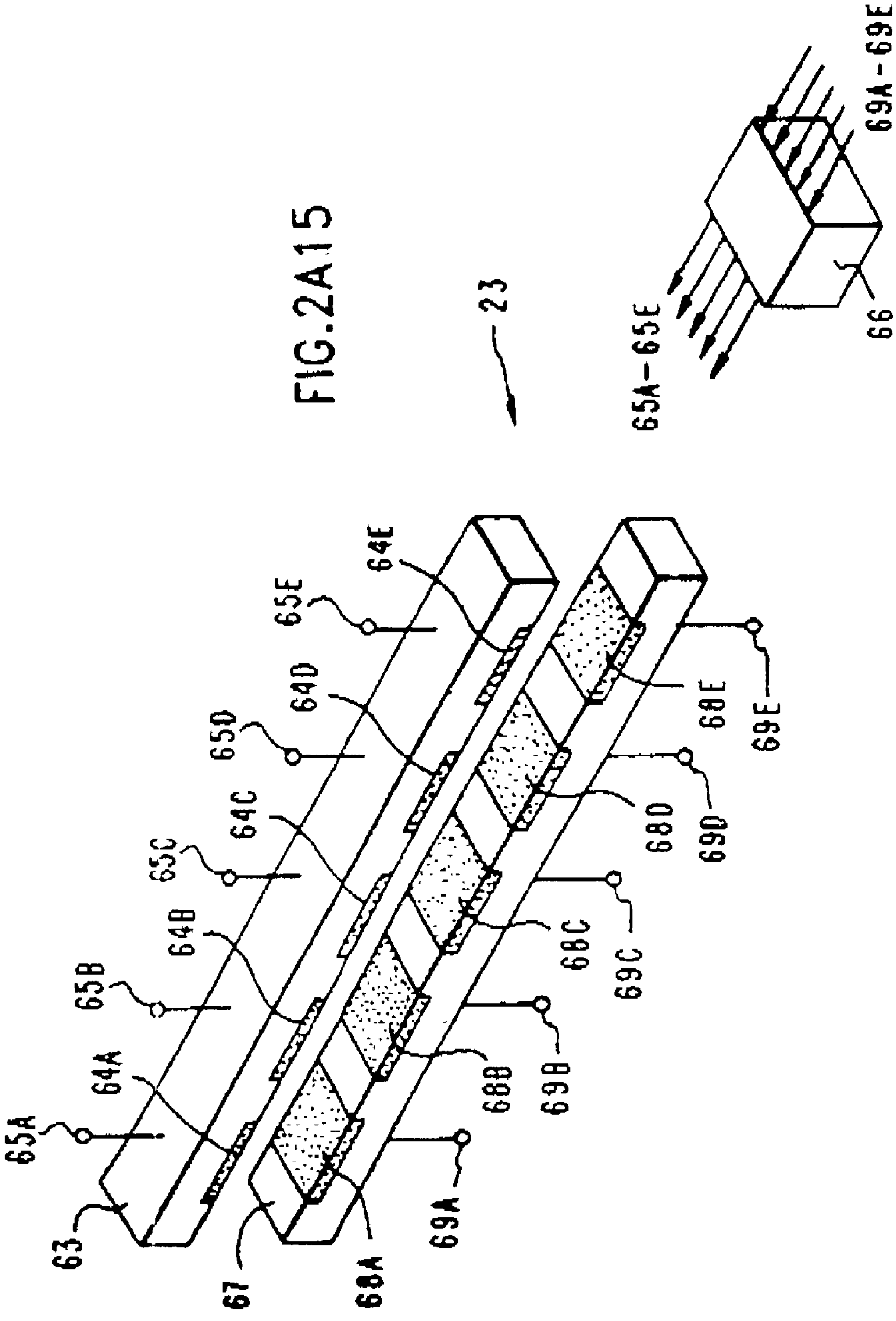

63
65A
64A
65B
64B
65C
64C
65D
64D
65E
64E
67
68A
69A
68B
69B
68C
69C
68D
69D
68E
69E
23
65A-65E
69A-69E
66

FIG.2A15

FUEL-TAPE CASSETTE NO.__	METAL-FUEL TRACK NO.1					METAL-FUEL TRACK NO.2	METAL-FUEL TRACK NO.3	METAL-FUEL TRACK NO.4	METAL-FUEL TRACK NO.5
ZONE NO.1 285	t_1	t_2	t_3	•••	t_n				
	i_{oc}			•••					
	V_{oc}			•••					
	V_1			•••					
	pO_2			•••					
	$H_2O\%$			•••					
	CM			•••					
ZONE NO.2									
ZONE NO.3									
ZONE NO.4									
ZONE NO.5									
⋮	⋮					⋮	⋮	⋮	⋮
ZONE NO.n									

FIG.2A16

DISCHARGE DATA STRUCTURE

FIG.2B1

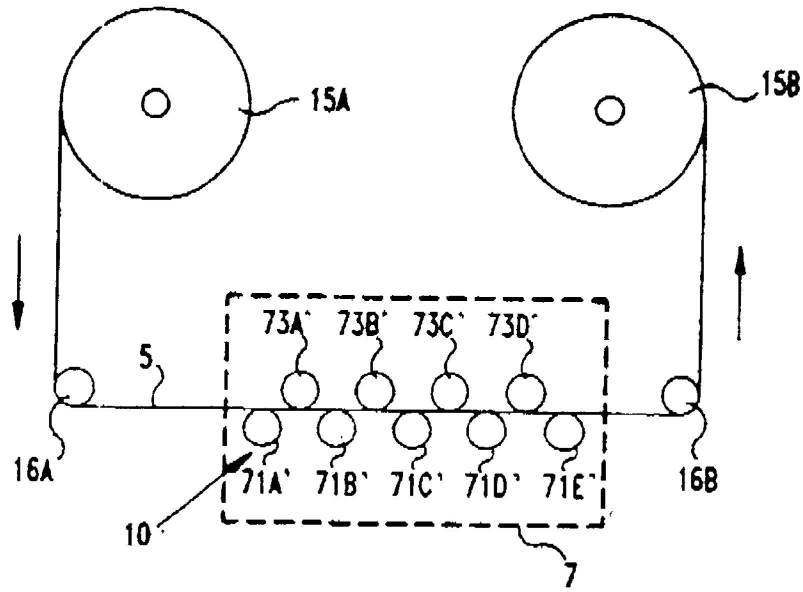
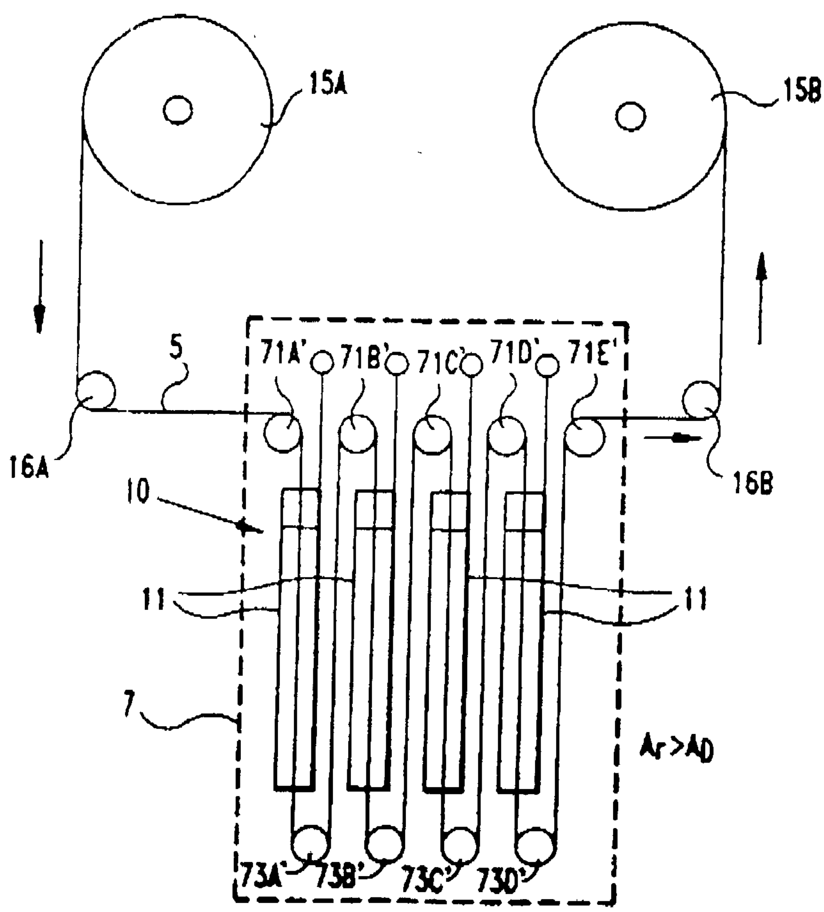


FIG.2B2



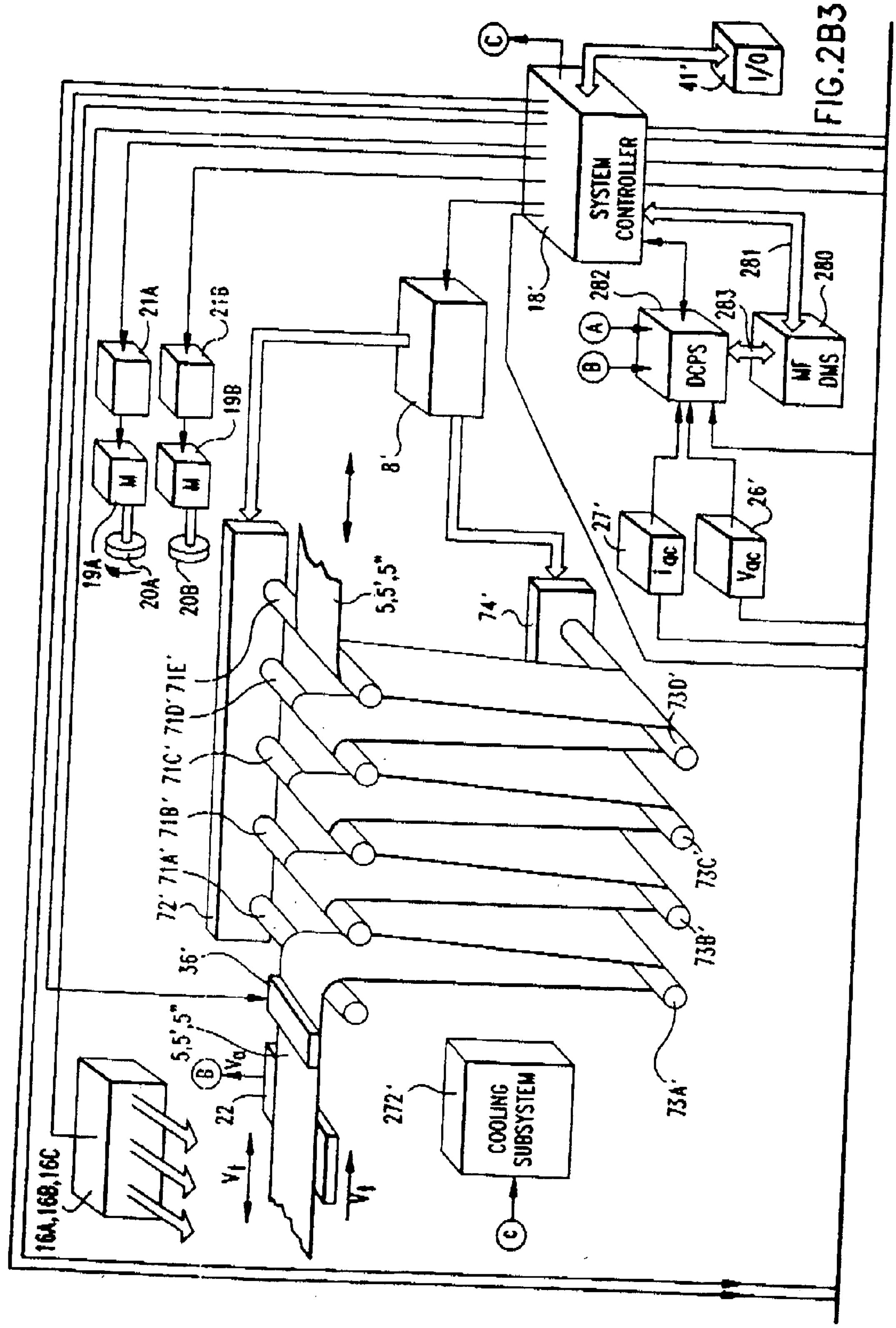

SYSTEM CONTROLLER
I/O
41'
C
18'
282
281
280
283
A
B
DCPS
MF DMS
21A
21B
19A
19B
20A
20B
M
8'
5,5',5"
74'
27'
26'
72'
71A'
71B'
71C'
71D'
71E'
73A'
73B'
73C'
73D'
36'
22
COOLING SUBSYSTEM
272'
16A,16B,16C

FIG.2B31

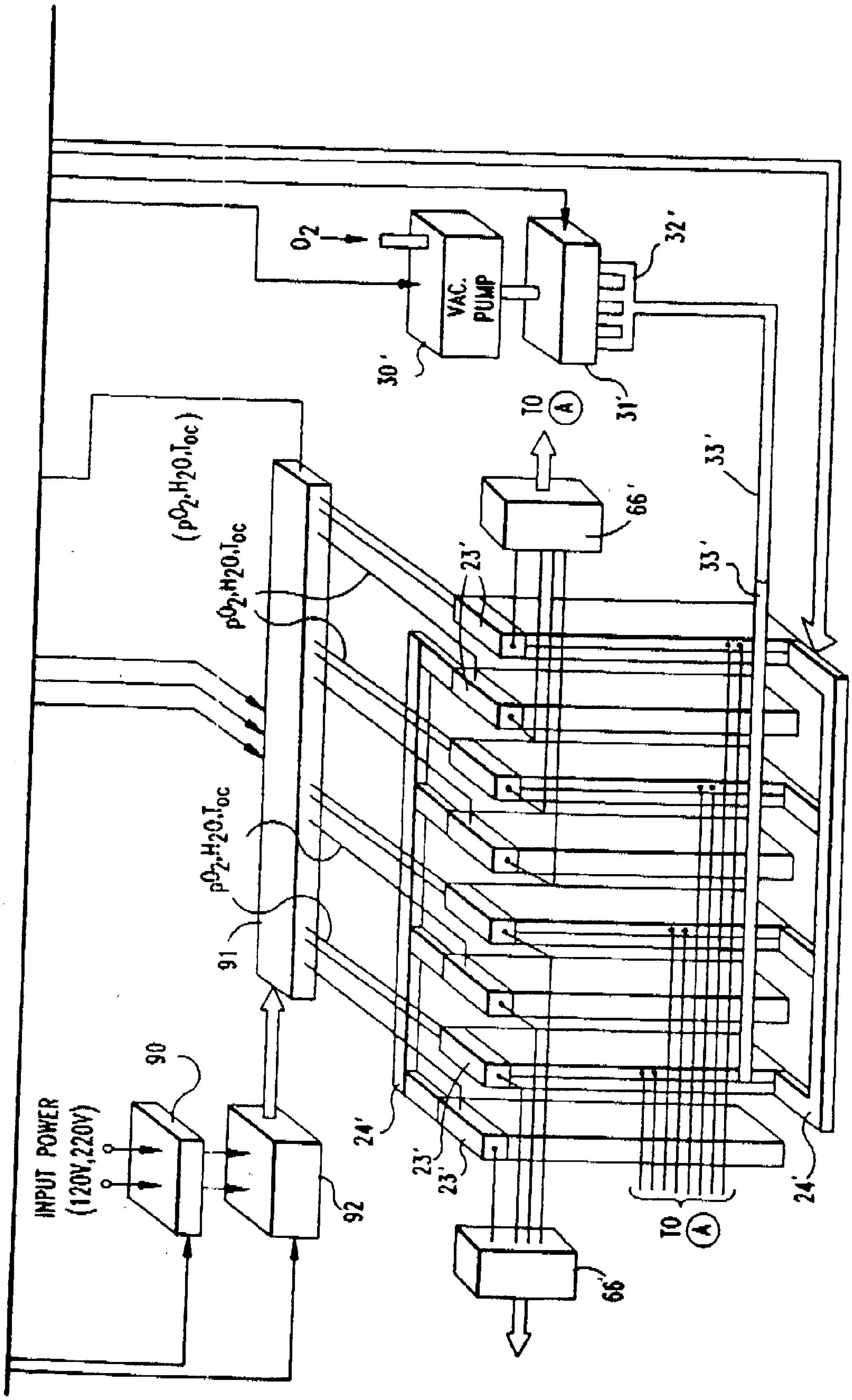

INPUT POWER
(120V,220V)
90
92
91
pO_2,H_2O,T_{oc}
pO_2,H_2O,T_{oc}
(pO_2,H_2O,T_{oc})
O_2
VAC.
PUMP
30'
31'
32'
33'
33'
23'
23'
23'
24'
24'
66'
66'
TO A
TO A

FIG.2B32

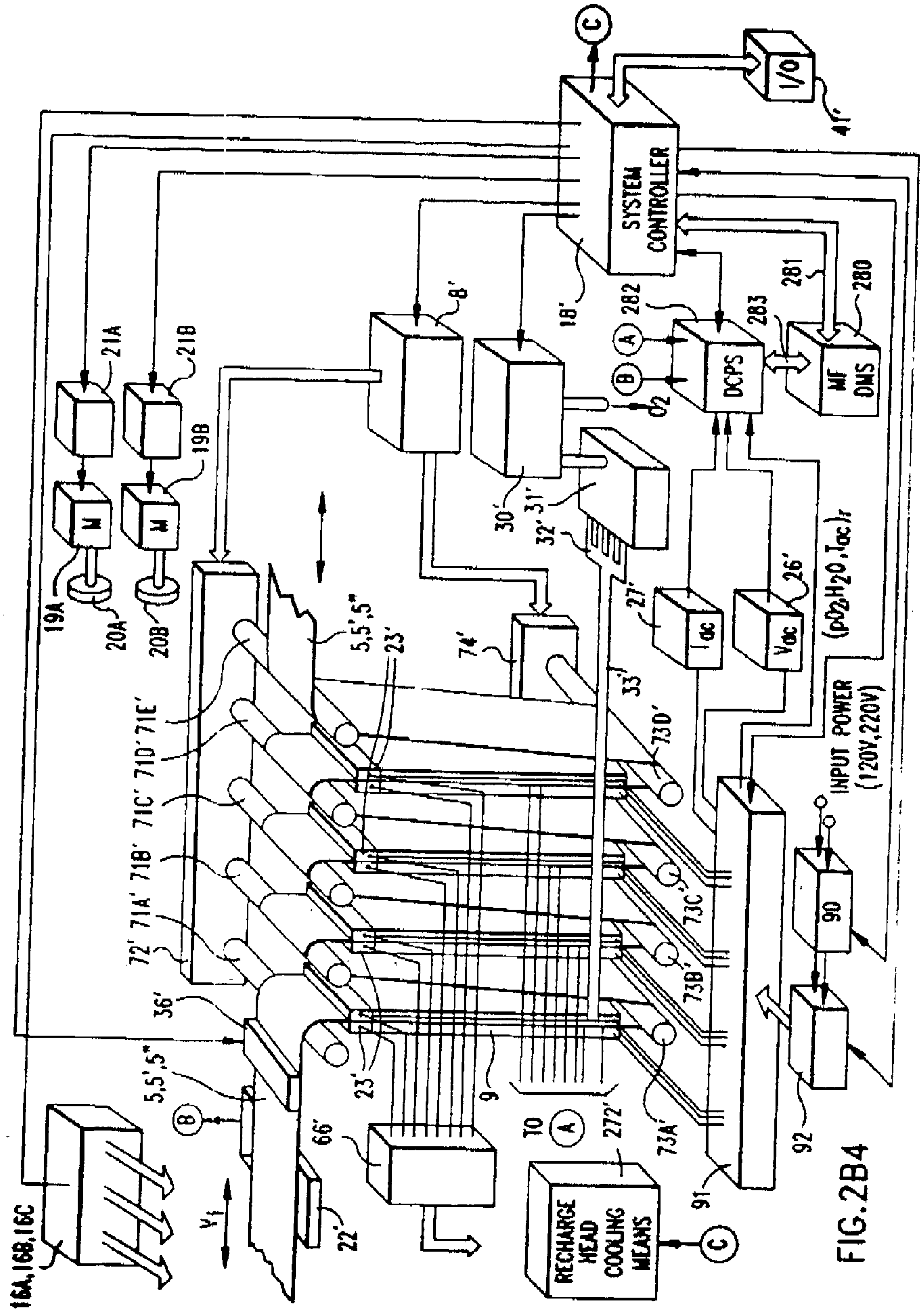
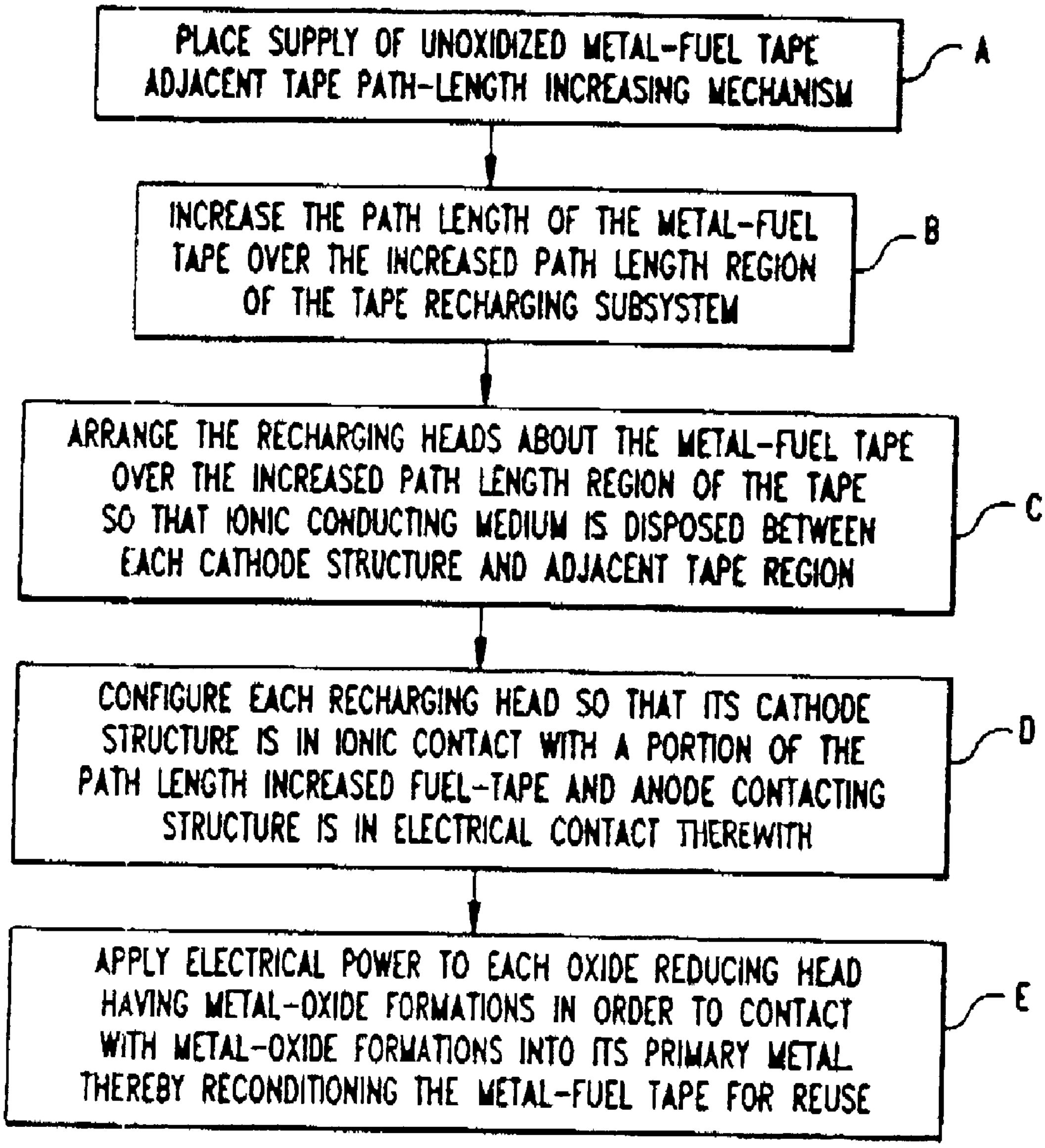

SYSTEM CONTROLLER
I/O
DCPS
MF OMS
RECHARGE HEAD COOLING MEANS
INPUT POWER (120V,220V)
TO A

FIG.2B4

FIG.2B5


PLACE SUPPLY OF UNOXIDIZED METAL-FUEL TAPE ADJACENT TAPE PATH-LENGTH INCREASING MECHANISM
A
INCREASE THE PATH LENGTH OF THE METAL-FUEL TAPE OVER THE INCREASED PATH LENGTH REGION OF THE TAPE RECHARGING SUBSYSTEM
B
ARRANGE THE RECHARGING HEADS ABOUT THE METAL-FUEL TAPE OVER THE INCREASED PATH LENGTH REGION OF THE TAPE SO THAT IONIC CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND ADJACENT TAPE REGION
C
CONFIGURE EACH RECHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A PORTION OF THE PATH LENGTH INCREASED FUEL-TAPE AND ANODE CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
D
APPLY ELECTRICAL POWER TO EACH OXIDE REDUCING HEAD HAVING METAL-OXIDE FORMATIONS IN ORDER TO CONTACT WITH METAL-OXIDE FORMATIONS INTO ITS PRIMARY METAL THEREBY RECONDITIONING THE METAL-FUEL TAPE FOR REUSE
E

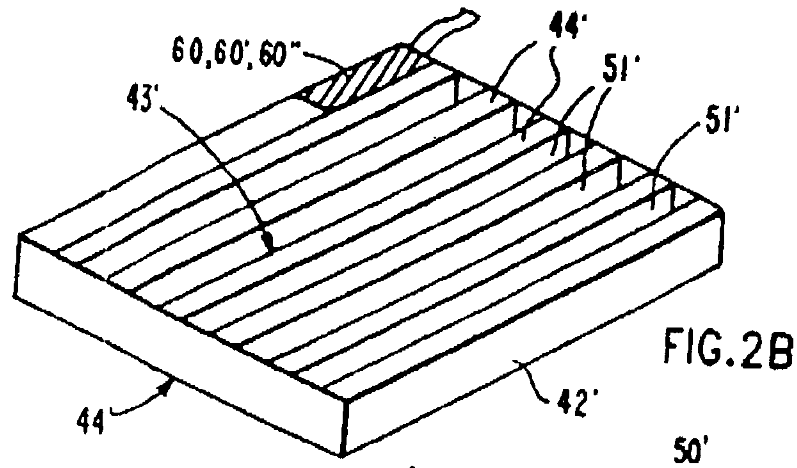


FIG.2B6

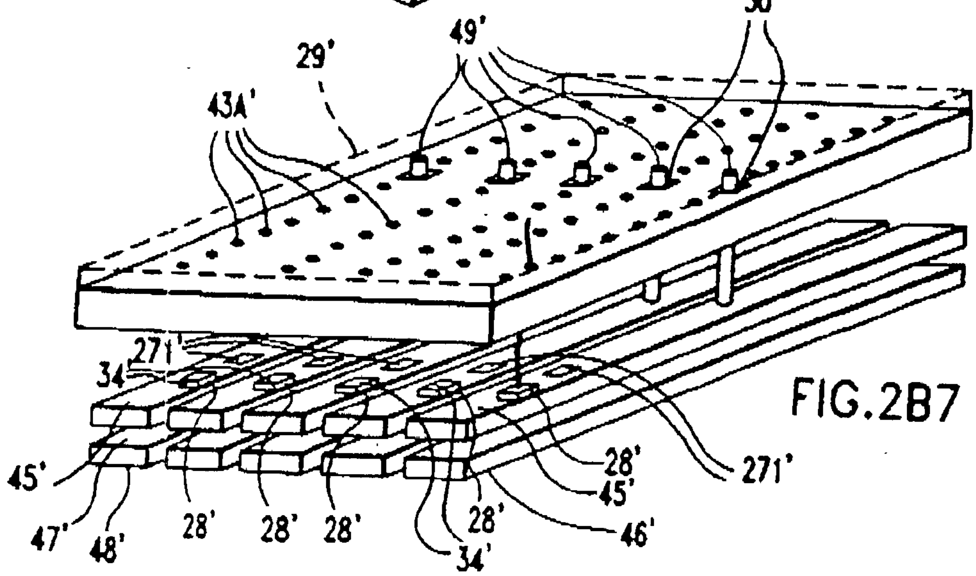


FIG.2B7

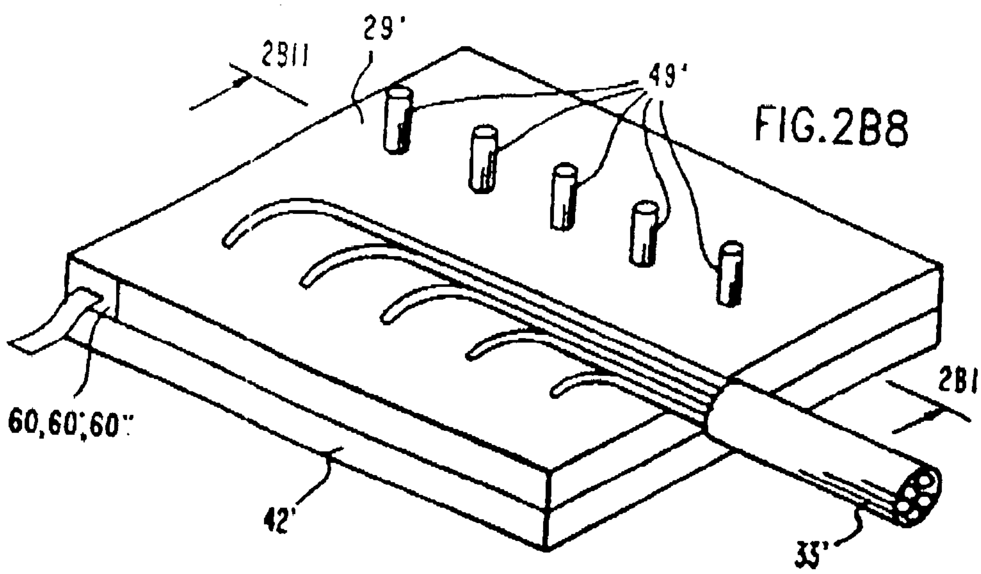


FIG.2B8

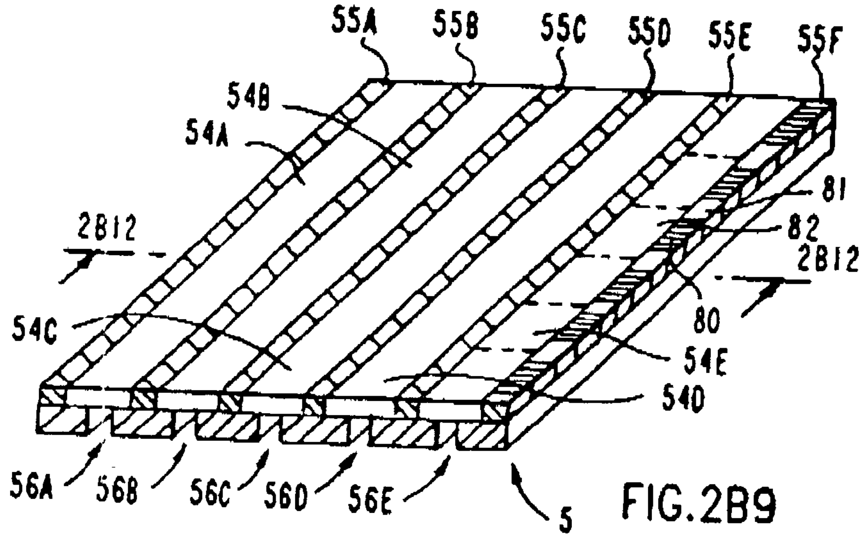


FIG.2B9

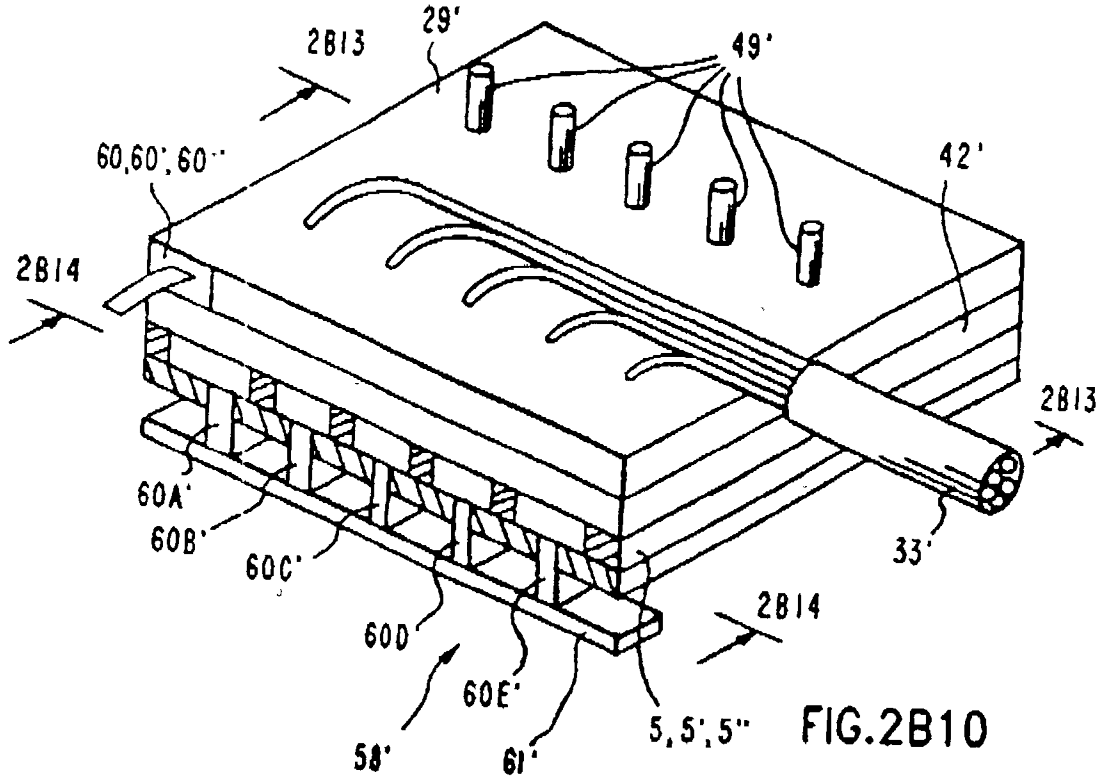


FIG.2B10

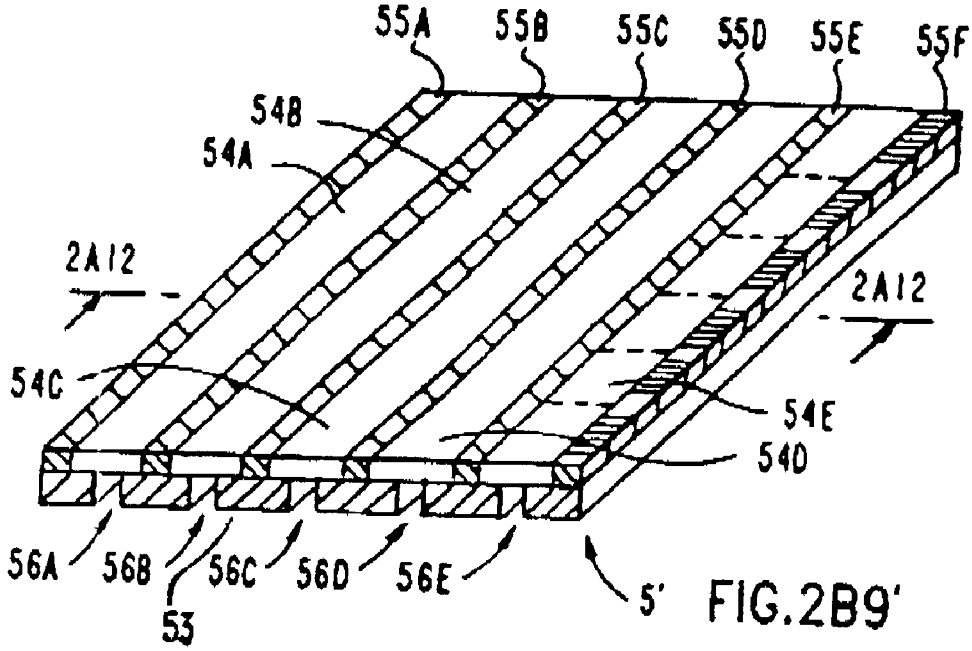


FIG.2B9'

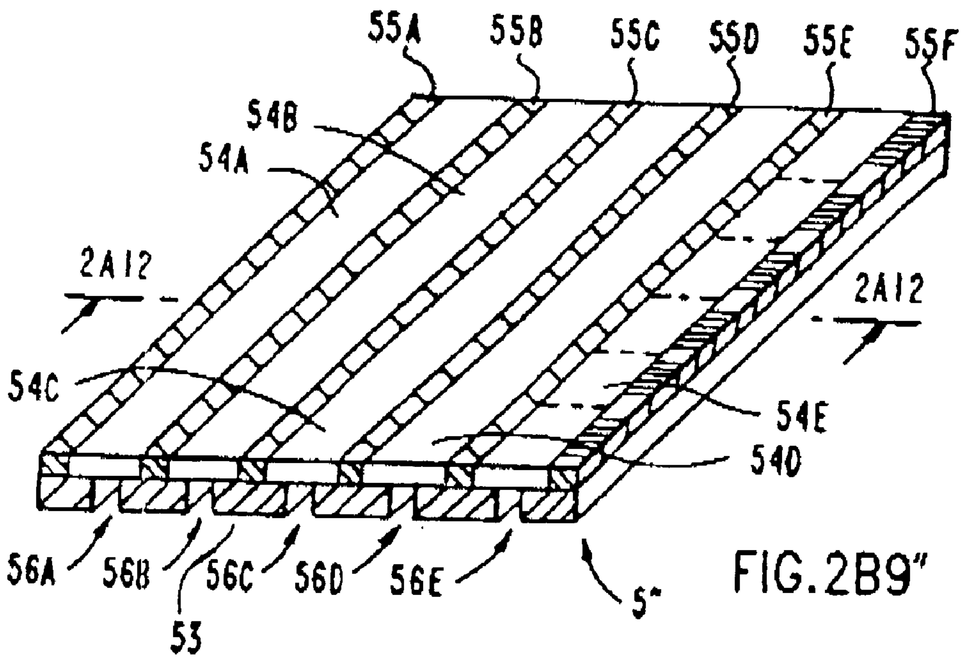


FIG.2B9"

FIG.2B11

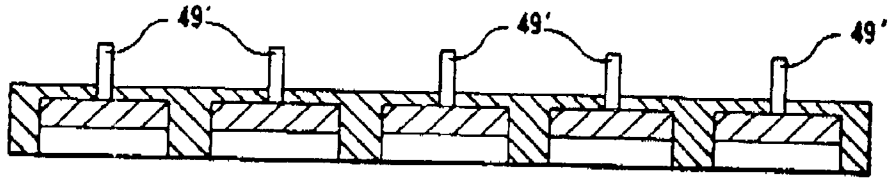


FIG.2B12

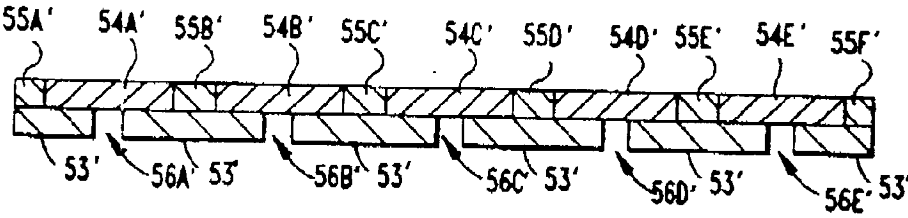


FIG.2B13

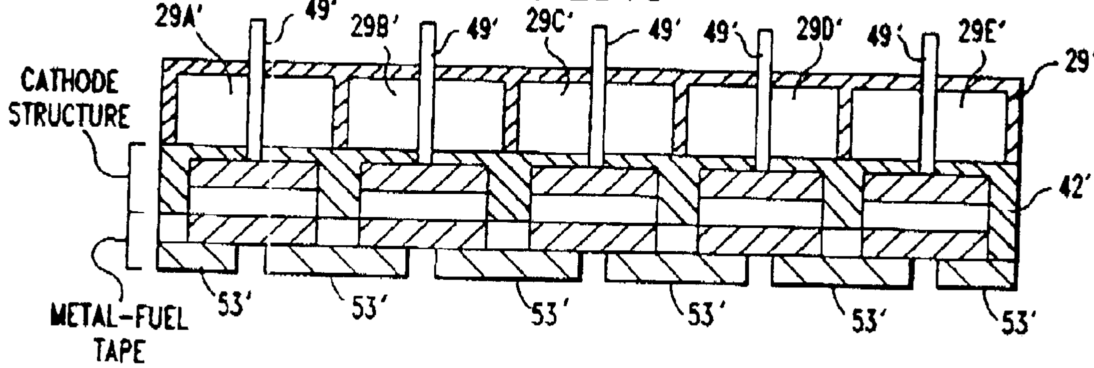
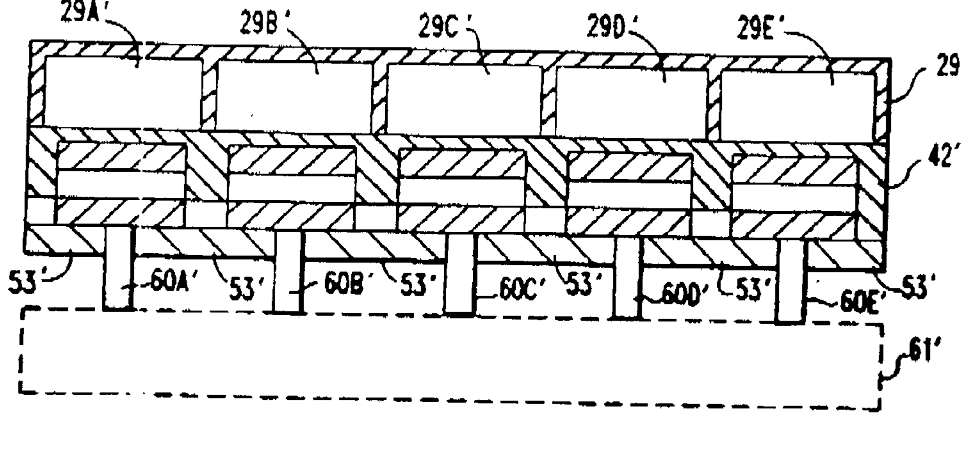


FIG.2B14



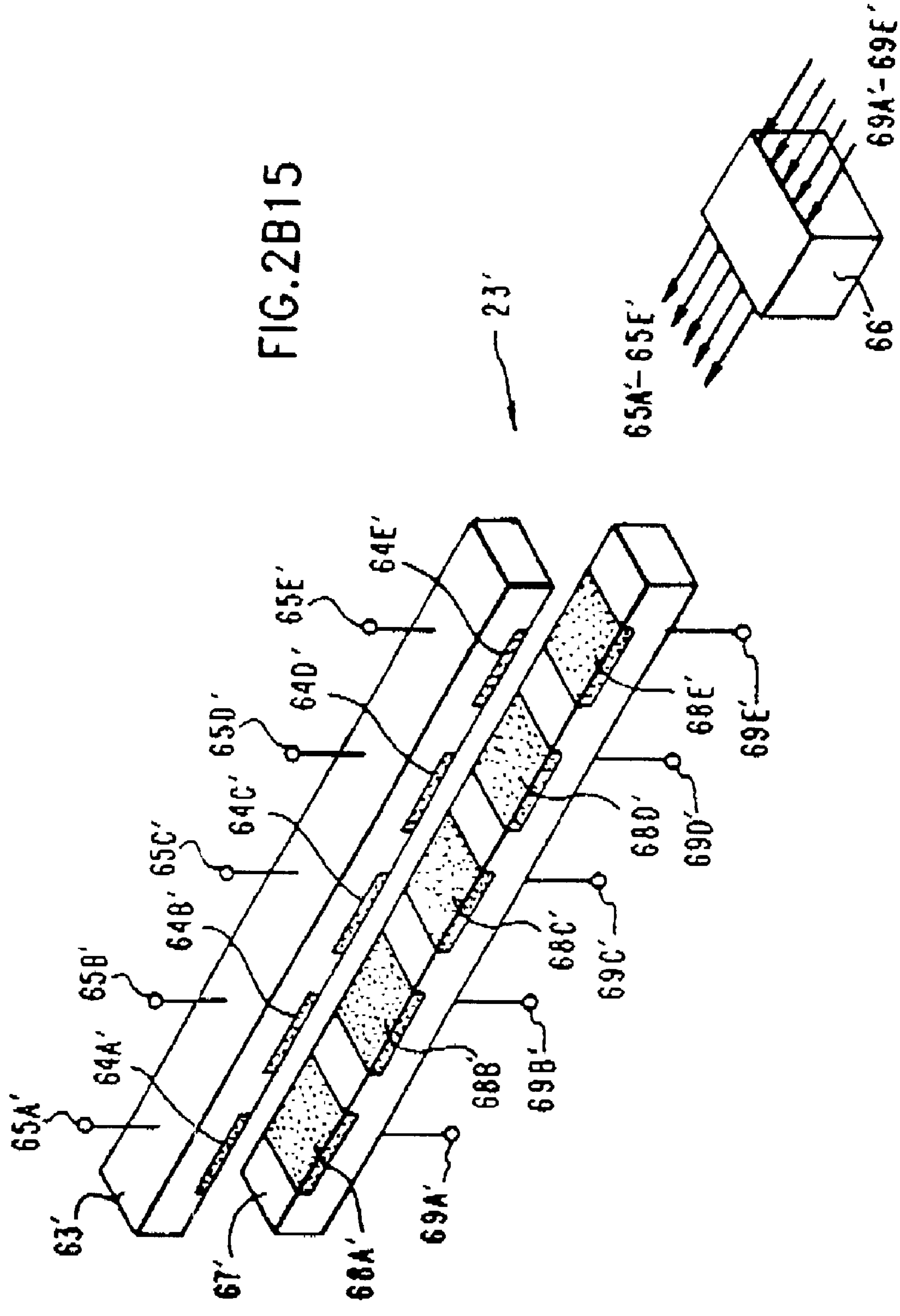

23'
65A'-65E'
69A'-69E'
66'
63'
67'
65A'
64A'
65B'
64B'
65C'
64C'
65D'
64D'
65E'
64E'
68A'
69A'
68B'
69B'
68C'
69C'
68D'
69D'
68E'
69E'

FIG.2B15

<table>
<tr><th>FUEL-TAPE CASSETTE NO.__</th><th colspan="6">METAL-FUEL TRACK NO.1</th><th>METAL-FUEL TRACK NO.2</th><th>METAL-FUEL TRACK NO.3</th><th>METAL-FUEL TRACK NO.4</th><th>METAL-FUEL TRACK NO.5</th></tr>
<tr><td rowspan="7">ZONE NO.1</td><td></td><td>t_1</td><td>t_2</td><td>t_3</td><td>•••</td><td>t_n</td><td rowspan="7"></td><td rowspan="7"></td><td rowspan="7"></td><td rowspan="7"></td></tr>
<tr><td>i_{ac}</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>V_{ac}</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>V_t</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>pO_2</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>$H_2O\%$</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>CM</td><td></td><td></td><td>•••</td><td></td><td></td></tr>
<tr><td>ZONE NO.2</td><td colspan="6"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>ZONE NO.3</td><td colspan="6"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>ZONE NO.4</td><td colspan="6"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>ZONE NO.5</td><td colspan="6"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>⋮</td><td colspan="6">⋮</td><td>⋮</td><td>⋮</td><td>⋮</td><td>⋮</td></tr>
<tr><td>ZONE NO.n</td><td colspan="6"></td><td></td><td></td><td></td><td></td></tr>
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FIG.2B16

RECHARGE DATA STRUCTURE

FIG.2B17

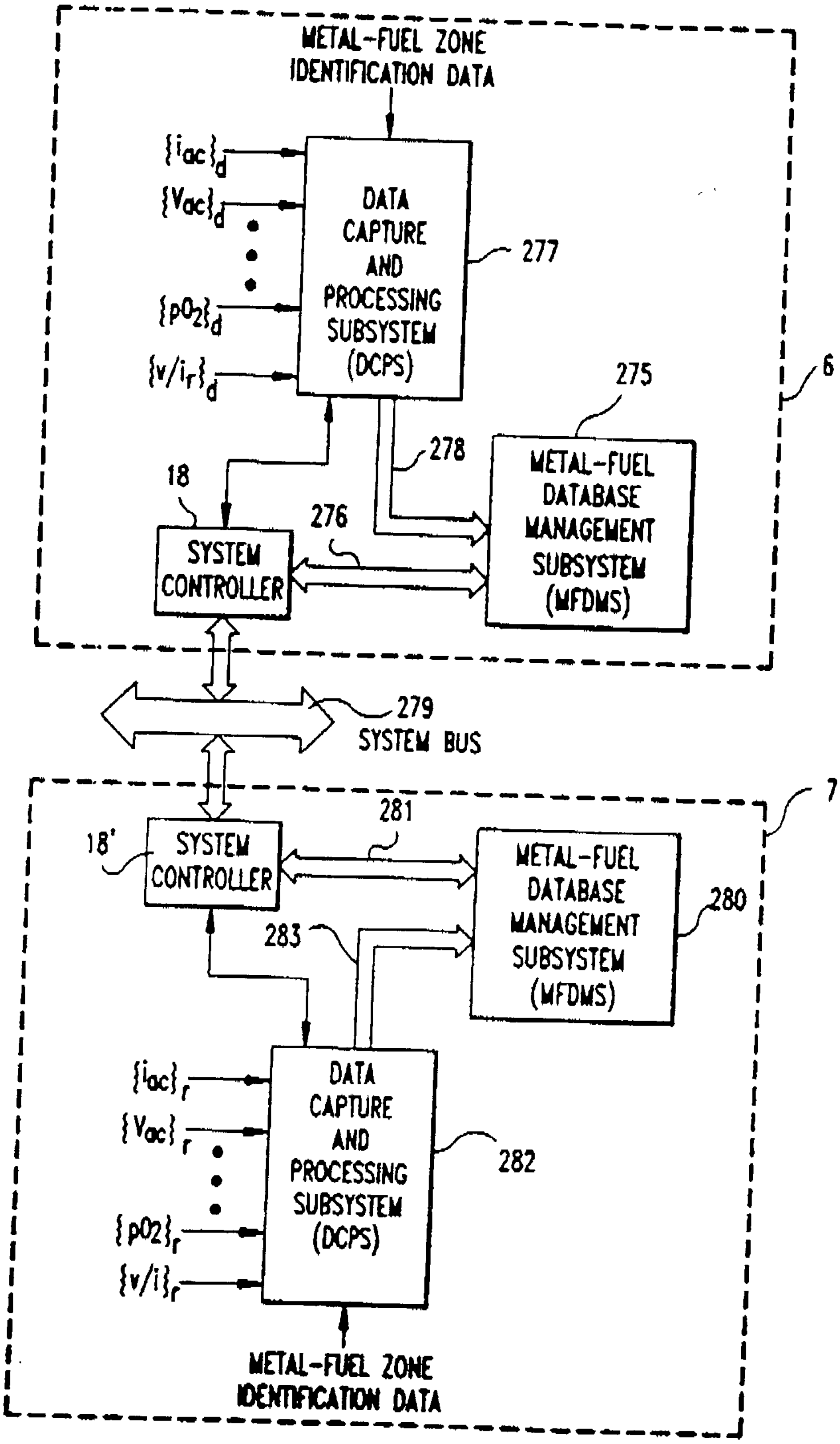

METAL-FUEL ZONE IDENTIFICATION DATA
$\{i_{ac}\}_d$
$\{V_{ac}\}_d$
$\{pO_2\}_d$
$\{v/i_r\}_d$
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
277
275
6
278
18
276
SYSTEM CONTROLLER
METAL-FUEL DATABASE MANAGEMENT SUBSYSTEM (MFDMS)
279
SYSTEM BUS
7
281
18'
SYSTEM CONTROLLER
METAL-FUEL DATABASE MANAGEMENT SUBSYSTEM (MFDMS)
280
283
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
282
$\{i_{ac}\}_r$
$\{V_{ac}\}_r$
$\{pO2\}_r$
$\{v/i\}_r$
METAL-FUEL ZONE IDENTIFICATION DATA

FIG.3A

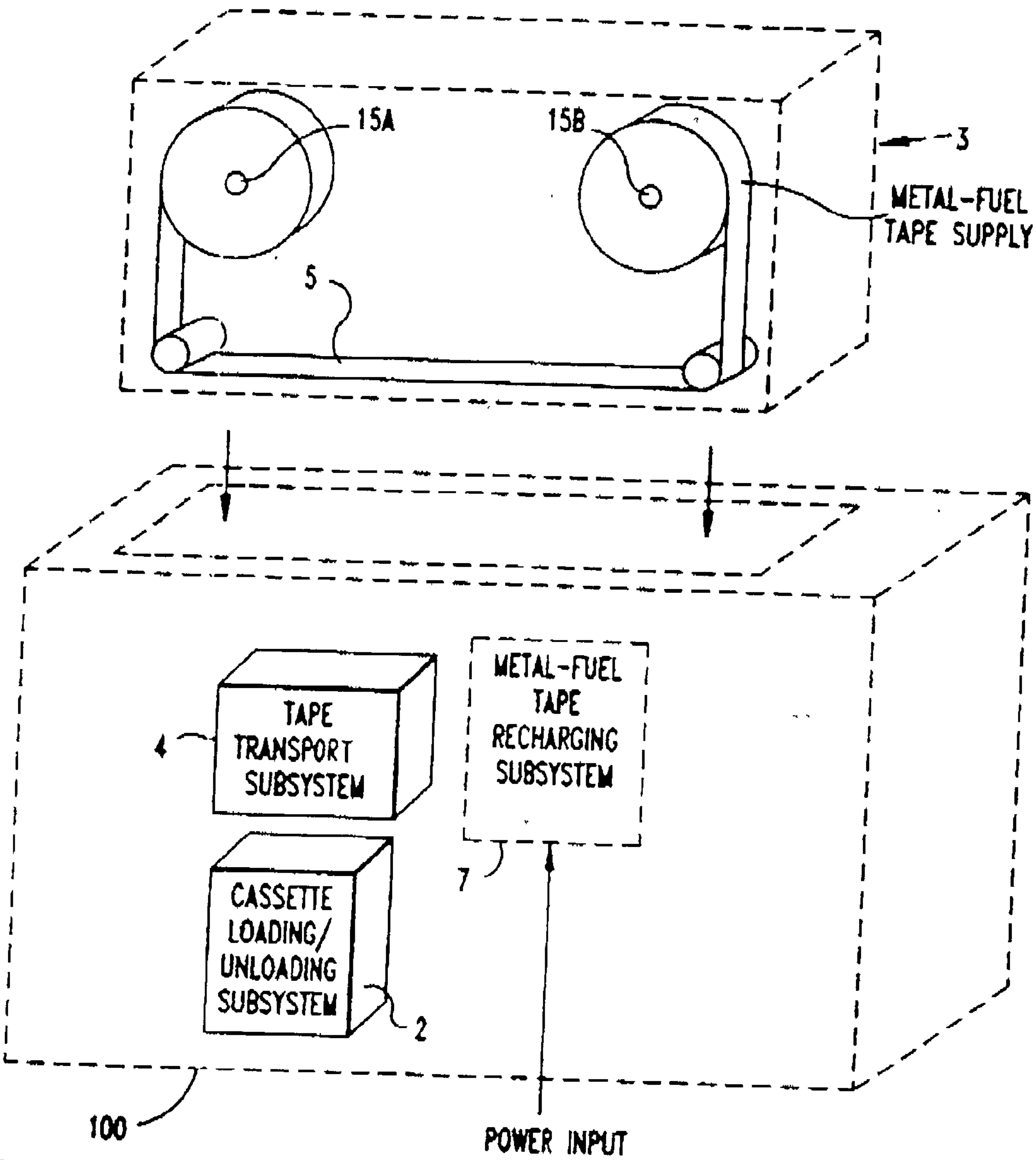

15A
15B
3
METAL-FUEL TAPE SUPPLY
5
TAPE TRANSPORT SUBSYSTEM
4
METAL-FUEL TAPE RECHARGING SUBSYSTEM
7
CASSETTE LOADING/ UNLOADING SUBSYSTEM
2
100
POWER INPUT

FIG.3B

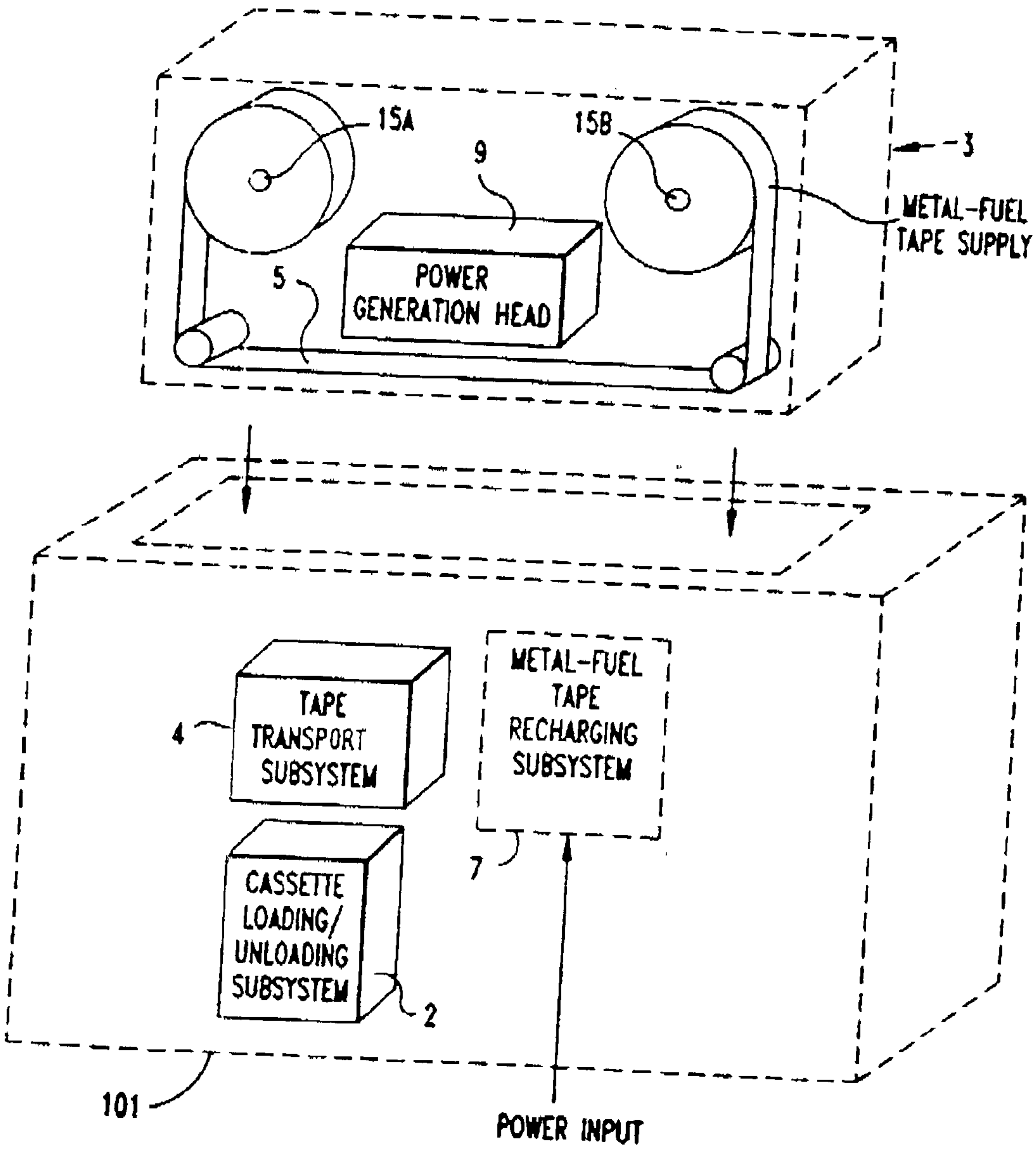
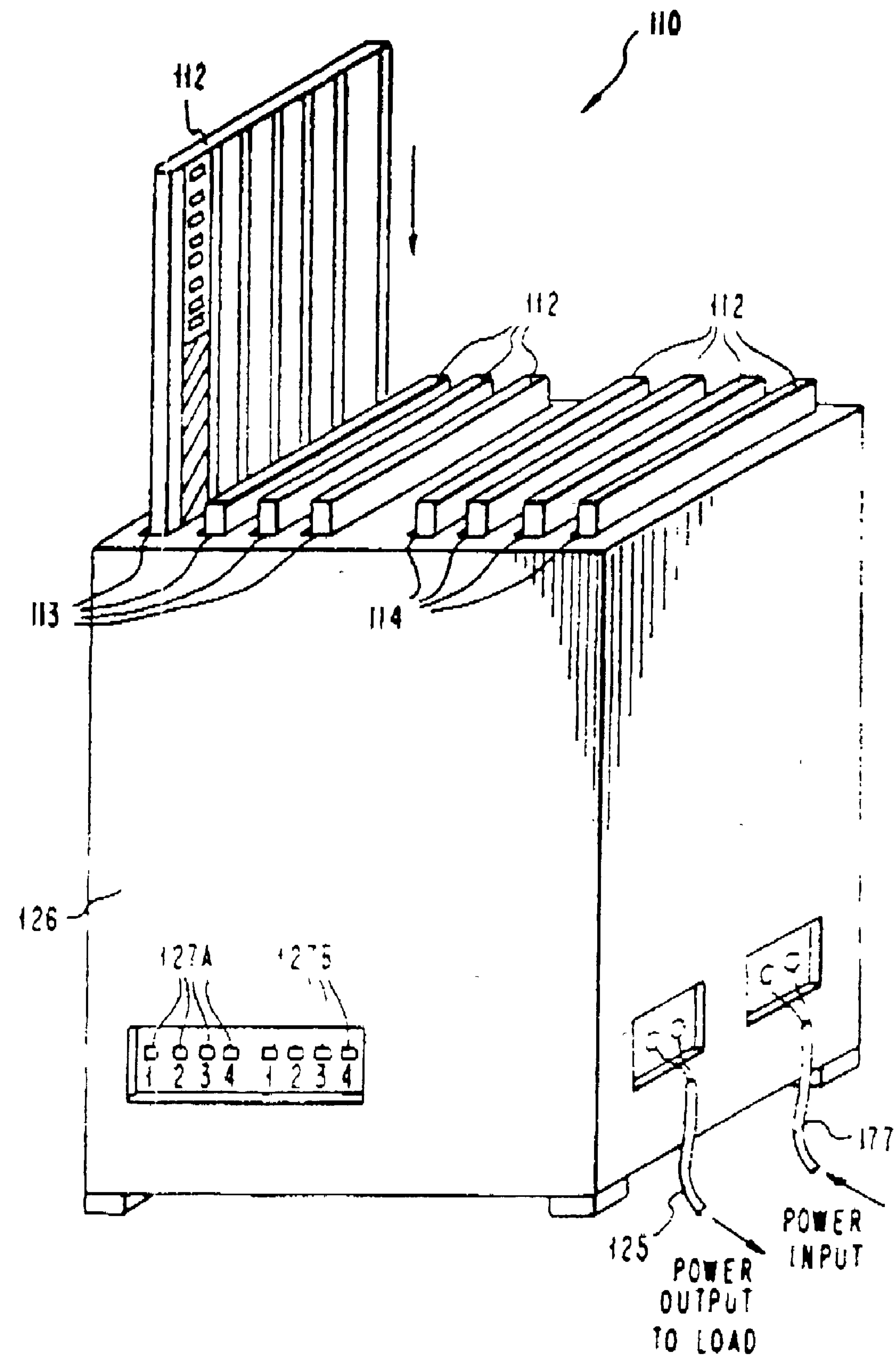

15A
15B
9
3
METAL-FUEL
TAPE SUPPLY
POWER
GENERATION HEAD
5
METAL-FUEL
TAPE
RECHARGING
SUBSYSTEM
TAPE
TRANSPORT
SUBSYSTEM
4
7
CASSETTE
LOADING/
UNLOADING
SUBSYSTEM
2
101
POWER INPUT

FIG.4



110
112
112
112
113
114
126
127A
127B
1 2 3 4 1 2 3 4
177
125
POWER INPUT
POWER OUTPUT TO LOAD

FIG.5A1

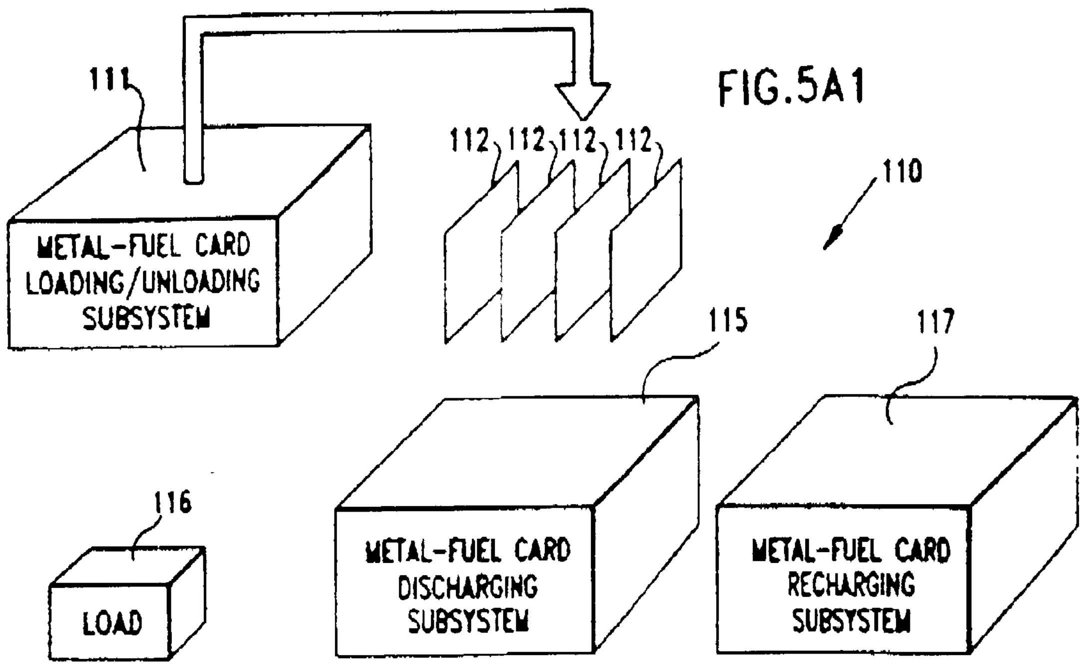
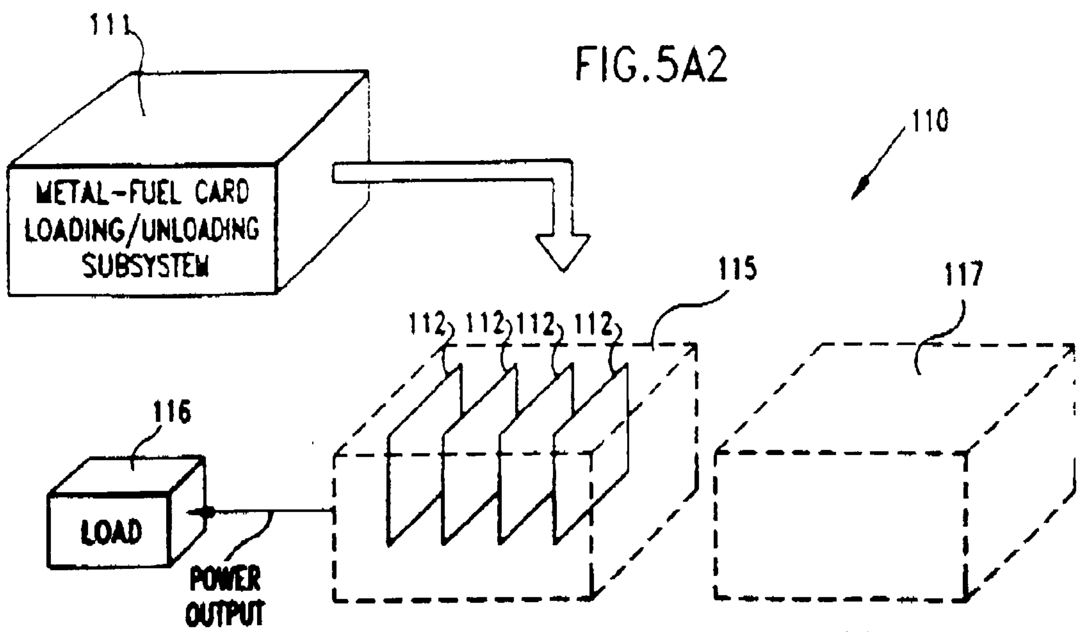


FIG.5A2



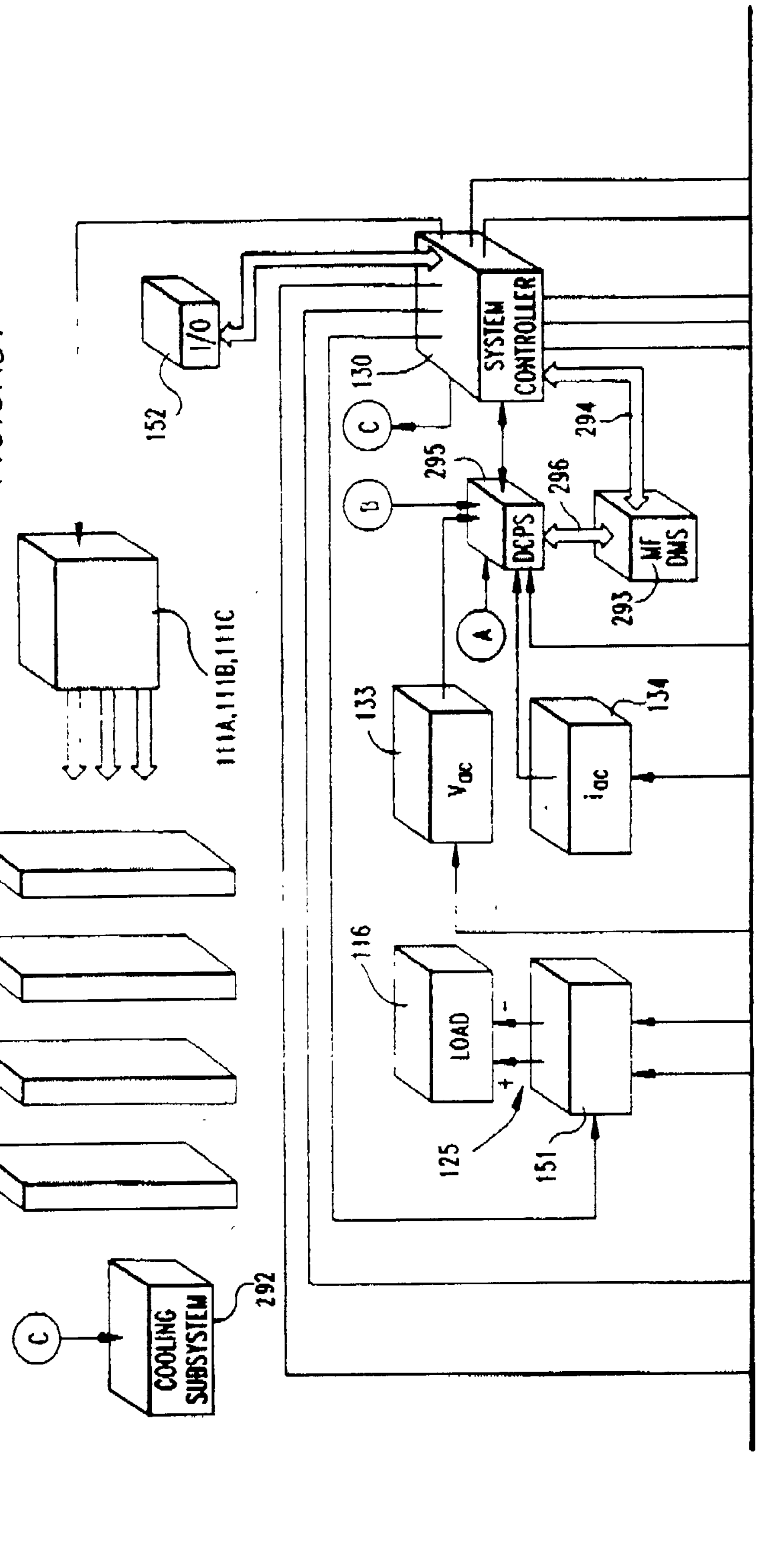
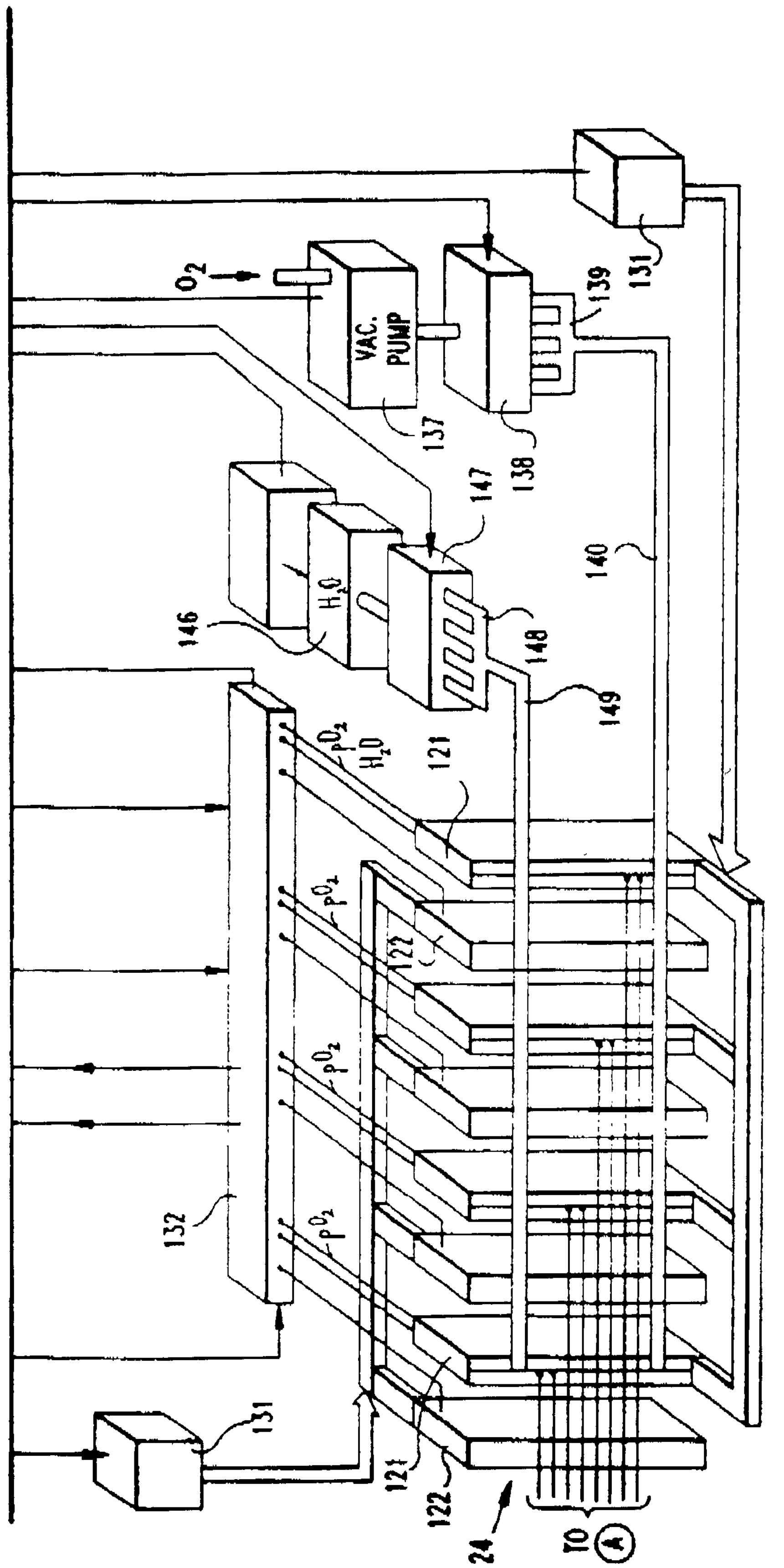

SYSTEM CONTROLLER
130
I/O
152
C
B
A
295
DCPS
296
MF DMS
293
294
111A,111B,111C
112
112
112
112
133
V_{ac}
134
i_{ac}
116
LOAD
+
-
125
151
COOLING SUBSYSTEM
292
C

FIG.5A31



O_2
VAC. PUMP
137
138
139
131
147
146
H_2O
148
140
149
121
pO_2
H_2O
122
132
124
TO (A)
115

FIG.5A32

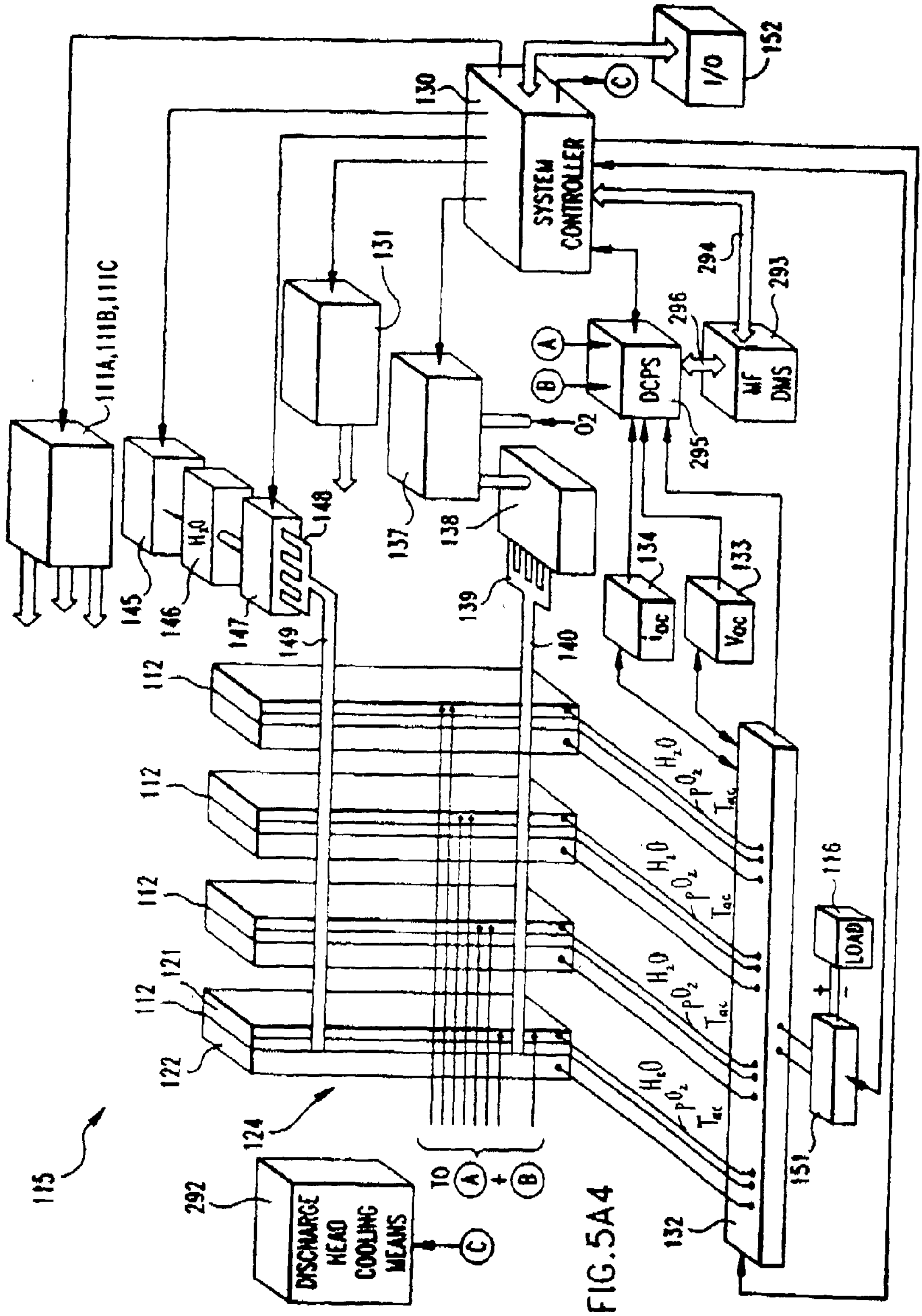
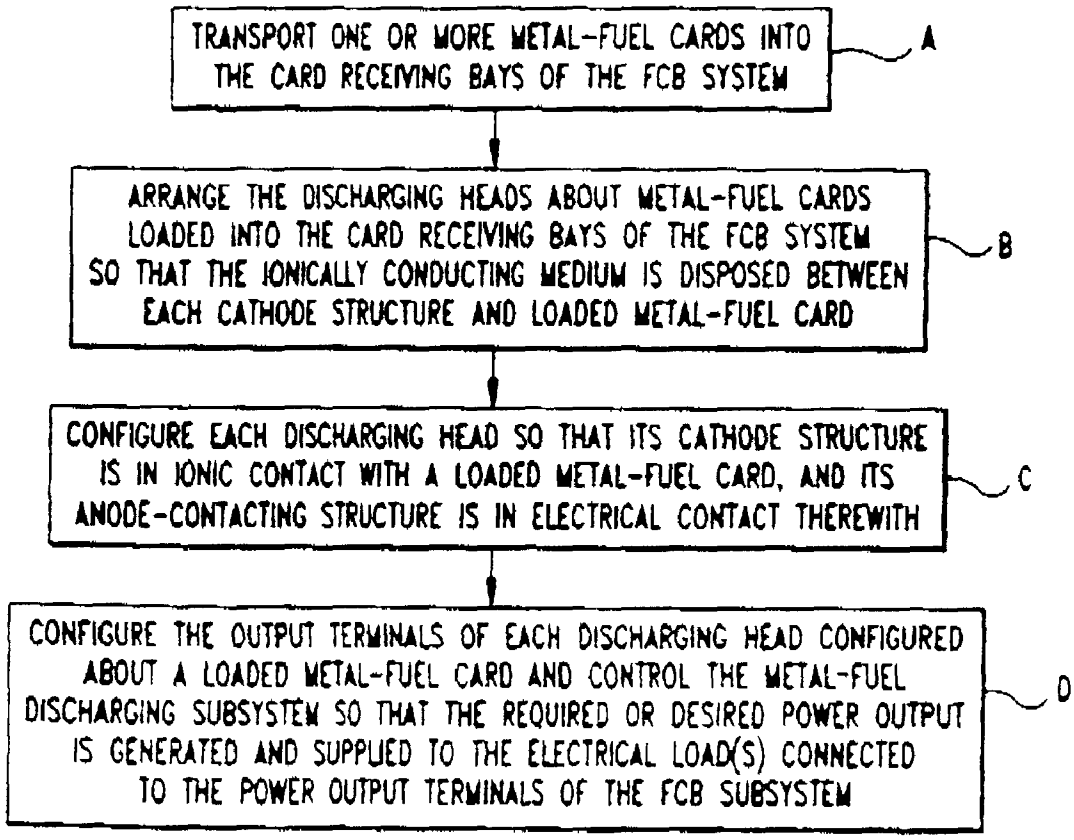

SYSTEM CONTROLLER
I/O
DCPS
MF DMS
DISCHARGE HEAD COOLING MEANS
LOAD
I_{oc}
V_{oc}
H_2O
pO_2
T_{ac}
O2
TO A + B
C
111A,111B,111C
115
112
121
122
124
130
131
132
133
134
137
138
139
140
145
146
147
148
149
151
152
116
292
293
294
295
296

FIG.5A4

FIG.5A5


TRANSPORT ONE OR MORE METAL-FUEL CARDS INTO THE CARD RECEIVING BAYS OF THE FCB SYSTEM
A
ARRANGE THE DISCHARGING HEADS ABOUT METAL-FUEL CARDS LOADED INTO THE CARD RECEIVING BAYS OF THE FCB SYSTEM SO THAT THE IONICALLY CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND LOADED METAL-FUEL CARD
B
CONFIGURE EACH DISCHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A LOADED METAL-FUEL CARD, AND ITS ANODE-CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
C
CONFIGURE THE OUTPUT TERMINALS OF EACH DISCHARGING HEAD CONFIGURED ABOUT A LOADED METAL-FUEL CARD AND CONTROL THE METAL-FUEL DISCHARGING SUBSYSTEM SO THAT THE REQUIRED OR DESIRED POWER OUTPUT IS GENERATED AND SUPPLIED TO THE ELECTRICAL LOAD(S) CONNECTED TO THE POWER OUTPUT TERMINALS OF THE FCB SUBSYSTEM
D

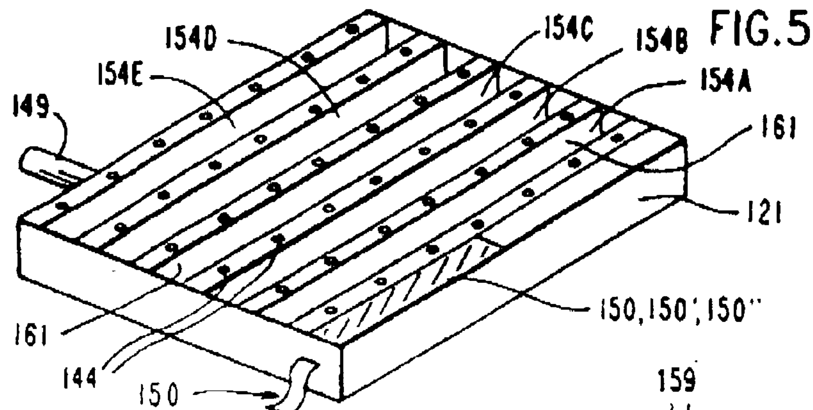
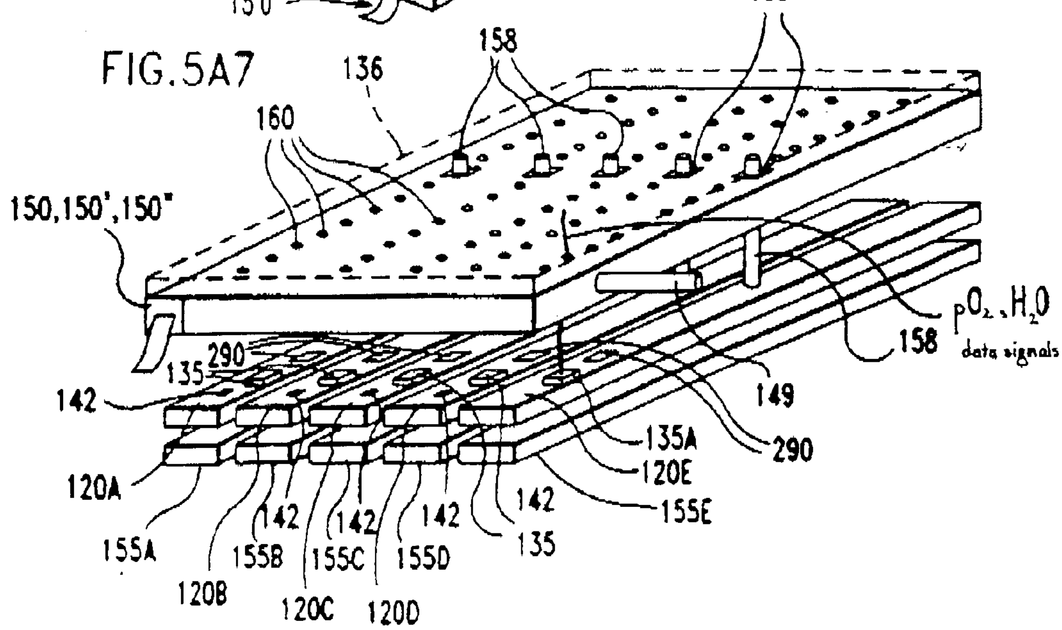


FIG.5A6

FIG.5A7



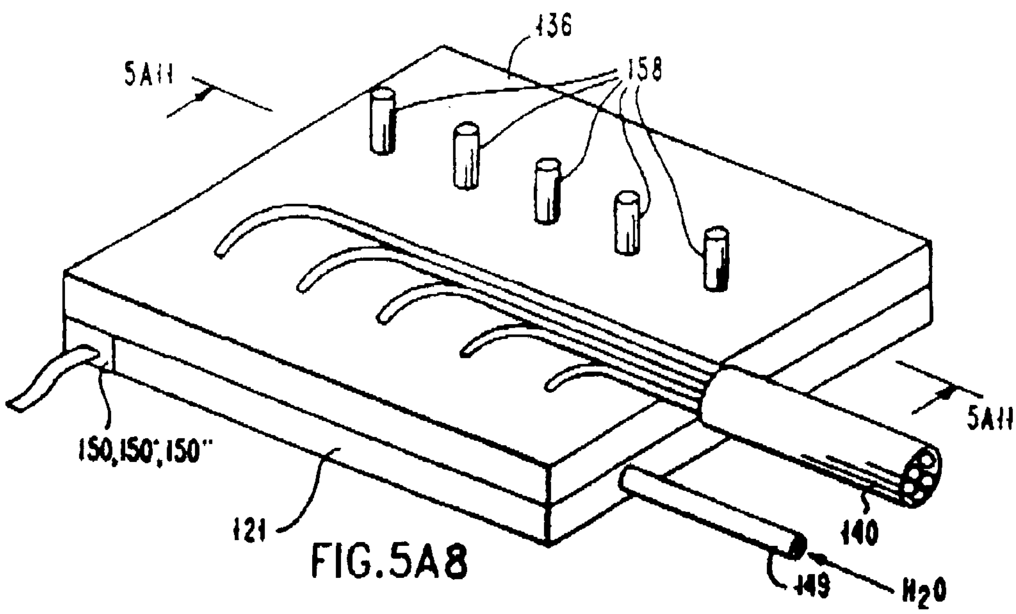


FIG.5A8

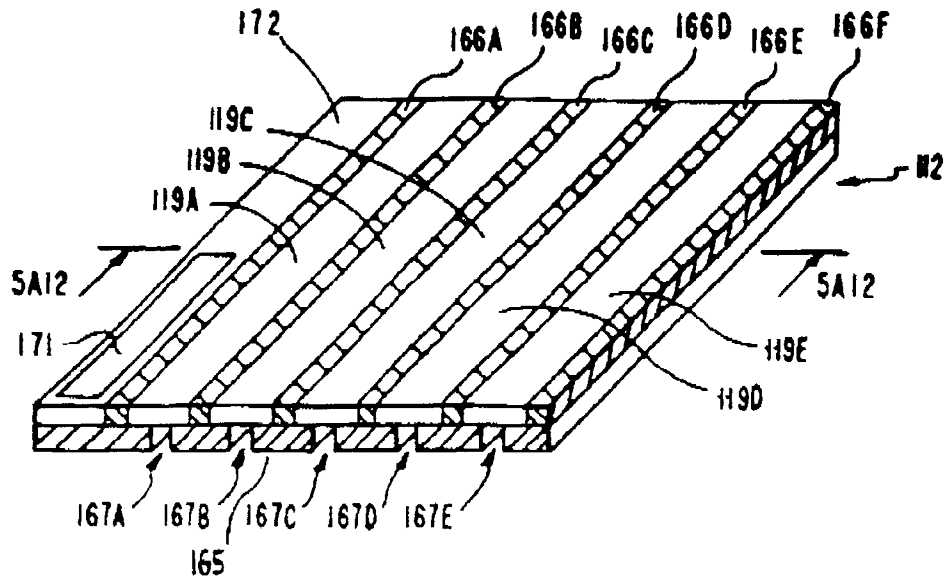


FIG.5A9

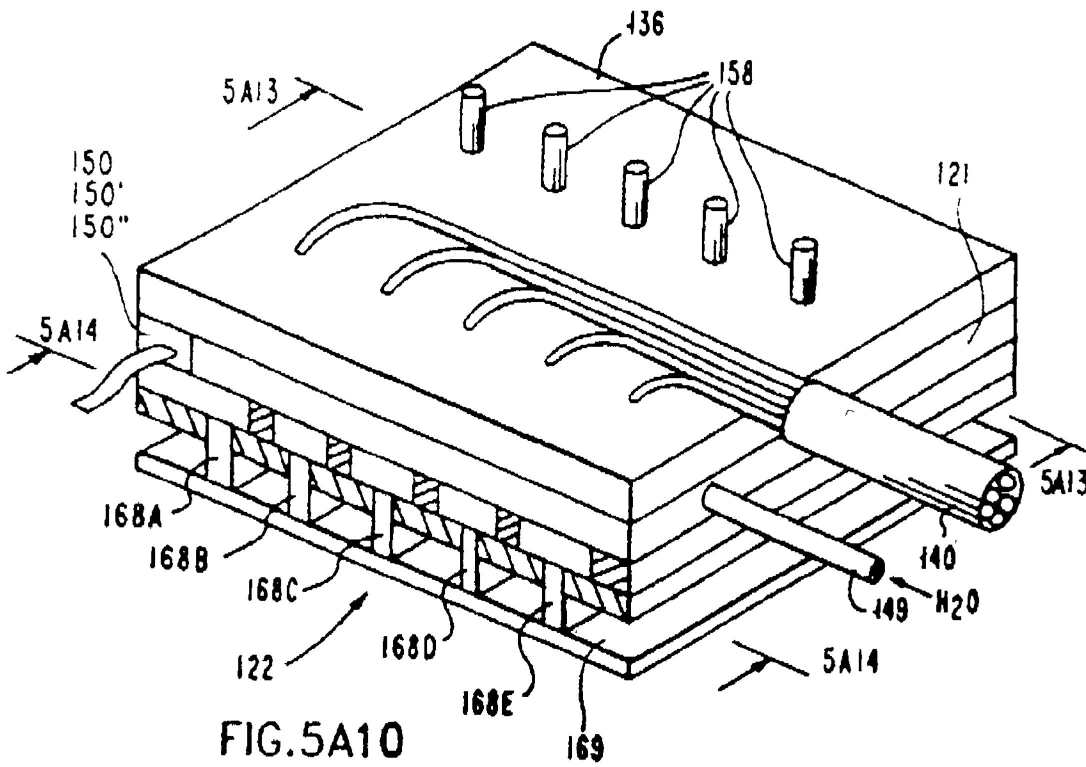


FIG.5A10

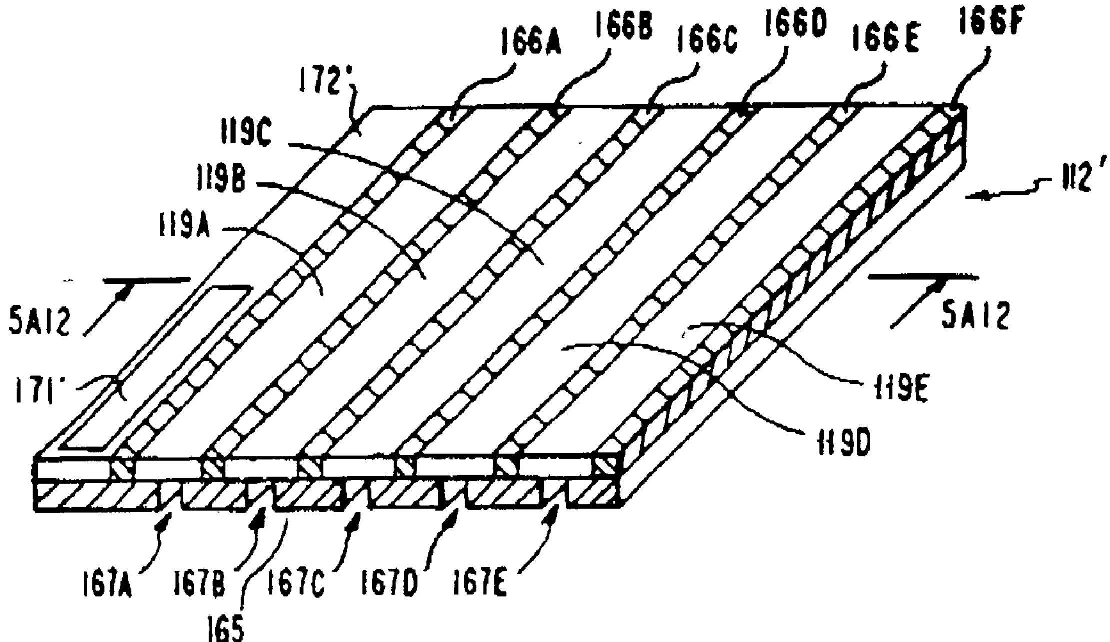


FIG.5A9'

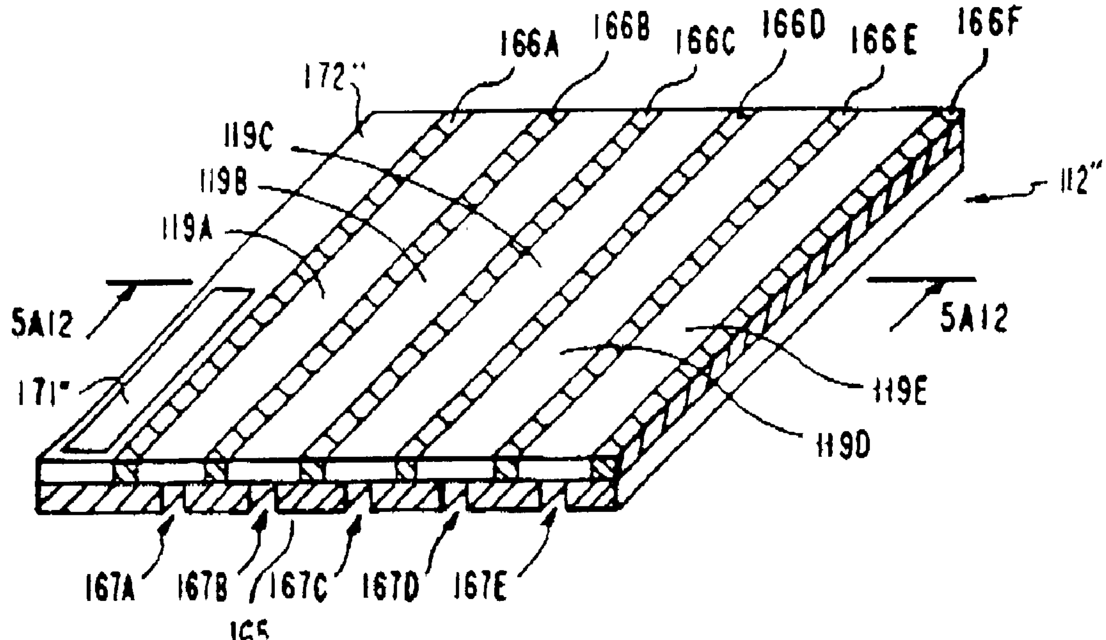


FIG.5A9"

FIG.5A11

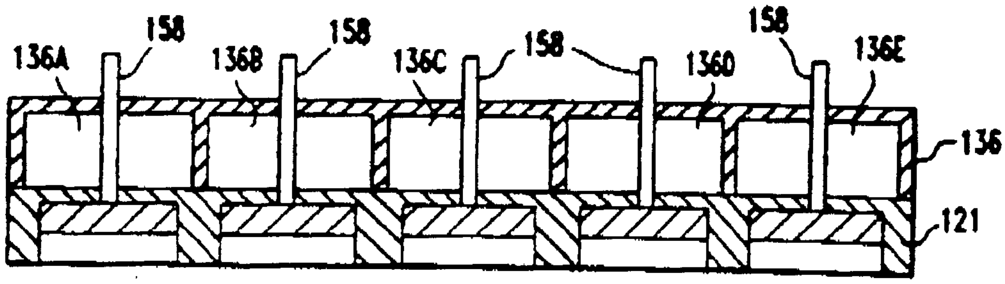


FIG.5A12

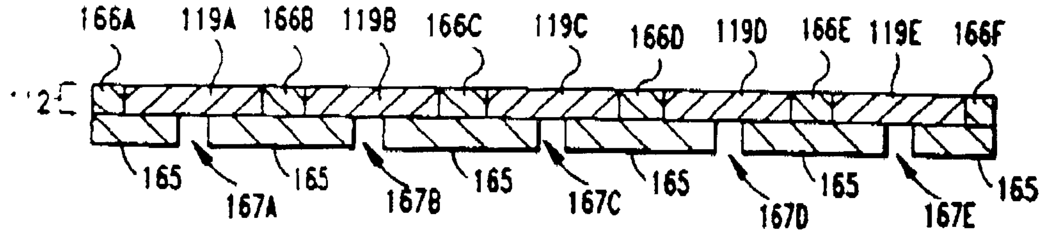


FIG.5A13

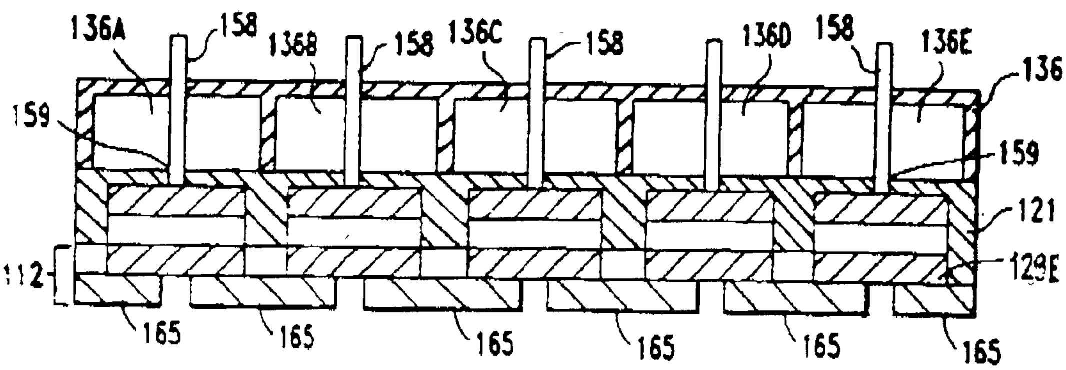


FIG.5A14

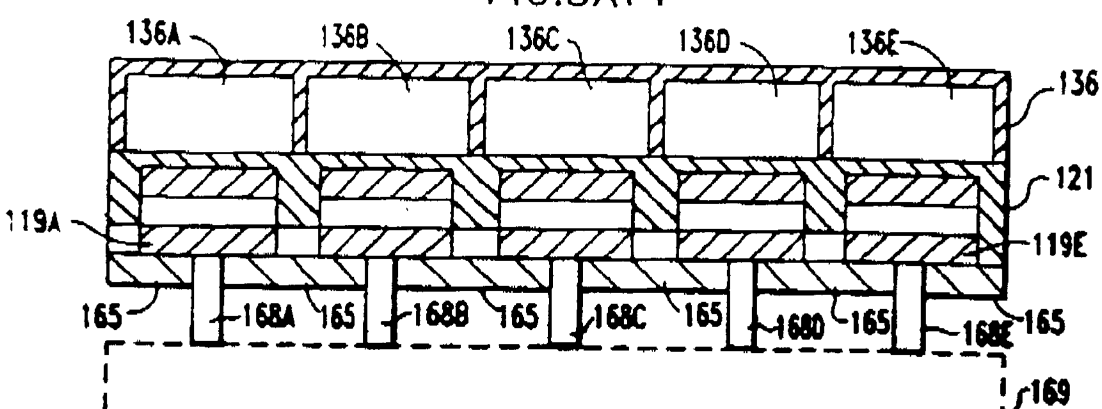
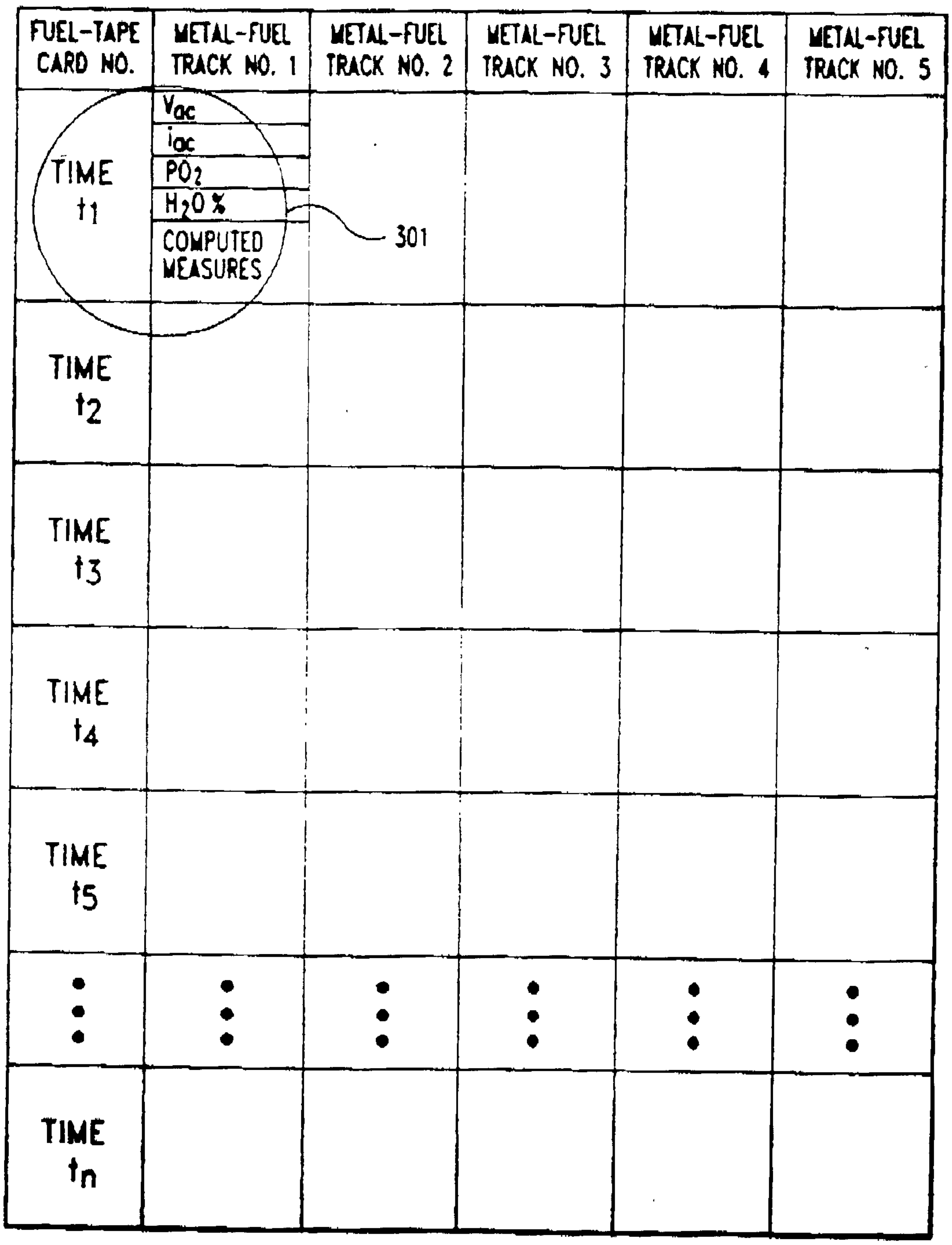


FIG.5A15

DISCHARGE DATA STRUCTURE



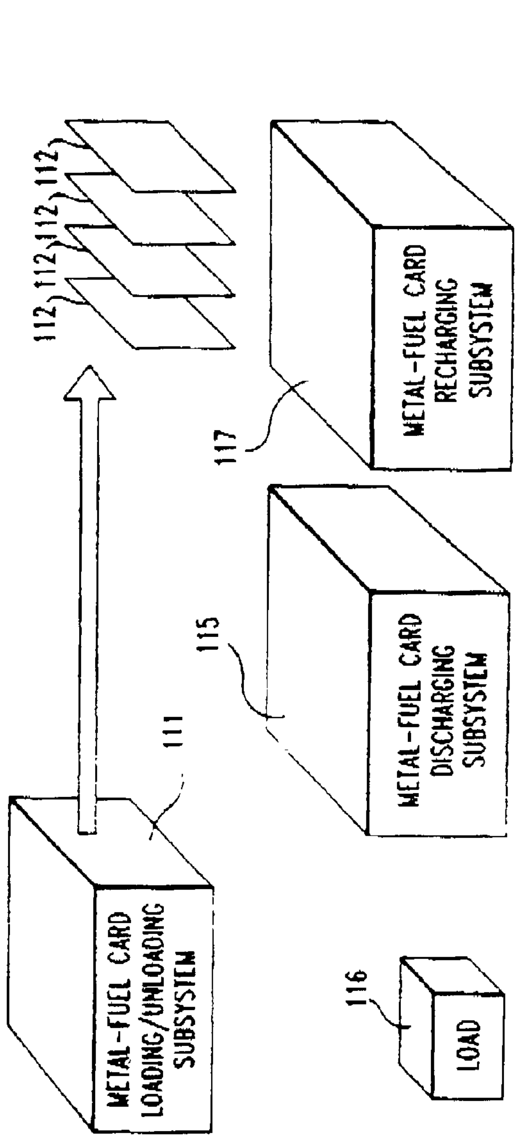


FIG.5B1

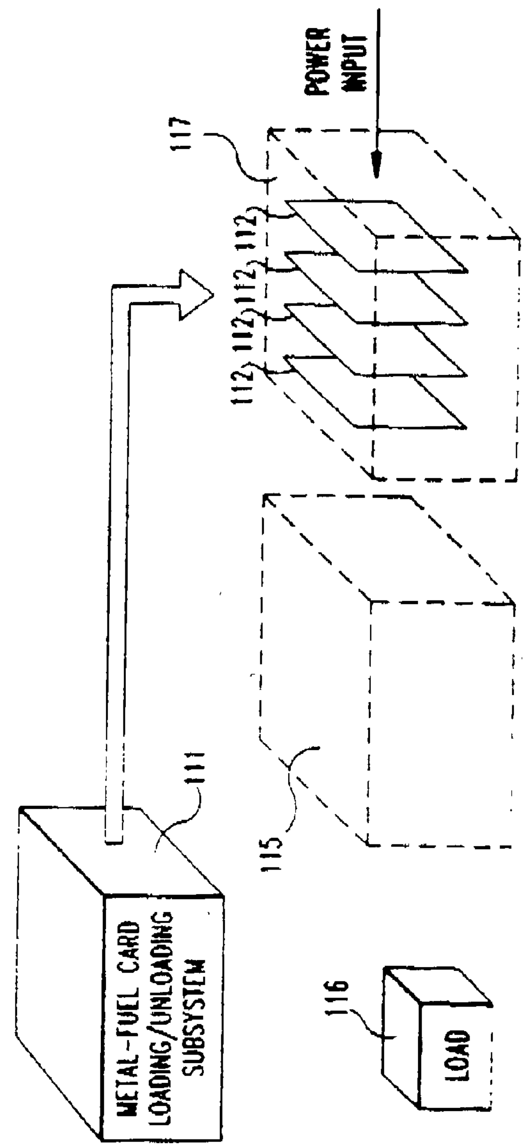
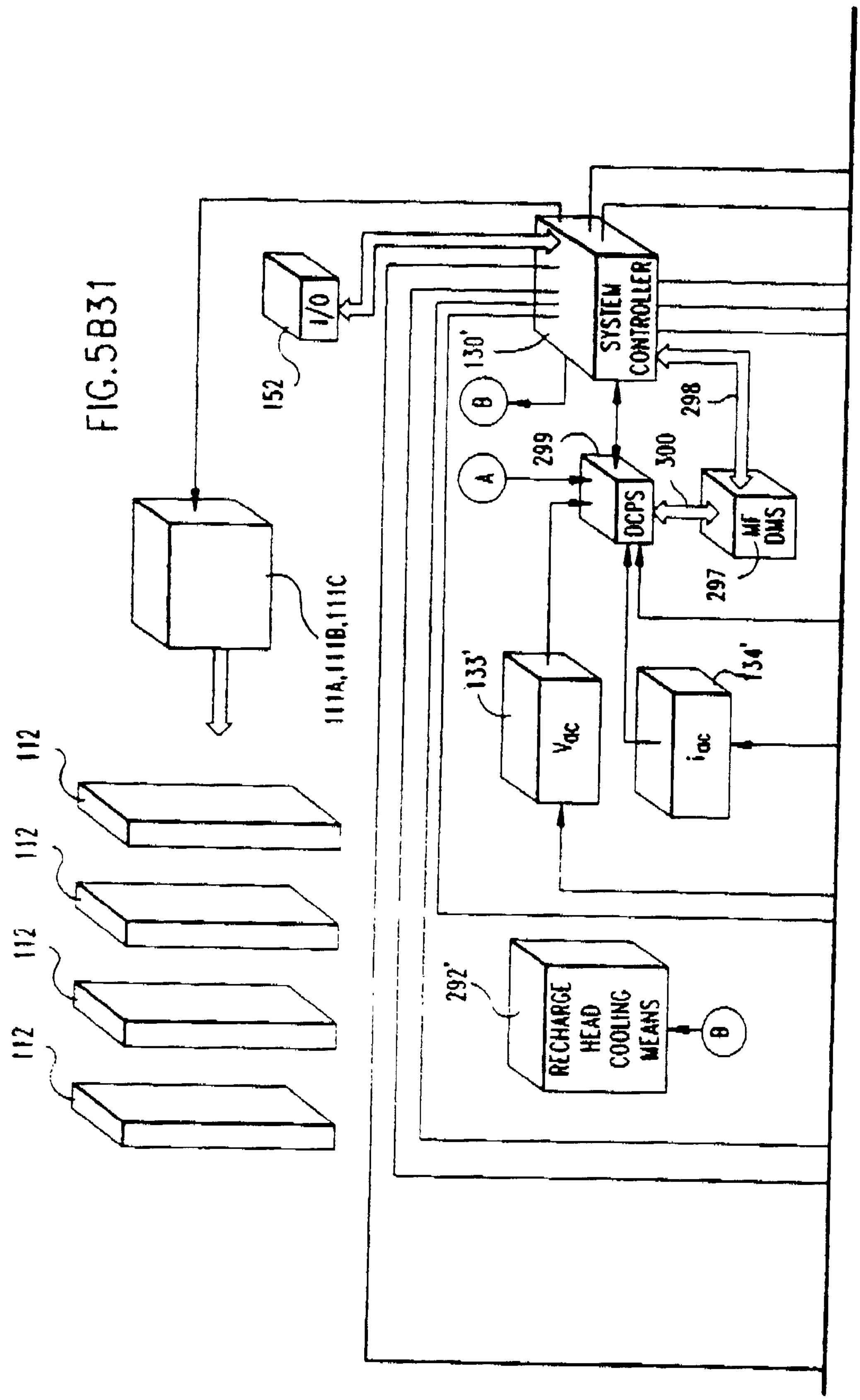


FIG.5B2



112
112
112
112
111A,111B,111C
152
I/O
SYSTEM CONTROLLER
130'
B
A
299
DCPS
300
298
MF DMS
297
133'
V_{dc}
134'
i_{dc}
292'
RECHARGE HEAD COOLING MEANS
B

FIG.5B31

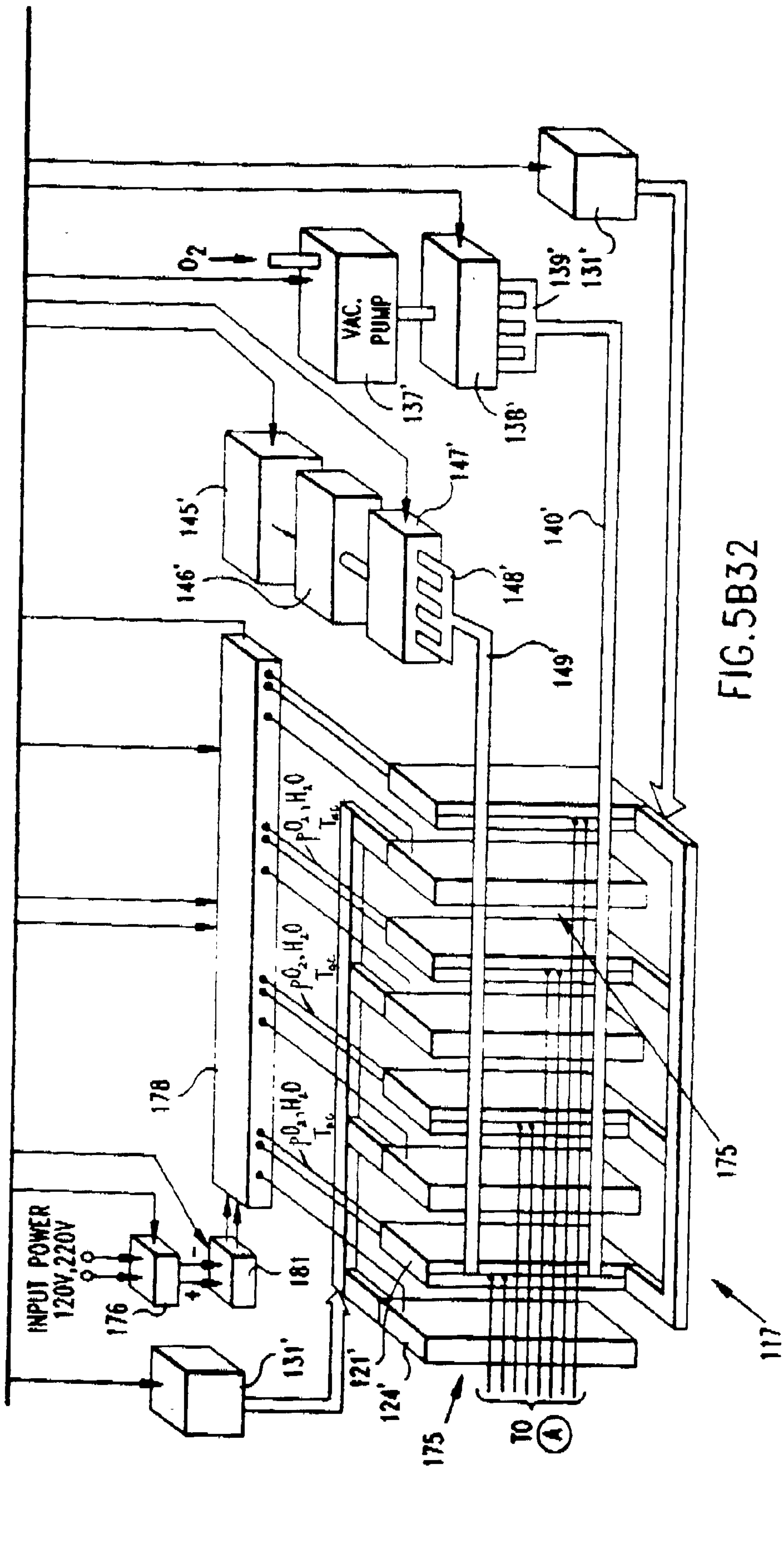

INPUT POWER
120V,220V
176
181
131'
178
121'
124'
175
TO A
117
175
149'
148'
146'
145'
147'
140'
137'
138'
139'
131'
VAC. PUMP
O_2

FIG.5B32

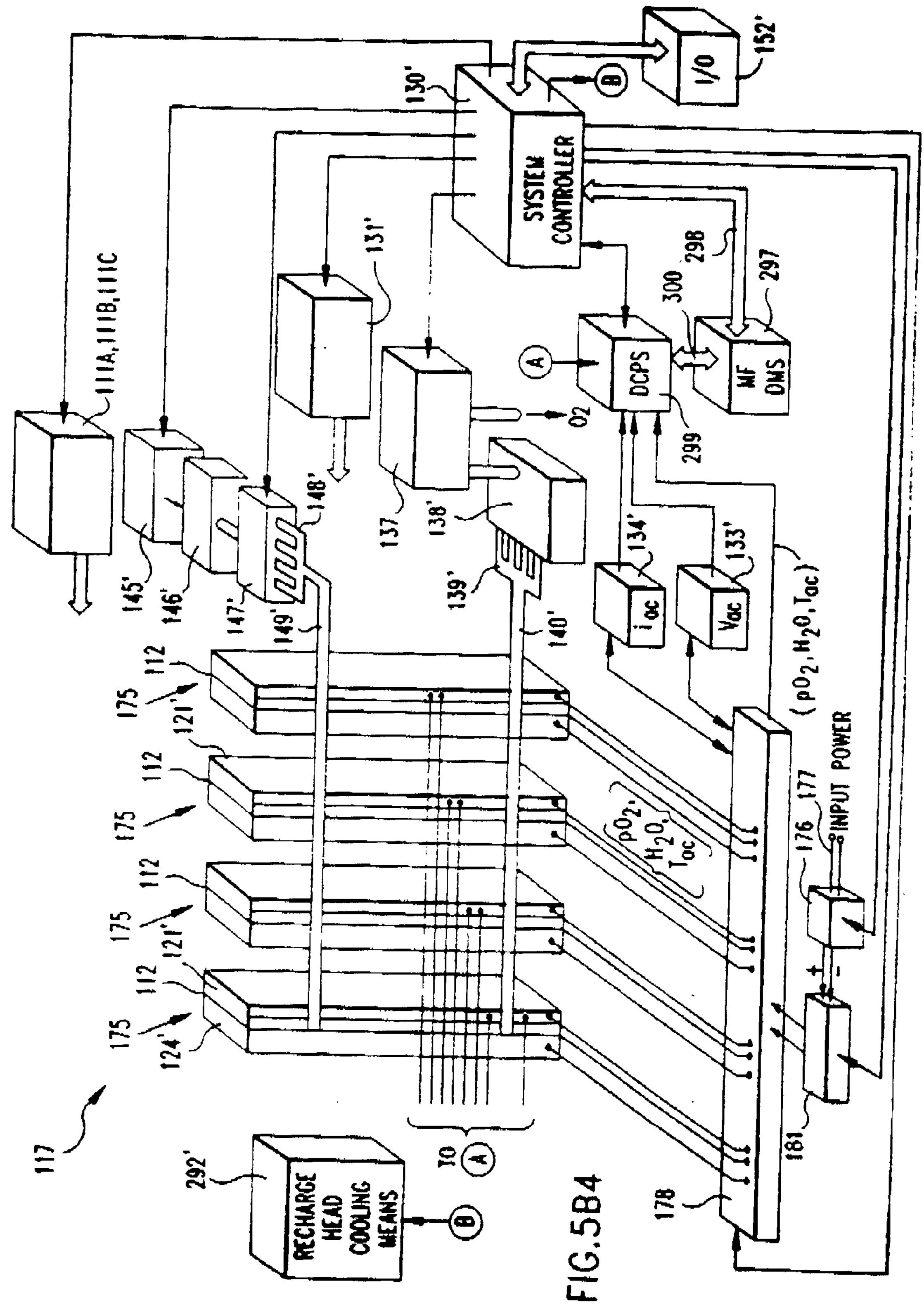
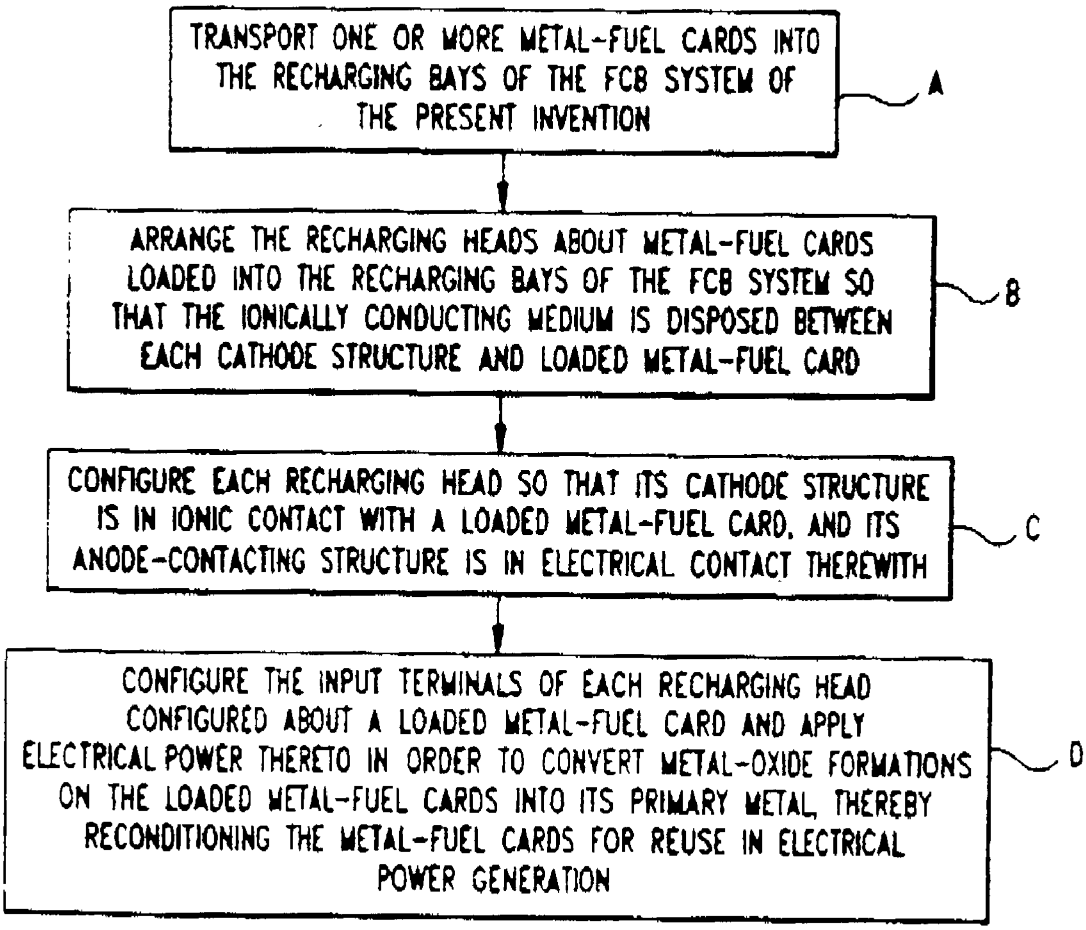

SYSTEM CONTROLLER
I/O
DCPS
MF ONS
RECHARGE HEAD COOLING MEANS
INPUT POWER
TO A
i_{ac}
V_{ac}
O_2
(pO_2, H_2O, T_{ac})
111A,111B,111C
117
130'
131'
133'
134'
137
138'
139'
140'
145'
146'
147'
148'
149'
152'
175
176
177
178
181
112
121'
124'
292'
297
298
299
300

FIG.5B4

FIG. 5B5


TRANSPORT ONE OR MORE METAL-FUEL CARDS INTO THE RECHARGING BAYS OF THE FCB SYSTEM OF THE PRESENT INVENTION
A
ARRANGE THE RECHARGING HEADS ABOUT METAL-FUEL CARDS LOADED INTO THE RECHARGING BAYS OF THE FCB SYSTEM SO THAT THE IONICALLY CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND LOADED METAL-FUEL CARD
B
CONFIGURE EACH RECHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A LOADED METAL-FUEL CARD, AND ITS ANODE-CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
C
CONFIGURE THE INPUT TERMINALS OF EACH RECHARGING HEAD CONFIGURED ABOUT A LOADED METAL-FUEL CARD AND APPLY ELECTRICAL POWER THERETO IN ORDER TO CONVERT METAL-OXIDE FORMATIONS ON THE LOADED METAL-FUEL CARDS INTO ITS PRIMARY METAL, THEREBY RECONDITIONING THE METAL-FUEL CARDS FOR REUSE IN ELECTRICAL POWER GENERATION
D

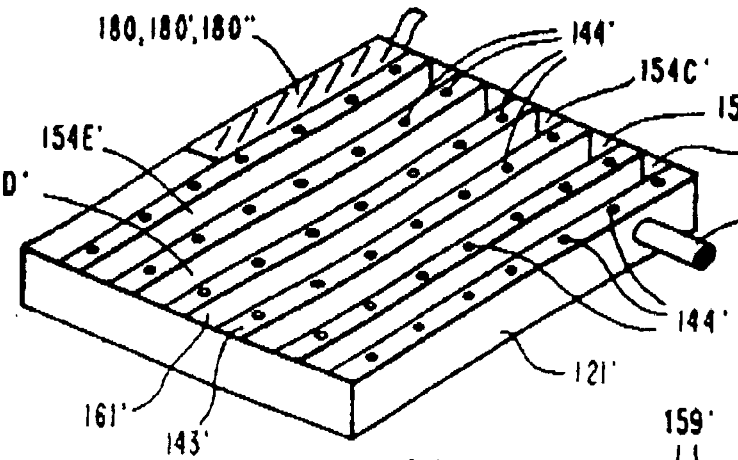


FIG.5B6

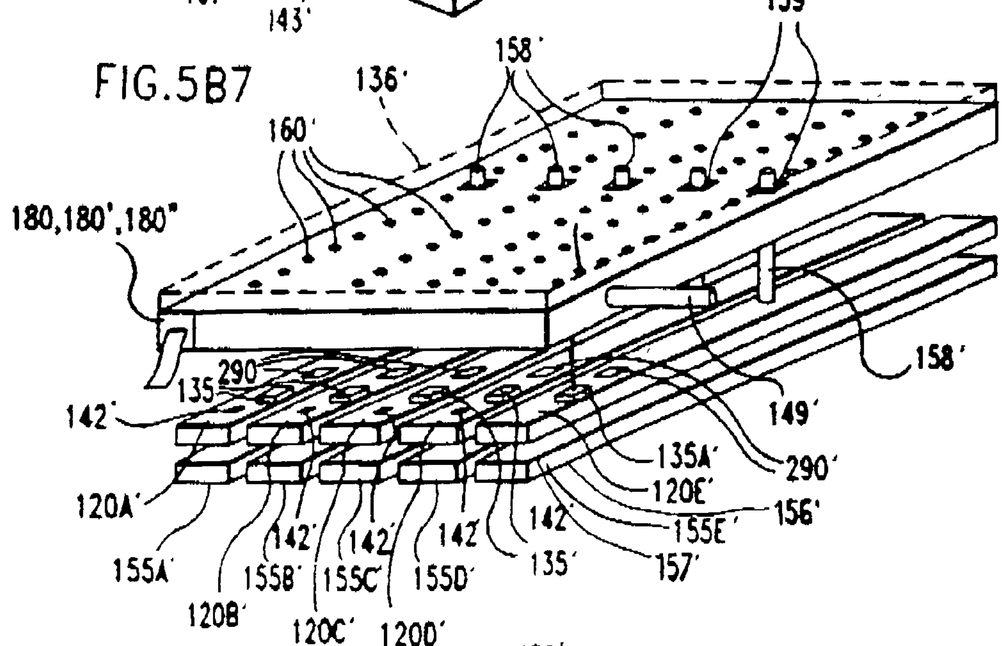


FIG.5B7

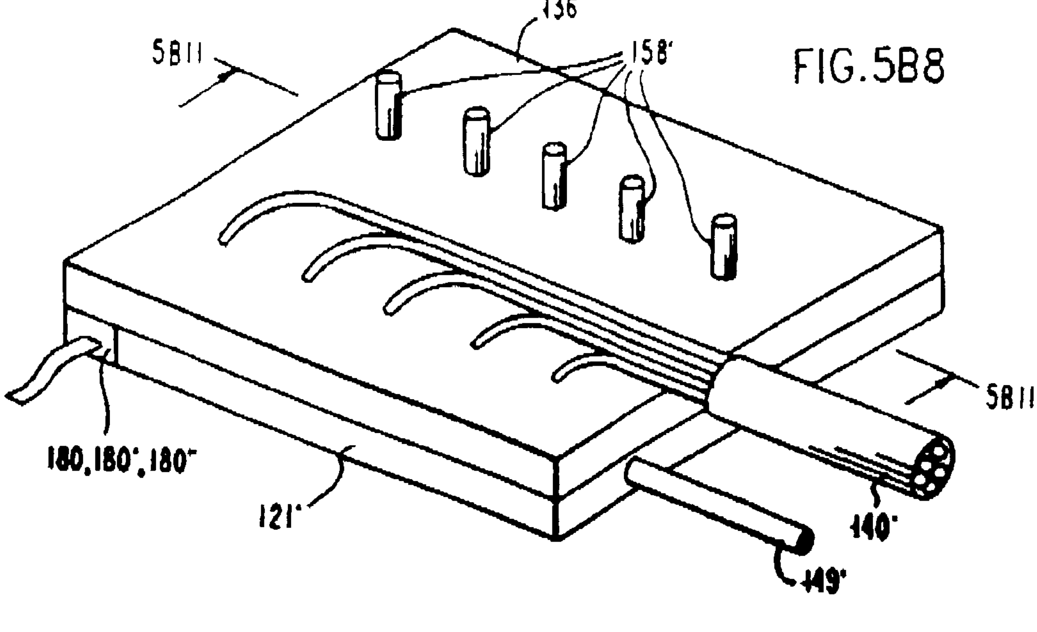


FIG.5B8

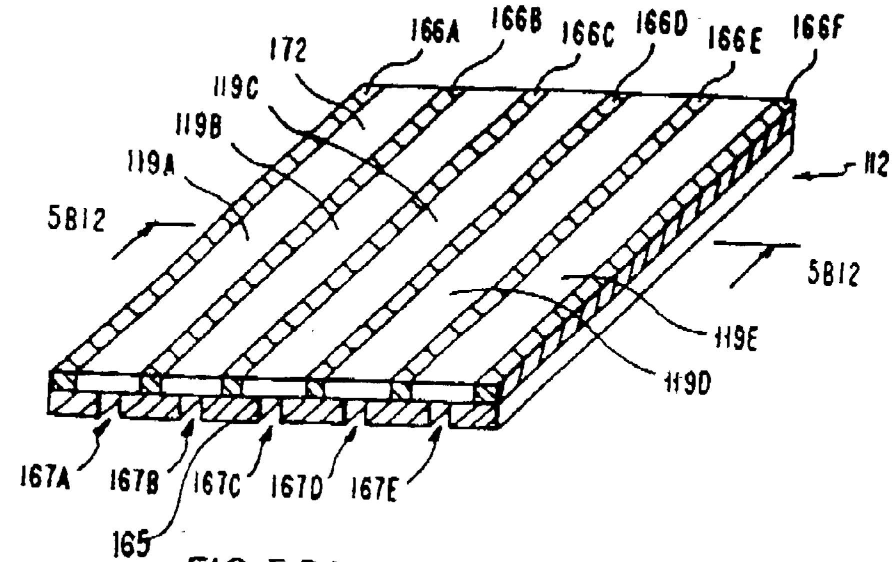


FIG.5B9

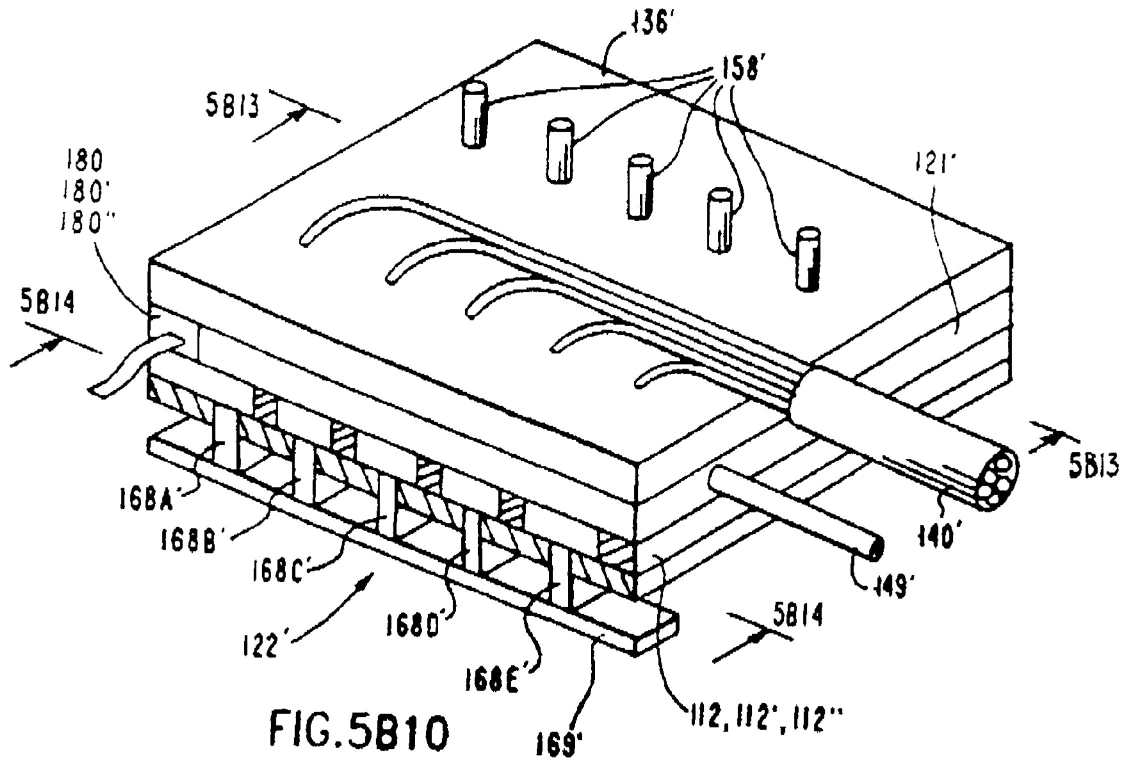


FIG.5B10

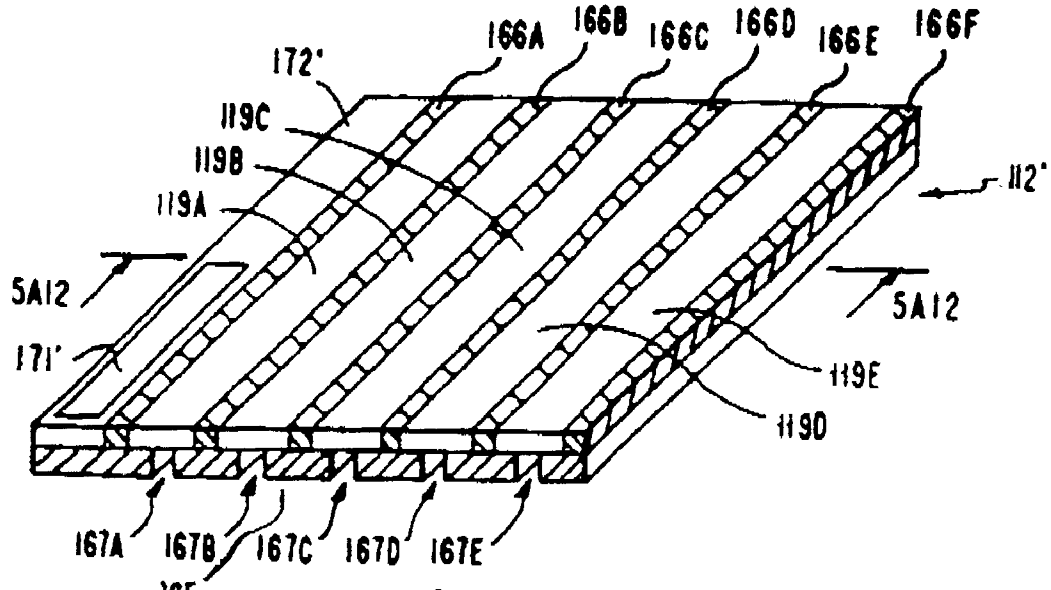


FIG.5B9'

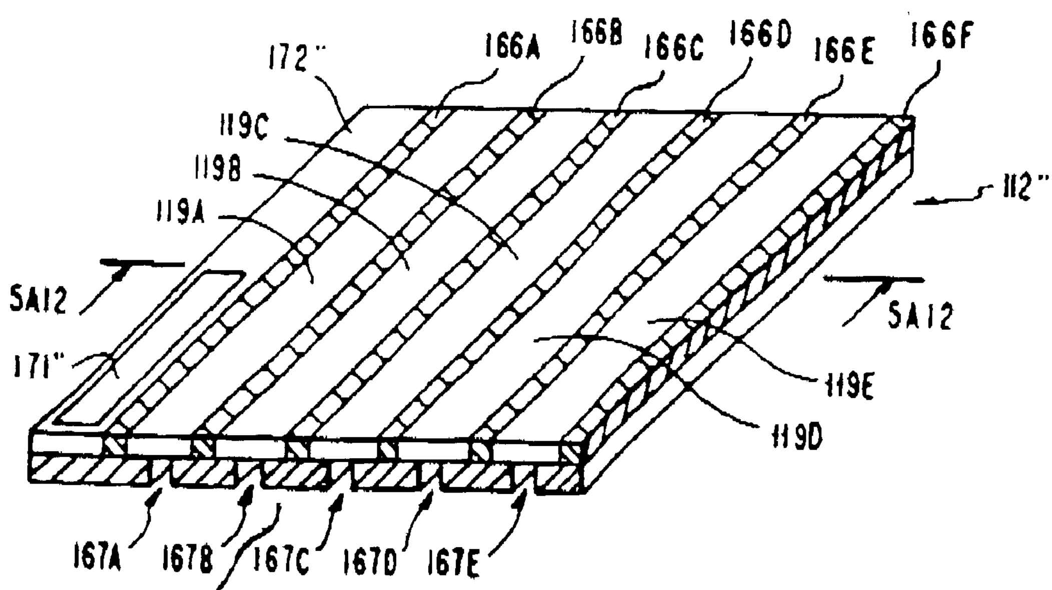


FIG.5B9"

FIG.5B11

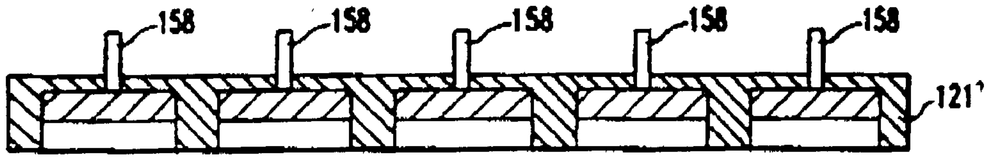


FIG.5B12

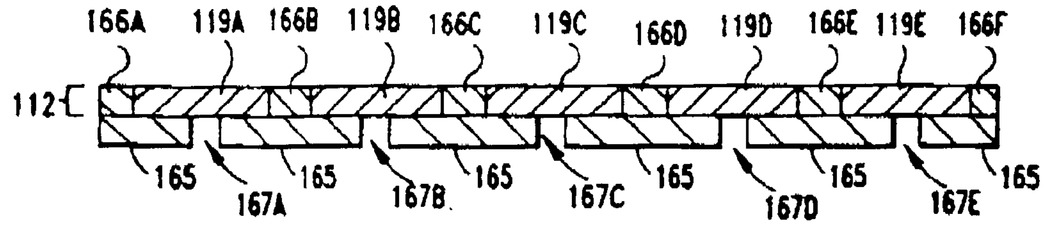


FIG.5B13

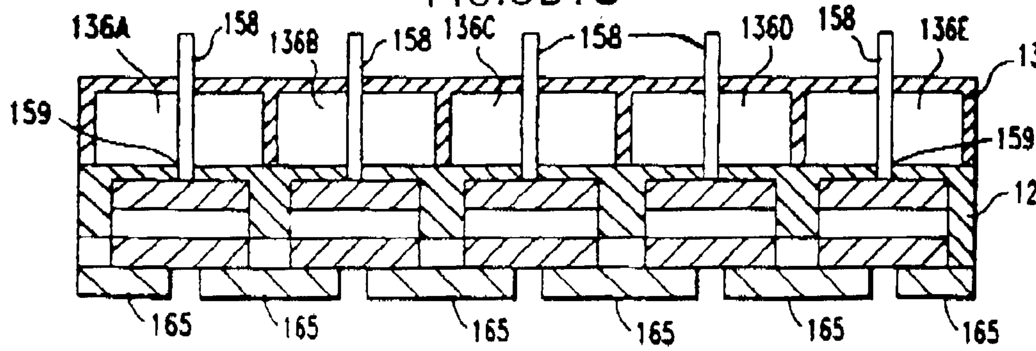


FIG.5B14

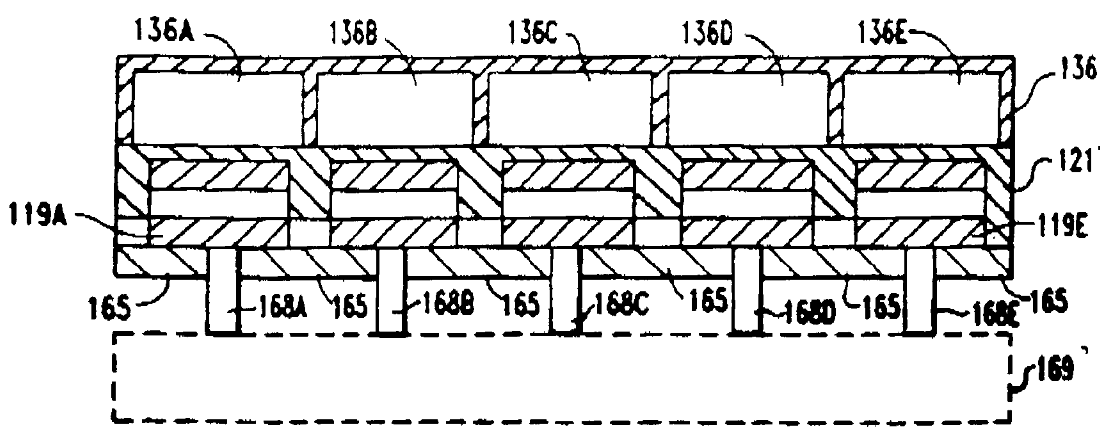


FIG.5B15

RECHARGE DATA STRUCTURE

FUEL-TAPE CARD NO.	METAL-FUEL TRACK NO. 1	METAL-FUEL TRACK NO. 2	METAL-FUEL TRACK NO. 3	METAL-FUEL TRACK NO. 4	METAL-FUEL TRACK NO. 5
TIME t_1	V_{oc} i_{ac} PO_2 H_2O % COMPUTED MEASURES	302			
TIME t_2					
TIME t_3					
TIME t_4					
TIME t_5					
⋮	⋮	⋮	⋮	⋮	⋮
TIME t_n					

FIG.5B16

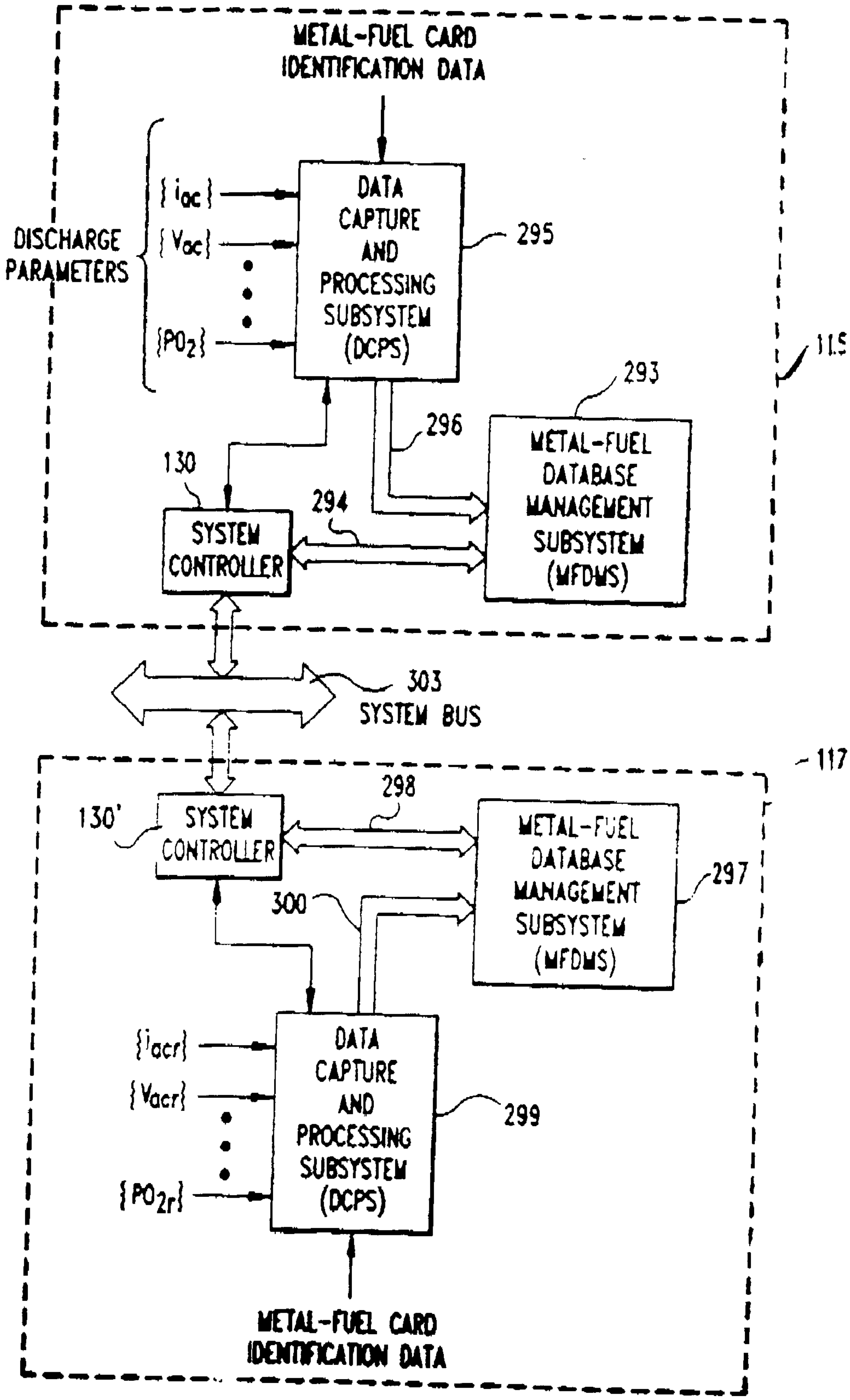
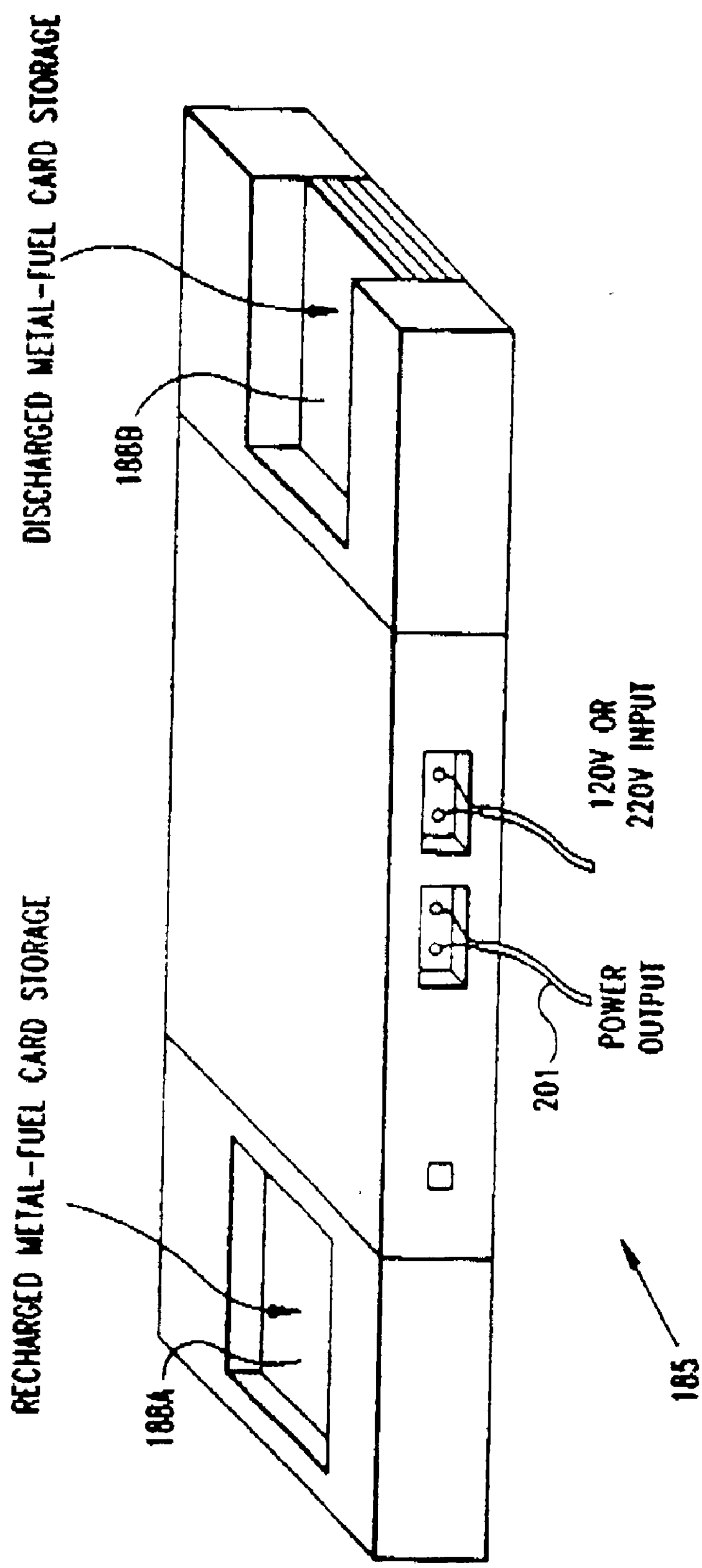

METAL-FUEL CARD
IDENTIFICATION DATA
DISCHARGE PARAMETERS
{i_{ac}}
{V_{ac}}
{PO_2}
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
295
115
293
296
METAL-FUEL DATABASE MANAGEMENT SUBSYSTEM (MFDMS)
130
294
SYSTEM CONTROLLER
303
SYSTEM BUS
117
298
130'
SYSTEM CONTROLLER
METAL-FUEL DATABASE MANAGEMENT SUBSYSTEM (MFDMS)
297
300
{i_{acr}}
{V_{acr}}
{PO_{2r}}
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
299
METAL-FUEL CARD
IDENTIFICATION DATA

FIG.6


DISCHARGED METAL-FUEL CARD STORAGE
188B
RECHARGED METAL-FUEL CARD STORAGE
188A
120V OR
220V INPUT
POWER
OUTPUT
201
185

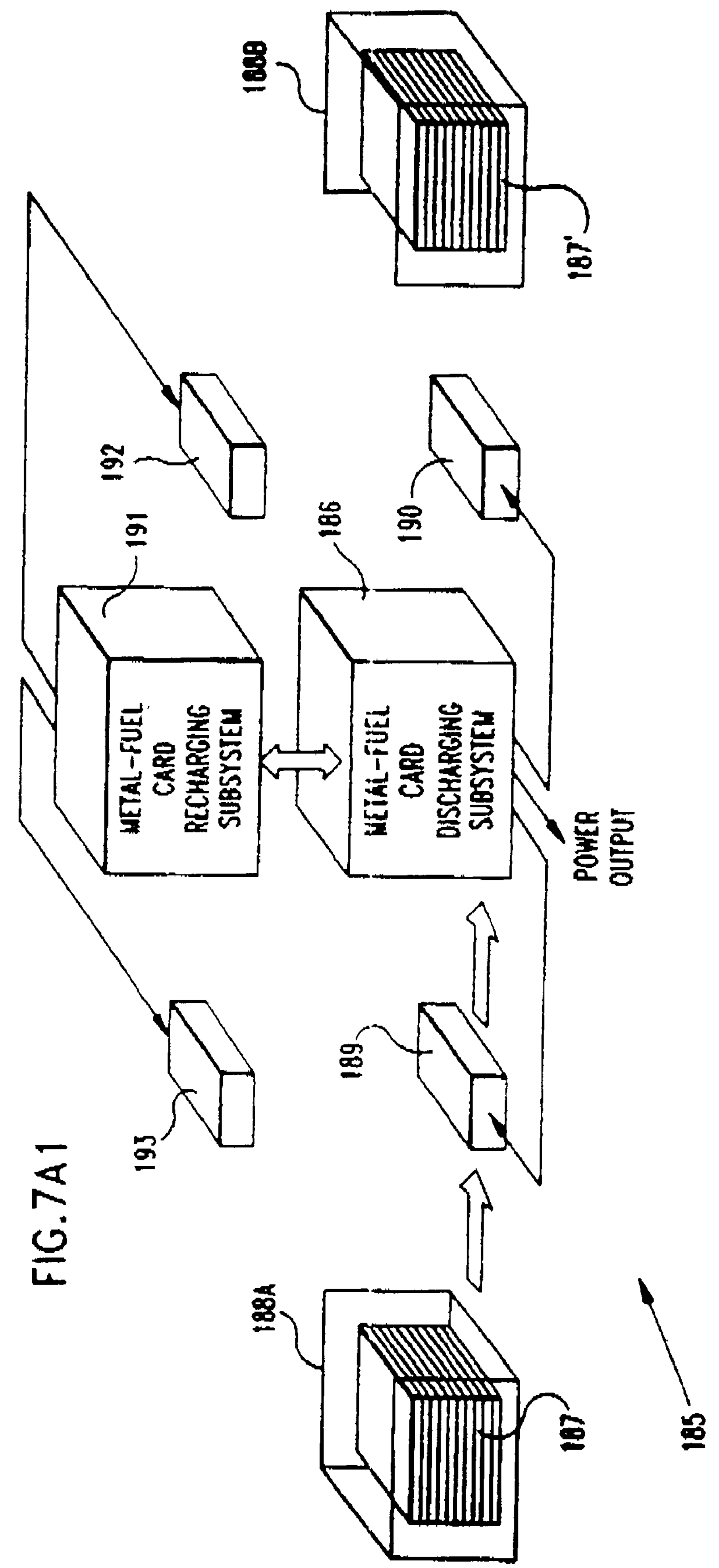

188B
187'
192
191
186
190
METAL-FUEL CARD RECHARGING SUBSYSTEM
METAL-FUEL CARD DISCHARGING SUBSYSTEM
POWER OUTPUT
193
189
188A
187
185

FIG. 7A1

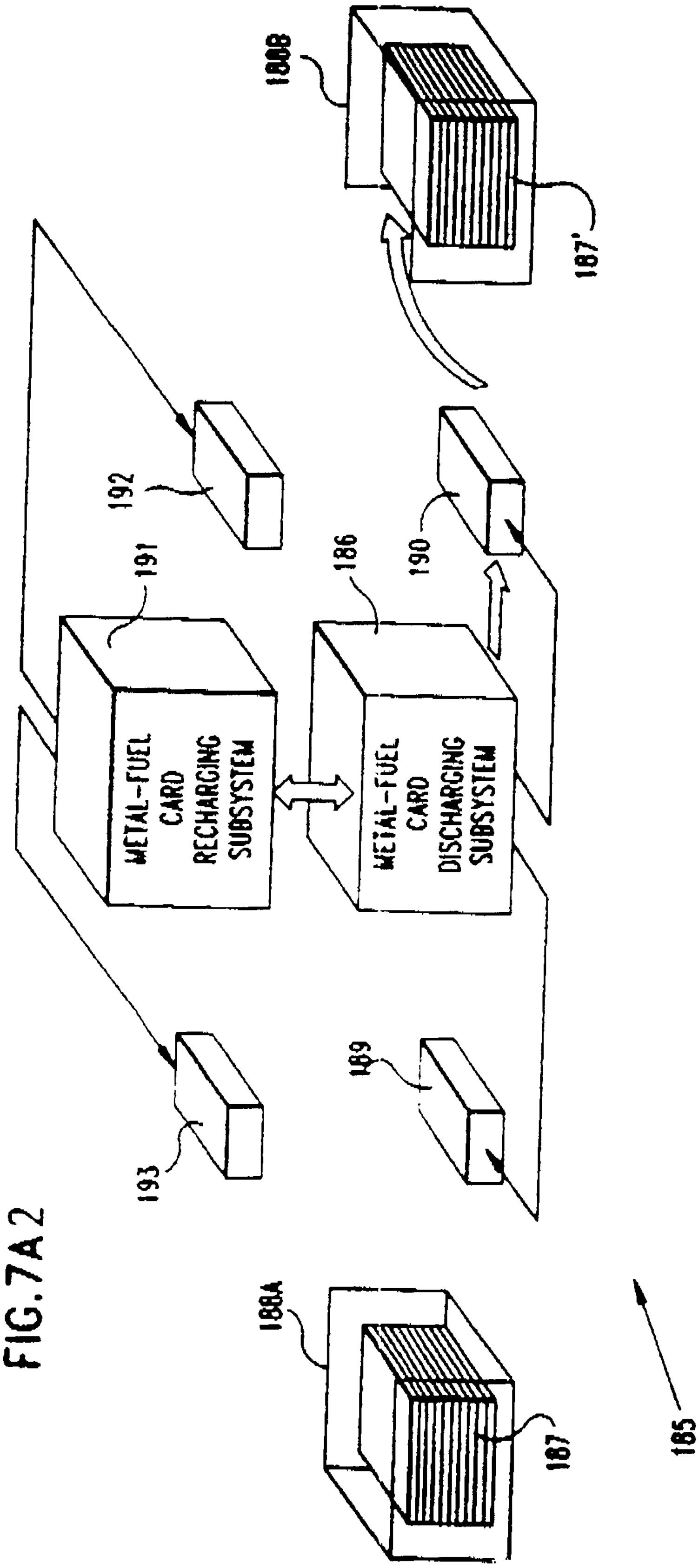

188B
187'
192
191
186
190
METAL-FUEL CARD RECHARGING SUBSYSTEM
METAL-FUEL CARD DISCHARGING SUBSYSTEM
193
189
188A
187
185

FIG. 7A2

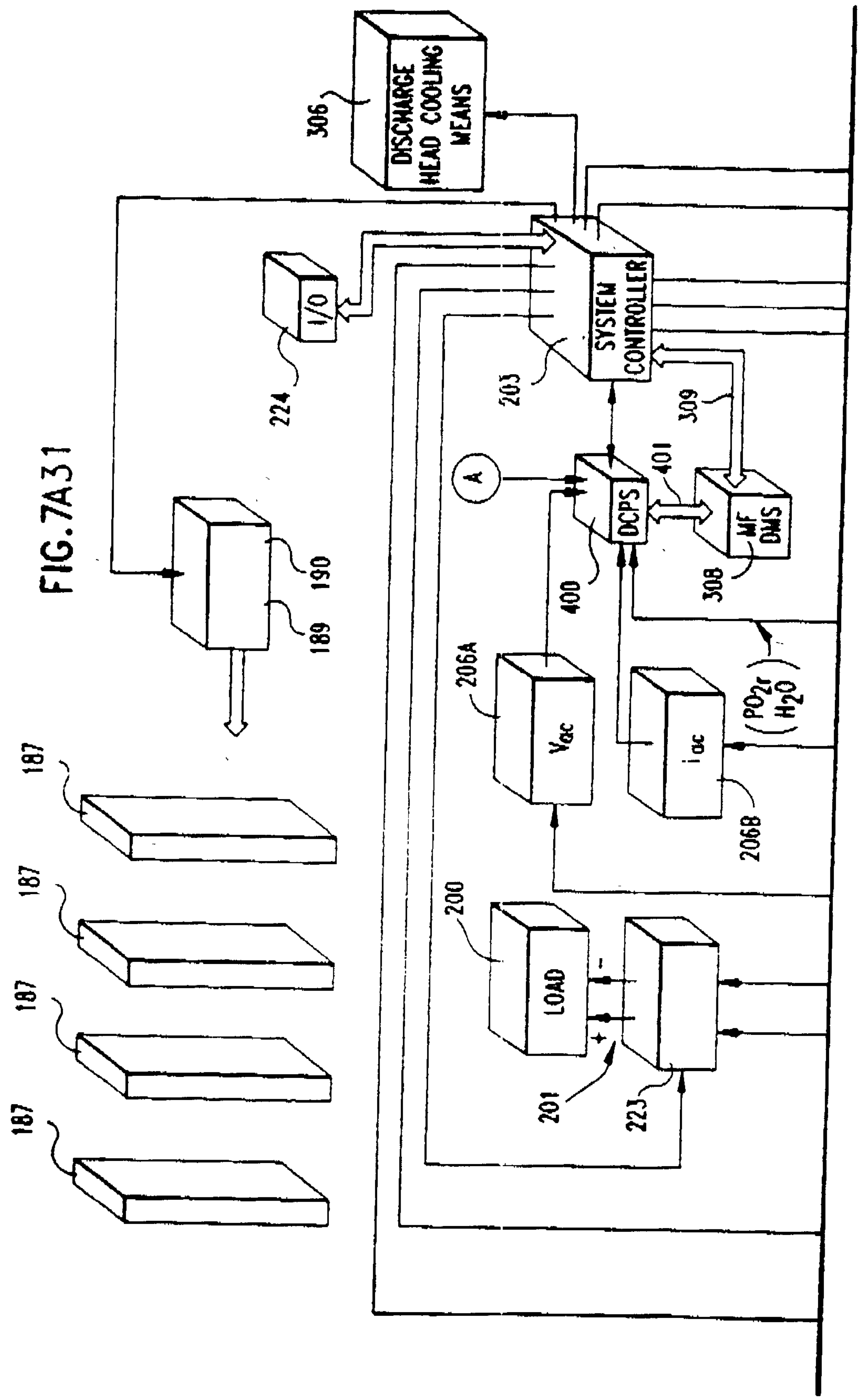
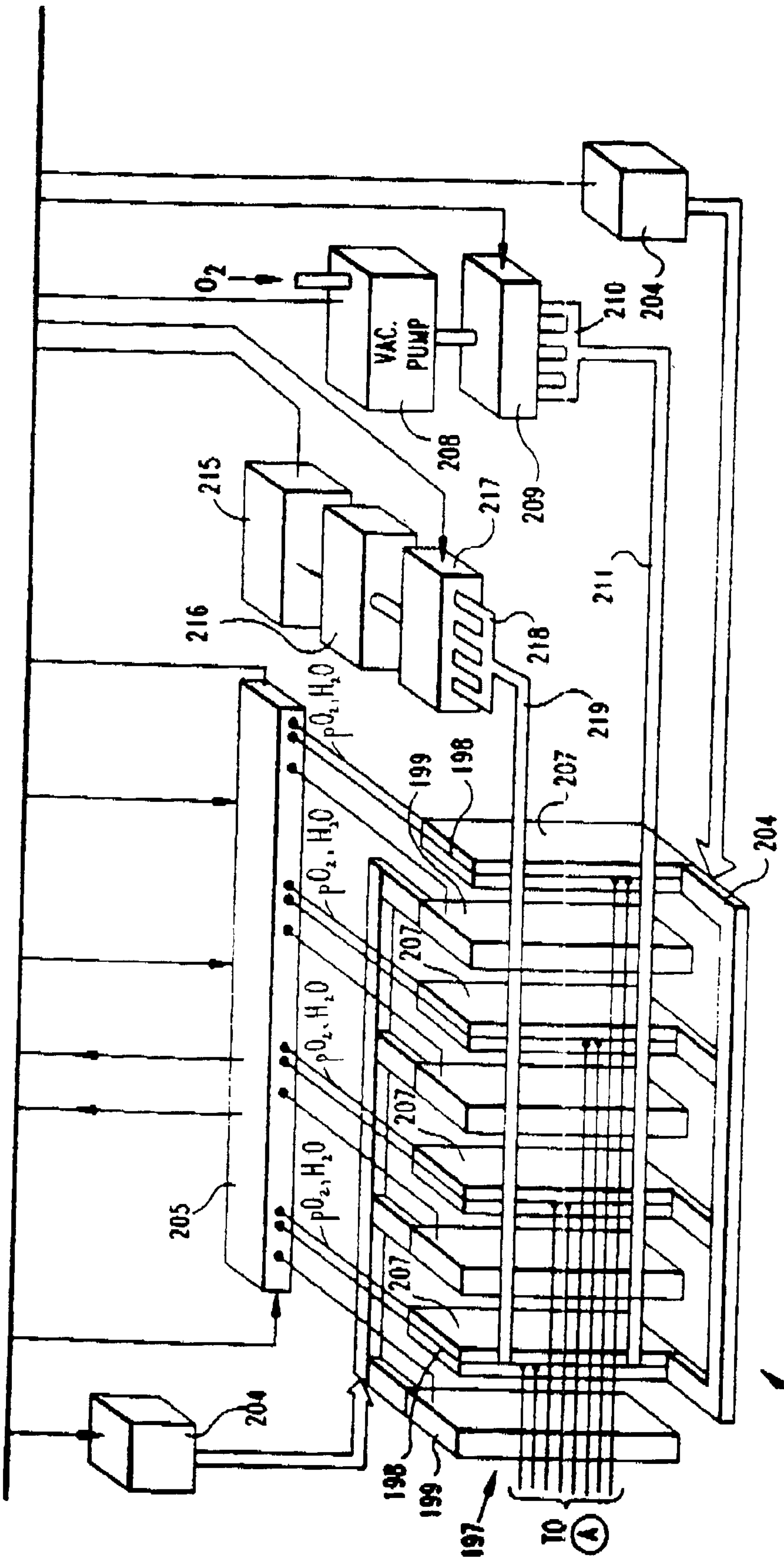

306
DISCHARGE HEAD COOLING MEANS
224
I/O
203
SYSTEM CONTROLLER
309
A
401
DCPS
MF DMS
400
308
190
189
206A
Vac
iac
206B
(PO2 or H2O)
187
187
187
187
200
LOAD
201
223

FIG. 7A31



VAC. PUMP
O_2
pO_2, H_2O
pO_2, H_2O
pO_2, H_2O
pO_2, H_2O
TO (A)
186
197
198
199
204
205
207
208
209
210
211
215
216
217
218
219

FIG. 7A32

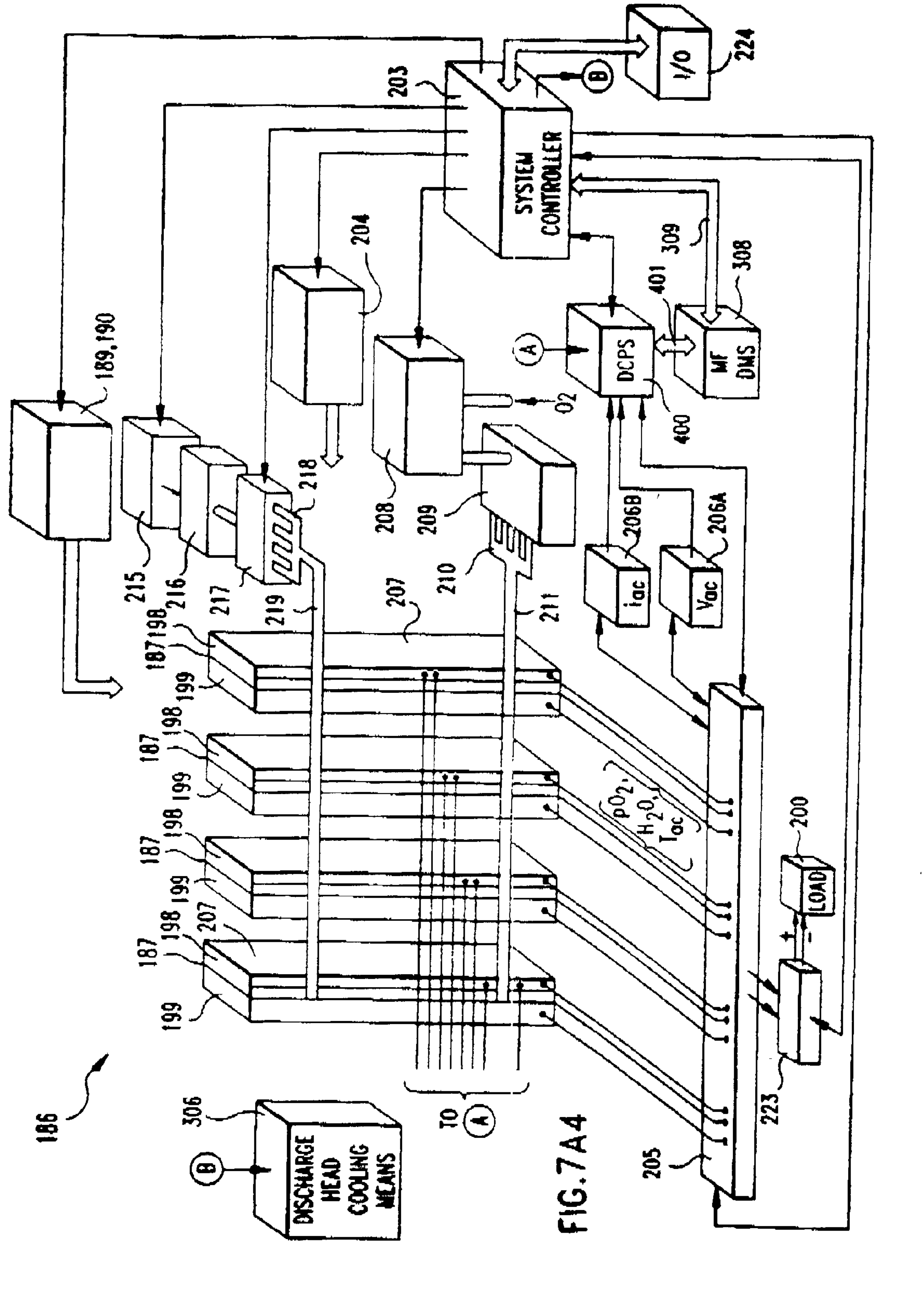

SYSTEM CONTROLLER
I/O
DCPS
MF DMS
LOAD
iac
Vac
DISCHARGE HEAD COOLING MEANS
TO A
pO2, H2O, Tac
O2
186
189,190
203
204
205
206A
206B
207
208
209
210
211
215
216
217
218
219
223
224
187
198
199
200
306
308
309
400
401

FIG. 7A4

FIG.7A5

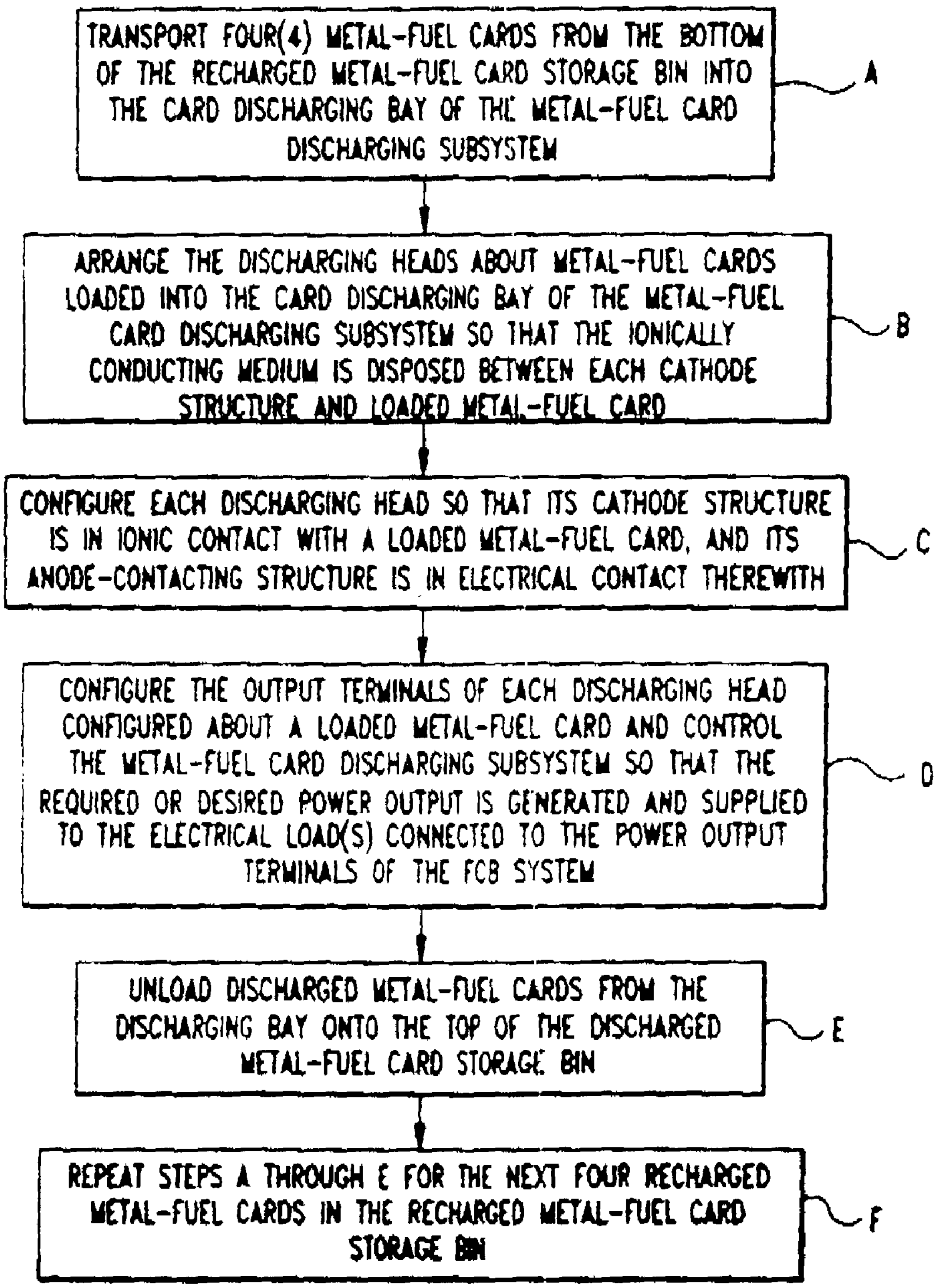
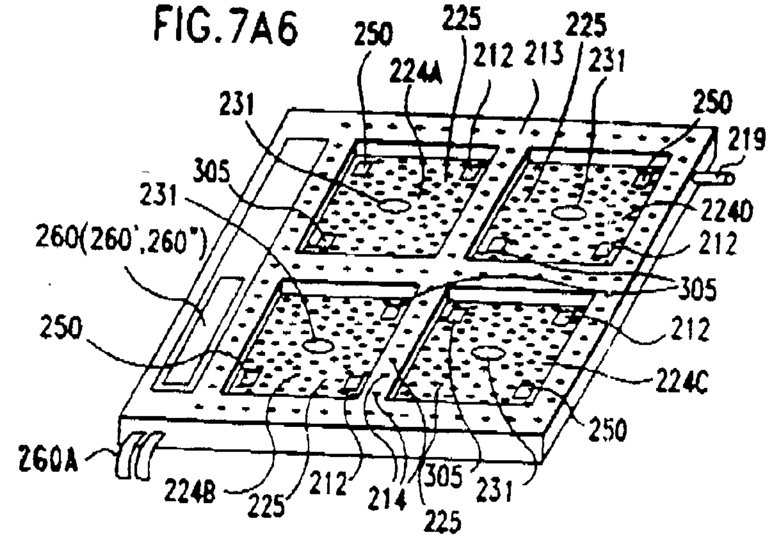

TRANSPORT FOUR(4) METAL-FUEL CARDS FROM THE BOTTOM OF THE RECHARGED METAL-FUEL CARD STORAGE BIN INTO THE CARD DISCHARGING BAY OF THE METAL-FUEL CARD DISCHARGING SUBSYSTEM
A
ARRANGE THE DISCHARGING HEADS ABOUT METAL-FUEL CARDS LOADED INTO THE CARD DISCHARGING BAY OF THE METAL-FUEL CARD DISCHARGING SUBSYSTEM SO THAT THE IONICALLY CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND LOADED METAL-FUEL CARD
B
CONFIGURE EACH DISCHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A LOADED METAL-FUEL CARD, AND ITS ANODE-CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
C
CONFIGURE THE OUTPUT TERMINALS OF EACH DISCHARGING HEAD CONFIGURED ABOUT A LOADED METAL-FUEL CARD AND CONTROL THE METAL-FUEL CARD DISCHARGING SUBSYSTEM SO THAT THE REQUIRED OR DESIRED POWER OUTPUT IS GENERATED AND SUPPLIED TO THE ELECTRICAL LOAD(S) CONNECTED TO THE POWER OUTPUT TERMINALS OF THE FCB SYSTEM
D
UNLOAD DISCHARGED METAL-FUEL CARDS FROM THE DISCHARGING BAY ONTO THE TOP OF THE DISCHARGED METAL-FUEL CARD STORAGE BIN
E
REPEAT STEPS A THROUGH E FOR THE NEXT FOUR RECHARGED METAL-FUEL CARDS IN THE RECHARGED METAL-FUEL CARD STORAGE BIN
F

FIG.7A6



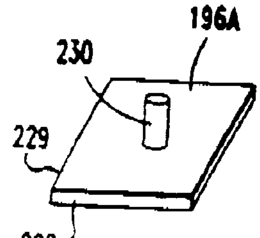


FIG.7A8A

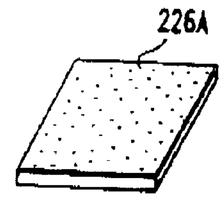


FIG.7A8B

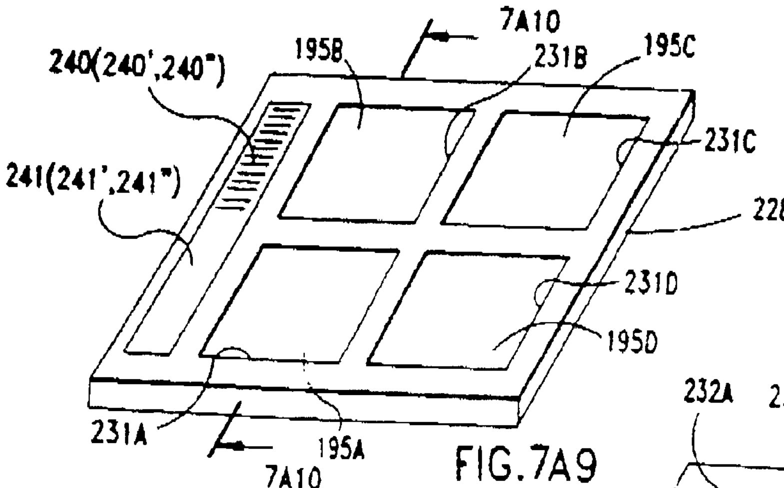


FIG.7A9

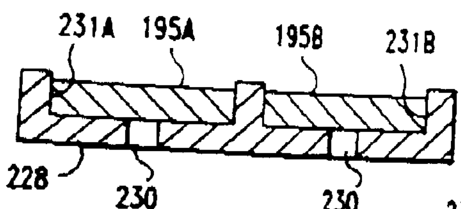
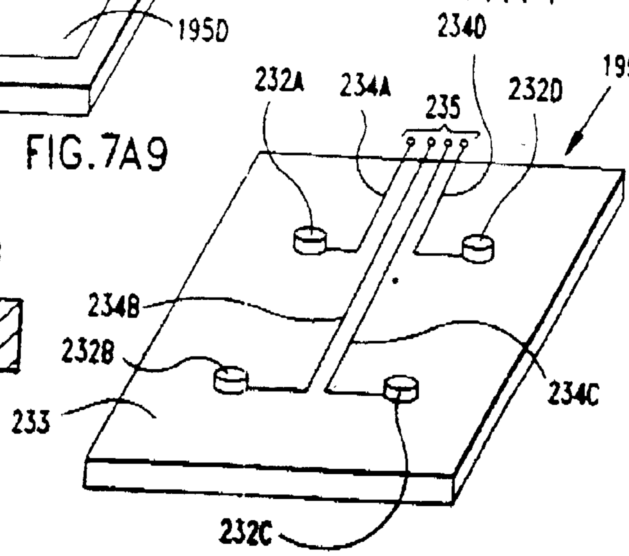
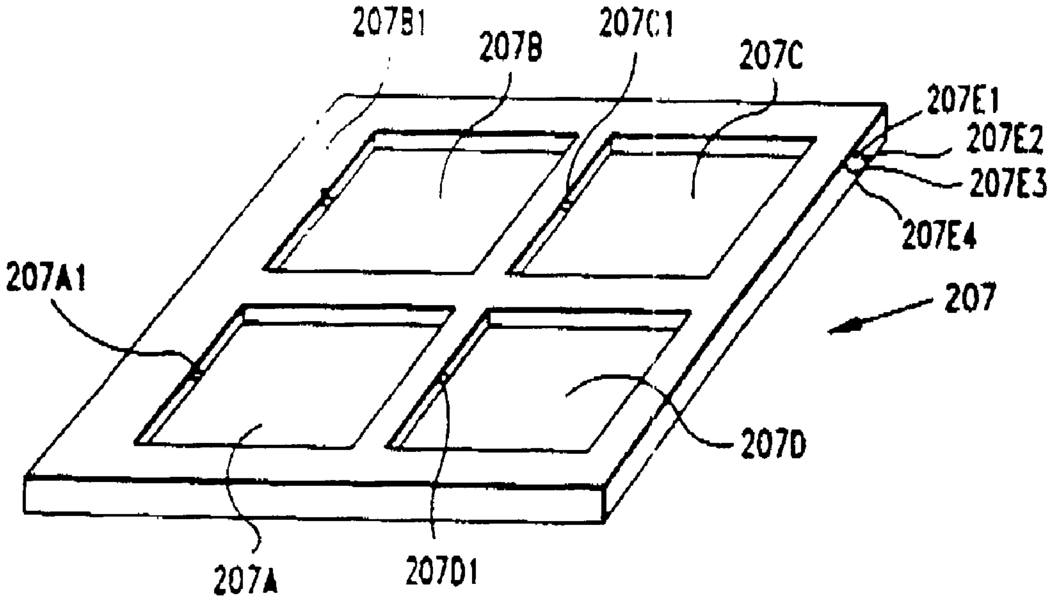


FIG.7A10

FIG.7A11





207B1
207B
207C1
207C
207E1
207E2
207E3
207E4
207A1
207
207D
207A
207D1

FIG.7A7

FIG.7A12

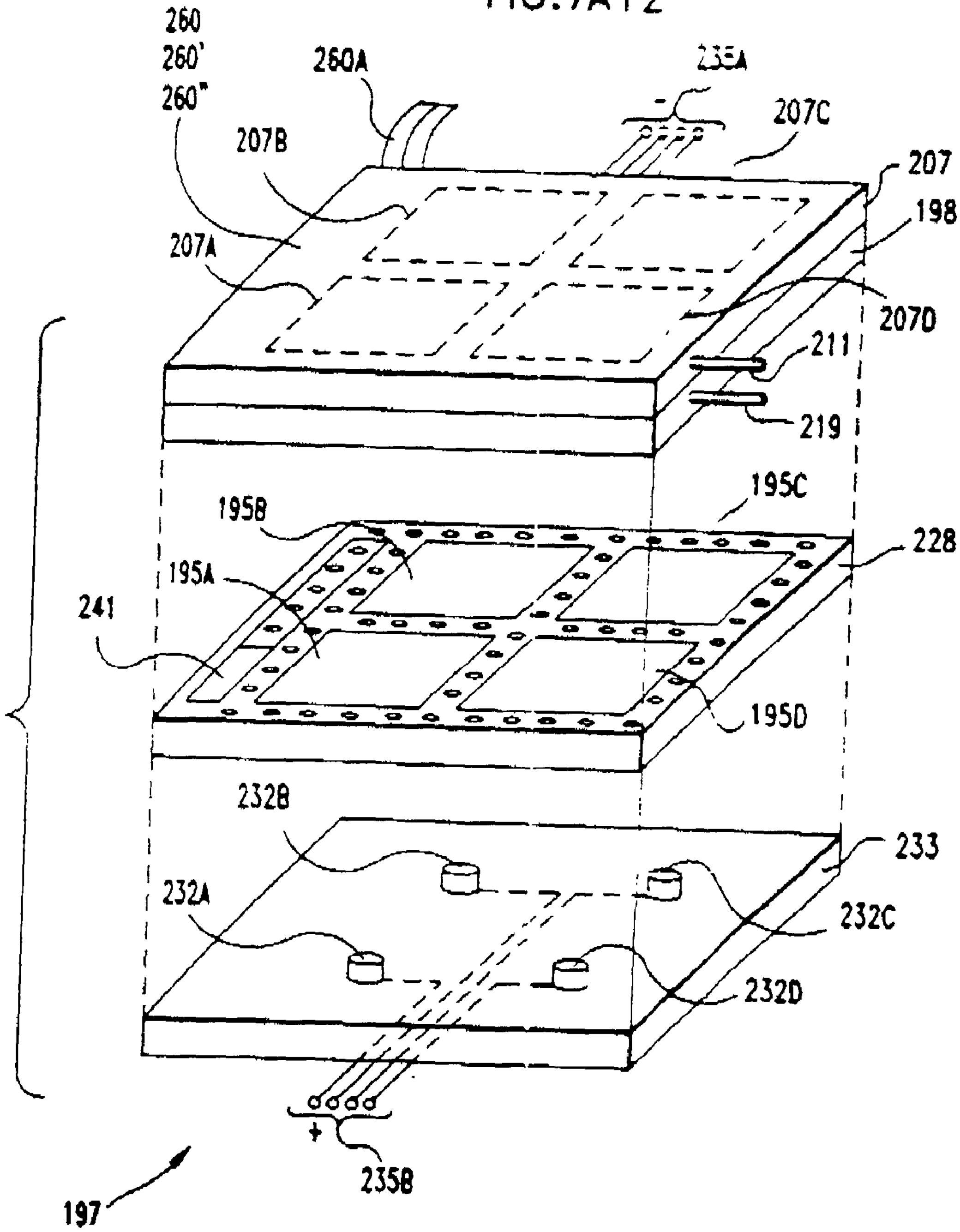

260
260'
260"
260A
235A
-
207C
207B
207
198
207A
207D
211
219
195C
195B
228
195A
241
195D
232B
233
232A
232C
232D
+
235B
197

FIG.7A13

DISCHARGE DATA STRUCTURE

FUEL-TAPE CARD NO.	METAL-FUEL ZONE NO. 1	METAL-FUEL ZONE NO. 2	METAL-FUEL ZONE NO. 3	METAL-FUEL ZONE NO. 4
TIME t_1	V_{ac} i_{ac} PO_2 H_2O % T_{ac} COMPUTED PARAMETERS			
TIME t_2				
TIME t_3				
TIME t_4				
TIME t_5				
⋮	⋮	⋮	⋮	⋮
TIME t_n				

409

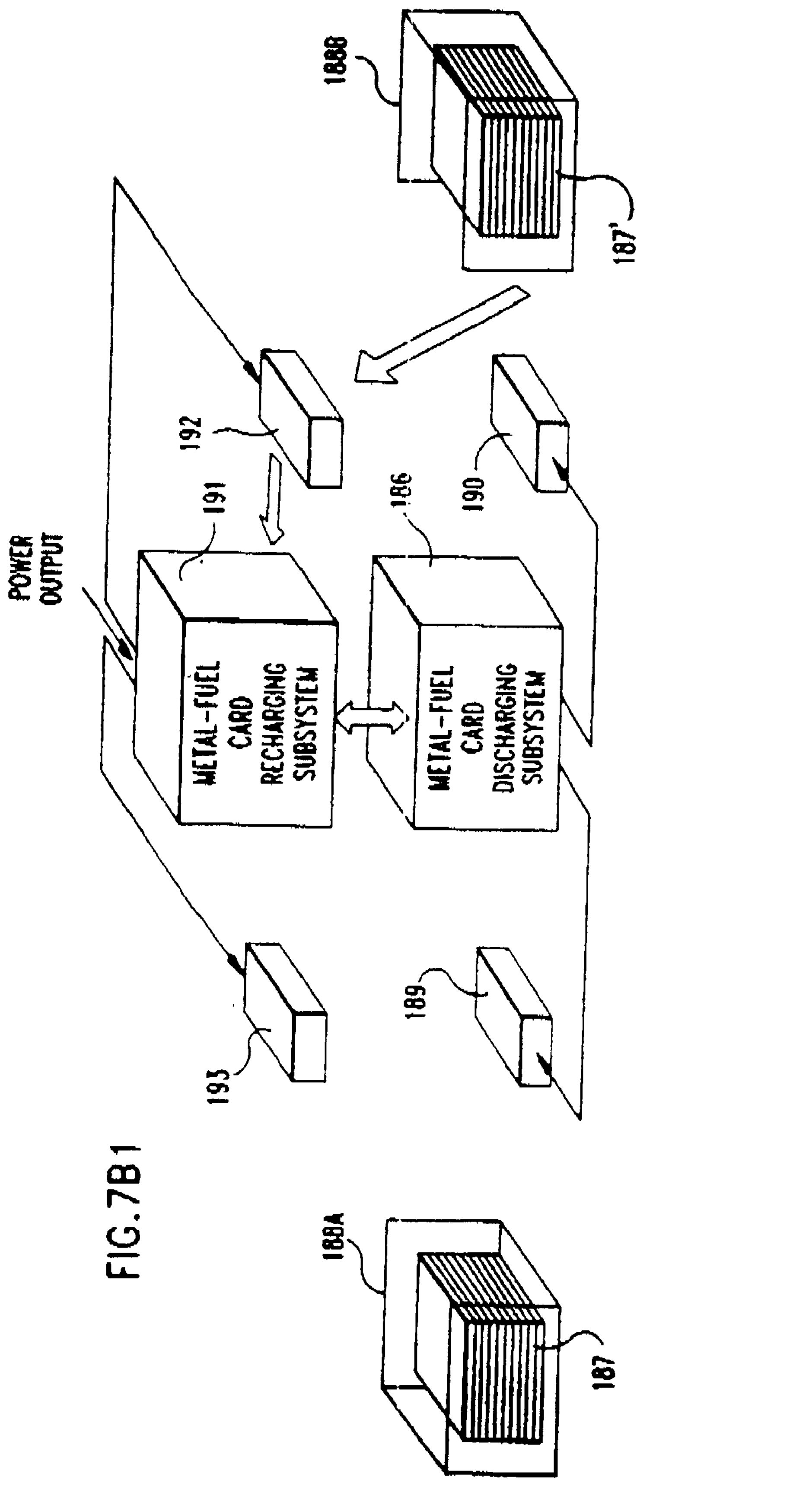

188B
187'
192
191
POWER OUTPUT
METAL-FUEL CARD RECHARGING SUBSYSTEM
186
190
METAL-FUEL CARD DISCHARGING SUBSYSTEM
193
189
188A
187

FIG.7B1

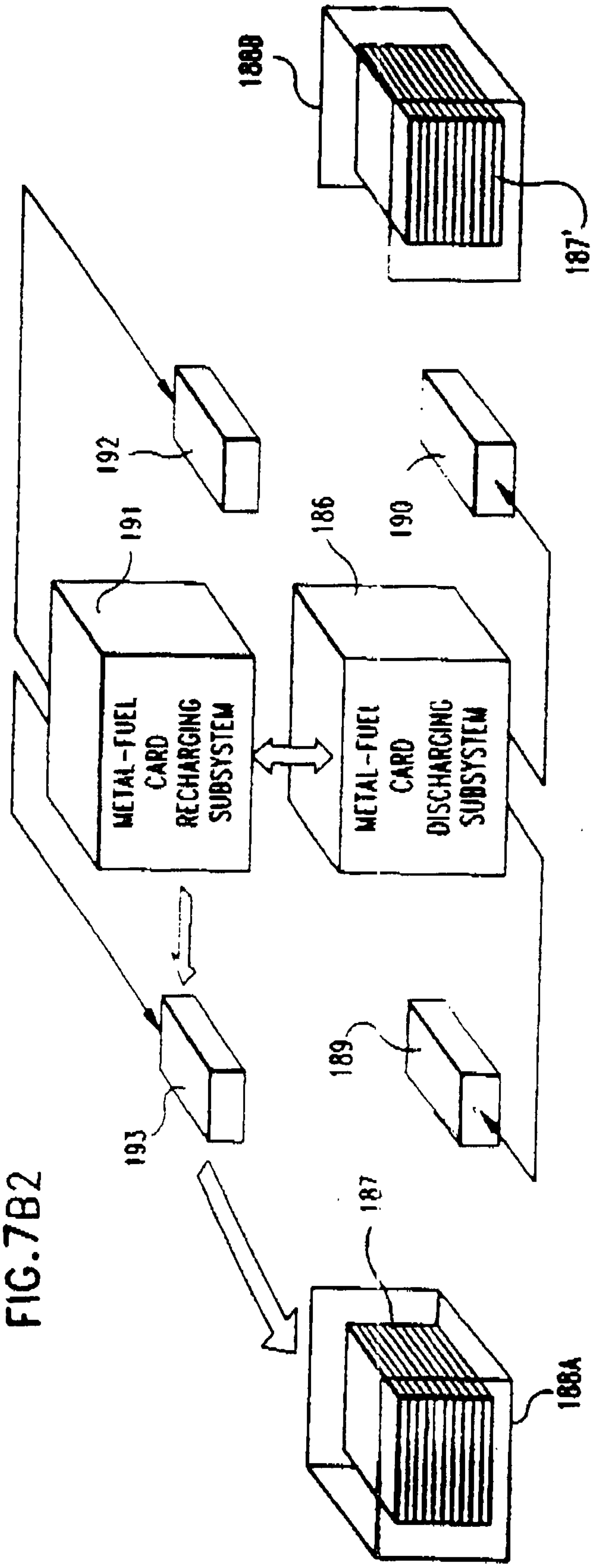

METAL-FUEL
CARD
RECHARGING
SUBSYSTEM
METAL-FUEL
CARD
DISCHARGING
SUBSYSTEM
188B
187'
192
191
186
190
189
193
187
188A

FIG.7B2

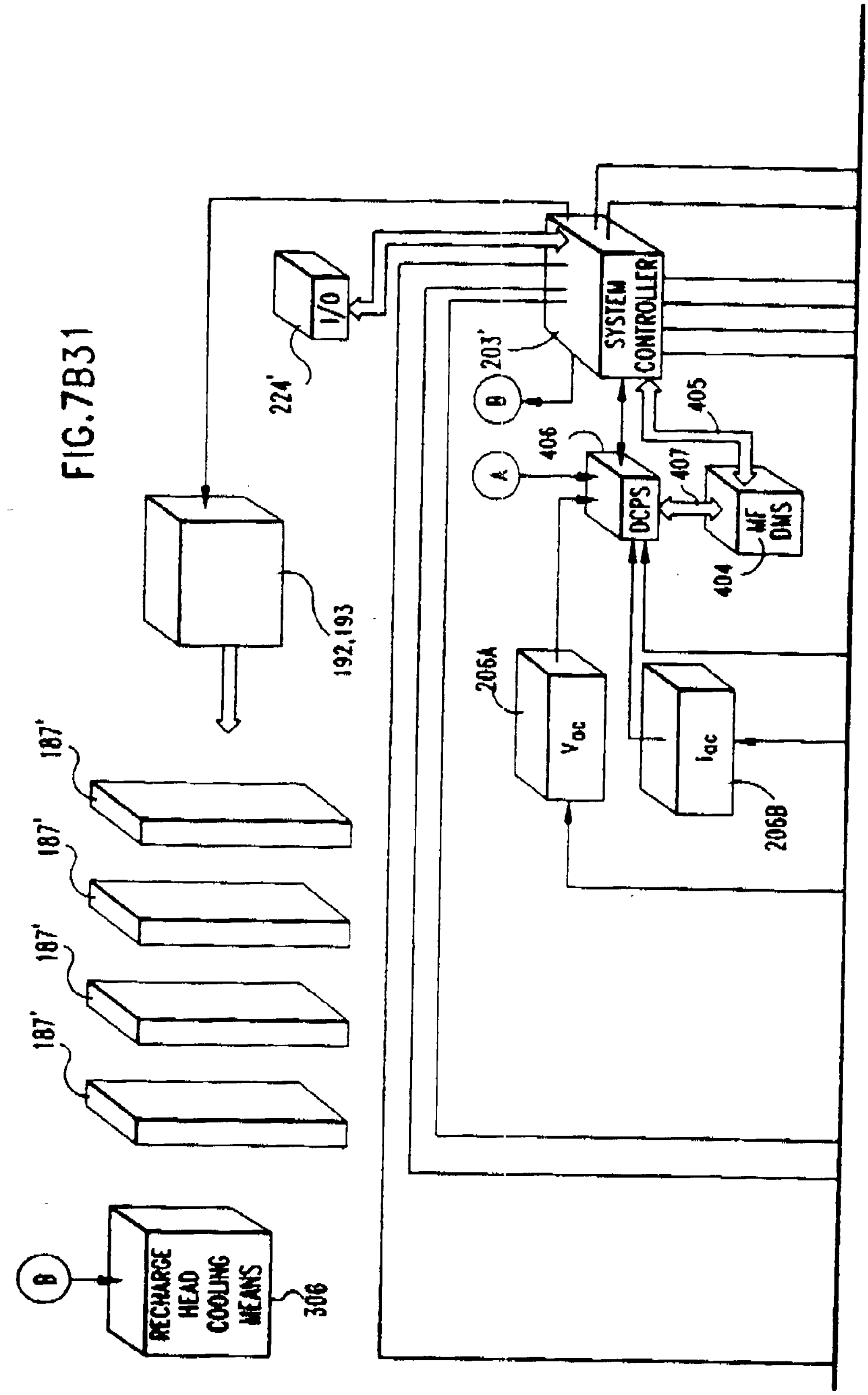

SYSTEM CONTROLLER
I/O
224'
203'
B
A
406
DCPS
407
405
MF DMS
404
192,193
206A
V_{ac}
I_{ac}
206B
187'
187'
187'
187'
B
RECHARGE HEAD COOLING MEANS
306

FIG.7B31

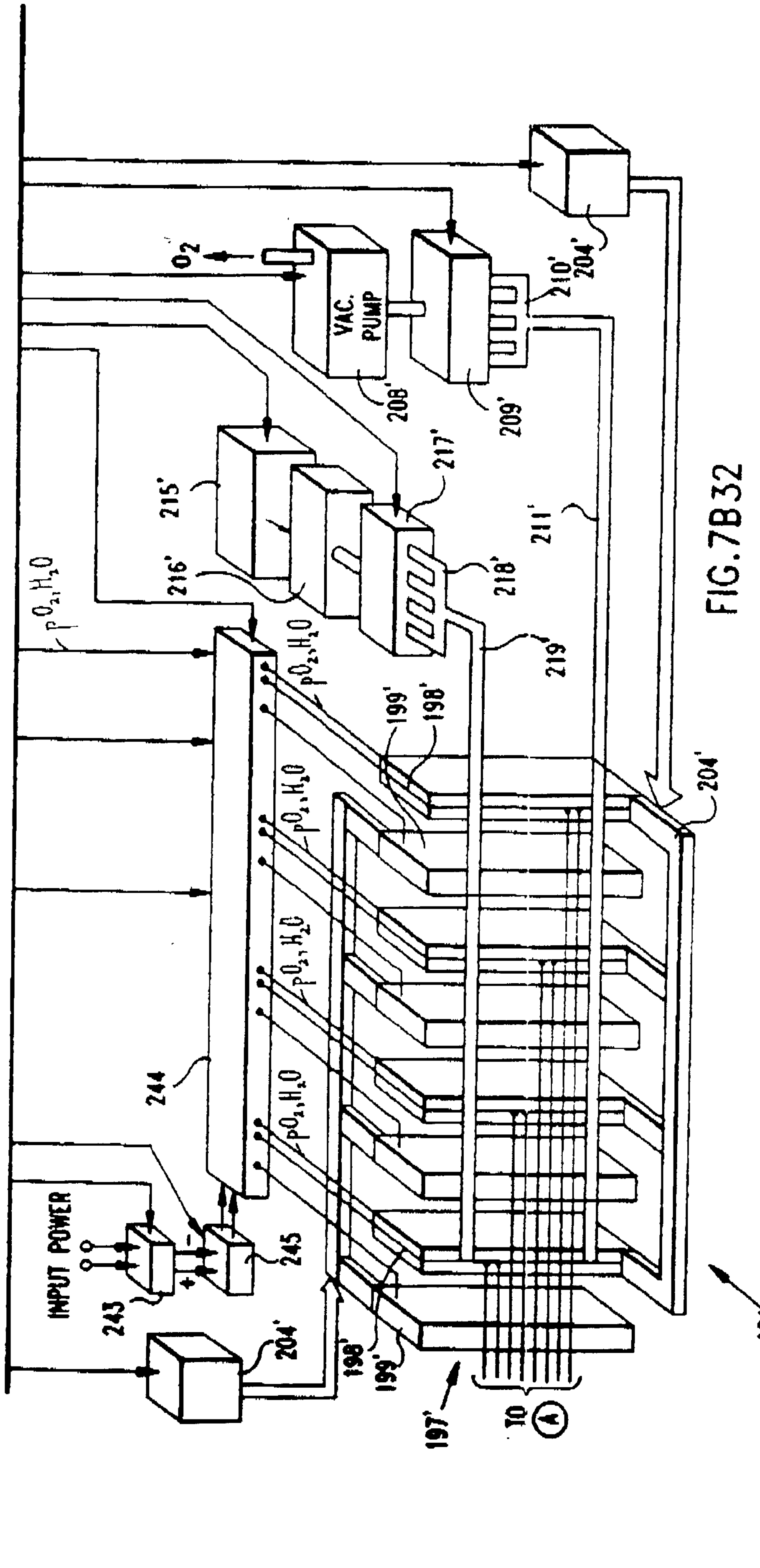

INPUT POWER
VAC.
PUMP
O2
pO2, H2O
243
244
245
204'
208'
209'
210'
211'
215'
216'
217'
218'
219'
198'
199'
197'
191
TO A

FIG. 7B32

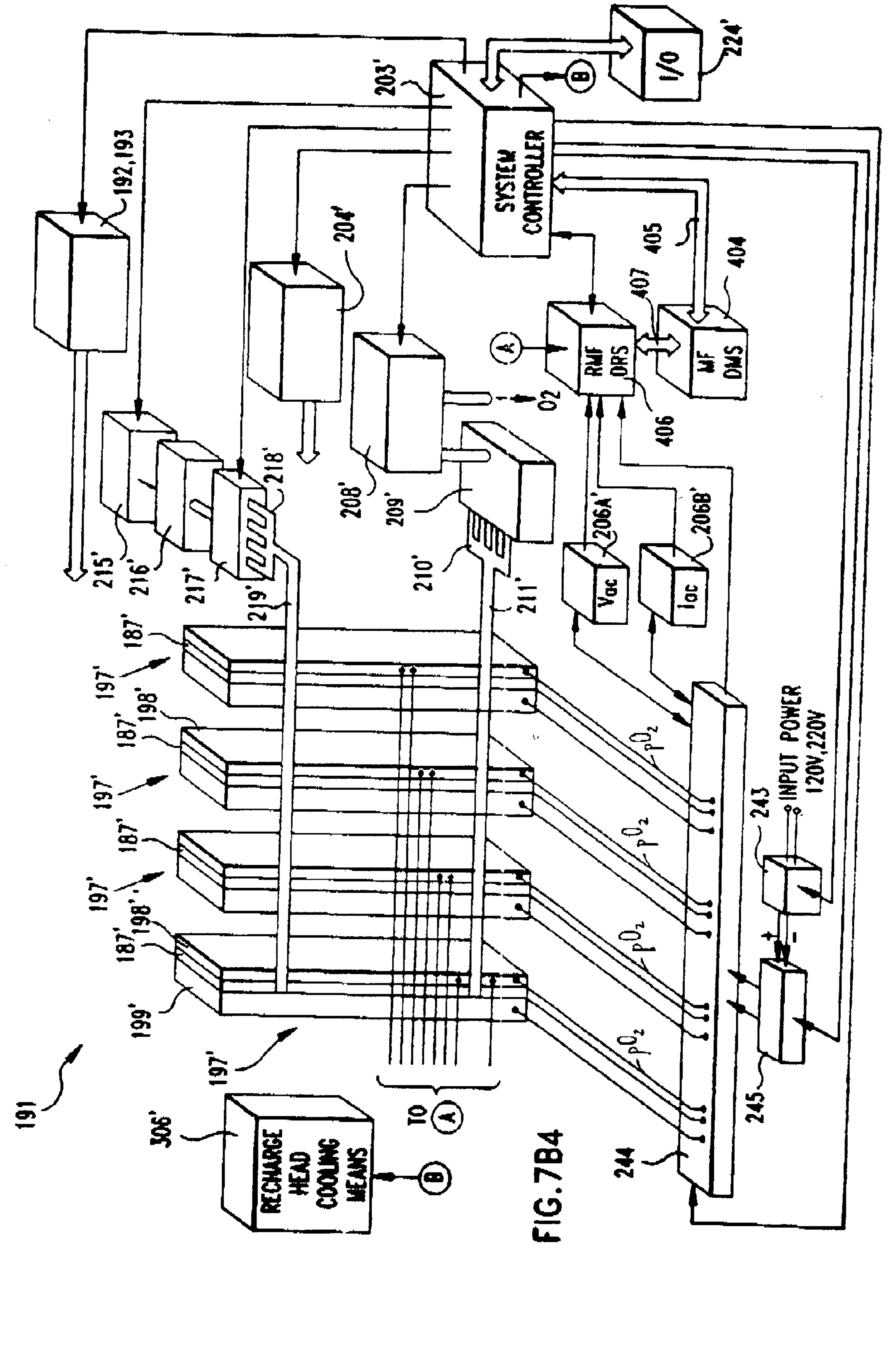

191
192,193
203'
SYSTEM CONTROLLER
I/O
224'
B
204'
208'
209'
210'
211'
O2
A
RMF DRS
MF DMS
405
404
407
406
206A'
206B'
Vac
Iac
215'
216'
217'
218'
219'
187'
197'
198'
199'
pO2
243
INPUT POWER 120V,220V
245
244
TO A
306'
RECHARGE HEAD COOLING MEANS

FIG.7B4

FIG.7B5

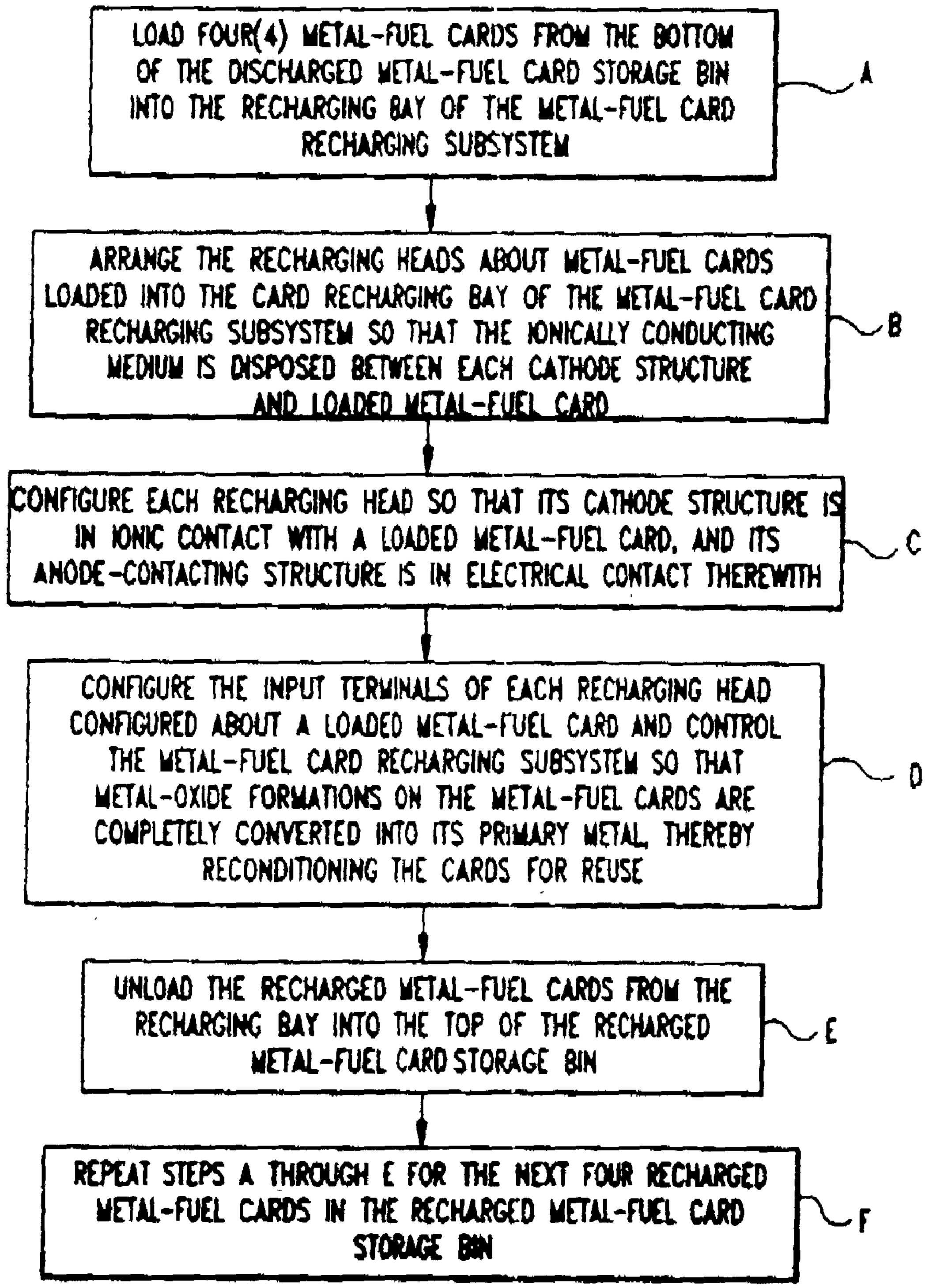
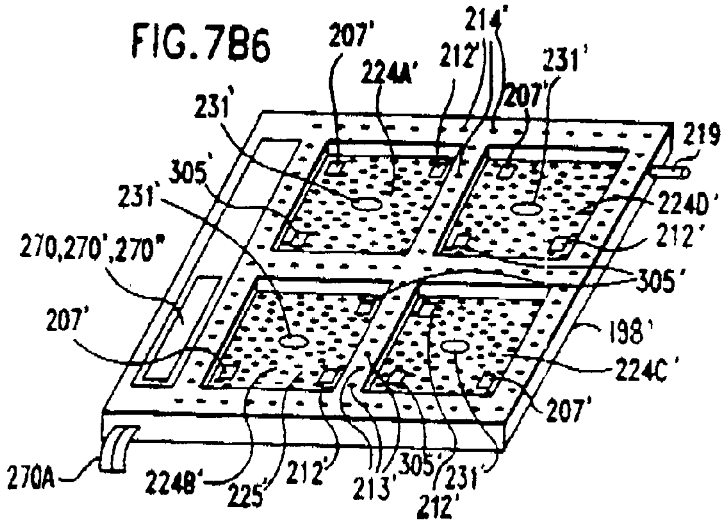

LOAD FOUR(4) METAL-FUEL CARDS FROM THE BOTTOM OF THE DISCHARGED METAL-FUEL CARD STORAGE BIN INTO THE RECHARGING BAY OF THE METAL-FUEL CARD RECHARGING SUBSYSTEM
A
ARRANGE THE RECHARGING HEADS ABOUT METAL-FUEL CARDS LOADED INTO THE CARD RECHARGING BAY OF THE METAL-FUEL CARD RECHARGING SUBSYSTEM SO THAT THE IONICALLY CONDUCTING MEDIUM IS DISPOSED BETWEEN EACH CATHODE STRUCTURE AND LOADED METAL-FUEL CARD
B
CONFIGURE EACH RECHARGING HEAD SO THAT ITS CATHODE STRUCTURE IS IN IONIC CONTACT WITH A LOADED METAL-FUEL CARD, AND ITS ANODE-CONTACTING STRUCTURE IS IN ELECTRICAL CONTACT THEREWITH
C
CONFIGURE THE INPUT TERMINALS OF EACH RECHARGING HEAD CONFIGURED ABOUT A LOADED METAL-FUEL CARD AND CONTROL THE METAL-FUEL CARD RECHARGING SUBSYSTEM SO THAT METAL-OXIDE FORMATIONS ON THE METAL-FUEL CARDS ARE COMPLETELY CONVERTED INTO ITS PRIMARY METAL, THEREBY RECONDITIONING THE CARDS FOR REUSE
D
UNLOAD THE RECHARGED METAL-FUEL CARDS FROM THE RECHARGING BAY INTO THE TOP OF THE RECHARGED METAL-FUEL CARD STORAGE BIN
E
REPEAT STEPS A THROUGH E FOR THE NEXT FOUR RECHARGED METAL-FUEL CARDS IN THE RECHARGED METAL-FUEL CARD STORAGE BIN
F

FIG.7B6



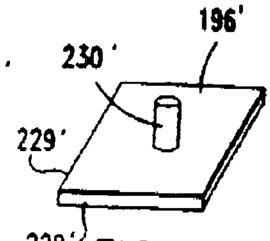


FIG.7B8A

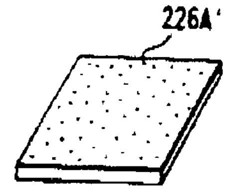


FIG.7B8B

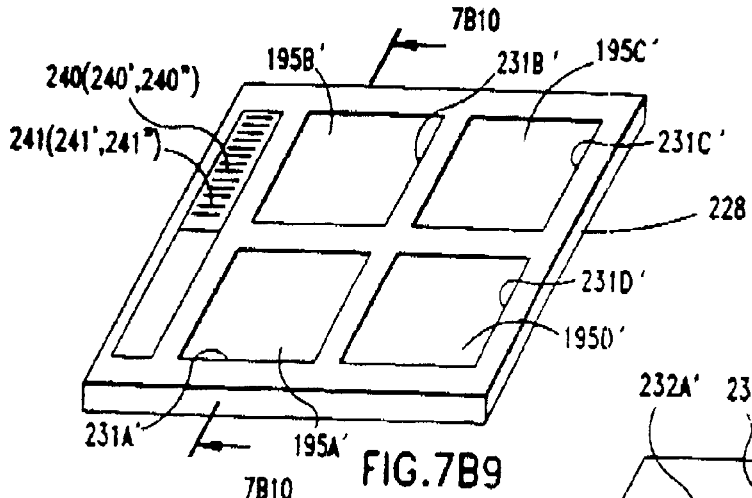


FIG.7B9

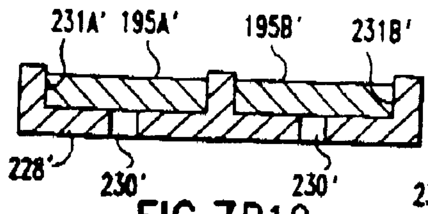
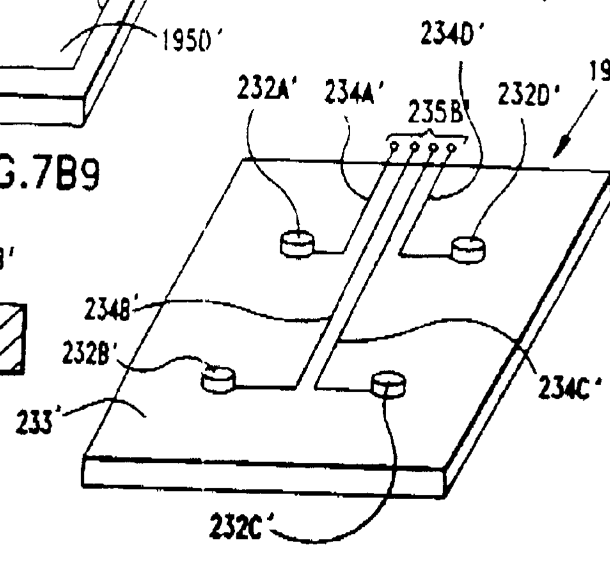


FIG.7B10

FIG.7B11



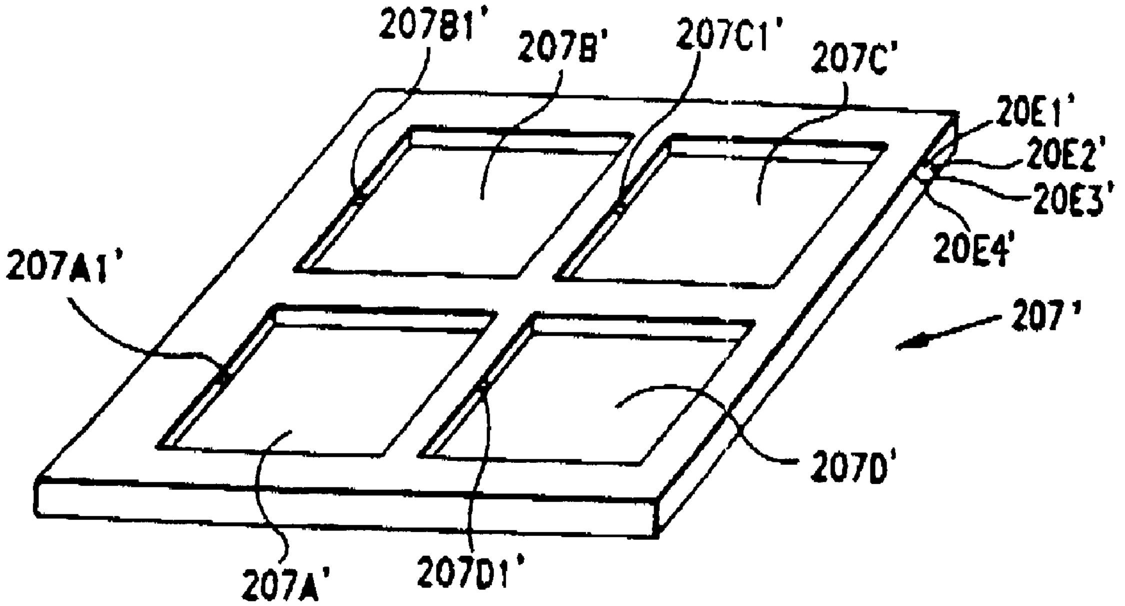

207B1'
207B'
207C1'
207C'
20E1'
20E2'
20E3'
20E4'
207A1'
207'
207D'
207A'
207D1'

FIG.7B7

FIG.7B12

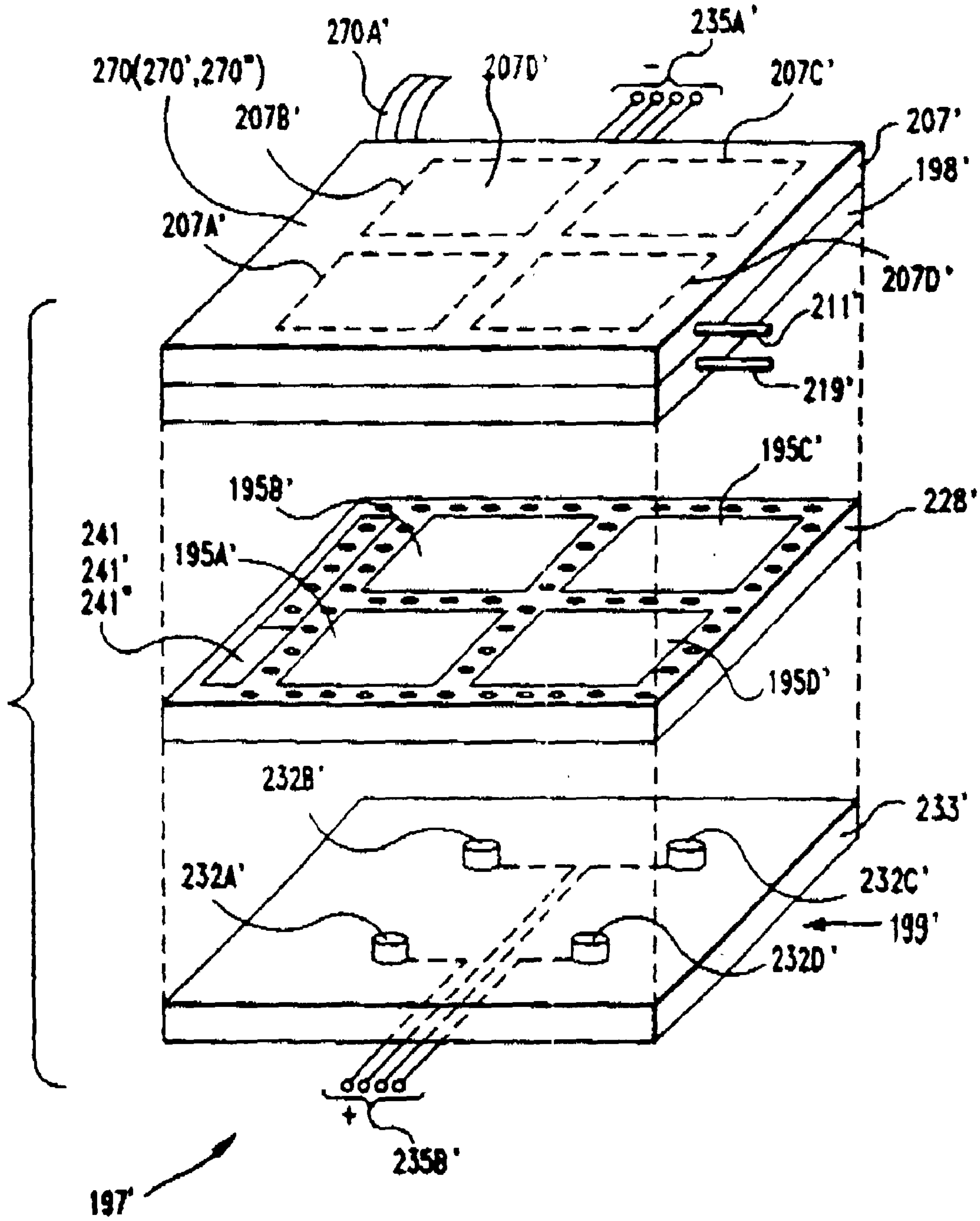
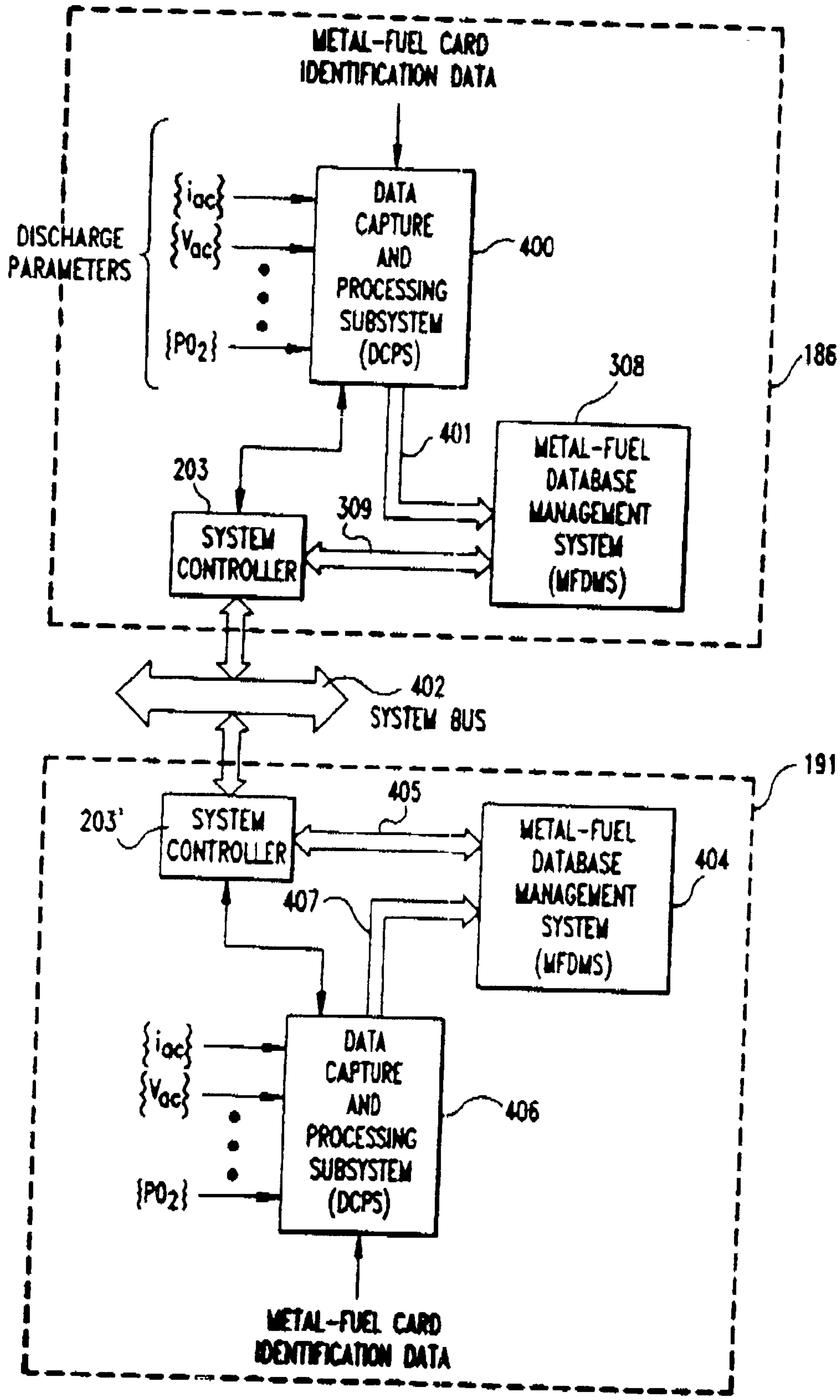

270A'
235A'
270(270',270")
207D'
207C'
207B'
207'
198'
207A'
207D'
211'
219'
195C'
195B'
228'
241
241'
241"
195A'
195D'
232B'
233'
232A'
232C'
199'
232D'
235B'
197'

FIG.7B13

RECHARGE DATA STRUCTURE

FUEL-TAPE CARD NO.	METAL-FUEL ZONE NO. 1	METAL-FUEL ZONE NO. 2	METAL-FUEL ZONE NO. 3	METAL-FUEL ZONE NO. 4
TIME t_1	V_{oc} i_{oc} PO_2 H_2O % T_{oc} COMPUTED PARAMETERS (410)			
TIME t_2				
TIME t_3				
TIME t_4				
TIME t_5				
⋮	⋮	⋮	⋮	⋮
TIME t_n				

FIG.7B14


METAL-FUEL CARD IDENTIFICATION DATA
DISCHARGE PARAMETERS
{iac}
{Vac}
{PO2}
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
400
186
308
401
METAL-FUEL DATABASE MANAGEMENT SYSTEM (MFDMS)
203
309
SYSTEM CONTROLLER
402
SYSTEM BUS
191
203'
405
SYSTEM CONTROLLER
METAL-FUEL DATABASE MANAGEMENT SYSTEM (MFDMS)
404
407
{iac}
{Vac}
{PO2}
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
406
METAL-FUEL CARD IDENTIFICATION DATA

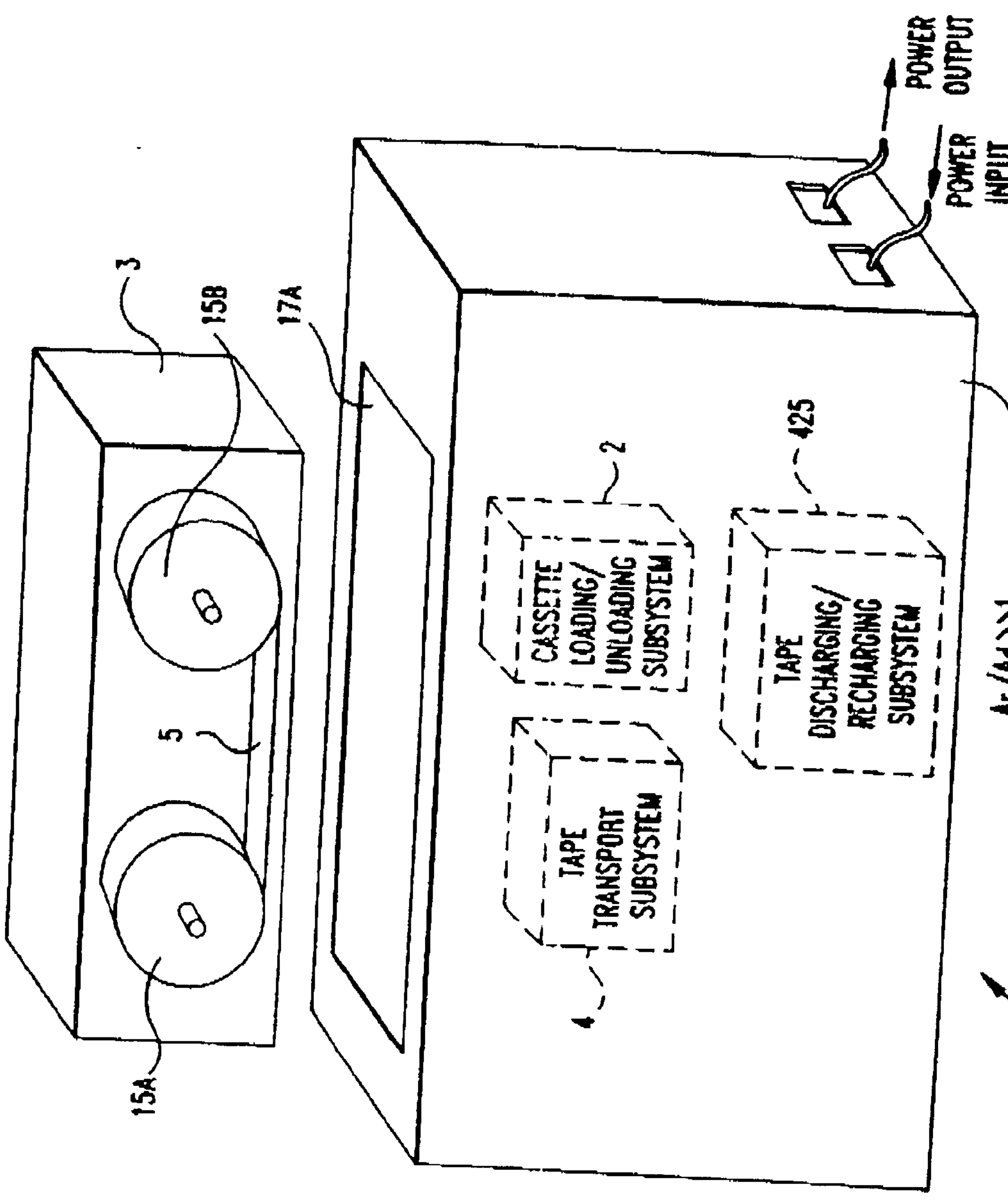

3
15B
17A
15A
5
2
CASSETTE LOADING/ UNLOADING SUBSYSTEM
TAPE TRANSPORT SUBSYSTEM
4
425
TAPE DISCHARGING/ RECHARGING SUBSYSTEM
Ar/Ad>>1
15
420
POWER OUTPUT
POWER INPUT

FIG.8

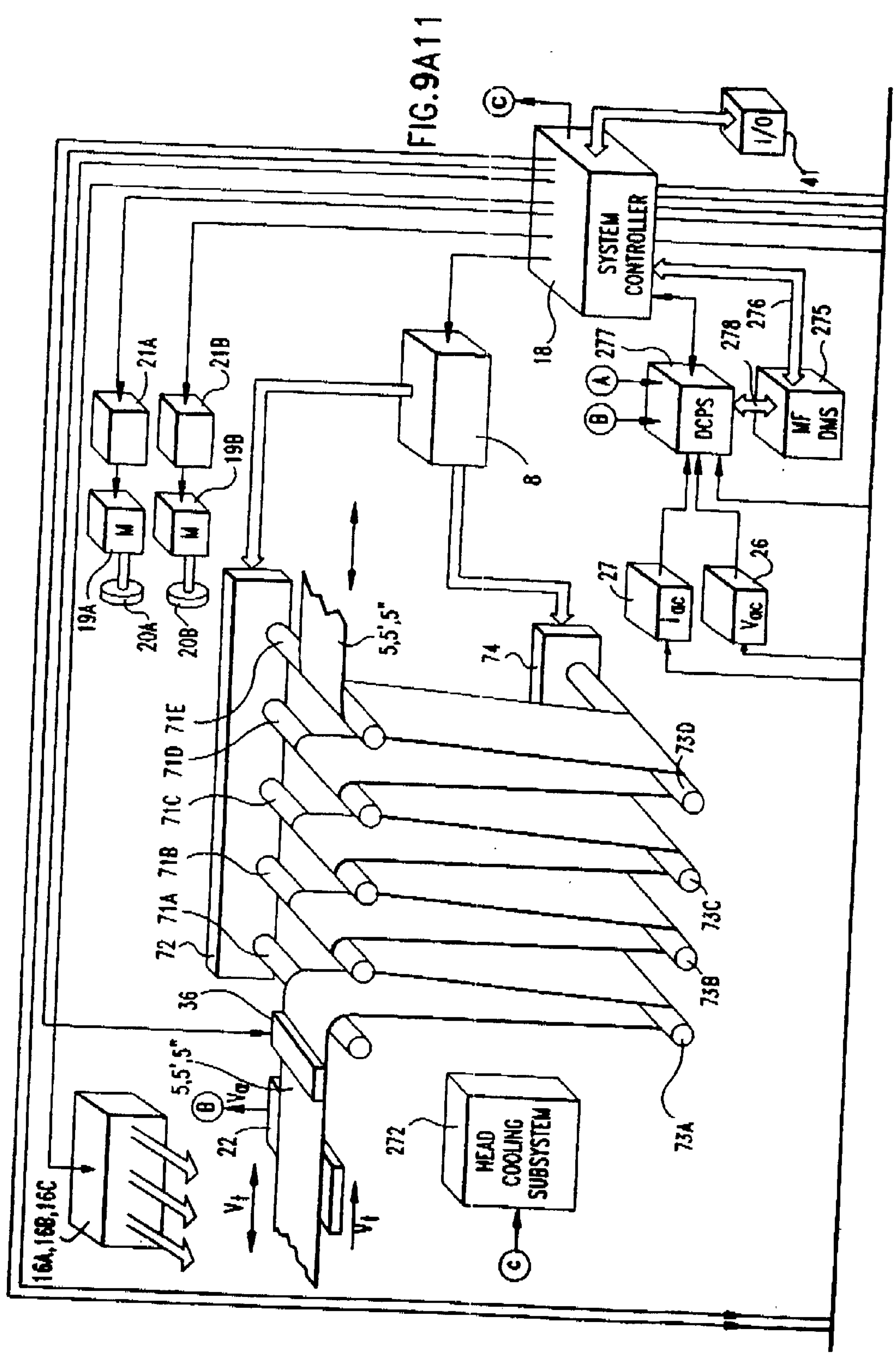
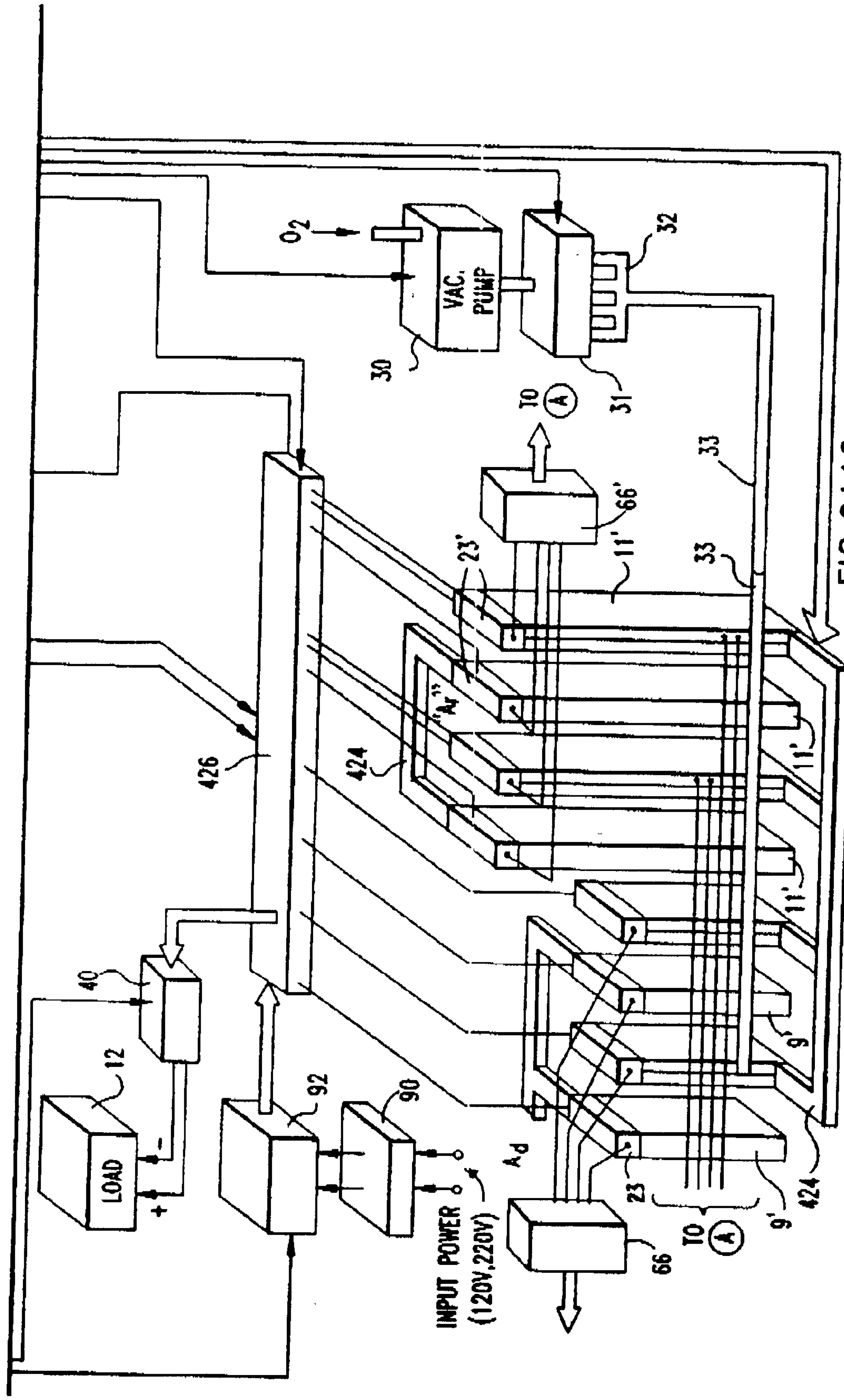
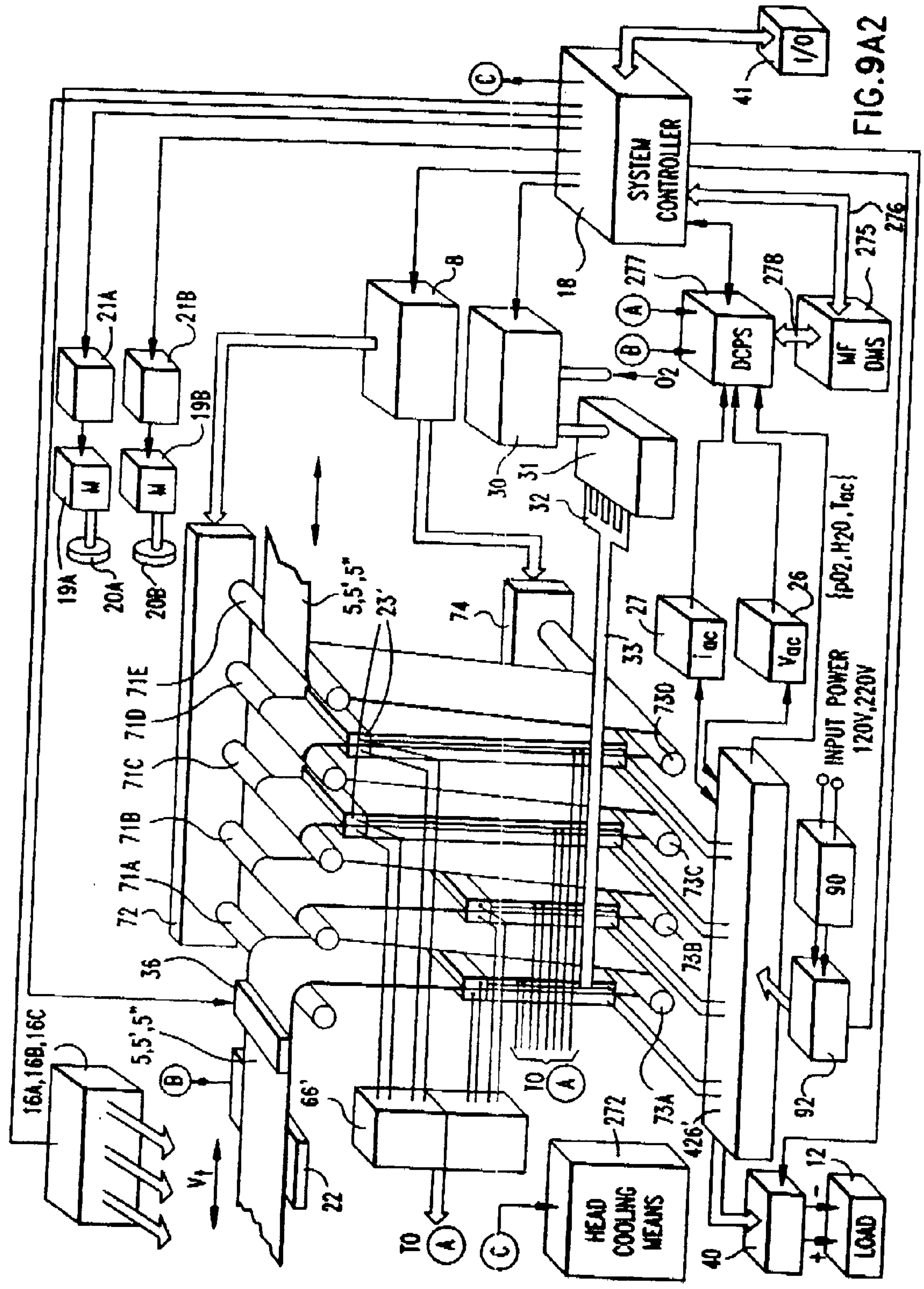

SYSTEM CONTROLLER
18
I/O
41
DCPS
277
278
276
275
MF DMS
8
21A
21B
19A
19B
20A
20B
M
M
I_{oc}
V_{oc}
27
26
74
5,5',5"
71A 71B 71C 71D 71E
72
36
73A
73B
73C
73D
22
V_t
V_a
272
HEAD COOLING SUBSYSTEM
16A,16B,16C
A
B
C

FIG.9A11



VAC. PUMP
30
31
32
O2
TO A
66'
23'
11'
33
"Ar"
424
426
40
12
LOAD
+
-
92
90
INPUT POWER (120V,220V)
Ad
23
66
TO A
9'

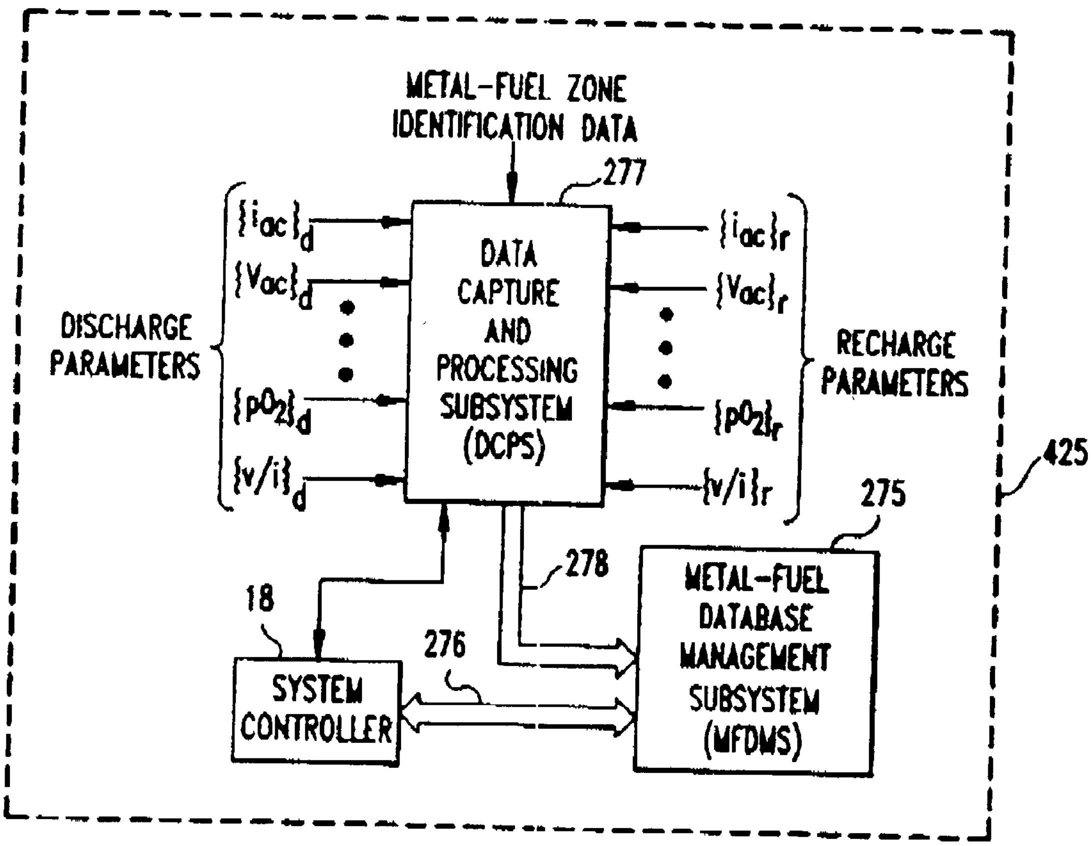
FIG. 9A12



SYSTEM CONTROLLER
I/O
41
18
8
30
31
32
33
DCPS
MF OMS
277
278
275
276
A
B
C
O2
21A
21B
19A
19B
20A
20B
M
72
71A
71B
71C
71D
71E
5,5',5"
23'
74
73A
73B
73C
73D
27
26
Iac
Vac
{pO2, H2O, Tac}
INPUT POWER
120V, 220V
90
92
12
LOAD
40
426'
HEAD COOLING MEANS
272
TO A
66'
22
Vt
36
16A, 16B, 16C

FIG.9A2

FIG.9B


METAL-FUEL ZONE IDENTIFICATION DATA
277
DATA CAPTURE AND PROCESSING SUBSYSTEM (DCPS)
DISCHARGE PARAMETERS
{iac}d
{Vac}d
{pO2}d
{v/i}d
RECHARGE PARAMETERS
{iac}r
{Vac}r
{pO2}r
{v/i}r
425
275
278
METAL-FUEL DATABASE MANAGEMENT SUBSYSTEM (MFDMS)
18
276
SYSTEM CONTROLLER

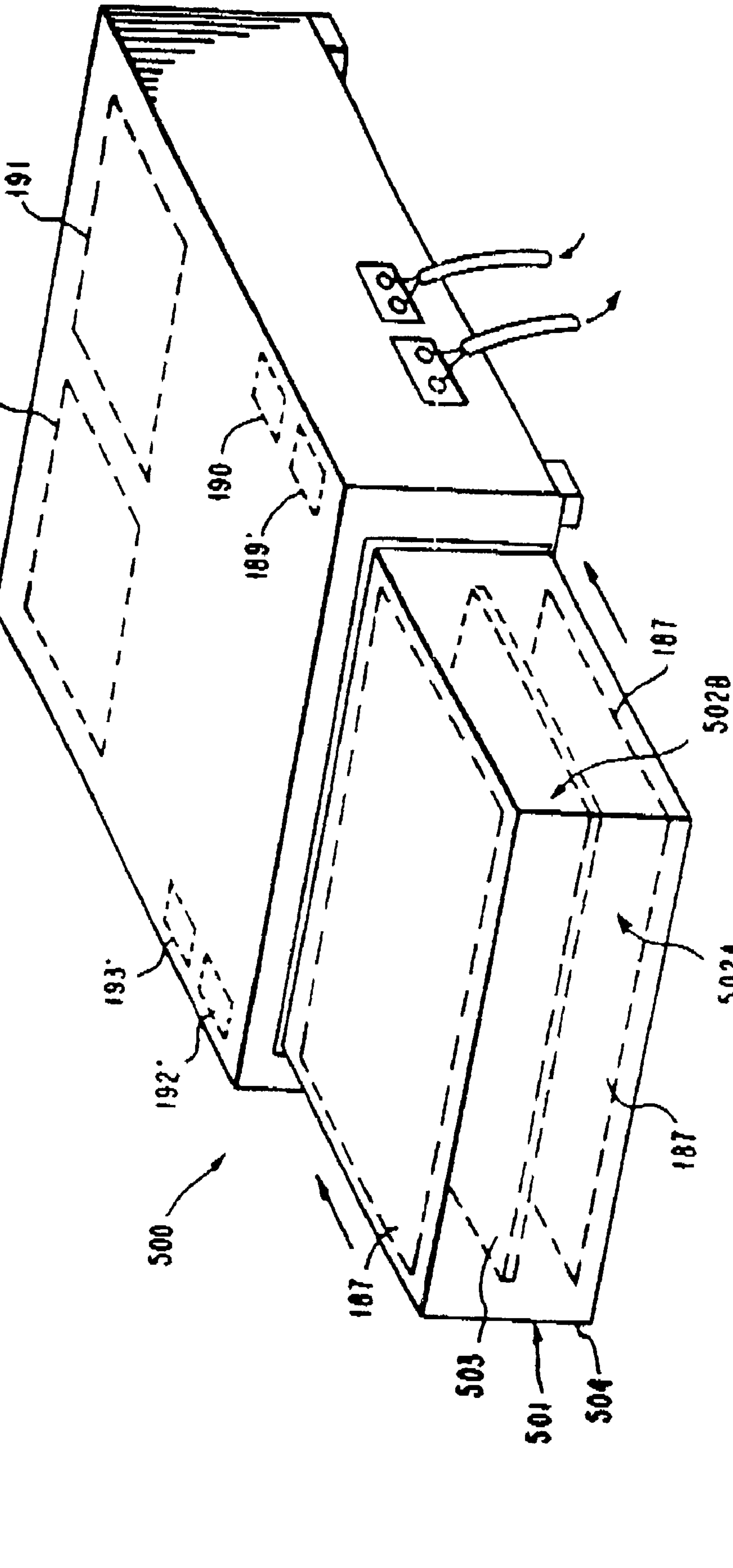


FIG. 10

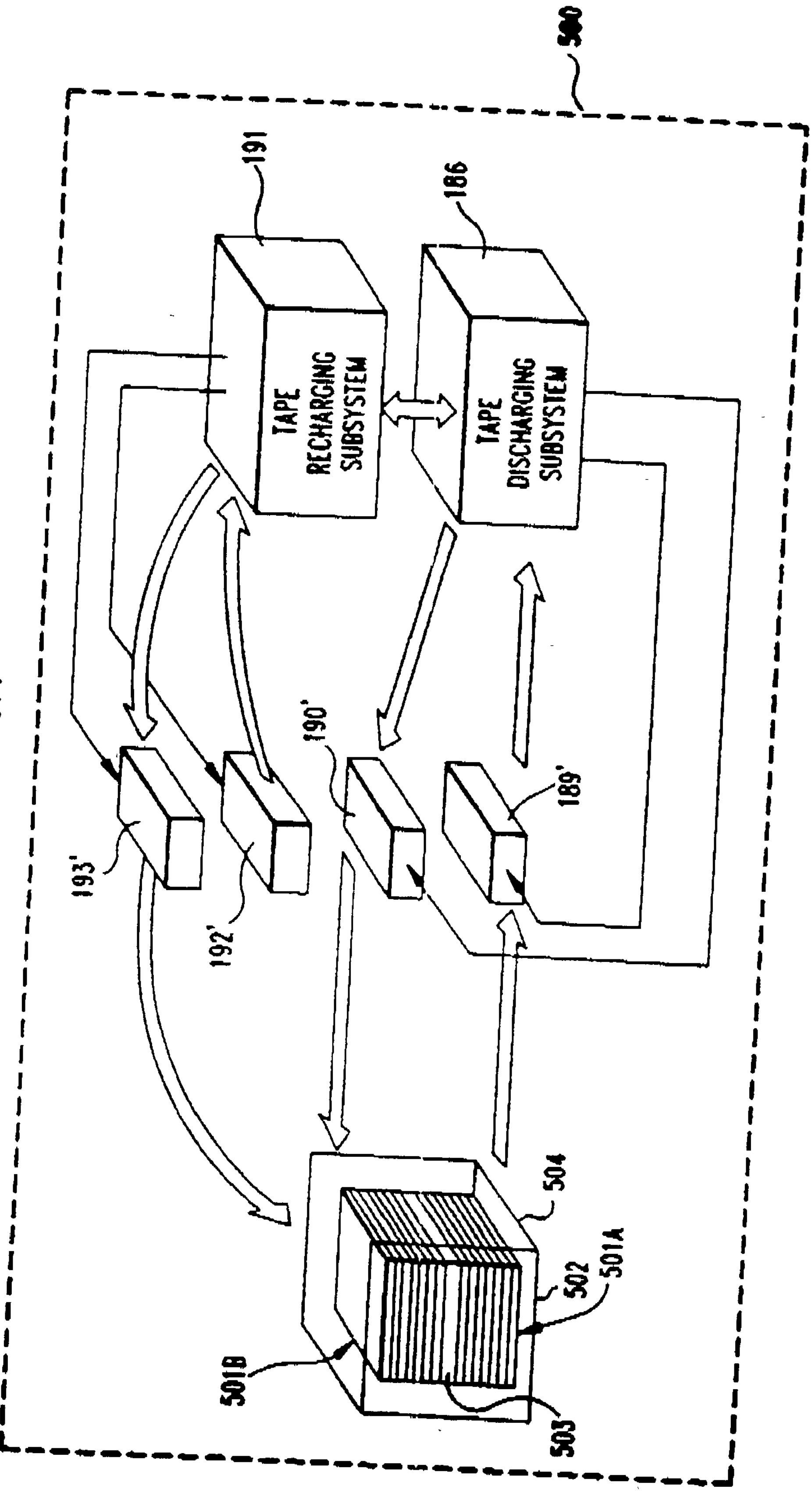

500
191
186
TAPE RECHARGING SUBSYSTEM
TAPE DISCHARGING SUBSYSTEM
193'
192'
190'
189'
504
502
501A
501B
503

FIG.10A

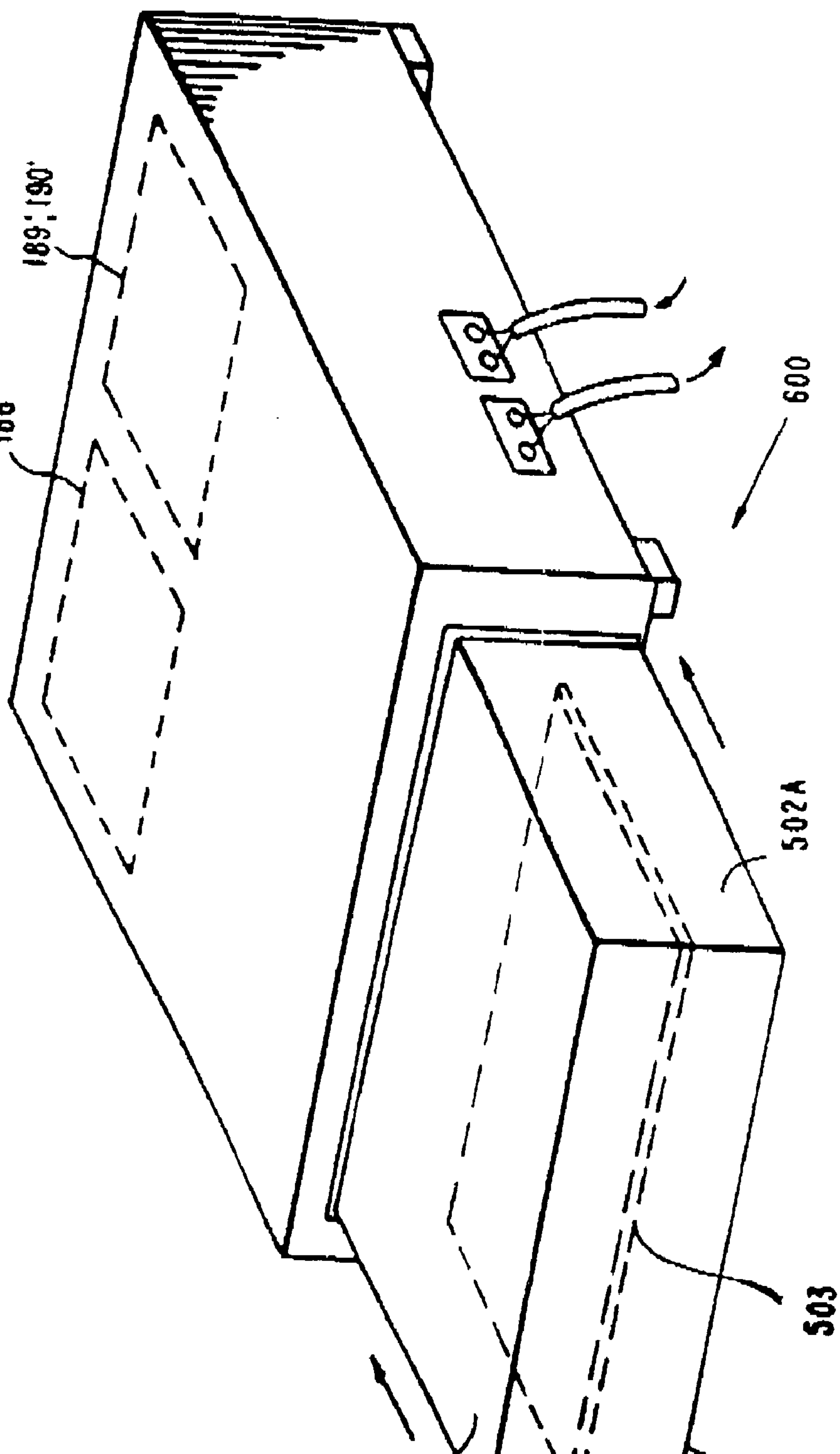


FIG.11

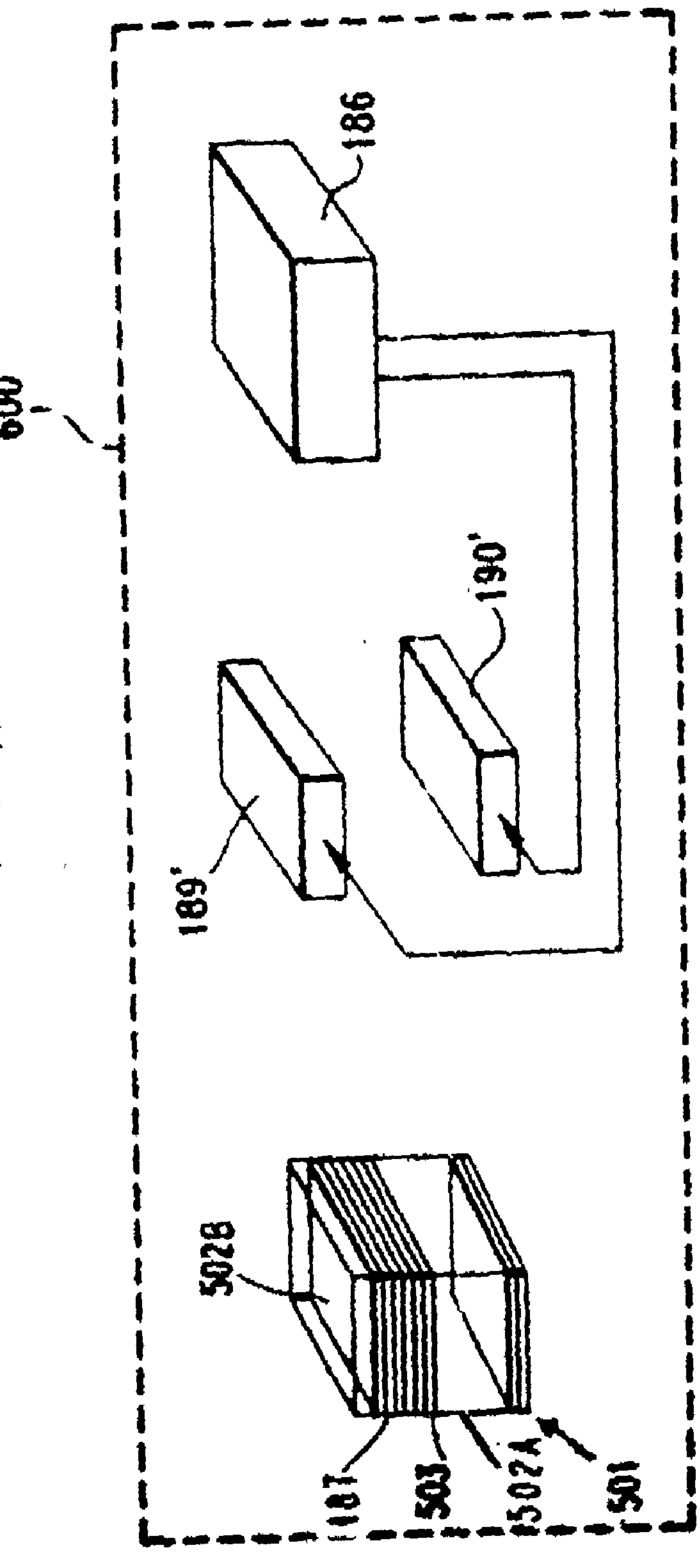


FIG. 11A

METAL-AIR FUEL CELL BATTERY SYSTEMS HAVING A METAL-FUEL CARD STORAGE CASSETTE, INSERTABLE WITHIN A PORT IN A SYSTEM HOUSING, CONTAINING A SUPPLY OF SUBSTANTIALLY PLANAR DISCRETE METAL-FUEL CARDS, AND FUEL CARD TRANSPORT MECHANISMS THEREIN

RELATED CASES

[0001] This is a Divisional of: copending application Ser. No. 09/074,337 entitled "Metal-Air Fuel Cell Battery Systems Having A Metal-Fuel Card Storage Cassette, Insertable Within A Port In A System Housing, Containing A Supply Of Substantially Planar Discrete Metal-Fuel Cards, And Fuel Card Transport Mechanisms Therein", filed May 7, 1998, which is a Continuation-in-Part of: copending application Ser. No. 08/944,507 entitled "High-Power Density Metal-Air Fuel Cell Battery System" by Sadeg Faris, et al. filed Oct. 6, 1997, said applications being assigned to Reveo, Inc. and incorporated herein by reference in its entirely.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to improved methods and systems for optimally discharging metal-air fuel cell battery (FCB) systems and devices, as well as improved methods and systems for optimally recharging the same in a quick and efficient manner.

[0004] 2. Description of the Prior Art

[0005] In copending U.S. application Ser. No. 08/944,507, Applicant discloses several types of novel metal-air fuel cell battery (FCB) systems. During power generation, metal-fuel tape is transported over a stationary cathode structure in the presence of an ionically-conducting medium, such as an electrolyte-impregnated gel. In accordance with well known principles of electrochemistry, the transported metal-fuel tape is oxidized as electrical power is produced from the system.

[0006] Metal-air FCB systems of the type disclosed in U.S. application Ser. No. 08/944,507 have numerous advantages over prior art electro-chemical discharging devices. For example, one advantage is the generation of electrical power over a range of output voltage levels required by particular electrical load conditions. Another advantage is that oxidized metal-fuel tape can be repeatedly reconditioned (i.e. recharged) during battery recharging cycles carried out during electrical discharging operation, as well as separately therefrom.

[0007] In U.S. Pat. No. 5,250,370, Applicant discloses an improved system and method for recharging oxidized metal-fuel tape used in prior art metal-air FCB systems. By integrating a recharging head within a metal-air FCB discharging system, this technological improvement theoretically enables quicker recharging of metal-fuel tape for reuse in FCB discharging operations. In practice, however, a number of important problems have remained unsolved which has hitherto rendered rechargeable FCB systems commercially unfeasible.

[0008] In particular, prior art FCB systems have required very large volumes of physical space to accommodate enlarged recharging electrodes. In practice, this is often not possible, or practical.

[0009] Prior art FCB systems have suffered from problems associated with over and under recharging oxidized metal-fuel tape and sheets produced during discharging operations. Consequently, it has not been possible to optimally recharge metal-fuel tape and sheets using prior art tape recharging systems and methodologies.

[0010] Also, using prior art FCB systems it has not been possible to optimally discharge metal-fuel tape and sheets using prior art tape recharging systems and methodologies.

[0011] Thus there is a great need in the art for an improved method and apparatus for discharging and recharging metal-fuel tape, sheets, cards, and the like in a manner which overcomes the limitations of prior art technologies.

OBJECTS AND SUMMARY OF THE INVENTION

[0012] Accordingly, a primary object of the present invention is to provide an improved method of and apparatus for discharging and recharging metal-air fuel cell batteries (FCB) in a manner which avoids the shortcomings and drawbacks of prior art technologies.

[0013] Another object of the present invention is to provide such apparatus in the form of a Metal-Fuel Tape Recharging Subsystem, wherein recharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the recharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically controlled in order to optimally recharge oxidized metal-fuel material (i.e. anodes) for reuse in metal-air FCB systems.

[0014] Another object of the present invention is to provide such apparatus in the form of a Metal-Fuel Tape Discharging Subsystem, wherein discharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the discharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically controlled in order to optimally discharge metal-fuel material (i.e. anodes) for use in generating electrical power within metal-air FCB systems.

[0015] Another object of the present invention is to provide such a system, wherein a subsystem is provided for controlling the electro-chemical reduction of metal-oxide along oxidized metal-fuel tape so as to completely reduce the metal-oxide at the fastest rate possible without destroying the porous structure of the metal-fuel tape.

[0016] Another object of the present invention is to provide such a system, wherein the metal-fuel anodes to be recharged (i.e. electro-chemically reduced) can be used with stationary and/or moving cathode structures employed in metal-air FCB systems.

[0017] Another object of the present invention is to provide such a system, wherein the metal-fuel structures to be recharged are realized in the form of oxidized metal-fuel tape which, during discharging operations, is transported across a cathode structure associated with the discharging head of a metal-air FCB system.

[0018] Another object of the present invention is to provide such a system, wherein the path-length of oxidized metal-fuel tape is substantially extended during recharging operations in order that a supply of oxidized metal-fuel tape contained within a cassette device or on a supply reel can be rapidly recharged.

[0019] Another object of the present invention is to provide such a system, wherein the oxidized metal-fuel tape to be recharged is contained within a cassette-type device insertable in the storage bay of a compact FCB discharging unit.

[0020] Another object of the present invention is to provide such a system, wherein the oxidized metal-fuel tape to be recharged comprises multiple metal-fuel tracks for use in generating different output voltages from a metal-air FCB system.

[0021] An object of the present invention is to provide such a system, wherein the path-length of oxidized metal-fuel tape is significantly extended within the recharging bay of the system using a tape path-length extension mechanism.

[0022] Another object of the present invention is to provide such a system, wherein the recharging head assembly comprises a plurality of cathode and anode structures which are selectively arranged about the extended path-length of oxidized metal-fuel tape during recharging operations.

[0023] Another object of the present invention is to provide such a system, wherein a recharging power regulating subsystem is provided for regulating operating parameters during electrochemical reduction of metal-oxide during recharging operations.

[0024] Another object of the present invention is to provide such a system, wherein oxygen, generated from within the porous cathode elements of the recharging head of the system during electrochemical reduction, is evacuated under the control of the recharging power regulation subsystem thereof.

[0025] Another object of the present invention is to provide such a system, wherein the relative humidity within the cathode elements of the recharging head of the system is controlled by the recharging power regulation subsystem thereof.

[0026] Another object of the present invention is to provide such a system, wherein the speed of the oxidized fuel tape transported over the recharging heads is regulated under the control of the recharging power regulation subsystem thereof.

[0027] Another object of the present invention is to provide such a system, wherein the voltage applied across and current driven through oxidized metal-fuel tape during recharging operations is regulated under the control of the recharging power control subsystem thereof.

[0028] Another object of the present invention is to provide such a system, wherein a metal-oxide sensing head is provided up-stream for sensing which metal-fuel tracks along a length of multi-tracked metal-fuel tape have been discharged (i.e. oxidized), and a recharging head is disposed downstream having multiple pairs of electrically-isolated cathode and anode structures for selectively recharging only those metal-fuel tracks that have been sufficiently oxidized (i.e. consumed).

[0029] Another object of the present invention is to provide a novel system for discharging a supply of metal-fuel cards or plates contained within a cassette storage cartridge.

[0030] Another object of the present invention is to provide such a system, wherein each metal-fuel card or plate is automatically loaded from the cassette cartridge into the recharging bay of the system.

[0031] Another object of the present invention is to provide a novel system for recharging metal-fuel cards or plates that have been oxidized during the discharging mode of operation.

[0032] Another object of the present invention is to provide such a system, wherein each oxidized metal-fuel card or plate is manually loaded into the recharging bay of the system, and after recharging (i.e. reducing) is completed, the card is ejected from the recharging bay in a semi-automatic manner.

[0033] Another object of the present invention is to provide such a system, wherein each oxidized metal-fuel card or plate is automatically loaded into the recharging bay of the system, and after recharging (i.e. reducing) is completed, the card is automatically ejected from the recharging bay, and another oxidized metal-fuel card is automatically loaded thereinto for recharging.

[0034] Another object of the present invention is to provide such a system, wherein each zone or subsection of metal fuel along the length of metal-fuel tape track is labeled with a digital code, through optical or magnetic means, for enabling the recording of discharging-related data during the discharging mode of operation, for future access and use in carrying out various types of management operations, including rapid and efficient recharging operations.

[0035] Another object of the present invention is to provide such a system, wherein metal-fuel tape can be transported through its discharging head assembly and recharging head assembly in a bi-directional manner while the availability of metal-fuel therealong is automatically managed in order to improve the performance of the system.

[0036] Another object of the present invention is to provide such a system, wherein the recharging bay contains an assembly of recharging heads, each of which comprises an electrically conductive cathode structure, an ionically conductive medium, and an anode contacting structure.

[0037] Another object of the present invention is to provide such a system, wherein a plurality of oxidized metal-fuel cards or plates is automatically transported into the system for high-speed recharging.

[0038] Another object of the present invention is to provide an improved method of and apparatus for electrochemically generating electrical power across an electrical load by discharging metal-air fuel cell batteries in a manner which allows for optimal recharging of the same during recharging cycles.

[0039] Another object of the present invention is to provide such a system and method, wherein during discharging cycles, multiple discharging heads are employed to discharge metal-fuel tape at controlled anode-cathode current levels in order to control the formation of optimally-reducible metal-oxide patterns therealong during discharge cycles.

[0040] Another object of the present invention is to provide such a system and method, wherein during discharging cycles, the use of multiple discharging heads enables each discharging head to be "lightly loaded", thus permitting improved control over the formation of metal-oxide during discharging cycles so that complete conversion thereof into its primary metal can be achieved in an optimal manner.

[0041] Another object of the present invention is to provide such a system, wherein information regarding the instantaneous loading conditions along each zone (i.e. frame) of the metal-fuel tape is recorded in memory by the system controller.

[0042] Another object of the present invention is to provide such a system, wherein (i) instantaneous loading condition data for each metal-fuel zone along a spool of metal-fuel tape is acquired by optically sensing bar code symbol data imprinted along the zone of metal-fuel tape to determine the identity thereof, (ii) loading conditions at the discharging head through which the identified metal-fuel zone passes are automatically sensed, and then (iii) such data is automatically recorded in memory for future use during subsequent tape recharging operations.

[0043] Another object of the present invention is to provide such a system, wherein, during tape recharging operations, such recorded loading condition information is read from memory and used to set current and voltage levels maintained at the recharging heads of the system.

[0044] Another object of the present invention is to provide such a system and method, wherein metal-fuel tape discharging conditions are recorded at the time of discharge and used to optimally recharge discharged metal-fuel tape during tape recharging operations.

[0045] Another object of the present invention is to provide such a system, wherein, during tape discharging operations, optical sensing of bar code data along each zone of metal-fuel tape is carried out using a miniaturized bar code symbol reader embedded within the cathode structure of each discharging head of the system.

[0046] Another object of the present invention is to provide such a system, wherein, during tape recharging operations, optical sensing of bar code data along each zone of discharged metal-fuel tape is carried out using a miniaturized bar code symbol reader embedded within the cathode structure of each recharging head of the system.

[0047] Another object of the present invention is to provide such a system, wherein both the metal-fuel tape discharging subsystem and the metal-fuel tape recharging subsystem thereof can be simultaneously operated in order to quickly recharge oxidized metal-fuel tape passing through the metal-fuel tape recharging subsystem as electrical power is being generated across an electrical loaded connected to the discharging subsystem.

[0048] Another object of the present invention is to provide such a system, wherein the subsystems thereof are remotely controllable through an input/output subsystem operably connected to the system controller.

[0049] Another object of the present invention is to provide a metal-air FCB system, wherein a metal-fuel tape discharging subsystem and a metal-fuel tape recharging subsystem are integrated within a single, stand-alone electrical discharging unit, and the tape path-length extension mechanism employed in the metal-fuel tape recharging subsystem extends oxidized metal-fuel tape over a path-length which is substantially greater than the path-length maintained by the metal-fuel tape path-length extension mechanism employed in the metal-fuel tape discharging subsystem.

[0050] Another object of the present invention is to provide a metal-air FCB system, wherein a plurality of metal-fuel cards can be loaded within a metal-fuel card discharging bay and simultaneously discharged within its metal-fuel card discharging subsystem in order to generate and deliver electrical power across an electrical load connected thereto.

[0051] Another object of the present invention is to provide such a metal-air FCB system, wherein a plurality of metal-fuel cards can be loaded within a metal-fuel card recharging bay and simultaneously recharged within its Metal-Fuel Card Recharging Subsystem in order to convert metal-oxide along the metal-fuel card into its primary metal fuel for reuse during discharging operations.

[0052] Another object of the present invention is to provide such a metal-air FCB system, wherein both the metal-fuel card discharging and recharging subsystems can be operated simultaneously as well as under the management of a system controller associated with a resultant system, such as an electrical power management system.

[0053] These and other objects of the present invention will become apparent hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0054] For a more complete understanding of the Objects of the Present Invention, the following detailed Description of the Illustrative Embodiments Of the Present Invention should be read in conjunction with the accompanying Drawings, wherein:

[0055] **FIG. 1** is a schematic block diagram of a first illustrative embodiment of the metal-air FCB system of the present invention, wherein a Metal-Fuel Tape Discharging Subsystem and a Metal-Fuel Tape Recharging Subsystem are integrated within a single, stand-alone rechargeable power generation unit, and the tape path-length extension mechanism employed in the Metal-Fuel Tape Recharging Subsystem extends oxidized metal-fuel tape over a path-length which is substantially greater than the path-length maintained by the tape path-length extension mechanism in the Metal-Fuel Tape Discharging Subsystem (i.e. $A_{Recharge} >> A_{Discharge}$);

[0056] **FIG. 2A1** is a generalized schematic representation of the Metal-Fuel Tape Discharging Subsystem of **FIG. 1**, wherein the tape path-length extension mechanism associated therewith is shown in its non-extended configuration;

[0057] **FIG. 2A2** is a generalized schematic representation of the Metal-Fuel Tape Discharging Subsystem of **FIG. 1**, wherein the tape path-length extension mechanism associated therewith is shown in its extended configuration and the assembly of discharging heads thereof configured about the extended path of metal-fuel tape for generating electrical power across an electrical load connected to the metal-air FCB system;

[0058] FIGS. **2A31** and **2A32** taken together set forth a generalized schematic representation of the Metal-Fuel Tape Discharging Subsystem shown in **FIG. 1**, wherein the subcomponents thereof are shown in greater detail, and the discharging heads thereof withdrawn from the extended path of unoxidized metal-fuel tape;

[0059] **FIG. 2A4** is a schematic representation of the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A31** and **2A32**, wherein the tape path-length extension mechanism is arranged in its extended configuration with its four independent discharging heads arranged about the extended path of unoxidized metal-fuel tape, and metal-fuel zone (MFZ) identification data is generated from each discharging head during tape discharging operations so that the system controller can record, in memory, "discharge parameters" of the Metal-Fuel Tape Discharging Subsystem during the discharging of each metal-fuel zone identified along the metal-fuel tape being transported through the discharge head assembly;

[0060] **FIG. 2A5** is a high-level flow chart setting forth the basic steps involved during the discharging of metal-fuel tape (i.e. electrical power generation therefrom) when using the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A31**, **2A32** and **2A4**;

[0061] **FIG. 2A6** is a perspective view of the cathode support structure employed in each discharging head of the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A31**, **2A32** and **2A4**, showing five parallel channels within which electrically-conductive cathode strips and ionically-conducting electrolyte-impregnated strips are securely supported in its assembled state;

[0062] **FIG. 2A7** is a perspective, exploded view of cathode and electrolyte impregnated strips and oxygen pressure (pO2) sensors installed within the support channels of the cathode support structure shown in **FIG. 2A6**;

[0063] **FIG. 2A8** is a perspective view of the cathode structure and oxygen-injecting chamber of the first illustrative embodiment of the present invention, shown in its fully assembled state and adapted for use in the discharging head assembly shown in FIGS. **2A31**, **2A32** and **2A4**;

[0064] **FIG. 2A9** is a perspective view of a section of unoxidized metal-fuel tape for use in the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **1**, **2A3** and **2A4**, showing (i) its parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 2A8**, and (ii) a graphically-encoded data track containing sequences of code symbols along the length of metal-fuel tape for identifying each metal-fuel zone therealong and facilitating, during discharging operations, (i) reading (or accessing), from data storage memory, recharge parameters and/or metal-fuel indicative data correlated to metal-fuel zone identification data prerecorded during previous recharging and/or discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters and computed metal-oxide indicative data correlated to metal-fuel zone identification data read during the discharging operation;

[0065] **FIG. 2A9'** is a perspective view of a section of unoxidized metal-fuel tape for use in the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **1**, **2A31**, **2A32** and **2A4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 2A8**, and (ii) a magnetically-encoded data track embodying sequences of code symbols along the length of metal-fuel tape for identifying each metal-fuel zone therealong and facilitating, during discharging operations, (i) reading (or accessing), from data storage memory, recharge parameters and/or metal-fuel indicative data correlated to metal-fuel zone identification data prerecorded during previous recharging and/or discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters and computed metal-oxide indicative data correlated to metal-fuel zone identification data read during the discharging operation;

[0066] **FIG. 2A9"** is a perspective view of a section of unoxidized metal-fuel tape for use in the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **1**, **2A31**, **2A32** and **2A4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 2A8**, and (ii) an optically-encoded data track containing sequences of light-transmission aperture-type code symbols along the length of metal-fuel tape for identifying each metal-fuel zone therealong, and facilitating, during discharging operations, (i) reading (or accessing), from data storage memory, recharge parameters and/or metal-fuel indicative data correlated to metal-fuel zone identification data prerecorded during previous recharging and/or discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters and computed metal-oxide indicative data correlated to metal-fuel zone identification data read during recharging operations;

[0067] **FIG. 2A10** is a perspective view of an assembled discharging head within the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A31**, **2A32** and **2A4**, wherein during the Discharging Mode thereof, metal-fuel tape is transported past the air-pervious cathode structures shown in **FIG. 2A8**, and multiple anode-contacting elements establishing electrical contact with the metal-fuel strips of metal-fuel tape transported through the discharging head;

[0068] **FIG. 2A11** is a cross-sectional view of the assembled cathode structure, taken along line **2A11-2A11** of **FIG. 2A8**, showing its cross-sectional details;

[0069] **FIG. 2A12** is a cross-sectional view of the metal-fuel tape shown in **FIG. 2A9**, taken along line **2A12-2A12** thereof, showing its cross-sectional details;

[0070] **FIG. 2A13** is a cross-sectional view of the cathode structure and oxygen-injecting chamber of the discharging head shown in **FIG. 2A10**, taken along line **2A13-2A13** therein;

[0071] **FIG. 2A14** is a cross-sectional view of the discharging head shown in **FIG. 2A10**, taken along line **2A14-2A14** therein, showing its cross-sectional details;

[0072] **FIG. 2A15** is a perspective view of the multi-track metal-oxide sensing head assembly employed in the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A1** through **2A4**, particularly adapted for real-time sensing (i.e. detecting) metal-oxide formations along each metal-fuel zone to assess the presence or absence of metal-fuel therelong during discharging operations;

[0073] **FIG. 2A16** is a schematic representation of the information structure maintained within the Metal-Fuel Tape Discharging Subsystem of **FIG. 1**, comprising a set of information fields for recording discharge parameters, and metal-oxide and metal-fuel indicative data for each metal-fuel zone identified (i.e. addressed) along a discharged section of metal-fuel tape during the discharging mode of operation;

[0074] **FIG. 2B1** is a generalized schematic representation of the Metal-Fuel Tape Recharging Subsystem of **FIG. 1**, wherein the tape path-length extension mechanism employed therein is shown in its non-extended configuration;

[0075] **FIG. 2B2** is a generalized schematic representation of the Metal-Fuel Tape Recharging Subsystem of **FIG. 1**, wherein the tape path-length extension mechanism employed therein is shown in its extended configuration and the recharging heads thereof are configured about the extended path of oxidized metal-fuel tape for recharging the same;

[0076] FIGS. **2B31** and **2B32**, taken together, set forth a generalized schematic representation of the Metal-Fuel Tape Recharging Subsystem shown in **FIG. 1**, wherein the subcomponents thereof are shown in greater detail, and the recharging heads thereof withdrawn from the extended path of oxidized metal-fuel tape;

[0077] **FIG. 2B4** is a schematic representation of the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **2B31** and **2B32**, wherein the subcomponents thereof are shown in greater detail, the tape path-length extension mechanism is arranged in its extended configuration with four independent recharging heads arranged about the extended path of oxidized metal-fuel tape, and metal-fuel zone identification data (MFZID) is generated from the recharging heads during tape recharging operations so that the system controller can access previously recorded discharge parameters and metal-fuel indicative data from system memory, correlated to each metal-fuel zone along the metal-fuel tape, thereby enabling optimal setting of recharge parameters during tape recharging operations;

[0078] **FIG. 2B5** is a high-level flow chart setting forth the basic steps involved during the recharging of oxidized metal-fuel tape when using the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **2B31** through **2B4**;

[0079] **FIG. 2B6** is a perspective view of the cathode support structure employed in each recharging head of the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **2B31**, **2B32** and **2B4**, and comprises five parallel channels within which electrically-conductive cathode strips and ionically-conducting electrolyte-impregnated strips are securely supported;

[0080] **FIG. 2B7** is a perspective, exploded view of cathode and electrolyte-impregnated strips and oxygen pressure (pO2) sensors installed within the support channels of the cathode support structure shown in **FIG. 2B8**;

[0081] **FIG. 2B8** is a perspective view of the cathode structure and oxygen-evacuation chamber of the first illustrative embodiment of the present invention, shown in its fully assembled state and adapted for use in the recharging heads shown in FIGS. **2B31**, **2B32** and **2B4**;

[0082] **FIG. 2B9** is a perspective view of a section of oxidized metal-fuel tape for recharging in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **2B31**, **2B32** and **2B4**, and comprising parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure (i.e. recharging head) of **FIG. 2B8**, and an optically encoded data track containing sequences of bar of code symbols along the length of metal-fuel tape for identifying each metal-fuel zone along the reel of metal-fuel tape, and facilitating, during recharging operations, (i) reading (or accessing), from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording, in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data read during the recharging operation;

[0083] **FIG. 2B9'** is a perspective view of a section of oxidized metal-fuel tape for use in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **1**, **2B31**, **2B32** and **2B4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the recharging head partially shown in **FIG. 2B8**, and (ii) a magnetically-encoded data track embodying sequences of digital words along the length thereof identifying each metal-fuel zone therealong, and facilitating, during recharging operations, (i) reading (or accessing), from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording, in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data read during the recharging operation;

[0084] **FIG. 2B9"** is a perspective view of a section of reoxidized metal-fuel tape for use in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **1**, **2B31**, **2B32** and **2B4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the recharging head partially shown in **FIG. 2B8**, and (ii) an optically-encoded data track containing sequences of light-transmission aperture-type code symbols along the length of metal-fuel tape for identifying each metal-fuel zone therealong, and facilitating, during recharging operations, (i) reading (or accessing), from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording, in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data read during the recharging operation;

[0085] **FIG. 2B10** is a perspective view of a recharging head within the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **2B31**, **2B32** and **2B4**, wherein during the Recharging Mode thereof, metal-fuel tape is transported past the air-pervious cathode structure shown in **FIG. 2B8**, and five anode-contacting elements establishing electrical contact with the metal-fuel strips of the transported metal-fuel tape;

[0086] **FIG. 2B11** is a cross-sectional view of the cathode support structure head in the Metal-Fuel Tape Recharging Subsystem hereof, taken along line **2B11-2B11** of **FIG. 2B8**, showing a plurality of cathode and electrolyte-impregnated strips supported therein;

[0087] FIG. 2B12 is a cross-sectional view of the metal-fuel tape shown in FIG. 2B9, taken along line 2B12-2B12 thereof;

[0088] FIG. 2B13 is a cross-sectional view of the cathode structure of the recharging head shown in FIG. 2B10, taken along line 2B13-2B13 therein;

[0089] FIG. 2B14 is a cross-sectional view of the recharging head assembly shown in FIG. 2B10, taken along line 2B14-2B14 therein;

[0090] FIG. 2B15 is a perspective view of the multi-track metal-oxide sensing head employed in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. 2B31, 2B32 and 2B4, particularly adapted for sensing which metal-fuel tracks have been discharged and thus require recharging by the subsystem;

[0091] FIG. 2B16 is a schematic representation of the information structure maintained within the Metal-Fuel Tape Recharging Subsystem of FIG. 1, comprising a set of information fields for recording recharge parameters and metal-fuel and metal-oxide indicative data for each metal-fuel zone identified (i.e. addressed) along a section of metal-fuel tape during the recharging mode of operation;

[0092] FIG. 2B17 is a schematic representation of the FCB system of FIG. 1 showing a number of subsystems which enable, during the recharging mode of operation, (a)(i) reading metal-fuel zone identification data from transported metal-fuel tape, (a)(ii) recording in memory, sensed recharge parameters and computed metal-fuel indicative data derived therefrom, and (a)(iii) reading (i.e., accessing) from memory, discharge parameters and computed metal-oxide indicative data recorded during the previous discharging and/or recharging mode of operation through which the identified metal-fuel zone has been processed, and during the discharging mode of operation, (b)(i) reading metal-fuel zone identification data from transported metal-fuel tape, (b)(ii) recording in memory, sensed discharge parameters and computed metal-oxide indicative data derived therefrom, and (b)(iii) reading (i.e., accessing) from memory, recharge parameters and computed metal-fuel indicative data recorded during the previous recharging and/or discharging operations through which the identified metal-fuel zone has been subjected;

[0093] FIG. 3A is a schematic block diagram of a second illustrative embodiment of the metal-air FCB system of the present invention shown realized as an external stand-alone unit, into which a cassette-type device containing a supply of oxidized metal-fuel tape can be received and quickly recharged for reuse in generating of electrical power;

[0094] FIG. 3B is a schematic block diagram of a third illustrative embodiment of the metal-air FCB system of the present invention shown realized as an external stand-alone unit, into which a cassette-type device containing a supply of oxidized metal-fuel tape and at least a portion of the metal-fuel tape discharging subsystem (e.g. the discharging head) can be received and quickly recharged for reuse in generating-electrical power;

[0095] FIG. 4 is a schematic diagram showing a fourth illustrative embodiment of the metal-air FCB system of the present invention, wherein a first plurality of recharged metal-fuel cards (or sheets) are semi-manually loaded into the discharging bay of its Metal-Fuel Card Discharging Subsystem, while a second plurality of discharged metal-fuel cards (or sheets) are semi-manually loaded into the recharging bay of its Metal-Fuel Card Recharging Subsystem;

[0096] FIG. 5A1 is a generalized schematic representation of the metal-air FCB system of FIG. 4, wherein metal-fuel cards are shown about-to-be inserted within the discharging bays of the Metal-Fuel Card Discharging Subsystem;

[0097] FIG. 5A2 is a generalized schematic representation of the metal-air FCB system of FIG. 4, wherein metal-fuel cards of FIG. 1 are shown loaded within the discharging bays of the Metal-Fuel Card Discharging Subsystem;

[0098] FIGS. 5A31 and 5A32, taken together, set forth a generalized schematic representation of the Metal-Fuel Card Discharging Subsystem shown in FIGS. 5A1 and 5A2, wherein the subcomponents thereof are shown in greater detail, with all metal-fuel cards withdrawn from the discharging head assembly thereof;

[0099] FIG. 5A4 is a schematic representation of the Metal-Fuel Card Discharging Subsystem shown in FIGS. 5A1 and 5A2, wherein the subcomponents thereof are shown in greater detail, with the metal-fuel cards inserted between the cathode and anode-contacting structures of each discharging head thereof;

[0100] FIG. 5A5 is a high-level flow chart setting forth the basic steps involved during the discharging of metal-fuel cards (i.e. generating electrical power therefrom) when using the Metal-Fuel Card Discharging Subsystem shown in FIGS. 5A31 through 5A4;

[0101] FIG. 5A6 is a perspective view of the cathode support structure employed in each discharging head of the Metal-Fuel Card Discharging Subsystem shown in FIGS. 5A31, 5A32 and 5A4, and comprising five parallel channels within which electrically-conductive cathode strips and ionically-conducting electrolyte-impregnated strips are securely supported in its assembled state;

[0102] FIG. 5A7 is a perspective, exploded view of cathode and electrolyte impregnated strips and partial oxygen pressure (pO2) sensors installed within the support channels of the cathode support structure shown in FIG. 5A6;

[0103] FIG. 5A8 is a perspective view of the cathode structure of the first illustrative embodiment of the present invention, shown in its fully assembled state and adapted for use in the discharging heads shown in FIGS. 5A31, 5A32 and 5A4;

[0104] FIG. 5A9 is a perspective view of a section of unoxidized metal-fuel card for use in the Metal-Fuel Card Discharging Subsystem shown in FIGS. 4, 5A31, 5A32 and 5A4, showing (i) its parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in FIG. 5A8, and (ii) a graphically-encoded data track containing code symbols identifying the metal-fuel card, and facilitating, during discharging operations, (i) reading (or access), from data storage memory, recharge parameters and/or metal-fuel indicative data correlated to metal-fuel zone identification data prerecorded during previous recharging and/or discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters and computed metal-oxide indicative data correlated to metal-fuel zone identification data being read during the discharging operation;

[0105] **FIG. 5A9'** is a perspective view of a section of unoxidized metal-fuel card for use in the Metal-Fuel Card Discharging Subsystem shown in FIGS. **4**, **5A31**, **5A32** and **5A4**, showing (i) its parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 5A8**, and (ii) a magnetically-encoded data track embodying digital code symbols identifying the metal-fuel card, and facilitating during discharging operations, (i) reading (or accessing) from data storage memory, prerecorded recharge parameters and/or metal-fuel indicative data correlated to the metal-fuel identification data read by the subsystem during discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters correlated to metal-fuel zone identification data being read during the discharging operation;

[0106] **FIG. 5A9"** is a perspective view of a section of unoxidized metal-fuel card for use in the Metal-Fuel Card Discharging Subsystem shown in FIGS. **4**, **5A31**, **5A32** and **5A4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 5A8**, and (ii) an optically-encoded data track containing light-transmission aperture-type code symbols identifying the metal-fuel card, and facilitating during discharging operations (i) reading (or accessing) from data storage memory, recharge parameters and/or metal-fuel indicative data correlated to metal-fuel zone identification data prerecorded during previous recharging and/or discharging operations, and (ii) recording, in data storage memory, sensed discharge parameters and computed metal-oxide indicative data correlated to metal-fuel zone identification data being read during the discharging operation;

[0107] **FIG. 5A10** is a perspective view of a discharging head within the Metal-Fuel Card Discharging Subsystem shown in FIGS. **5A31**, **5A32** and **5A4**, wherein during the Discharging Mode thereof, metal-fuel card is transported past the air-pervious cathode structure shown in **FIG. 5A10**, and five anode-contacting elements establish electrical contact with the metal-fuel strips of the transported metal-fuel card;

[0108] **FIG. 5A11** is a cross-sectional view of the discharging head in the Metal-Fuel Card Discharging Subsystem hereof, taken along line **5A11-5A11** of **FIG. 5A8**, showing the cathode structure in electrical contact with the metal-fuel card of **FIG. 5A9**;

[0109] **FIG. 5A12** is a cross-sectional view of the metal-fuel card shown in **FIG. 5A9**, taken along line **5A12-5A12** thereof;

[0110] **FIG. 5A13** is a cross-sectional view of the cathode structure of the discharging head shown in **FIG. 5A10**, taken along line **5A13-5A13** therein;

[0111] **FIG. 5A14** is a cross-sectional view of the cathode structure of the discharging head shown in **FIG. 5A10**, taken along line **5A14-5A14** therein;

[0112] **FIG. 5A15** is a schematic representation of the information structure maintained within the Metal-Fuel Card Discharging Subsystem of **FIG. 4**, comprising a set of information fields for use in recording discharge parameters and metal-oxide and metal-fuel indicative data for each metal-fuel track within an identified (i.e. addressed) metal-fuel card during the discharging mode of operation;

[0113] **FIG. 5A16** is a schematic representation of the FCB system of **FIG. 4** showing a number of subsystems which enable, during the discharging mode of operation, (i) the reading of metal-fuel card identification data from a loaded metal-fuel card, (ii) the recording of memory, sensed discharge parameters and computed metal-oxide indicative data derived therefrom, and (iii) the reading (i.e., accessing) from memory, recharge parameters and computed metal-fuel and metal-oxide indicative data recorded during previous recharging and/or discharging operations through which the identified metal-fuel card has been processed;

[0114] **FIG. 5B1** is a generalized schematic representation of the metal-air FCB system of **FIG. 4**, wherein metal-fuel cards are shown about-to-be loaded within the recharging bays of the Metal-Fuel Card Recharging Subsystem thereof;

[0115] **FIG. 5B2** is a generalized schematic representation of the metal-air FCB system of **FIG. 4**, wherein metal-fuel cards are shown loaded within the recharging bays of the Metal-Fuel Card Recharging Subsystem;

[0116] FIGS. **5B31** and **5B32**, taken together, set forth a generalized schematic representation of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **5B1** and **5B2**, wherein the subcomponents thereof are shown in greater detail, with the metal-fuel cards withdrawn from the recharging head assembly thereof;

[0117] **FIG. 5B4** is a schematic representation of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **5B31** and **5B32**, wherein the metal-fuel cards are shown loaded between the cathode and anode-contacting structure of recharging heads thereof;

[0118] **FIG. 5B5** is a high-level flow chart setting forth the basic steps involved during the recharging of oxidized metal-fuel cards when using the Metal-Fuel Card Recharging Subsystem shown in FIGS. **5B31** through **5B4**;

[0119] **FIG. 5B6** is a perspective view of the cathode support structure employed in each recharging head of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **5B31**, **5B32** and **5B4**, showing five parallel channels within which electrically-conductive cathode strips and ionically-conducting electrolyte-impregnated strips are securely supported;

[0120] **FIG. 5B7** is a perspective, exploded view of cathode and electrolyte impregnated strips and oxygen pressure (pO2) sensors being installed within the support channels of the cathode support structure shown in **FIG. 5B8**;

[0121] **FIG. 5B8** is a perspective view of the cathode structure and its associated oxygen-evacuation chamber of the first illustrative embodiment of the present invention, shown in its fully assembled state and adapted for use in the recharging heads shown in FIGS. **5B31**, **5B32** and **5B4**;

[0122] **FIG. 5B9** is a perspective view of a section of an oxidized metal-fuel card adapted for use in the Metal-Fuel Card Recharging Subsystem shown in FIGS. **4**, **5B31**, **5B32** and **5B4**, showing (i) its parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the recharging head partially shown in **FIG. 5B8**, and (ii) a graphically-encoded data track containing code symbols for identifying each metal-fuel zone therealong, and facilitating during recharging operations, (i) reading (or accessing), from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording, in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data being read during the recharging operation;

[**0123**] **FIG. 5B9'** is a perspective view of a section of an oxidized metal-fuel card adapted for use in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **4**, **5B31**, **5B32** and **5B4**, showing (i) its parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the discharging head partially shown in **FIG. 5B8**, and (ii) a magnetically encoded data track embodying digital data for identifying each metal-fuel zone therealong, and facilitating during recharging operations, (i) reading (or access), from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data being read during the recharging operation;

[**0124**] **FIG. 5B9"** is a perspective view of a section of an oxidized metal-fuel card adapted for use in the Metal-Fuel Tape Recharging Subsystem shown in FIGS. **4**, **5A31**, **5A32** and **5A4**, showing (i) parallel metal-fuel strips spatially registerable with the cathode strips in the cathode structure of the recharging head partially shown in **FIG. 5A8**, and (ii) an optically-encoded data track containing a light-transmission aperture-type code symbols on the metal-fuel card for identifying each metal-fuel card, and facilitating during recharging operations, (i) reading (or accessing) from data storage memory, discharge parameters and/or metal-oxide indicative data correlated to metal-fuel zone identification data prerecorded during previous discharging and/or recharging operations, and (ii) recording, in data storage memory, sensed recharge parameters and computed metal-fuel indicative data correlated to metal-fuel zone identification data being read during the recharging operation;

[**0125**] **FIG. 5B10** is a perspective view of a recharging head within the Metal-Fuel Card Recharging Subsystem shown in FIGS. **5B31**, **5B32** and **5B4**, wherein during the Recharging Mode thereof, metal-fuel card is transported past the air-pervious cathode structure shown in **FIG. 5B10**, and five anode-contacting elements establish electrical contact with the metal-fuel strips of the transported metal-fuel card;

[**0126**] **FIG. 5B11** is a cross-sectional view of each recharging head in the Metal-Fuel Card Recharging Subsystem hereof, taken along line **5B11-5B11** of **FIG. 5B8**, showing the cathode structure in electrical contact with the metal-fuel card structure of **FIG. 5B9**;

[**0127**] **FIG. 5B12** is a cross-sectional view of the metal-fuel card shown in **FIG. 5B9**, taken along line **5B12-5B12** thereof;

[**0128**] **FIG. 5B13** is a cross-sectional view of the cathode structure of the recharging head shown in **FIG. 5B10**, taken along line **5B13-5B13** therein;

[**0129**] **FIG. 5B14** is a cross-sectional view of the cathode structure of the recharging head shown in **FIG. 5B10**, taken along line **5B14-5B14** therein;

[**0130**] **FIG. 5B15** is a schematic representation of the information structure maintained within the Metal-Fuel Card Recharging Subsystem of **FIG. 4**, comprising a set of information fields for recording recharge parameters and metal-oxide and metal-fuel indicative data for each metal-fuel track within an identified (i.e. addressed) metal-fuel card during the recharging mode of operation;

[**0131**] **FIG. 5B16** is a schematic representation of the FCB system of **FIG. 4** showing a number of subsystems which enable, during the recharging mode of operation, (a)(i) reading metal-fuel card identification data from a loaded metal-fuel card, (a)(ii) recording in memory, sensed recharge parameters and computed metal-fuel indicative data derived therefrom, and (a)(iii) reading (accessing) from memory, discharge parameters and computed metal-oxide and metal-fuel indicative data recorded during previous discharging and/or recharging operations through which the identified metal-fuel card has been processed, and during the discharging mode of operation, (b)(i) reading metal-fuel card identification data from a loaded metal-fuel card, (b)(ii) recording in memory, sensed discharge parameters and computed metal-oxide indicative data derived therefrom, and (b)(iii) reading (accessing) from memory, recharge parameters and computed metal-oxide and metal-oxide and metal-fuel indicative data recorded during previous discharging and/or recharging operations through which the identified metal-fuel card has been processed;

[**0132**] **FIG. 6** is a perspective diagram of a fifth illustrative embodiment of the metal-air FCB system of the present invention, wherein a first plurality of recharged metal-fuel cards can be to automatically transported from its recharged metal-fuel card storage bin into the discharging bay of its Metal-Fuel Card Discharging Subsystem, while a second plurality of oxidized metal-fuel cards are automatically transported from the discharged metal-fuel card storage bin into the recharging bay of its Metal-Fuel Card Recharging Subsystem for use in electrical power generation operations;

[**0133**] **FIG. 7A1** is a generalized schematic representation of the metal-air FCB system of **FIG. 6**, wherein recharged metal-fuel cards are shown being automatically transported from the bottom of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage bin, into the discharging bay of the Metal-Fuel Card Discharging Subsystem;

[**0134**] **FIG. 7A2** is a generalized schematic representation of the metal-air FCB system of **FIG. 6**, wherein discharged metal-fuel cards are shown being automatically transported from the discharging bay of the Metal Fuel Card Discharging Subsystem onto the top of the stack of discharged metal fuel cards in the discharged metal-fuel card storage bin;

[**0135**] FIGS. **7A31** and **7A32**, taken together, set forth a generalized schematic representation of the Metal-Fuel Card Discharging Subsystem shown in FIGS. **7A1** and **7A2**, wherein the subcomponents thereof are shown in greater detail, with a plurality of recharged metal-fuel cards arranged and ready for insertion between the cathode and anode-contacting structures of the discharging heads thereof;

[0136] **FIG. 7A4** is a schematic representation of the Metal-Fuel Card Discharging Subsystem shown in FIGS. **7A31** and **7A32**, wherein the plurality of recharged metal-fuel cards are inserted between the cathode and anode-contacting structures of the discharging heads thereof;

[0137] **FIG. 7A5** sets forth a high-level flow chart setting forth the basic steps involved during the discharging of metal-fuel cards (i.e. generating electrical power therefrom) using the Metal-Fuel Card Discharging Subsystem shown in FIGS. **7A31** through **7A4**;

[0138] **FIG. 7A6** is a perspective view of the cathode support structure employed in each discharging head of the Metal-Fuel Card Discharging Subsystem shown in FIGS. **7A31**, **7A32** and **7A4**, wherein four cathode element receiving recesses are provided for receiving cathode structures and electrolyte-impregnated pads therein;

[0139] **FIG. 7A7** is a schematic diagram of the oxygen-injection chamber adapted for use with the cathode support structure shown in **FIG. 7A6**;

[0140] **FIG. 7A8**A is a schematic diagram of a cathode structure insertable within the lower portion of a cathode receiving recess of the cathode support plate shown in **FIG. 7A6**;

[0141] **FIG. 7A8**B is a schematic diagram of an electrolyte-impregnated pad for insertion over a cathode structure within the upper portion of a cathode receiving recess of the cathode support plate shown in **FIG. 7A6**;

[0142] **FIG. 7A9** is a perspective view of an unoxidized metal-fuel card for discharging within the Metal-Fuel Discharging Subsystem of **FIG. 6**, and which comprises four spatially-isolated recesses each supporting a metal-fuel strip and permitting electrical contact with an anode-contacting electrode through an aperture formed in the bottom surface of the recess when loaded within the discharging head;

[0143] **FIG. 7A10** is a cross-sectional view of the metal-fuel support structure of **FIG. 7A9**, taken along line **7A10**-**7A10** of **FIG. 7A9**;

[0144] **FIG. 7A11** is a perspective view of an electrode support plate supporting a plurality of electrodes which are designed to establish electrical contact with the anodic metal-fuel strips supported within the metal-fuel support plate of **FIG. 7A9**, during discharging operations carried out by the Metal-Fuel Card Discharging Subsystem of **FIG. 6**;

[0145] **FIG. 7A12** is a perspective, exploded view of a discharging head within the Metal-Fuel Card Discharging Subsystem of **FIG. 6**, showing its cathode support structure, oxygen-injection chamber, metal-fuel support structure, and anode electrode-contacting plate thereof in a disassembled yet registered relationship;

[0146] **FIG. 7A13** is a schematic representation of the information structure maintained within the Metal-Fuel Card Discharging Subsystem of **FIG. 6**, comprising a set of information fields for use in recording discharge parameters, and metal-oxide and metal-fuel indicative data for each metal-fuel zone within an identified (i.e. addressed) metal-fuel card during discharging operations;

[0147] **FIG. 7B1** is a generalized schematic representation of the metal-air FCB system of **FIG. 6**, wherein a plurality of oxidized metal-fuel cards are shown being automatically transported from the bottom of the stack of discharged metal-fuel cards in the discharged metal-fuel card storage bin into the recharging bay of the Metal-Fuel Card Recharging Subsystem thereof;

[0148] **FIG. 7B2** is a generalized schematic representation of the metal-air FCB system of **FIG. 6**, wherein recharged metal-fuel cards are shown being automatically transported from the recharging bay of the Metal-Fuel Card Recharging Subsystem onto the top of the stack of recharged metal fuel cards in recharged metal-fuel card storage bin;

[0149] FIGS. **7B31** and **7B32**, taken together, set forth a generalized schematic representation of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **7B1** and **7B2**, wherein the subcomponents thereof are shown in greater detail, with a plurality of discharged metal-fuel cards ready for insertion between the cathode and anode-contacting structures of the recharging heads thereof;

[0150] **FIG. 7B4** is a schematic representation of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **7B31** and **7B32**, wherein a plurality of discharged metal-fuel cards are shown inserted between the cathode and anode-contacting structures of the metal-oxide recharging heads thereof;

[0151] **FIG. 7B5** sets forth a high-level flow chart setting forth the basic steps involved during the recharging of metal-fuel cards (i.e. converting metal-oxide into its primary metal) when using the Metal-Fuel Card Recharging Subsystem shown in FIGS. **7B31** through **7B4**;

[0152] **FIG. 7B6** is a perspective view of the cathode support structure employed in each recharging head of the Metal-Fuel Card Recharging Subsystem shown in FIGS. **7B31**, **7B32** and **7B4**, wherein four cathode element receiving recesses are provided for receiving cathode structures and electrolyte-impregnated pads therein;

[0153] **FIG. 7B7** is a schematic diagram of a cathode structure insertable within the lower portion of a cathode receiving recess of the cathode support structure shown in **FIG. 7B6**;

[0154] **FIG. 7B8**A is a schematic diagram of a cathode structure insertable within the lower portion of a cathode receiving recess in the cathode support plate of **FIG. 7B6**;

[0155] **FIG. 7B8**B is a schematic diagram of an oxygen-evacuation chamber adapted for use in cathode support structure shown in **FIG. 7B6**;

[0156] **FIG. 7B9** is a perspective view of a partially-oxidized metal-fuel card designed for recharging in the Metal-Fuel Recharging Subsystem of **FIG. 6**, and comprising four spatiallyisolated recesses each supporting a metal-fuel strip and permitting electrical contact with an anode-contacting electrode through an aperture formed in the bottom surface of the recess when loaded within a recharging head;

[0157] **FIG. 7B10** is a cross-sectional view of the metal-fuel support structure of **FIG. 7B9**, taken along line **7B10**-**7B10** of **FIG. 7B9**;

[0158] **FIG. 7B11** is a perspective view of a metal-fuel support plate for supporting a plurality of electrodes designed to establish electrical contact with the metal-fuel strips supported within the metal-fuel support plate of **FIG. 7B10**, during recharging operations carried out by the Metal-Fuel Card Recharging Subsystem of **FIG. 6**;

[0159] **FIG. 7B12** is a perspective, exploded view of a recharging head within the Metal-Fuel Card Recharging Subsystem of **FIG. 6**, showing the cathode support structure, the metal-fuel support structure and the anode electrode-contacting plate thereof in a disassembled yet registered relationship;

[0160] **FIG. 7B13** is a schematic representation of the information structure maintained within the Metal-Fuel Card Discharging Subsystem of **FIG. 6**, comprising a set of information fields for use in recording recharge parameters, and metal-fuel and metal-oxide indicative data for each metal-fuel track within an identified (i.e. addressed) metal-fuel card during recharging operations;

[0161] **FIG. 7B14** is a schematic representation of the FCB system of **FIG. 6** showing a number of subsystems which enable, during recharging operations, (a)(i) reading metal-fuel card identification data from a loaded metal-fuel card, (a)(ii) recording in memory, sensed recharge parameters and computed metal-fuel indicative data derived therefrom, and (a)(iii) reading (accessing) from memory, discharge parameters and computed metal-oxide and metal-oxide indicative data recorded during previous discharging and/or recharging operations through which the identified metal-fuel card has been processed;

[0162] **FIG. 8** is a is a schematic block diagram of a sixth illustrative embodiment of the metal-air FCB system of the present invention, wherein metal-fuel tape discharging and recharging functions are realized in a single hybrid-type Metal-Fuel Tape Discharging/Recharging Subsystem, wherein the tape path-length extension mechanism employed therein extends metal-fuel tape to be recharged over a path which is substantially greater than the path maintained for metal-fuel tape to be discharged;

[0163] FIGS. **9A11** and **9A12**, taken together, set forth a schematic representation of the hybrid Metal-Fuel Tape Discharging/Recharging Subsystem shown in **FIG. 8**, wherein the configured discharging heads and recharging heads thereof are shown withdrawn from the extended path-length of metal-fuel tape;

[0164] **FIG. 9A2** is a schematic representation of the hybrid Metal-Fuel Tape Discharging/Recharging Subsystem shown in **FIG. 8**, wherein the configured discharging heads and recharging heads are arranged about the extended path-length of metal-fuel tape to enable simultaneous discharging and recharging operations to be carried out in an optimal manner;

[0165] **FIG. 9B** is a schematic representation of the FCB system of **FIG. 8** showing a number of subsystems which enable data capture, processing and storage of discharge and recharge parameters as well as metal-fuel and metal-oxide indicative data for use during discharging and recharging modes of operation;

[0166] **FIG. 10** is a schematic diagram of the seventh illustrative embodiment of the metal-air FCB system hereof, wherein metal-fuel is provided in the form of metal-fuel cards (or sheets) contained within a cassette cartridge-like device having a partitioned interior volume for storing (re)charged and discharged metal-fuel cards in separate storage compartments formed within the same cassette cartridge-like device;

[0167] **FIG. 10A** is a generalized schematic representation of the metal-air FCB system of **FIG. 10**, wherein recharged metal-fuel cards are shown being automatically transported from the bottom of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage compartment, into the discharging bay of the Metal-Fuel Card Discharging Subsystem thereof, whereas discharged metal-fuel cards are shown being automatically transported from the discharging bay of the Metal-Fuel Card Discharging Subsystem onto the top of the stack of discharged metal fuel cards in the discharged metal-fuel card storage compartment;

[0168] **FIG. 11** is a schematic diagram of the eighth illustrative embodiment of the metal-air FCB system hereof, wherein metal-fuel is provided in the form of metal-fuel cards (or sheets) contained within a cassette cartridge-like device having a partitioned interior volume for storing (re)charged and discharged metal-fuel cards in separate storage compartments formed within the same cassette cartridge-like device; and

[0169] **FIG. 11A** is a generalized schematic representation of the metal-air FCB system of **FIG. 11**, wherein recharged metal-fuel cards are shown being automatically transported from the bottom of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage compartment, into the discharging bay of the Metal-Fuel Card Discharging Subsystem thereof, whereas discharged metal-fuel cards are shown being automatically transported from the discharging bay of the Metal-Fuel Card Discharging Subsystem onto the top of the stack of discharged metal fuel cards in discharged metal-fuel card storage compartment.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS OF THE PRESENT INVENTION

[0170] Referring now to the figures in the accompanying Drawings, the illustrative embodiments of the present invention will now be described in great technical detail, wherein like elements are indicated by like reference numbers.

[0171] In general, many of the rechargeable metal-air FCB-based systems according to the present invention can be decomposed into a number of subsystems including, for example: a Metal-Fuel Transport Subsystem; a Metal-Fuel Discharging Subsystem; and a Metal-Fuel Recharging Subsystem. The function of the Metal-Fuel Transport Subsystem is to transport metal-fuel material, in the form of tape, cards, sheets, cylinders and the like, to the Metal-Fuel Discharge Subsystem, or the Metal-Fuel Recharge Subsystem, depending on the mode of the system selected. When transported to or through the Metal-Fuel Discharge Subsystem, the metal-fuel is discharged by (i.e. electro-chemically reaction with) one or more discharging heads in order produce electrical power across an electrical load connected to the subsystem while H_2O and O_2 are consumed at the cathode-electrolyte interface during the electrochemical reaction. When transported to or through the Metal-Fuel Recharging Subsystem, discharged metal-fuel is recharged by one or more recharging heads in order to convert the oxidized metal-fuel material into its source metal material suitable for reuse in power discharging operations, while O_2 is released at the cathode-electrolyte interface during the electro-chemical reaction. The electrochemistry upon which such discharging and recharging operations are based is described in Applicant's copending application Ser. No. 08/944,507, U.S. Pat. No. 5,250,370, and other applied science publications well known in the art. These applied science principles will be briefly summarized below.

[**0172**] During discharging operations within metal-air FCB systems, metal-fuel such as zinc, aluminum, magnesium or beryllium is employed as an electrically-conductive anode of a particular degree of porosity (e.g. 50%) which is brought in "ionic-contact" with an electrically-conductive oxygen-pervious cathode structure of a particular degree of porosity, by way of an ionically-conductive medium such as an electrolyte gel, KOH, NaOH or ionically-conductive polymer. When the cathode and anode structure are brought into ionic contact, a characteristic open-cell voltage is automatically generated. The value of this open-cell voltage is based on the difference in electro-chemical potential of the anode and cathode materials. When an electrical load is connected across the cathode and anode structures of the metal-air FCB cell, so constructed, electrical power is delivered to the electrical load, as oxygen O_2 from the ambient environment is consumed and metal-fuel anode material oxidizes. In the case of a zinc-air FCB system or device, the zinc-oxide (ZnO) is formed on the zinc anode structure during the discharging cycle, while oxygen is consumed at within the region between the adjacent surfaces of the cathode structure and electrolytic medium (hereinafter referred to as the "cathode-electrolyte interface" for purposes of convenience).

[**0173**] During recharging operations, the Metal-Fuel Recharging Subsystem hereof applies an external voltage source (e.g. more than 2 volts for zinc-air systems) across the cathode structure and oxidized metal-fuel anode of the metal-air FCB system. Therewhile, the Metal-Fuel Recharging Subsystem controls the electrical current flowing between the cathode and metal-fuel anode structures, in order to reverse the electrochemical reaction which occurred during discharging operations. In the case of the zinc-air FCB system or device, the zinc-oxide (ZnO) formed on the zinc anode structure during the discharging cycle is converted into (i.e. reduced back) into zinc, while oxygen O_2 is released at the cathode-electrolyte interface to the ambient environment.

[**0174**] Specific ways and means for optimally carrying out such discharging and recharging processes in metal-air FCB systems and devices will be described in detail below in connection with the various illustrative embodiments of the present invention.

The First Illustrative Embodiment of the Metal-Air FCB System of The Present Invention

[**0175**] The first illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIGS. 1 through 2B16**. As shown in **FIG. 1**, this metal-air FCB system **1** comprises a number of subsystems, namely: a Metal-Fuel Tape Cassette Cartridge Loading/Unloading Subsystem **2** for loading and unloading a metal-fuel tape cassette device **3** into the FCB system during its Cartridge Loading and Unloading Modes of operation, respectively; a Metal-Fuel Tape Transport Subsystem **4** for transporting metal-fuel tape **5**, supplied by the loaded cassette device, through the FCB system during its Discharging and Recharging Modes of operation alike; a Metal-Fuel Tape Discharging (i.e. Power Generation) Subsystem **6** for generating electrical power from the metal-fuel tape during the Discharging Mode of operation; and a Metal-Fuel Tape Recharging Subsystem **7** for electro-chemically recharging (i.e. reducing) sections of oxidized metal-fuel tape during the Recharging Mode of operation. In the illustrative embodiment of the Metal-Fuel Tape Discharging Subsystem **6** to be described in greater detail hereinebelow, an assembly of discharging (i.e. discharging) heads are provided for discharging metal-fuel tape in the presence of air (O_2) and water and (H_2O) and generating electrical power across an electrical load connected to the FCB system.

[**0176**] In order to equip the metal-air FCB system with multiple discharging heads arranged within an ultra-compact space, the Metal-Fuel Tape Discharging Subsystem **6** comprises a metal-fuel tape path-length extension mechanism **8**, as shown in FIGS. **2A1** and **2A2**. In **FIG. 2A1**, the path-length extension mechanism **8** is shown in its unextended configuration. When a cassette cartridge **3** is loaded into the cassette storage bay of the FCB system, the path-length extension mechanism **8** within the Metal-Fuel Tape Discharging Subsystem **6** automatically extends the path-length of the metal-fuel tape **5**, as shown in **FIG. 2A2**, thereby permitting an assembly of discharging heads **9** to be arranged thereabout for generating electrical power during the Discharging Mode of the system. The many advantages of providing multiple discharging heads in the Metal-Fuel Tape Discharging Subsystem will become apparent hereinafter.

[**0177**] Similarly, in order to equip the metal-air FCB system with multiple metal-oxide reducing (i.e. recharging) heads arranged within an ultra-compact space, the Metal-Fuel Tape Recharging Subsystem **7** also comprises a metal-fuel tape path-length extension mechanism **10**. In FIG. **2B1**, the path-length extension mechanism **10** is shown in its unextended configuration. When a cassette cartridge **3** is loaded into the cassette storage bay of the FCB system, the path-length extension mechanism **10** within the Metal-Fuel Tape Recharging Subsystem **7** automatically extends the path-length of the metal-fuel tape **5**, as shown in **FIG. 2B2**, thereby permitting the assembly of recharging heads **11** to be inserted between and arranged about the path-length extended metal-fuel tape, for converting metal-oxide formations into its primary metal during the Recharging Mode of operation.

[**0178**] In order to provide for rapid recharging of the metal-fuel tape in the metal-air FCB system of the first illustrative embodiment, the total surface area $A_{recharge}$ of the recharging heads in the Metal-Fuel Tape Recharging Subsystem **7** is designed to be substantially greater than the total surface area $A_{discharge}$ of the discharging heads within the Metal-Fuel Tape Discharging Subsystem **6** (i.e. $A_{recharge} >> A_{discharge}$), as taught in Applicant's prior U.S. Pat. No. 5,250,370, incorporated herein by reference. This design feature enables a significant decrease in recharging time, without requiring a significant increase in volume in the housing of the FCB system. These subsystem features will be described in greater detail hereinafter in connection with the description of the Metal-Fuel Tape Discharging and Recharging Subsystems hereof.

[0179] Brief Summary of Modes of Operation of the FCB System of the First Illustrative Embodiment of the Present Invention

[0180] During the Cartridge Loading Mode, the cassette cartridge **3** containing a supply of charged metal-fuel tape **5** is loaded into the FCB system, by the Cassette Loading/Unloading Subsystem **2**. During the Discharging Mode, the charged metal-fuel tape within the cartridge is mechanically manipulated by path-length extension mechanism hereof **8** to substantially increase its path-length so that the assembly of discharging heads **9** can be arranged thereabout for electro-chemically generating electrical power therefrom for supply to an electrical load connected thereto. During the Recharging Mode, the oxidized metal-fuel tape **5** within the cartridge is mechanically manipulated by path-length extension mechanism hereof **10** to substantially increase its path-length so that the assembly of metal-oxide reducing (i.e. recharging) heads **11** can be arranged thereabout for electro-chemically reducing (i.e. recharging) the oxide formations on the metal-fuel tape transported therethrough into its primary metal during recharging operations. During the Cartridge Unloading Mode, the cassette cartridge is unloaded (e.g. ejected) from the FCB system by the Cassette Loading/Unloading Subsystems.

[0181] While it may be desirable in some applications to suspend tape recharging operations while carryout tape discharging operations, the FCB system of the first illustrative embodiment enables concurrent operation of the Discharging and Recharging Modes. Notably, this feature of the present invention enables simultaneous discharging and recharging of metal-fuel tape during power generating operation.

[0182] Multi-Track Metal-Fuel Tape Used in the FCB System of the First Illustrative Embodiment

[0183] In the FCB system of **FIG. 1**, the metal-fuel tape **5** has multiple fuel-tracks (e.g. five tracks) as taught in copending application Ser. No. 08/944,507, supra. When using such a metal-fuel tape design, it is desirable to design each discharging head **9** within the Metal-Fuel Tape Discharging Subsystem **6** as a "multi-track" discharging head. Similarly, each recharging head **11** within the Metal-Fuel Tape Recharging Subsystem **7** hereof should be designed as a multi-track recharging head in accordance with the principles of the present invention. As taught in great detail in copending application Ser. No. 08/944,507, the use of "multi-tracked" metal-fuel tape and multi-track discharging heads enables the simultaneous production of multiple supply voltages (e.g. 1.2 Volts), and thus the generation and delivery of a wide range of output voltages {V1, V2, . . . , Vn} to electrical loads having various loading requirements. Such output voltages can be used suitable for driving various types of electrical loads **12** connected to output power terminals **13** of the FCB system. This is achieved by configuring the individual output voltages produced across each anode-cathode pair during tape discharging operations. This system functionality will be described in greater detail hereinbelow.

[0184] In general, multi-track and single-track metal-fuel tape alike can be made using several different techniques. Preferably, the metal-fuel tape contained with the cassette device **3** is made from zinc as this metal is inexpensive, environmentally safe, and easy to work. Several different techniques will be described for making zinc-fuel tape according to the present invention.

[0185] For example, in accordance with a first fabrication technique, a thin metal layer (e.g. nickel or brass) of about 1 to 10 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of tape). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of this thin metal layer is to provide efficient current collection at the anode surface. Thereafter, zinc powder is mixed with a binder material and then applied as a coating (e.g. about 10 to 1000 microns thick) upon the surface thin metal layer. The zinc layer should have a uniform porosity of about 50% to allow ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the current collecting elements of the cathode and anode structures.

[0186] In accordance with a second fabrication technique, a thin metal layer (e.g. nickel or brass) of about 1 to 10 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of tape). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of the thin metal layer is to provide efficient current collection at the anode surface. Thereafter zinc is electroplated onto the surface of the thin layer of metal. The zinc layer should have a uniform porosity of about 50% to allow ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the current collecting elements of the cathode and anode structures.

[0187] In accordance with a third fabrication technique, zinc power is mixed with a low-density plastic base material and drawn into electrically-conductive tape. The low-density plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The electrically-conductive tape should have a uniform porosity of about 50% to allow ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the current collecting elements of the cathode and anode structures. Then a thin metal layer (e.g. nickel or brass) of about 1 to 10 microns thickness is applied to the surface of the electrically-conductive tape. The function of the thin metal layer is to provide efficient current collection at the anode surface.

[0188] Each of the above-described techniques for manufacturing metal-fuel tape can be ready modified to produce "double-sided" metal-fuel tape, in which single track or multi-track metal-fuel layers are provided on both sides of the flexible base (i.e. substrate) material. Such embodiments of metal-fuel tape will be useful in applications where discharging heads are to be arranged on both sides of metal-fuel tape loaded within the FCB system. When making double-sided metal-fuel tape, it will be necessary in most embodiments to form a current collecting layer (of thin metal material) on both sides of the plastic substrate so that current can be collected from both sides of the metal-fuel tape, associated with different cathode structures. When making double-sided multi-tracked fuel tape, it may be desirable or necessary to laminate together two lengths of multi-track metal-fuel tape, as described hereinabove, with the substrates of each tape-length in physical contact. Adaptation of the above-described methods to produce double-sided metal-fuel tape will be readily apparent to those skilled in the art having had the benefit of the present disclosure. In such illustrative embodiments of the present invention, the anode-contacting structures within the each discharging head will be modified so that electrical contact is established with each electrically-isolated current collecting layer formed within the metal-fuel tape structure being employed therewith.

[0189] Methods and Devices for Packaging Metal-Fuel Tape of the Present Invention

[0190] Multi-track metal-fuel tape **5** made in the manner described above can be packaged in a variety of different ways. One packaging technique would be to roll the metal-fuel tape off a supply reel, and take it up on a take-up reel in the manner that 9-track digital recording tape is handled. Another handling technique, which is preferred over the reel-to-reel technique, involves storing the metal-fuel tape within a compact cassette cartridge device ("cassette fuel cartridge"). As shown in **FIG. 1**, the cassette device **5** has a housing **14** containing a pair of spaced-apart spindles **15**A and **15**B, about which a supply of metal-fuel tape **5** (**5**', **5**") is wound in a manner similar to a video-cassette tape. The cassette cartridge device **5** also includes a pair of spaced apart tape guiding rollers **16**A, and **16**B mounted in the front corners of the cassette housing, and an opening **17** formed in the front end portion **14**A (i.e. side wall and top surface) thereof.

[0191] Front-end opening **14**A serves a number of important functions, namely: it allows the "multi-track" discharging head assembly **9** to be moved into a properly aligned position with respect to the "path-length extended" metal-fuel tape during discharging operations; it allows the discharging head assembly to be moved away from the extended path-length of metal-fuel tape when the cassette cartridge is removed from the discharging bay of the Metal-Fuel tape Discharging Subsystem; it allows the tape path-length extension mechanism **10**, integrated into the FCB recharging subsystem **7**, to engage a section of the metal-fuel tape and then extend its path length by way of the two-step process illustrated in FIGS. **2**A**1** through **2**B**2**.

[0192] Cassette housing opening **14**A also allows the "multi-track" recharging head assembly **11** associated with the Metal-Fuel Recharging Subsystem **7** to be moved into properly aligned position with respect to the "path-length extended" portion of the discharged metal-fuel tape during recharging operations; it also allows the recharging head assembly **11** to be removed (i.e. withdrawn) from the metal-fuel tape when the cassette cartridge is removed from the cassette storage bay **15** of the FCB system. A retractable window or door **14**B can be mounted over this opening within the cassette housing in order to close off the cassette interior from the environment when the device is not installed within the cassette storage bay of the system. Various types of spring-biased mechanisms can be used to realize the retractable window of the cassette cartridge of the present invention.

[0193] While not shown, tape-tensioning mechanisms may also be included within the cassette housing in order to ensure that the metal-fuel tape maintains proper tension during unwinding and rewinding of the metal-fuel tape in either the Discharging Mode or Recharging Mode of operation. The cassette housing can be made from any suitable material designed to withstand heat and corrosion. Preferably, the housing material is electrically non-conducting to provide an added measure of user-safety during tape discharging and recharging operations.

[0194] Cassette Cartridge Loading/Unloading Subsystem for the First Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0195] As schematically illustrated in FIGS. **1**, **2**A**3** and **2**A**4**, and shown in detail in copending U.S. application Ser. No. 08/944,507, the Cassette Cartridge Loading/Unloading Transport Subsystem **2** in the FCB system of **FIG. 1** comprises a number of cooperating mechanisms, namely: a cassette receiving mechanism **16**A for automatically (i) receiving the cassette cartridge **3** at a cassette insertion port **17**A formed in the front panel of the system housing **17**, and (ii) withdrawing the cartridge into the cassette storage bay therewithin; an automatic door opening mechanism **16**B for opening the door formed in the cassette cartridge (for metal-fuel tape access) when the cartridge is received within the cassette storage bay of the FCB system; and an automatic cassette ejection mechanism **16**C for ejecting the cassette cartridge from the cassette storage bay through the cassette insertion port in response to a predetermined condition (e.g., the depression of an "ejection" button provided on the front panel of the system housing, automatic sensing of the end of the metal-fuel tape, etc.).

[0196] In the illustrative embodiment of **FIG. 1**, the cassette receiving mechanism **16**A can be realized as a platform-like carriage structure that surrounds the exterior of the cassette cartridge housing. The platform-like carriage structure can be supported on a pair of parallel rails, by way of rollers, and translatable therealong by way of an electric motor and cam mechanism. These devices are operably connected to the system controller which will be described in greater detail hereinafter. The function of the cam mechanism is to convert rotational movement of the motor shaft into a rectilinear motion necessary for translating the platform-like carriage structure along the rails when a cassette is inserted within the platform-like carriage structure. A proximity sensor, mounted within the system housing, can be used to detect the presence of the cassette cartridge being inserted through the insertion port and placed within the platform-like carriage structure. The signal produced from the proximity sensor can be provided to the system controller in order to initiate the cassette cartridge withdrawal process in an automated manner.

[0197] Within the system housing, the automatic door opening mechanism **16**B can be realized by any suitable mechanism that can slide the cassette door **14**B into its open position when the cassette cartridge is completely withdrawn into the cassette storage bay. In the illustrative embodiment, the automatic cassette ejection mechanism **16**C employs the same basic structures and functionalities of the cassette receiving mechanism described above. The primary difference is the automatic cassette ejection mechanism responds to the depression of an "ejection" button provided on the front panel of the system housing, or functionally equivalent triggering condition or event. When the button is depressed, the system controller automatically causes the discharging heads to be transported away from the metal-fuel tape, the path-length extended metal-fuel tape to become unextended, and the cassette cartridge automatically ejected from the cassette storage bay, through the cassette insertion port.

[0198] Notably, the control functions required by the Cassette Cartridge Loading/Unloading Subsystem **2**, as well as all other subsystems within the FCB system of the first illustrative embodiment, are carried out by the system controller **18**, shown in FIGS. **2A3** and **2A4**. In the illustrative embodiments hereof, the system controller is realized by a programmed microcontroller (i.e. microcomputer) having program storage memory (ROM), data storage memory (RAM) and the like operably connected by one or more system buses well known in the microcomputing and control arts.

[0199] Metal-Fuel Tape Transport Subsystem for the First Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0200] As shown in FIGS. **2A3** and **2A4**, the metal-fuel tape transport subsystem **4** of the first illustrative embodiment comprises: a pair of synchronized electric motors **19A** and **19B** for engaging spindles **20A** and **20B** in the metal-fuel fuel cartridge **3** when it is inserted in the cassette receiving bay of the system, and driving the same in either forward or reverse directions under synchronous control during the Discharging Mode and (Tape) Recharging Mode of operation; electrical drive circuits **21A** and **21B** for producing electrical drive signals for the electric motors **19A** and **19B**; and a tape-speed sensing circuit **22** for sensing the speed of the metal-fuel tape (i.e. motors) and producing signals indicative thereof for use by the system controller **18** to control the speed of the metal-fuel tape during discharging and recharging operations. As the metal-fuel tape transport subsystem **4** of the first illustrative embodiment employs the system controller **18**, it is proper to include the system controller **18** as a supporting subsystem within the metal-fuel tape transport subsystem **4**.

[0201] The Metal-Fuel Tape Discharging Subsystem for the First Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0202] As shown in FIGS. **2A3** and **2A4**, the metal-fuel tape discharging subsystem **6** of the first illustrative embodiment comprises a number of subsystems, namely: an assembly of multi-track discharging heads **9**, each having multi-element cathode structures and anode-contacting structures with electrically-conductive output terminals connectable in a manner to be described hereinbelow; an assembly of metal-oxide sensing heads **23** for sensing the presence of metal-oxide formation along particular zones of metal fuel tracks as the metal fuel tape is being transported past the discharging heads during the Discharging Mode; a metal-fuel tape path-length extension mechanism **8**, as schematically illustrated in FIGS. **2A1** and **2A2** and described above, for extending the path-length of the metal-fuel tape over a particular region of the cassette device **5**, and enabling the assembly of multi-track discharging heads to be arranged thereabout during the Discharging Mode of operation; a discharging head transport subsystem **24** for transporting the subcomponents of the discharging head assembly **9** (and the metal-oxide sensing head assembly **24**) to and from the metal-fuel tape when its path-length is arranged in an extended configuration by the metal-fuel tape path-length extension mechanism **8**; a cathode-anode output terminal configuration subsystem **25** for configuring the output terminals of the cathode and anode-contacting structures of the discharging heads under the control of the system controller **18** so as to maintain the output voltage required by a particular electrical load connected to the Metal-Fuel Tape Discharging Subsystem; a cathode-anode voltage monitoring subsystem **26**, connected to the cathode-anode output terminal configuration subsystem **25** for monitoring (i.e. sampling) the voltage produced across cathode and anode of each discharging head, and producing (digital) data representative of the sensed voltage level; a cathode-anode current monitoring subsystem **27**, connected to the cathode-anode output terminal configuration subsystem **25**, for monitoring (e.g. sampling) the current flowing across the cathode and anode of each discharging head during the Discharging Mode, and producing digital data signals representative of the sensed current levels; a cathode oxygen pressure control subsystem, comprising the system controller **18**, solid-state pO_2 sensors **28**, vacuum chamber (structure) **29** shown in FIGS. **2A7** and **2A8**, vacuum pump **30**, airflow control device **31**, manifold structure **32**, and multi-lumen tubing **33** shown in FIGS. **2A8**, for sensing and controlling the pO_2 level within the cathode structure of each discharging head **9**; a metal-fuel tape speed control subsystem, comprising the system controller **18**, motor drive circuits **21A** and **21B**, and tape velocity (i.e. speed and direction) sensor/detector **22**, for bi-directionally controlling the speed of metal-fuel tape relative to the discharging heads, in either forward or reverse tape directions; an ion-concentration control subsystem, comprising the system controller **18**, solid-state moisture sensor **34**, moisturizing (e.g. humidifying or wicking element) **35**, for sensing and modifying conditions within the FCB system (e.g. the moisture or humidity level at the cathode-electrolyte interface of the discharging heads) so that the ion-concentration at the cathode-electrolyte interface is maintained within an optimal range during the Discharge Mode of operation; discharge head temperature control subsystem comprising the system controller **18**, solid-state temperature sensors (e.g. thermistors) **271** embedded within each channel of the multi-cathode support structure hereof, and a discharge head cooling device **272**, responsive to control signals produced by the system controller **18**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations; a relational-type metal-fuel database management subsystem (MFDMS) **275** operably connected to system controller **18** by way of local bus **276**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Tape Discharging Subsystem **6**; a Data Capture and Processing Subsystem (DCPS) **277**, comprising data reading head **38** embedded within or mounted closely to the cathode support structure of each discharging head **9**, metal-oxide sensing head assembly **23** and associated circuitry, and a programmed microprocessor-based data processor adapted to receive data signals produced from voltage monitoring subsystem **26**, cathode-anode current monitoring subsystem **27**, metal-oxide sensing head assembly **23**, the cathode oxygen pressure control subsystem and the ion-concentration control subsystem hereof, and enable (i) the reading of metal-fuel zone identification data from transported metal-fuel tape **5**, (ii) the recording of sensed discharge parameters and computed metal-oxide indicative data derived therefrom in the Metal-Fuel Database Management Subsystem (MFDMS) **275** using local system bus **278** shown in **FIG. 2**B17, and (iii) the reading of prerecorded recharge parameters and prerecorded metal-fuel indicative data stored in the Metal-Fuel Database Management Subsystem (MFDMS) using the same local system bus **278**; an output (i.e. discharging) power regulation subsystem **40** connected between the output terminals of the cathode-anode output terminal configuration subsystem **25** and the input terminals of the electrical load **12** connected to the Metal-Fuel Tape Discharging Subsystem **6**, for regulating the output power delivered across the electrical load (and regulate the voltage and/or current characteristics as required by the Discharge Control Method carried out by the system controller); an input/output control subsystem **41**, interfaced with the system controller **18**, for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **18**, interfaced with system controller **18**' within the Metal-Fuel Tape Recharging Subsystem **7** by way of global system bus **279**, as shown in **FIG. 2**B17, and having various means for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[**0203**] Multi-Track Discharging Head Assembly within the Metal-Fuel Tape Discharging Subsystem

[**0204**] The function of the assembly of multi-track discharging heads **9** is to generate electrical power across the electrical load as metal-fuel tape is transported therethrough during the Discharging Mode of operation. In the illustrative embodiment, each discharging head **9** comprises: a cathode element support plate **42** having a plurality of isolated channels **43** permitting the free passage of oxygen (O2) through the bottom portion **44** of each such channel; a plurality of electrically-conductive cathode elements (e.g. strips) **45** for insertion within the lower portion of these channels, respectively; a plurality of electrolyte-impregnated strips **46** for placement over the cathode strips **45**, and support within the channels **29**, respectively, as shown in **FIG. 2**C2; and an oxygen-injection chamber **29** mounted over the upper (back) surface of the cathode element support plate **44**, in a sealed manner.

[**0205**] As shown in **FIG. 2**A13 and **2**A14, each oxygen-injection chamber **29** has a plurality of subchambers **29**A through **29**E physically associated with channels **35**A and **35**E, respectively, wherein each subchamber is isolated from all other subchamber and is arranged in fluid communication with one channel in the electrode support plate supporting one electrode element and one electrolyte impregnated element. As shown, each subchamber within the discharging head assembly is arranged in fluid communication with an air compressor or O_2 gas supply means (e.g. tank or cartridge) **30** via one lumen of multi-lumen tubing **33**, one channel of manifold assembly **32** and one channel of electronically-controlled air-flow switch **31**, shown in FIGS. **3**A3 and **2**A4, and whose operation is controlled by system controller **18**. This arrangement enables the system controller **18** to independently control the pO_2 level in each oxygen-injection chamber **29**A through **29**E within an optimal range during discharging operations, within the discharging head assembly, by selectively pumping pressurized air through the corresponding air flow channel in the manifold assembly **32** under the management of the system controller **18**.

[**0206**] In the illustrative embodiment, electrolyte-impregnated strips are realized by impregnating an electrolyte-absorbing carrier medium with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for each discharging cell is made from a formula consisting of an alkali solution (e.g. KOH), a gelatin material, water, and additives known in the art.

[**0207**] In the illustrative embodiment, each cathode strip is made from a sheet of nickel wire mesh **47** coated with porous carbon material and granulated platinum or other catalysts **48** to form a cathode suitable for use in metal-air FCB systems. Details of cathode construction are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor **49** is soldered to the underlying wire mesh sheet of each cathode strip. As shown in **FIG. 2**C2, each electrical conductor **49** is passed through a small hole **50** formed in the bottom surface of a channel **43** of the cathode support plate, and is connected to the cathode-anode output terminal configuration subsystem **25**. As shown, the cathode strip pressed into the lower portion of the channel to secure the same therein. As shown in **FIG. 2**A7, the bottom surface **44** of each channel **43** has numerous perforations **43**A formed therein to allow the free passage of oxygen to the cathode strip. In the illustrative embodiment, an electrolyte-impregnated strip **46** is placed over a cathode strip **45** and is secured within the upper portion of the cathode supporting channel **43**. As shown in **FIG. 2**A8, when the cathode strip and thin electrolyte strip are mounted in their respective channel in the cathode support plate, the outer surface of the electrolyte-impregnated strip is disposed flush with the upper surface of the plate defining the channels, thereby permitting metal-fuel tape to be smoothly transported thereover during tape discharging operations.

[**0208**] Hydrophobic agents are added to the carbon material constituting the oxygen-pervious cathode elements within the discharging head assembly **9** to ensure the expulsion of water therefrom during discharging operations. Also, the interior surfaces of the cathode support channels are coated with a hydrophobic film (e.g. Teflon®) **51** to ensure the expulsion of water within electrolyte-impregnated strips **47** and thus achieve optimum oxygen transport across the cathode strips, to the injection-chamber **29** during the Discharging Mode. Preferably, the cathode support plate is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate and evacuation chamber can be fabricated using injection molding technology also well known in the art.

[**0209**] In order to sense the partial oxygen pressure within the cathode structure during the Discharging Mode, for use in effective control of electrical power generated from discharging heads, a solid-state pO_2 sensor **28** is embedded within each channel of the cathode support plate **42**, as illustrated in **FIG. 2**A7, and operably connected to the system controller **18** as an information input device thereto. In the illustrative embodiment, the pO_2 sensor can be realized using well-known pO_2 sensing technology employed to measure (in vivo) pO_2 levels in the blood of humans. Such prior art sensors can be constructed using miniature diodes which emit electromagnetic radiation at two or more different wavelengths that are absorbed at different levels in the presence of oxygen in the blood, and such information can be processed and analyzed to produce a computed measure of pO2 in a reliable manner, as taught in U.S. Pat. No. 5,190,038 and references cited therein, each being incorporated herein by reference. In the present invention, the characteristic wavelengths of the light emitting diodes can be selected so that similar sensing functions can be carried out within the structure of the cathode in each discharging head, in a straightforward manner.

[**0210**] The multi-tracked fuel tape contained within the cassette fuel cartridge of **FIG. 2** is shown in greater structural detail in **FIG. 2A9**. As shown, the metal-fuel tape **5** comprises: an electrically non-conductive base layer **53** of flexible construction (i.e. made from a plastic material stable in the presence of the electrolyte); a plurality of parallel extending, spatially-separated strips of metal (e.g. zinc) **54**A, **54**B, **54**C, **54**D and **54**E disposed upon the ultra-thin current-collecting layer (not shown) itself disposed upon the base layer **53**; a plurality of electrically non-conductive strips **55**A, **55**B, **55**C, **55**D and **55**E disposed upon the base layer, between pairs of fuel strips **54**A, **54**B, **54**C, **54**D and **54**E; and a plurality of parallel extending channels (e.g. grooves) **56**, **56**B, **56**B, **56**D and **56**E formed in the underside of the base layer, opposite the metal fuel strips thereabove, for allowing electrical contact with the metal-fuel tracks **54**A, **54**B, **54**C, **54**D and **54**E through the grooved base layer. Notably, the spacing and width of each metal-fuel strip is designed so that it is spatially-registered with a corresponding cathode strip in the discharging head of the system in which the metal-fuel tape is intended to be used.

[**0211**] The metal-fuel tape described above can be made by applying zinc strips onto a layer of base plastic material **53** in the form of tape, using any of the fabrication techniques described hereinabove. The metal strips can be physically spaced apart, or separated by Teflon®, in order to ensure electrical isolation therebetween. Then, the gaps between the metal strips can be filled in by applying a coating of electrically insulating material, and thereafter, the base layer can be machined, laser etched or otherwise treated to form fine channels therein for allowing electrical contact with the individual metal fuel strips through the base layer. Finally, the upper surface of the multi-tracked fuel tape can be polished to remove any electrical insulation material from the surface of the metal fuel strips which are to come in contact with the cathode structures during discharging.

[**0212**] In **FIG. 2A10**, an exemplary metal-fuel (anode) contacting structure **58** is disclosed for use with the multi-tracked cathode structure shown in FIGS. **2A7** and **2A8**. As shown, a plurality of electrically-conductive elements **60A**, **60**B, **60**C, **60**D, and **60**E are supported from an platform **61** disposed adjacent the travel of the fuel tape within the cassette cartridge. Each conductive element **60**A through **60**E has a smooth surface adapted for slidable engagement with one track of metal-fuel through the fine groove formed in the base layer **53** of the metal-fuel tape corresponding to fuel track. Each conductive element is connected to an electrical conductor which is connected to the cathode-anode output terminal configuration subsystem **25** under the management of the system controller **18**. The platform **61** is operably associated with the discharging head transport subsystem **24** and can be designed to be moved into position with the fuel tape during the Discharging Mode of the system, under the control of the system controller.

[**0213**] Notably, the use of multiple discharging heads, as in the illustrative embodiments hereof, rather than a single discharging head, allows more power to be produced from the discharging head assembly for delivery to the electrical load while minimizing heat build-up across the individual discharging heads. This feature of the Metal-Fuel Tape Discharging Subsystem extends the service-life of the cathodes employed within the discharging heads thereof.

[**0214**] Metal-Oxide Sensing Head Assembly within the Metal-Fuel Tape Discharging Subsystem

[**0215**] The function of the Metal-Oxide Sensing Head Assembly **23** is to sense (in real-time) the current levels produced across the individual fuel tracks during discharging operations, and generate electrical data signals indicating the degree to which portions of metal-fuel tracks have been oxidized and thus have little or no power generation potential. As shown in FIGS. **2A15**, each multi-track metal-oxide sensing head **23** in the assembly thereof comprises a number of subcomponents, namely: a positive electrode support structure **63** for supporting a plurality of positively electrode elements **64**A, **64**B, **64**C, **64**D and **64**E, each in registration with the upper surface of one of the fuel tracks (that may have been oxidized) and connected to a low voltage power supply terminal **65**A, **65**B, **65**C, **65**D and **65**E provided by current sensing circuitry **66** which is operably connected to the Data Capture and Processing Subsystem **277** within the Metal-Fuel Tape Discharging Subsystem **6**, as shown in FIGS. **2A3** and **2A4**; and a negative electrode support structure **67** for supporting a plurality of negative electrode elements **68**A, **68**B, **68**C, **628**D and **68**E, each in registration with the lower surface of the fuel tracks and connected to a low voltage power supply terminal **69**A, **69**B, **69**C, **69**D and **69**E, respectively, provided by current sensing circuitry **66**.

[**0216**] In the illustrative embodiment shown in FIGS. **2A3** and **2A4**, each multi-track metal-oxide sensing head **23** is disposed immediately before a discharging head **9** in order to sense the actual condition of the metal-fuel tape therebefore and provide a data signal to the system controller **18** for detection and determination of the actual amount of metal-oxide present thereon before the discharging. While only one metal-oxide sensing head assembly **23** is shown in the first illustrative embodiment of the FCB system hereof, it is understood that for bi-directional tape-based FCB systems, it would be preferred to install one metal-oxide sensing head assembly **23** on each end of the discharging head assembly so that the system controller can "anticipate" which metal-fuel zones are "dead" or devoid of metal-fuel regardless of the direction that the metal-fuel tape is being transported at any particular instant in time. With such an arrangement, the Metal-Fuel Tape Discharging Subsystem **6** is capable of determining (i.e. estimating) which portions of which metal-fuel tracks have sufficient electrical power generation capacity for discharge operations, and which do not, and to control the metal-fuel tape transport subsystem so as to discharge metal-fuel tape in an optimal manner during the Discharging Mode of operation. Details concerning this aspect of the present invention will be described hereinafter.

[0217] Metal-Fuel Tape Path-Length Extension Mechanism within the Metal-Fuel Tape Discharging Subsystem

[0218] As shown in FIGS. 2A3 and 2A4, the tape path-length extension mechanism 8 of the illustrative embodiment comprises: a first array of rollers 71A through 71E mounted on support structure 72 for contacting the metal-fuel portion of the metal-fuel tape when the cassette device 3 inserted into the cassette receiving port of the FCB system; a second array of rollers 73A through 73E disposed between the array of stationary rollers 71A through 71E and mounted on support structure 74, for contacting the base portion of the metal-fuel tape when the cassette device is inserted into the cassette receiving port of the FCB system; and a transport mechanism 75 of electromechanical construction, for transporting roller support structures 72 and 74 relative to the system housing and each other in order to carry out the functions of this subsystem described in greater detail hereinbelow.

[0219] In the configuration shown in FIG. 2A3, the tape path-length mechanism 8 is arranged so that the first and second sets of rollers 71A through 71E and 73A through 73E barely contacting opposite sides of the metal-fuel tape when the cassette device 3 is inserted within the cassette receiving port of the FCB system. As shown in FIG. 2A4, the second set of rollers 73A through 73E are displaced (i.e. transported) a distance relative to the first set of stationary rollers 71A through 71E, thereby causing the path-length of the metal-fuel tape to become substantially extended from the path-length shown in the configuration of FIG. 2A3. This extended path-length permits a plurality of discharging heads 9 to be arranged thereabout during the discharging mode of operation. In this configuration, the cathode structure 76 of each discharging head is in ionic contact with the metal-fuel structures along the metal-fuel tape, while the anode-contacting structure 77 of each discharging head is in electrical contact with the metal-fuel structures of the tape. In this configuration, the metal-fuel tape so arranged so that a plurality of discharging heads can be arranged about the metal-fuel tape during power discharging operations. The use of multiple discharging heads enables low current loading of the metal-fuel tape during power generation, and thus provides improved control over the formation of metal-oxide during power generation. Such advantages will become apparent hereinafter.

[0220] Discharging Head Transport Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0221] The primary function of the discharging head transport subsystem is to transport the assembly of discharging heads 9 (and metal-oxide sensing heads 23 supported thereto) about the metal-fuel tape that has been path-length extended, as shown in FIG. 2A3. When properly transported, the cathode and anode-contacting structures of the discharging heads are brought into "ionically-conductive" and "electrically-conductive" contact with the metal-fuel tracks of metal-fuel tape while the metal-fuel tape is transported through the discharging head assembly by the metal-fuel tape transport subsystem during the discharging mode of operation.

[0222] Discharging head transport subsystem 24 can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode structure 76 and anode-contacting structure 77 of each discharging head away from the metal-fuel tape 5, as shown in FIG. 2A3, and about the metal-fuel tape as shown in FIG. 2A4. As shown, these transport mechanisms are operably connected to system controller 18 and controlled by the same in accordance with the system control program carried out thereby.

[0223] Cathode-Anode Output Terminal Configuration Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0224] As shown in FIGS. 2A3 and 2A4, the cathode-anode output terminal configuration subsystem 25 is connected between the input terminals of the discharging power regulation subsystem 40 and the output terminals of the cathode-anode pairs within the assembly of discharging heads 9. The system controller 18 is operably connected to cathode-anode output terminal configuration subsystem 25 in order to supply control signals for carrying out its functions during the Discharging Mode of operation.

[0225] The function of the cathode-anode output terminal configuration subsystem 25 is to automatically configure (in series or parallel) the output terminals of selected cathode-anode pairs within the discharging heads of the Metal-Fuel Tape Discharging Subsystem so that the required output voltage level is produced across the electrical load connected to the FCB system during tape discharging operations. In the illustrative embodiment of the present invention, the cathode-anode output terminal configuration mechanism 25 can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the discharging heads 9 are connected to the input terminals of the output power regulating subsystem 40. Such switching operations are carried out under the control of the system controller 18 so that the required output voltage is produced across the electrical load connected to the output power regulating subsystem of the FCB system.

[0226] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0227] As shown in FIGS. 2A3 and 2A4, the cathode-anode voltage monitoring subsystem 26 is operably connected to the cathode-anode output terminal configuration subsystem 25 for sensing voltage levels and the like therewithin. While not shown, this subsystem is also operably connected to the system controller 18 for receiving control signals required to carry out its functions. In the first illustrative embodiment, the cathode-anode voltage monitoring subsystem 26 has two primary functions: to automatically sense the instantaneous voltage level produced across the cathode-anode structures associated with each metal-fuel track being transported through each discharging head during the Discharging Mode; and to produce a (digital) data signal indicative of the sensed voltages for detection, analysis and processing within the Data Capture and Processing Subsystem 277, and subsequent recording within the Metal-Fuel Database Management Subsystem 275 which is accessible by the system controller 18 during the Discharge Mode of operation.

[0228] In the first illustrative embodiment of the present invention, the Cathode-Anode Voltage Monitoring Subsystem 26 can be realized using electronic circuitry adapted for sensing voltage levels produced across the cathode-anode structures associated with each metal-fuel track transported through each discharging head within the Metal-Fuel Tape Discharging Subsystem **6**. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels.

[**0229**] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Tape Discharging Subsystem

[**0230**] As shown in FIGS. **2A3** and **2A4**, the cathode-anode current monitoring subsystem **27** is operably connected to the cathode-anode output terminal configuration subsystem **25**. The cathode-anode current monitoring subsystem **27** has two primary functions: to automatically sense the magnitude of electrical current flowing through the cathode-anode pair of each metal-fuel track along each discharging head assembly within the Metal-Fuel Tape Discharging Subsystem during the discharging mode; and to produce a digital data signal indicative of the sensed current for detection, analysis and processing within the Data Capture and Processing Subsystem **277**, and subsequent recording within the Metal-Fuel Database Management Subsystem **275** which is accessible by the system controller **18** during the Discharge Mode of operation.

[**0231**] In the first illustrative embodiment of the present invention, the Cathode-Anode Current Monitoring Subsystem **27** can be realized using current sensing circuitry for sensing the electrical current passed through the cathode-anode pair of each metal-fuel track along each discharging head assembly, and producing a digital data signal indicative of the sensed current. As will be explained in greater detail hereinafter, these detected current levels are stored in the Metal-Fuel Database Subsystem _and can be readily accessed by the system controller **18** in various ways, namely: carrying out its discharging power regulation method; creating a "discharging condition history" for each zone or subsection of discharged metal-fuel tape; etc.

[**0232**] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Tape Discharging Subsystem

[**0233**] The function of the cathode oxygen pressure control subsystem defined above is to sense the oxygen pressure (pO_2) within each channel of the cathode structure of the discharging head **9**, and in response thereto, control (i.e. increase or decrease) the same by regulating the air (O_2) pressure within such cathode structures. In accordance with the present invention, the partial oxygen pressure (PO_2) within each channel of the cathode structure of each discharging head provides a measure of the oxygen concentration therewithin and thus is maintained at an optimal level in order to allow optimal oxygen consumption within the discharging heads during the Discharging Mode. By maintaining the pO_2 level within each channel of the cathode structure, power output produced from the discharging heads can be increased in a controllable manner. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by the system controller, the system controller **18** is provided with a controllable variable for use in regulating electrical power supplied to the electrical load **12** during the Discharging Mode.

[**0234**] In the first illustrative embodiment of the FCB system hereof shown in **FIG. 1**, the data signals produced by the solid-state pO_2 sensors **28**A through **28**E embodied within the discharging heads **9** are provided to the Data Capture and Processing Subsystem **277**, as shown in FIGS. **2A3** and **2A4**. The Data Capture and Processing Subsystem **277** receives these signals, converts them into digital data and the like and then records the resulting information items within the information structure shown in **FIG. 2A16**, managed within the Metal-Fuel Database Management Subsystem **275** with the Metal-Fuel Tape Discharging Subsystem **6**. Such discharging parameters can be accessed by the system controller **18** at any time over local bus **276** in order to independently control the level of pO_2 within each of the channels of the discharging heads **9** hereof during discharging operations.

[**0235**] Metal-Fuel Tape Speed Control Subsystem within the Metal-Fuel Tape Discharging Subsystem

[**0236**] During the Discharging Mode, the function of Metal-Tape Speed Control Subsystem **4** is to control the speed of the metal-fuel tape over the discharging heads within the Metal-Fuel Tape Discharging Subsystem **6**. In the illustrative embodiment, metal-fuel tape speed control subsystem **18** comprises a number of subcomponents, namely: the system controller **18**; the motor speed circuits **21**A and **21**B; and tape velocity sensor **22**. In response to the transport of tape past the velocity sensor **22**, a data signal indicative of the tape velocity (i.e. speed and direction) is generated and supplied to the Data Capture and Processing Subsystem **277**. Upon processing this data signal, the Data Capture and Processing Subsystem **277** produces digital data representative of the sampled tape velocity which is then stored in the Metal-Fuel Database Management Subsystem **275**, correlated with the metal-fuel identification data (i.e. Code) read by the same subsystem. In accordance with the Power Discharge Regulation Method being carried out, the system controller **18** automatically reads the tape velocity data from the Metal-Fuel Database Management Subsystem **275** by way of local system bus **276**. Using this information, the system controller **18** automatically controls (i.e. increases or decreases) the instantaneous velocity of the metal-fuel tape, relative to the discharging heads. Such tape velocity control is achieved by generating appropriate control signals for driving electric motors **19**A and **19**B coupled to the supply and take-up reels of metal-fuel tape being discharged.

[**0237**] The primary reason for controlling the velocity of metal-fuel tape is that this parameter determines how much electrical current (and thus power) can be produced from metal-fuel tape during transport through each discharging head within the Metal-Fuel Tape Discharging Subsystem **6**. Ideally, during the Discharging Mode, it is desirable to transport the metal-fuel tape as slow as possible through the discharging head assembly in order to deliver the amount of electrical power required by the connected load **12**. However, for practical reasons, the velocity of the metal-fuel tape will be controlled so that the cathode-anode current (iac) generated in each discharging head will satisfy the electrical power requirements of the connected load **12**. In many applications where the power requirements of the electrical load are below the maximum output power capacity of the FCB system, the velocity of the metal-fuel tape will be controlled so that that the total metal fuel amount (TMFA) along each metal-fuel zone is completely consumed upon a single complete pass through all of the discharging heads within the discharging head assembly, thereby distributing the electrical load and heat generation evenly across each of the discharging heads. This will serve to maximize the service-life of the discharging heads.

[0238] Ion-Concentration Control Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0239] In order to achieve high-energy efficiency during the Discharging Mode, it is necessary to maintain an optimal concentration of (charge-carrying) ions at the cathode-electrolyte interface of each discharging head within the Metal-Fuel Tape Discharging Subsystem **6**. Thus it is the primary function of the ion-concentration control subsystem to sense and modify conditions within the FCB system so that the ion-concentration at the cathode-electrolyte interface within the discharging heads is maintained within an optimal range during the Discharge Mode of operation.

[0240] In the case where the ionically-conducting medium between the cathode and anode is an electrolyte containing potassium hydroxide (KOH), it will be desirable to maintain its concentration at 6N (−6M) during the Discharging Mode of operation. As the moisture level or relative humidity (RH %) can significantly affect the concentration of KOH in the electrolyte, it is desirable to regulate the moisture level or relative humidity at the cathode-electrolyte interface within each discharging heads. In the illustrative embodiment, ion-concentration control is achieved in a variety of different ways: (e.g. by embedding a miniature solid-state moisture sensor **34** within the FCB system (as close as possible to the anode-cathode interfaces of the discharging heads) in order to sense moisture conditions and produce a digital data signal indicative thereof. As shown in FIGS. **2A3** and **2A4**, the digital data signals are supplied to the Data Capture and Processing Subsystem **277** for detection, analysis and subsequent recording within the information structure of **FIG. 2A16** which is maintained by the Metal-Fuel Data Management Subsystem **275**. In the event that the moisture level (or relative humidity) within a particular channel of the discharging head drops below the predetermined threshold value set within the information structure of **FIG. 2A16**, the system controller **18** responds to such changes in moisture-level by automatically generating a control signal that is supplied to moisturizing (H_2O dispensing) element **35** for the purpose of increasing the moisture level within the particular channel. In general, moisturizing element **35** can be realized in a number of different ways. One such way would be to controllably release a supply of water to the surface of the metal-fuel tracks on the tape using a wicking (e.g. H_2O applying) device **36** arranged in physical contact with the metal-fuel tracks as the metal-fuel tape is being transported through the discharging head assembly during the Discharging Mode. Another technique may involve spraying fine water droplets (e.g. ultra-fine mist) from micro-nozzles realized along the top surfaces of each cathode support structure, facing the metal-fuel tape during transport. Such operations will increase the moisture level (or relative humidity) within the interior of the discharging heads and thus ensure that the concentration of KOH within electrolyte-impregnated strips **46A** through **46E** is maintained for optimal ion transport and thus power generation.

[0241] Discharge Head Temperature Control Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0242] As shown in FIGS. **2A3**, **2A4**, and **2A7**, the discharge head temperature control subsystem incorporated within the Metal-Fuel Tape Discharging Subsystem **6** of the first illustrative embodiment comprises a number of subcomponents, namely: the system controller **18**; solid-state temperature sensors (e.g. thermistors) **271** embedded within each channel of the multi-cathode support structure hereof **42**, as shown in **FIG. 2A7**; and a discharge head cooling device **272**, responsive to control signals produced by the system controller **18**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations. The discharge head cooling device **272** can be realized using a wide variety of heat-exchanging techniques, including forced-air cooling, water-cooling, and/or refrigerant cooling, each well known in the heat exchanging art. In some embodiments of the present invention, where high levels of electrical power are being generated, it may be desirable to provide a jacket-like structure about each discharge head in order to circulate air, water or refrigerant for temperature control purposes.

[0243] Data Capture and Processing Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0244] In the illustrative embodiment of **FIG. 1**, Data Capture And Processing Subsystem (DCPS) **277** shown in FIGS. **2A3** and **2A4** carries out a number of functions, including, for example: (1) identifying each zone or subsection of metal-fuel tape immediately before it is transported through each discharging head within the discharging head assembly and producing metal-fuel zone identification data representative thereof; (2) sensing (i.e. detecting) various "discharge parameters" within the Metal-Fuel Tape Discharging Subsystem **6** existing during the time period that the identified metal-fuel zone is transported through the discharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-oxide produced during tape discharging operations, and producing "metal-oxide indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **275** (accessible by system controller **18**), sensed discharge parameter data as well as computed metal-oxide indicative data both correlated to its respective metal-fuel zone identified during the Discharging Mode of operation. As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **275** by Data Capture and Processing Subsystem **277** can be used by the system controller **18** in various ways including, for example: optimally discharging (i.e. producing electrical power from) partially or completely oxidized metal-fuel tape in an efficient manner during the Discharging Mode of operation; and optimally recharging partially or completely oxidized metal-fuel tape in a rapid manner during the Recharging Mode of operation.

[0245] During discharging operations, the Data Capture and Processing Subsystem **277** automatically samples (or captures) data signals representative of "discharge parameters" associated with the various subsystems constituting the Metal-Fuel Tape Discharging Subsystem **6** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Discharging Mode. In accordance with the principles of the present invention, tape-type "discharge parameters" shall include, but are not limited to: the voltages produced across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-anode voltage monitoring subsystem **26**; the electrical currents flowing across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-anode current monitoring subsystem **27**; the velocity (i.e. speed and direction) of the metal-fuel tape during discharging of a particular zone of metal-fuel tape, monitored by the metal-fuel tape speed control subsystem; the oxygen saturation level (pO_2) within the cathode structure of each discharging head, monitored by the cathode oxygen pressure control subsystem (**28**,**30**,**31**,**18**); the moisture (H_2O) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular discharging heads monitored, for example, by the ion-concentration control subsystem (**18**, **34**, **35** and **36**); and the time duration (ΔT) of the state of any of the above-identified discharge parameters.

[**0246**] In general, there are a number of different ways in which the Data Capture and Processing Subsystem **277** can record tape-type "discharge parameters" during the Discharging Mode of operation. These different methods will be detailed hereinbelow.

[**0247**] According to a first method of data recording shown in **FIG. 2A9**, a unique zone identifying code or indicia **80** (e.g. miniature bar code symbol encoded with zone identifying information) is graphically printed on an "optical" data track **81** realized as, for example, as a strip of transparent of reflective film material affixed or otherwise attached along the edge of each zone or subsection **82** of metal-fuel tape, as shown in **FIG. 2A9**. The function of this optical data track is to record a unique identifying code or symbol (i.e. digital information label) alongside each metal-fuel zone along the supply of metal-fuel tape. The position of the graphical zone identifying code should physically coincide with the particular metal-fuel zone to which it relates. This optical data track, with zone identifying codes recorded therein by printing or photographic techniques, can be formed at the time of manufacture of the multi-track metal-fuel tape hereof. The metal-fuel zone identifying indicia **80** along the edge of the tape is then read by an optical data reader **38** realized using optical techniques (e.g. laser scanning bar code symbol readers, or optical decoders). In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2A16**, which is created for each metal-fuel zone identified along the tape by tape data reader **38** of the Data Capture and Processing Subsystem **277**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem **277** within the Metal-Fuel Tape Discharging Subsystem **6** during the discharge operations.

[**0248**] According to a second method of data recording shown in **FIG. 2A9'**, a unique digital "zone identifying" code **83** is magnetically recorded in a magnetic data track **84** disposed along the edge of each zone or subsection **85** of the metal-fuel tape **5'**. The position of the code should coincide with the particular metal-fuel zone to which it relates. This magnetic data track, with zone identifying codes recorded therein, can be formed at the time of manufacture of the multi-track metal-fuel tape hereof. The zone identifying indicia along the edge of the tape is then read by a magnetic reading head **38'** realized using magnetic information reading techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2A16**, created for each metal-fuel zone identified along the tape by the data reader **38'**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem **277** within the Metal-Fuel Tape Discharging Subsystem **6** during the discharge operations.

[**0249**] According to a third method of data recording shown in **FIG. 2A9"**, a unique digital "zone identifying" code is recorded as a sequence of light transmission apertures **86** formed in an optically opaque data track **87** disposed along the edge of each zone or subsection **88** of the metal-fuel tape **5"**. In this aperturing technique, information is encoded in the form of light transmission apertures whose relative spacing and/or width is the means by which information encoding is achieved. The position of the code (i.e. unique identification number or address) should spatially coincide with the particular metal-fuel zone to which it relates. This optical data track, with zone identifying codes recorded therein, can be formed at the time of manufacture of the multi-track metal-fuel tape hereof. The zone identifying indicia **86** along the edge of the tape is then read by an optical sensing head **38"** realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2A16**, created for each metal-fuel zone identified along the tape by the data reader **38"**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem **277** within the Metal-Fuel Tape Discharging Subsystem **6** during the discharge operations.

[**0250**] According to a fourth alternative method of data recording, both unique digital "zone identifying" code and discharge parameters for each identified metal-fuel zone are recorded in a magnetic, optical, or apertured data track, realized as a strip attacked to and extending along the edge of the metal-fuel tape of the present invention. The block of information pertaining to a particular zone or subsection of metal-fuel, schematically indicated in **FIG. 2A16**, can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information during the Recharging Mode of operation. Typically, the block of information will include the metal-fuel zone identification number and a set of discharge parameters detected by the Data Capture and Processing Subsystem **275** as the metal-fuel zone is transported through the discharging head assembly **9**.

[**0251**] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel tape can have a very low information capacity. This is because very little information needs to be recorded to tag each metal-fuel zone with a unique identifier (i.e. address number or zone identification number), to which sensed tape discharge parameters are recorded in the Metal-Fuel Database Management Subsystem **275**. Also, formation of a data track in accordance with the first and second methods should be very inexpensive, as well as providing apparatus for reading zone identifying information recorded along such data tracks.

[0252] Discharging Power Regulation Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0253] As shown in FIGS. **2A3** and **2A4**, the input port of the discharging power regulation subsystem **40** is operably connected to the output port of the cathode-anode output terminal configuration subsystem **25**, whereas the output port of the discharging power regulation subsystem **40** is operably connected to the input port of the electrical load **12**. While the primary function of the discharging power regulation subsystem **40** is to regulate the electrical power delivered the electrical load during its Discharging Mode of operation, the discharging power regulation subsystem can also regulate the output voltage across the electrical load, as well as the electrical current flowing across the cathode-electrolyte interface during discharging operations. Such control functions are managed by the system controller **18** and can be programmably selected in a variety of ways in order to achieve optimal discharging of multi-tracked and single-tracked metal-fuel tape according to the present invention while satisfying dynamic loading requirements.

[0254] The discharging power regulating subsystem of the first illustrative embodiment can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistor-controlled technology, in which a current-controlled source is connectable in electrical series with electrical load **12** in order to control the electrical current therethrough in response to control signals produced by the system controller carrying out a particular Discharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which a voltage-controlled source is connectable in electrical parallel with the electrical load in order to control the output voltage therethrough in response to control signals produced by the system controller. Such circuitry can be combined and controlled by the system controller **12** in order to provide constant power control across the electrical load.

[0255] In the illustrative embodiment of the present invention, the primary function of the discharging power regulation subsystem **40** is to carry out real-time power regulation to the electrical load using any one of the following Discharge Power Control (i.e. Regulation) Methods, namely: (1) a Constant Output Voltage/Variable Output Current Method, wherein the output voltage across the electrical load is maintained constant while the current is permitted to vary in response to loading conditions; (2) a Constant Output Current/Variable Output Voltage Method, wherein the current into the electrical load is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Output Voltage/Constant Output Current Method, wherein the voltage across and current into the load are both maintained constant in response to loading conditions; (4) a Constant Output Power Method, wherein the output power across the electrical load is maintained constant in response to loading conditions; (5) a Pulsed Output Power Method, wherein the output power across the electrical load is pulsed with the duty cycle of each power pulse being maintained in accordance with preset conditions; (6) a Constant Output Voltage/Pulsed Output Current Method, wherein the output current into the electrical load is maintained constant while the current into the load is pulsed with a particular duty cycle; and (7) a Pulsed Output Voltage/Constant Output Current Method, wherein the output power into the load is pulsed while the current thereinto is maintained constant.

[0256] In the preferred embodiment of the present invention, each of the seven (7) Discharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **18**. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic or optical condition established or detected at the interface between the electrical load **12** and the Metal-Fuel Tape Discharging Subsystem **6**.

[0257] Input/Output Control Subsystem within the Metal-Fuel Tape Discharging Subsystem

[0258] In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Tape Discharging Subsystems in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Tape Discharging Subsystem **6** hereof includes an Input/Output Control Subsystem **41** which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Tape Discharging Subsystem **6** as if its system controller were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **41** is realized as a standard IEEE I/O bus architecture which provides an external and/or remote computer system with a way and means of directly interfacing with the system controller **18** of the Metal-Fuel Tape Discharging Subsystem **6** and managing various aspects of system and subsystem operation in a straightforward manner.

[0259] System Controller within the Metal-Fuel Tape Discharging Subsystem

[0260] As illustrated in the detailed description set forth above, the system controller **18** performs numerous operations in order to carry out the diverse functions of the FCB system within its Discharging Mode. In the preferred embodiment of the FCB system of **FIG. 1**, the system controller **18** is realized using a programmed microcontroller having program and data storage memory (e.g. ROM, EPROM, RAM and the like) and a system bus structure well known in the microcomputing and control arts. In any particular embodiment of the present invention, it is understood that two or more microcontrollers may be combined in order to carry out the diverse set of functions performed by the FCB system hereof. All such embodiments are contemplated embodiments of the system of the present invention.

[0261] Discharging Metal-Fuel Tape Within The Metal-Fuel Tape Discharging Subsystem

[0262] **FIG. 2A5** sets forth a high-level flow chart describing the basic steps of discharging metal-fuel tape (i.e. generating electrical power therefrom) using the Metal-Fuel Tape Discharging Subsystem shown in FIGS. **2A3** through **2A4**.

[0263] As indicated at Block A, the user places (i.e. inserts) a supply of unoxidized metal-fuel tape into the cartridge receiving port of the system housing so that the tape path-length expansion mechanism **8** is adjacent the metal-fuel tape ready for discharge within the Metal-Fuel Tape Discharging Subsystem.

[0264] As indicated at Block B, the path-length expansion mechanism within the Metal-Fuel Tape Discharging Subsystem increases the path-length of the metal-fuel tape over the increased path-length region thereof, as shown in FIGS. **2A3** and **2A4**.

[0265] As indicated at Block C, the Discharge Head Transport Subsystem **6** arranges the discharging heads about the metal-fuel tape over the expanded path-length of the Metal-Fuel Tape Discharging Subsystem so that the ionically-conducting medium is disposed between each cathode structure and the adjacent metal-fuel tape.

[0266] As indicated at Block D, the Discharge Head Transport Subsystem **6** then configures each discharging head so that its cathode structure is in ionic contact with a portion of the path-length extended metal-fuel tape and its anode contacting structure is in electrical contact therewith.

[0267] As indicated at Block E, the cathode-anode output terminal configuration subsystem **25** automatically configures the output terminals of the cathode-anode structures of each discharging head arranged about the path-length extended metal-fuel tape, and then the system controller **18** controls the Metal-Fuel Card Discharging Subsystem **6** so that electrical power is generated and supplied to the electrical load at the required output voltage. When all or a substantial portion of the metal-fuel tape has been discharged, then the Cartridge Loading/Unloading Subsystem **2** can be programmed to automatically eject the metal-fuel tape cartridge for replacement with a cartridge containing recharged metal-fuel tape.

[0268] Metal-Fuel Tape Recharging Subsystem for the First Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0269] As shown in FIGS. 2B3 and 2B4, the metal-fuel tape recharging subsystem **7** of the first illustrative embodiment comprises a number of subsystems, namely: an assembly of multi-track metal-oxide reducing (i.e. recharging) heads **11**, each having multi-element cathode structures and anode-contacting structures with electrically-conductive input terminals connectable in a manner to be described hereinbelow; an assembly of metal-oxide sensing heads **23'** for sensing the presence of metal-oxide formation along particular zones of metal fuel tracks as the metal fuel tape is being transported past the recharging heads during the Recharging Mode; a metal-fuel tape path-length extension mechanism **10**, as schematically illustrated in FIGS. **2B1** and **2B2** and described above, for extending the path-length of the metal-fuel tape over a particular region of the cassette device **5**, and enabling the assembly of multi-track metal-oxide reducing heads to be arranged thereabout during the Recharging Mode of operation; a recharging head transport subsystem **24'** for transporting the subcomponents of the recharging head assembly **11** (and the metal-oxide sensing head assembly **23'** to and from the metal-fuel tape when its path-length is arranged in an extended configuration by the metal-fuel tape path-length extension mechanism **11**; an input power supply subsystem **90** for converting externally supplied AC power signals into DC power supply signals having voltages suitable for recharging metal-fuel tracks being transported through the recharging heads of the Metal-Fuel Tape Recharging Subsystem; a cathode-anode input terminal configuration subsystem **91**, for connecting the output terminals (port) of the input power supply subsystem **90** to the input terminals (port) of the cathode and anode-contacting structures of the recharging heads **11**, under the control of the system controller **18'** so as to supply input voltages thereto for electro-chemically converting metal-oxide formations into its primary metal during the Recharging Mode; a cathode-anode voltage monitoring subsystem **26'**, connected to the cathode-anode input terminal configuration subsystem **91**, for monitoring (i.e. sampling) the voltage applied across cathode and anode of each recharging head, and producing (digital) data representative of the sensed voltage level; a cathode-anode current monitoring subsystem **27'**, connected to the cathode-anode input terminal configuration subsystem **91**, for monitoring (e.g. sampling) the current flowing across the cathode-electrolyte interface of each recharging head during the Recharging Mode, and producing digital data signals representative of the sensed current levels; a cathode oxygen pressure control subsystem comprising the system controller **18'**, solid-state pO_2 sensors **28'**, vacuum chamber (structure) **29'** shown in FIGS. **2B7** and **2B8**, vacuum pump **30'**, electronically-controlled airflow control device **31'**, manifold structure **32'**, and multi-lumen tubing **33'** shown in FIGS. **2B8**, for sensing and controlling the pO_2 level within each channel of the cathode structure of each recharging head **11**; a metal-fuel tape speed control subsystem comprising the system controller **18'**, motor drive circuits **21A** and **21B**, and tape velocity (i.e. speed and direction) sensor/detector **22'**, for bi-directionally controlling the velocity of metal-fuel tape relative to the recharging heads **11**, in the forward and reverse tape directions; an ion-concentration control subsystem comprising the system controller **18'**, solid-state moisture sensor **34'**, moisturizing (e.g. humidifying or wicking element) **35'**, for sensing and modifying conditions within the FCB system (e.g. the relative humidity at the cathode-electrolyte interface of the discharging heads) so that the ion-concentration at the cathode-electrolyte interface is maintained within an optimal range during the Recharge Mode of operation; recharge head temperature control subsystem comprising the system controller **18'**, solid-state temperature sensors (e.g. thermistors) **271'** embedded within each channel of the multi-cathode support structure hereof, and a discharge head cooling device **272'**, responsive to control signals produced by the system controller **18'**, for lowering the temperature of each recharging channel to within an optimal temperature range during recharging operations; a relational-type Metal-Fuel Database Management Subsystem (MRDMS) **280** operably connected to system controller **18'** by way of local bus **281**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Tape Recharging Subsystem **7**; a Data Capture and Processing Subsystem (DCPS) **282**, comprising data reading head **38'** embedded within or mounted closely to the cathode support structure of each recharging head **11**, metal-oxide sensing head assembly **23'** and associated circuitry, and a programmed microprocessor-based data processor adapted to receive data signals produced from voltage monitoring subsystem **26'**, current monitoring subsystem **27'**, metal-oxide sensing head assembly **23'**, the tape velocity control subsystem, the cathode oxygen pressure control subsystem, and the ion-concentration control subsystem hereof, and enable (i) the reading of metal-fuel zone identification data from transported metal-fuel tape **5**, (ii) the recording of sensed discharge parameters and computed metal-oxide indicative data derived therefrom in the Metal-Fuel Database Management Subsystem (MFDMS) **280** using local system bus **283**, and (iii) the reading of prerecorded recharge parameters and prerecorded metal-fuel indicative data stored in the Metal-Fuel Database Management Subsystem **280** using local system bus **281**; an input (i.e. recharging) power regulation subsystem **92** connected between the output terminals (i.e. port) of the input power supply subsystem **90** and the input terminal (i.e. port) of the cathode-anode input terminal configuration subsystem **91**, for regulating the input power (and voltage and/or current characteristics) delivered across the cathode and anode structures of each metal-fuel track being recharged during the Recharging Mode; an input/output control subsystem **41'**, interfaced with the system controller **18'**, for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **18'** for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[**0270**] Multi-Track Recharging Head Assembly within the Metal-Fuel Tape Recharging Subsystem

[**0271**] The function of the assembly of multi-track recharging heads **11** is to electrochemically reduce metal-oxide formations along the tracks of metal-fuel tape transported through the recharging head assembly **11** during the Recharging Mode of operation. In the illustrative embodiment, each recharging head **11** comprises: a cathode element support plate **42** having a plurality of isolated channels **43'** permitting the free passage of oxygen (O2) through the bottom portion **44'** of each such channel; a plurality of electrically-conductive cathode elements (e.g. strips) **45**A' through **45**E' for insertion within the lower portion of these channels, respectively; a plurality of electrolyte-impregnated strips **46**A' through **46**E' for placement over the cathode strips **45**A' through **45**E', respectively, and support within the channels **44'** as shown in **FIG. 2**B6; and an oxygen-evacuation chamber **29'** mounted over the upper (back) surface of the cathode element support plate **42'**, in a sealed manner, as shown in **FIG. 2**B7.

[**0272**] As shown in FIGS. 2B3 and 2B4, each oxygen-evacuation chamber **29'** has a plurality of subchambers **29**A' through **29**E' physically associated with recessed channels **154**A' and **154**E', respectively. Each vacuum subchamber **29**A' through **29**E' is isolated from all other subchambers and is in fluid communication with one channel supporting a cathode element and electrolyte-impregnated element. As shown, each subchamber **29**A' through **29**E' is arranged in fluid communication with a vacuum pump **30'** via multi-lumen tubing **38'**, manifold assembly **32'** and electronically-controlled air-flow switch **31'**, each of whose operation is controlled by system controller **18'**. This arrangement enables the system controllerl**8'** to maintain the pO_2 level in each subchamber within an optimal range during recharging operations by selectively evacuating air from subchamber through the corresponding air flow channel in the manifold assembly **32'**.

[**0273**] In the illustrative embodiment, electrolyte-impregnated strips within the recharging head assembly **11** are realized by impregnating an electrolyte-absorbing carrier medium with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for each discharging cell is made from a formula consisting of an alkali solution (e.g. KOH), a gelatin material, water, and additives known in the art.

[**0274**] In the illustrative embodiment, each cathode strip is made from a sheet of nickel wire mesh **47'** coated with porous carbon material and granulated platinum or other catalysts **48'** to form a cathode suitable for use in metal-air FCB systems. Details of cathode construction are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor **49'** is soldered to the underlying wire mesh sheet of each cathode strip. As shown in **FIG. 2**B7, each electrical conductor **49'** is passed through a small hole **50'** formed in the bottom surface of a channel of the cathode support plate, and is connected to the cathode-anode input terminal configuration subsystem **91**. As shown, the cathode strip pressed into the lower portion of the channel to secure the same therein. As shown in **FIG. 2**B7, the bottom surface of each channel **43** has numerous perforations **43**A formed therein to allow the evacuation of oxygen away from the cathode-electrolyte interface, and out towards the vacuum pump **30'**. In the illustrative embodiment, an electrolyteimpregnated strip **46**A' through **46**E' is placed over a cathode strip **45**A' through **45**E' and is secured within the upper portion of the cathode supporting channel **43'**. As shown in **FIG. 2**B8, when the cathode strip and thin electrolyte strip are mounted in their respective channel in the cathode support plate **42'**, the outer surface of the electrolyte-impregnated strip is disposed flush with the upper surface of the plate defining the channels, thereby permitting metal-fuel tape to be smoothly transported thereover during tape recharging operations.

[**0275**] Hydrophobic agents are added to the carbon material constituting the cathode elements within the recharging head assembly **11**, to ensure the expulsion of water from the oxygen-pervious cathode elements. Also, the interior surfaces **44** of the cathode support channels are coated with a hydrophobic film (e.g. Teflon®) **51'** to ensure the expulsion of water within electrolyte-impregnated strips **47'** and thus achieve optimum oxygen transport across the cathode strips during the Recharging Mode. Preferably, the cathode support plate is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate and evacuation chamber can be fabricated using injection molding technology also well known in the art.

[**0276**] In order to sense the partial oxygen pressure within the cathode structure during the Recharging Mode, for use in effective control of metal-oxide reduction within the recharging heads, a solid-state PO2 sensor **28'** is embedded within each channel of the cathode support plate **42'**, as illustrated in **FIG. 2**B7, and operably connected to the Data Capture and Processing Subsystem **282** as an information input device thereto. Data signals produced by the pO_2 sensors are received by the Data Capture and Processing Subsystem **282**, converted into an appropriate format and then recorded within the information structure shown in **FIG.** 2B**16**, maintained by the Metal-Fuel Database Management Subsystem **280**. The system controller **18**' has access to such information stored in the Database Management Subsystem by way of local system bus **281**, as shown in FIGS. 2B**3** and 2B**4**.

[**0277**] In the illustrative embodiment, each pO_2 sensor can be realized using well-known pO_2 sensing technology employed to measure (in vivo) pO2 levels in the blood of humans. Such prior art sensors can be constructed using miniature diodes which emit electromagnetic radiation at different wavelengths that are absorbed at different levels in the presence of oxygen in the blood, and such information can be processed and analyzed to produce a computed measure of pO_2 in a reliable manner, as taught in U.S. Pat. No. 5,190,038 and references cited therein, each being incorporated herein by reference. In the present invention, the characteristic wavelengths of the light emitting diodes can be selected so that similar sensing functions are carried out within the structure of the cathode in each recharging head, in a straightforward manner.

[**0278**] In **FIG.** 2B**9**, there is shown a section of multi-tracked fuel tape that has undergone partial discharge and thus has metal-oxide formations along the metal-fuel tracks thereof. Notably, this section of partially-discharged metal-fuel tape is contained within the cassette fuel cartridge shown in **FIG. 1** and requires recharging within the Metal-Fuel Tape Recharging Subsystem **7** while its cassette device is received within the cassette storage bay of the FCB system.

[**0279**] In **FIG.** 2B**10**, an exemplary metal-fuel (anode) contacting structure **58**' is disclosed for use with the cathode structure shown in FIGS. 2B**7** and 2B**8**. As shown, a plurality of electrically conductive elements **60**A through **60**E' are supported from an platform **61**' disposed adjacent the travel of the fuel tape within the cassette cartridge. Each conductive element **60**A' through **60**E' has a smooth surface adapted for slidable engagement with one track of metal fuel through the fine groove formed in the base layer of the fuel tape corresponding to the fuel track. Each conductive element is connected to an electrical conductor which is connected to the output port of the cathode-anode input terminal configuration subsystem **91**. The platform **61**' is operably associated with the recharging head transport subsystem **24**' and can be designed to be moved into position with the metal-fuel tape during the Recharging Mode of the system, under the control of the system controller.

[**0280**] Notably, the use of multiple recharging heads, as shown in the illustrative embodiments hereof, rather than a single recharging head, allows discharged metal-fuel tape to be recharged more quickly using lower recharging currents, thereby minimizing heat build-up across the individual recharging heads. This feature of the Metal-Fuel Tape Recharging Subsystem **7** extends the service-life of the cathodes employed within the recharging heads thereof.

[**0281**] Metal-Oxide Sensing Head Assembly within the Metal-Fuel Tape Recharging Subsystem

[**0282**] The function of the Metal-Oxide Sensing Head Assembly **23**' within the Metal-Fuel Tape Recharging Subsystem **7** is to sense (in real-time) the current levels produced across the individual fuel tracks during recharging operations, and generate electrical signals indicating the degree to which portions of metal-fuel tracks have been oxidized and thus require metal-oxide reduction. As shown in FIGS. 2B**15**, each multi-track metal-oxide sensing head **23**' in the assembly thereof comprises a number of subcomponents, namely: a positive electrode support structure **63**' for supporting a plurality of positively electrode elements **64**A' through **64**E', each in registration with the upper surface of one of the fuel tracks (that may have been oxidized) and connected to a low-voltage power supply terminal **59**A, **59**B, **59**C, **59**D and **59**E provided by current sensing circuitry **66** which is operably connected to the Data Capture and Processing Subsystem **282** within the Metal-Fuel Tape Recharging Subsystem **7**, as shown in FIGS. **2**B**3** and **2**B**4**; and a negative electrode support structure **67** for supporting a plurality of negative electrode elements **68**A' through **68**E', each in registration with the lower surface of the metal-fuel tracks and connected to a low voltage power supply terminal **69**A through **69**E provided by current sensing circuitry **66**.

[**0283**] In the illustrative embodiment shown in FIGS. **2**B**3** and **2**B**4**, each multi-track metal-oxide sensing head **23**' is disposed immediately before a recharging head **11** in order to sense the actual condition of the metal-fuel tape therebefore and provide a signal to the system controller **18**' for detection and determination of the amount (or percentage) of metal-oxide present thereon before recharging. While only one metal-oxide sensing head assembly **23**' is shown in the first illustrative embodiment of the FCB system hereof, it is understood that for bi-directional tape-based FCB systems, it would be preferred to install one assembly on each end of the recharging head assembly so that the system controller **18**' can "anticipate" which metal-fuel zones are fully charged, partially discharged or completely discharged, regardless of the direction that the metal-fuel tape is being transported at any particular instant in time.

[**0284**] With this arrangement, the Metal-Fuel Tape Recharging Subsystem **7** is capable of actually determining which portions of which metal fuel tracks require metal-oxide reducing during recharging operations. Such information gathering can be carried out using current sensing circuitry **66**' which automatically applies a test voltage (v_{acr}) across each metal-fuel track during the Recharge Mode, to measure the response current (i_{acr}). Such parameters are provided as input to the Data Capture and Processing Subsystem **282**. This subsystem then processes this captured data in one or more ways to determine the presence of metal-oxide formations. For example, this subsystem can compare the detected response current value against a threshold current value stored within the Metal-Fuel Database Management Subsystem **280**. Alternatively, the subsystem may compute the ratio v_{acr}/i_{acr} to determine a measure of electrical resistance for the cell and compare this measure with a reference threshold value to determine whether there is high electrical resistance across the cell and thus large metal-oxide formations therealong. This data is stored in the Metal-Fuel Database Management Subsystem **280** and is accessible by the system controller **18**' any time during recharging operations. The various ways in which the system controller **18**' may respond to real-time analysis of data within the Metal-Fuel Database Management Subsystem **280** will be described in greater detail hereinafter.

[0285] Metal-Fuel Tape Path-Length Extension Mechanism within the Metal-Fuel Tape Recharging Subsystem

[0286] As shown in FIGS. 2B3 and 2B4, the tape path-length extension mechanism **10** of the illustrative embodiment comprises: a first array of rollers **71**A' through **71**E' mounted upon support structure **72'**, for contacting the metal-fuel portion of the metal-fuel tape when the cassette device **3** inserted into the cassette receiving port of the FCB system; a second array of rollers **73**A' through **73**E', disposed between the array of stationary rollers **71**A' through **71**E', for contacting the base portion of the metal-fuel tape **5** when the cassette device **3** is inserted into the cassette receiving port of the FCB system, and a transport mechanism **75'** of the electromechanical construction, for transporting roller support structures **72** and **74** relative to the system housing and each other, in order to carry out the functions of this subsystem described in greater detail hereinbelow. Notably, these roller arrays **71**A' through **71**E' can be arranged to either the left of right of the roller arrays **73**A' through **73**E' of the tape-path extension mechanism provided for the Metal-Fuel Tape Discharging Subsystem **7**. Alternatively, in other embodiments of the present invention, it may be desirable to employ a single tape path-length extension mechanism for use with the discharging heads of the Metal-Fuel Tape Discharging Subsystem and the recharging heads of the Metal-Fuel Tape Recharging Subsystem.

[0287] In the configuration shown in **FIG. 2**B3, the tape path-length mechanism **10** for the Metal-Fuel Tape Recharging Subsystem is arranged so that the first and second sets of rollers **71**A' through **71**E' and **73**A' through **73**E' barely contact opposite sides of the metal-fuel tape when the cassette device **3** is inserted within the cassette receiving port of the FCB system. As shown in **FIG. 2**B4, the second set of rollers **73**A' through **73**E' are displaced a distance relative to the first set of stationary rollers **71**A' through **71**E', thereby causing the path-length of the metal-fuel tape to become substantially extended from the path-length shown in the configuration of **FIG. 2**B3. This extended path-length permits a plurality of recharging heads **11** to be arranged thereabout during the recharging mode of operation. In this configuration, the cathode structure **76'** of each recharging head **11** is in ionic contact with the metal-fuel structures along the metal-fuel tape, while the anode-contacting structure **77'** of each recharging head is in electrical contact with the metal-fuel structures of the tape. In this configuration, the metal-fuel tape is arranged so that a plurality of recharging heads **11** can be arranged about the metal-fuel tape during tape recharging operations. The use of multiple recharging heads enables recharging of metal-fuel tape using lower electrical currents and thus providing improved control over the metal-oxide conversion during tape recharging. Such advantages will become apparent hereinafter.

[0288] Recharging Head Transport Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0289] The primary function of the recharging head transport subsystem is to transport the assembly of recharging heads **11** (and metal-oxide sensing heads **23'** supported thereto) about the metal-fuel tape that has been path-length extended, as shown in **FIG. 2**B3. When properly transported, the cathode and anode-contacting structures of the recharging heads are brought into "ionically-conductive" and "electrically-conductive" contact with the metal-fuel tracks of metal-fuel tape while it is being is transported through the recharging head assembly during the Recharging Mode.

[0290] The recharging head transport subsystem **24'** can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode structure **76'** and anode-contacting structure **77'** of each recharging head away from the metal-fuel tape **5**, as shown in **FIG. 2**B3, and about the metal-fuel tape as shown in **FIG. 2**B4. As shown, these transport mechanisms are operably connected to system controller **18'** and controlled by the same in accordance with the system control program carried out thereby.

[0291] Input Power Supply Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0292] In the illustrative embodiment, the primary function of the Input Power Supply Subsystem **90** is to receive as input, standard alternating current (AC) electrical power (e.g. at 120 or 220 Volts) through an insulated power cord, and to convert such electrical power into regulated direct current (DC) electrical power at a regulated voltage required at the recharging heads of the Metal-Fuel Tape Recharging Subsystem **7** during the recharging mode of operation. For zinc anodes and carbon cathodes, the required "open-cell" voltage v_{ac} across each anode-cathode structure during recharging is about 2.2-2.3 Volts in order to sustain electrochemical reduction. This subsystem can be realized in various ways using AC-DC and DC-DC power conversion and regulation circuitry well known in the art.

[0293] Cathode-Anode Input Terminal Configuration Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0294] As shown in FIGS. **2**B3 and **2**B4, the cathode-anode input terminal configuration subsystem **91** is connected between the output terminals of the input power regulation subsystem **90** and the input terminals of the cathode-anode pairs associated with multiple tracks of the recharging heads **11**. The system controller **18'** is operably connected to cathode-anode input terminal configuration subsystem **91** in order to supply control signals thereto for carrying out its functions during the Recharge Mode of operation.

[0295] The primary function of the cathode-anode input terminal configuration subsystem **91** is to automatically configure (in series or parallel) the input terminals of selected cathode-anode pairs within the recharging heads of the Metal-Fuel Tape Recharging Subsystem **7** so that the required input (recharging) voltage level is applied across cathode-anode structures of metal-fuel tracks requiring recharging. In the illustrative embodiment of the present invention, the cathode-anode input terminal configuration mechanism **91** can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the recharging heads **11** are connected to the output terminals of the input power regulating subsystem **92**. Such switching operations are carried out under the control of the system controller **18'** so that the required output voltage produced by the input power regulating subsystem **92** is applied across the cathode-anode structures of metal-fuel tracks requiring recharging.

[0296] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0297] As shown in FIGS. 2B3 and 2B4, the cathode-anode voltage monitoring subsystem 26' is operably connected to the cathode-anode input terminal configuration subsystem 91 for sensing voltage levels across the cathode and anode structures connected thereto. This subsystem is also operably connected to the system controller 18' for receiving control signals therefrom required to carry out its functions. In the first illustrative embodiment, the cathode-anode voltage monitoring subsystem 26' has two primary functions: to automatically sense the instantaneous voltage level applied across the cathode-anode structures associated with each metal-fuel track being transported through each recharging head during the Recharging Mode; and to produce a (digital) data signals indicative of the sensed voltages for detection and analysis by the Data Capture and Processing Subsystem 280, and ultimately response by the system controller 18'.

[0298] In the first illustrative embodiment of the present invention, the Cathode-Anode Voltage Monitoring Subsystem 26' can be realized using electronic circuitry adapted for sensing voltage levels applied across the cathode-anode structures associated with each metal-fuel track transported through each recharging head within the Metal-Fuel Tape Recharging Subsystem 7. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels for detection, analysis and response at the data signal input of the system controller 18'. As will be described in greater detail hereinafter, such data signals can be used by the system controller to carry out its recharging power regulation method during the Recharging Mode of operation.

[0299] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0300] As shown in FIGS. 2B3 and 2B4, the cathode-anode current monitoring subsystem 27' is operably connected to the cathode-anode input terminal configuration subsystem 18'. The cathode-anode current monitoring subsystem 27' has two primary functions: to automatically sense the magnitude of electrical current flowing through the cathode-anode pair of each metal-fuel track along each recharging head assembly within the Metal-Fuel Tape Recharging Subsystem 11 during the discharging mode; and to produce a digital data signal indicative of the sensed current for detection and analysis by the system controller 18'.

[0301] In the first illustrative embodiment of the present invention, the Cathode-Anode Current Monitoring Subsystem 27' can be realized using current sensing circuitry for sensing the electrical current passed through the cathode-anode pair of each metal-fuel track along each recharging head assembly, and producing a digital data signal indicative of the sensed current for detection at the input of the system controller 18'. As will be explained in greater detail hereinafter, these detected current levels can be used by the system controller in carrying out its recharging power regulation method, and well as creating a "recharging condition history" information file for each zone or subsection of recharged metal-fuel tape.

[0302] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0303] The function of the cathode oxygen pressure control subsystem defined above is to sense the partial oxygen pressure (pO_2) (i.e. O_2 concentration) within each channel of the cathode structure in the recharging heads 11, and in response thereto, control (i.e. increase or decrease) the same by regulating the air (O_2) pressure within such cathode structures. In accordance with the present invention, partial oxygen pressure (pO_2) within each channel of the cathode structure in each recharging head is maintained at an optimal level in order to allow optimal oxygen evacuation from the recharging heads during the Recharging Mode. By lowering the pO_2 level within each channel of the cathode structure (by evacuation), metal-oxide along the metal-fuel tape can be completely recovered with optimal use of input power supplied to the recharging heads during the Recharging Mode. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by the system controller, the system controller is provided with a controllable variable for use in regulating the electrical power supplied to the electrical load during the Recharging Mode.

[0304] In the first illustrative embodiment of the FCB system hereof shown in FIG. 1, the data signals produced by the solid-state pO_2 sensors 28A' through 28E' embodied within the recharging heads 11 are provided to the Data Capture and Processing Subsystem 282, as shown in FIGS. 2B3 and 2B4. The Data Capture and Processing Subsystem 282 receives these signals, converts them into digital data and the like and then records the resulting information items within the information structure shown in FIG. 2B16, managed within the Metal-Fuel Database Management Subsystem 280 with the Metal-Fuel Tape Recharging Subsystem 7.

[0305] Metal-Fuel Tape Velocity Control Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0306] In the FCB system shown in FIG. 1, there is the need for only one metal-fuel tape control subsystem to be operative at any instant in time as metal-fuel tape is common to both the Metal-Fuel Tape Discharging Subsystem 6 and the Metal-Fuel Tape Recharging Subsystem 7 during discharging and/or recharging operations. Notwithstanding this fact, the system controllers 18 and 18' associated with these subsystems 6 and 7 can override each other, as required, in order to control the operation of the tape velocity control subsystem within such discharging and recharging subsystem.

[0307] For example, during the Recharging Mode, when the Metal-Fuel Tape Discharging Subsystem 6 is inoperative (i.e. no power generation occurring), the function of metal-tape speed control subsystem described hereinabove is to control the speed of the metal-fuel tape over the recharging heads within the metal-fuel tape recharging subsystem 7. In response to signals produced by the tape velocity sensor 22 and in accordance with the recharging power regulation method being carried out by the system controller 18', the system controller 18' automatically controls (i.e. increases or decreases) the speed of the metal-fuel tape relative to the recharging heads by generating appropriate control signals for driving electric motors 19A and 19B coupled to the supply and take-up reels of metal-fuel tape being recharged.

The primary reason for controlling the velocity of metal-fuel tape is that, during the Recharging Mode, this parameter determines how much electrical charge can be delivered to each zone or subsection of oxidized metal-fuel tape as it is being transported through each recharging head within the Metal-Fuel Tape Recharging Subsystem **7**. Ideally, during the Recharging Mode, it is desirable to transport the metal-fuel tape as fast as possible through the assembly of recharging heads in order to rapidly and completely recharge the metal-fuel tape within the cassette cartridge inserted within the FCB system. In contrast, the Discharge Mode, it will be desirable in many cases to transport the metal-fuel tape as slow as possible to conserve the supply of metal-fuel. In general, for a constant cathode-anode current applied to a recharging head with the requisite cathode-anode recharging voltage (i.e. Constant Input Current/Constant Input Voltage Method), the amount of electrical charge supplied to each zone of metal-fuel tape will decrease as the velocity of the metal-fuel zone is increased relative to the recharging head during the Recharging Mode. This inverse relationship can be explained by the fact that the metal-fuel zone has less time to accumulate electrical charge as it is transported past the recharging head. In such situations, the function of the metal-fuel tape speed control subsystem is to control the velocity of the tape so as to control the speed of the tape so as to optimally converts metal-oxide formations along the tape into its primary metal.

[0308] In instances where the recharging mode and recharging mode are both operative, it will be desired to enable the system controller **18** to override system controller **18'** so that the primary objective of the system is to optimally generate power from the FCB system. In other instances, however, where the primary objective of the FCB system is to optimally recharge the metal-fuel tape in a rapid manner, the system controller **18'** of the Recharging Subsystem **7** will override the system controller **18** of the Discharging Subsystem **6**, and thus control the velocity of the metal-fuel tape within the FCB system.

[0309] Ion-Concentration Control Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0310] To achieve high-energy efficiency during the Recharging Mode, it is necessary to maintain an optimal concentration of (charge-carrying) ions at the cathode-electrolyte interface of each recharging head within the Metal-Fuel Tape Recharging Subsystem **7**. Also, the optimal ion-concentration within the Metal-Fuel Tape Recharging Subsystem **7** may be different than that required within the Metal-Fuel Tape Discharging Subsystem **6**. For this reason, in particular applications of the FCB system hereof, it may be desirable and/or necessary to provide a separate ion-concentration control subsystem within the Metal-Fuel Tape Recharging Subsystem **7**. The primary function of such an ion-concentration control subsystem would be to sense and modify conditions within the FCB system so that the ion-concentration at the cathode-electrolyte interface of the recharging heads is maintained within an optimal range during the Recharging Mode of operation.

[0311] In the illustrative embodiment of such a subsystem, ion concentration control is achieved by embedding a miniature solid-state hydrometer (or moisture sensor) **34'** within the FCB system (as close as possible to the anode-cathode interfaces of the recharging heads) in order to sense moisture conditions and produce a digital data signal indicative thereof. This digital data signal is supplied to the Data Capture and Processing Subsystem **282** for detection and analysis. In the event that the moisture-level or relative humidity drops below the predetermined threshold value set in the Metal-Fuel Database Management Subsystem **280**, the system controller automatically generate a control signal supplied to a moisturizing element **35'** realizable, for example, by a wicking device **36'** arranged in contact with the metal-fuel tracks of the metal-fuel tape being transported during the Recharging Mode. Another technique may involve spraying fine water droplets (e.g. ultra-fine mist) from micro-nozzles realized along the top surfaces of each cathode support structure, facing the metal-fuel tape during transport. Such operations will increase the moisture-level or relative humidity within the interior of the recharging head (or system housing) and thus ensure that the concentration of KOH within the electrolyte within electrolyte-impregnated strips is optimally maintained for ion transport and thus metal-oxide reduction during tape recharging operations.

[0312] Recharging Head Temperature Control Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0313] As shown in FIGS. **2B3**, **2B4**, and **2B7**, the Recharge Head Temperature Control Subsystem incorporated within the Metal-Fuel Tape Recharging Subsystem **6** of the first illustrative embodiment comprises a number of subcomponents, namely: the system controller **18'**; solid-state temperature sensors (e.g. thermistors) **271'** embedded within each channel of the multi-cathode support structure hereof, as shown in **FIG. 2B7**; and a discharge head cooling device **272'**, responsive to control signals produced by the system controller **18'**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations. The recharge head cooling device **272'** can be realized using a wide variety of heat-exchanging techniques, including forced-air cooling, water-cooling, and/or refrigerant cooling, each well known in the heat exchanging art. In some embodiments of the present invention, where high levels of electrical power are being generated, it may be desirable to provide a jacket-like structure about each recharging head in order to circulate air, water or refrigerant for temperature control purposes. Data Capture and Processing Subsystem within the Metal-Fuel Tape Recharging Subsystem In the illustrative embodiment of **FIG. 1**, Data Capture And Processing Subsystem (DCPS) **282** shown in FIGS. **2B3** and **2B4** carries out a number of functions, including, for example: (1) identifying each zone or subsection of metal-fuel tape immediately before it is transported through each recharging head within the recharging head assembly and producing metal-fuel zone identification data representative thereof; (2) sensing (i.e. detecting) various "recharge parameters" within the Metal-Fuel Tape Recharging Subsystem existing during the time period that the identified metal-fuel zone is transported through the recharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-oxide produced during tape recharging operations, and producing "metal-oxide indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **280** (accessible by system controller **18'**), sensed recharge parameter data as well as computed metal-oxide indicative data both correlated to its respective metal-fuel zone identified during the Recharging Mode of operation.

[0314] As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **280** by Data Capture and Processing Subsystem **282** can be used by the system controller **18'** in various ways including, for example: optimally recharging partially or completely oxidized metal-fuel tape in a rapid manner during the Recharging Mode of operation.

[0315] During recharging operations, the Data Capture and Processing Subsystem **282** automatically samples (or captures) data signals representative of "recharge parameters" associated with the various subsystems constituting the Metal-Fuel Tape Recharging Subsystem **7** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Recharging Mode. In accordance with the principles of the present invention, tape-type "recharge parameters" shall include, but are not limited to: the voltages supplied across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode anode voltage monitoring subsystem **26'**; the electrical response currents flowing across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-anode current monitoring subsystem **27'**; the velocity (i.e. speed and direction) of the metal-fuel tape during recharging of a particular zone of metal-fuel tape, monitored by the metal-fuel tape speed control subsystem; the oxygen saturation (i.e. concentration) level (pO_2) within the cathode structure of each recharging head, monitored by the cathode oxygen pressure control subsystem (**28'**,**30'**,**31'**,**18'**); the moisture (H_2O) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular recharging heads monitored, for example, by the ion-concentration control subsystem (**18'**, **34'**, **35'** and **36'**); and the time duration (Δt) of the state of any of the above-identified recharge parameters.

[0316] In general, there a number of different ways in which the Data Capture and Processing Subsystem **282** can record tape-type "recharge parameters" during the Recharging Mode of operation. While these methods are similar to those employed during the recording of discharging parameters, such methods will be detailed hereinbelow for sake of completion.

[0317] According to a first method of data recording shown in **FIG. 2B9**, zone identifying code or indicia **80** (e.g. miniature bar code symbol encoded with zone identifying information) graphically printed on "optical" data track **81**, can be read by optical data reader **38** realized using optical techniques (e.g. laser scanning bar code symbol readers, or optical decoders). In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2B16**, which is created for each metal-fuel zone identified along the tape by data reader **38** of the Data Capture and Processing Subsystem **282**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem within the Metal-Fuel Database Management Subsystem **280** during the recharging operations.

[0318] According to a second method of data recording shown in **FIG. 2B9'**, digital "zone identifying" code **83** magnetically recorded in a magnetic data track **84'**, can be read by optical data reader **38'** realized using magnetic sensing techniques well known in the magstripe reading art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2B16**, which is created for each metal-fuel zone identified along the tape by data reader **38'** of the Data Capture and Processing Subsystem **282**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem within the Metal-Fuel Database Management Subsystem **280** during the recharging operations.

[0319] According to a third method of data recording shown in **FIG. 2B9"**, digital "zone identifying" code recorded as a sequence of light transmission apertures **86** in optically opaque data track **87**, can be read by optical sensing head **38"** realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is produced for recording in an information storage structure, as shown in **FIG. 2B16**, created for each metal-fuel zone identified along the tape by the data reader **38"**. Preferably, such information storage is realized by data writing operations carried out by the Data Capture and Processing and Subsystem within the Metal-Fuel Database Management Subsystem **282** during the recharging operations.

[0320] According to a fourth alternative method of data recording, both unique digital "zone identifying" code and discharge parameters for each identified metal-fuel zone are recorded in a magnetic, optical, or apertured data track, realized as a strip attacked to and extending along the edge of the metal-fuel tape of the present invention. The block of information pertaining to a particular zone or subsection of metal-fuel, schematically indicated in **FIG. 2B16**, can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information. Typically, the block of information will include the metal-fuel zone identification number and a set of recharge parameters detected by the Data Capture and Processing Subsystem **282** as the metal-fuel zone is transported through the recharging head assembly **11**.

[0321] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel tape can have a very low information capacity. This is because very little information needs to be recorded to tag each metal-fuel zone with a unique identifier (i.e. address number or zone identification number), to which sensed tape recharge parameters are recorded in the Metal-Fuel Database Management Subsystem **280**. Also, formation of a data track in accordance with the first and second methods should be inexpensive to fabricate and provide a convenient way of recording zone identifying information along metal-fuel tape.

[0322] Input/Output Control Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0323] In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Tape Recharging Subsystems in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Tape Recharging Subsystem **7** hereof includes an Input/Output Control Subsystem **41'** which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Tape Recharging Subsystem as if its system controller were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **41'** is realized as a standard IEEE I/O bus architecture which provides an external or remote computer system with a way and means of directly interfacing with the system controller of the Metal-Fuel Tape Recharging Subsystem and managing various aspects of system and subsystem operation in a straightforward manner.

[**0324**] Recharging Power Regulation Subsystem within the Metal-Fuel Tape Recharging Subsystem

[**0325**] As shown in FIGS. **2B3** and **2B4**, the output port of the recharging power regulation subsystem **92** is operably connected to the input port of the Cathode-Anode Input Terminal Configuration Subsystem **91** whereas the input port of the recharging power regulation subsystem **92** is operably connected to the output port of the input power supply subsystem. While the primary function of the recharging power regulation subsystem **92** is to regulate the electrical power supplied to metal-fuel tape during the Recharging Mode of operation, the recharging power regulation subsystem **92** can also regulate the voltage applied across the cathode-anode structures of the metal-fuel track, as well as the electrical currents flowing across the cathode-electrolyte interfaces thereof during recharging operations. Such control functions are managed by the system controller **18'** and can be programmably selected in a variety of ways in order to achieve optimal recharging of multi-tracked and single-tracked metal-fuel tape while satisfying dynamic loading requirements.

[**0326**] The recharging power regulating subsystem of the first illustrative embodiment can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistor-controlled technology, in which one or more current-controlled sources are connectable in electrical series with the cathode and anode structures of the recharging heads **11** in order to control the electrical currents therethrough in response to control signals produced by the system controller carrying out a particular Recharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which one or more voltage-controlled sources are connectable in electrical parallel with the cathode and anode structures in order to control the voltage thereacross in response to control signals produced by the system controller. Such circuitry can be combined and controlled by the system controller **18'** in order to provide constant power (and/or voltage and/or current) control across the cathode-anode structures of the recharging heads **11** of the FCB system.

[**0327**] In the illustrative embodiments of the present invention, the primary function of the recharging power regulation subsystem **92** is to carry out real-time power regulation to the cathode/anode structures of the recharging heads of the system using any one of the following Recharging Power Control Methods, namely: (1) a Constant Input Voltage/Variable Input Current Method, wherein the input voltage applied across each cathode-anode structure is maintained constant while the current therethrough is permitted to vary in response to loading conditions presented by metal-oxide formations on the recharging tape; (2) a Constant Input Current/Variable Input Voltage Method, wherein the current into each cathode-anode structure is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Input Voltage/Constant Input Current Method, wherein the voltage applied across and current into each cathode-anode structure during recharging are both maintained constant in response to loading conditions; (4) a Constant Input Power Method, wherein the input power applied across each cathode-anode structure during recharging is maintained constant in response to loading conditions; (5) a Pulsed Input Power Method, wherein the input power applied across each cathode anode structure during recharging is pulsed with the duty cycle of each power pulse being maintained in accordance with preset or dynamic conditions; (6) a Constant Input Voltage/Pulsed Input Current Method, wherein the input current into each cathode-anode structure during recharging is maintained constant while the current into the cathode-anode structure is pulsed with a particular duty cycle; and (7) a Pulsed Input Voltage/Constant Input Current Method, wherein the input power supplied to each cathode-anode structure during recharging is pulsed while the current thereinto is maintained constant.

[**0328**] In the preferred embodiment of the present invention, each of the seven (7) Recharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **18'**. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic an/or optical condition established or detected at the interface between the metal-fuel cassette device and the Metal-Fuel Tape Recharging Subsystem **7**.

[**0329**] System Controller within the Metal-Fuel Tape Recharging Subsystem

[**0330**] As illustrated in the detailed description set forth above, the system controller **18'** performs numerous operations in order to carry out the diverse functions of the FCB system within its Recharging Mode. In the preferred embodiment of the FCB system of **FIG. 1**, the enabling technology used to realize the system controller **18'** in the Metal-Fuel Tape Recharging Subsystem **7** is substantially the same subsystem used to realize the system controller **18** in the Metal-Fuel Tape Discharging Subsystem **6**, except that the system controller **18'** will have some programmed functions which system controller **18** does not have, and vice versa. While a common computing platform can be used to realize system controller **18** and **18'**, it is understood, however, the system controllers in the Discharging and Recharging Subsystems can be realized as separate subsystems, each employing one or more programmed microprocessors in order to carry out the diverse set of functions performed thereby within the FCB system hereof. In either case, the input/output control subsystem of one of these subsystems can be designed to be the primary input/output control subsystem, with which one or more external subsystems (e.g. a management subsystem) can be interfaced to enable external or remote management of the functions carried out within FCB system hereof.

[0331] Recharging Metal-Fuel Tape Within The Metal-Fuel Tape Recharging Subsystem

[0332] **FIG. 2B5** sets forth a high-level flow chart describing the basic steps of recharging metal-fuel tape using the Metal-Fuel Tape Recharging Subsystem **7** shown in FIGS. **2B3** through **2B4**.

[0333] As indicated at Block A, the user places (i.e. inserts) a supply of oxidized metal-fuel tape into the cartridge receiving port of the system housing so that the tape path-length expansion mechanism **10** is adjacent the metal-fuel tape ready for recharging within the Metal-Fuel Tape Recharging Subsystem **7**.

[0334] As indicated at Block B, the path-length extension mechanism **10** within the Metal-Fuel Tape Recharging Subsystem **7** increases the path-length of the metal-fuel tape **5** over the extended path-length region thereof, as shown in FIGS. **2B3** and **2B4**.

[0335] As indicated at Block C, the Recharge Head Transport Subsystem **24**' arranges the recharging heads **11** about the metal-fuel tape over the expanded path-length of the Metal-Fuel Tape Recharging Subsystem **7** so that the ionically-conducting medium is disposed between each cathode structure of the recharging head and the adjacent metal-fuel tape.

[0336] As indicated at Block D, the Recharge Head Transport Subsystem **24**' then configures each recharging head so that its cathode structure is in ionic contact with a portion of the path-length extended metal-fuel tape and its anode contacting structure is in electrical contact therewith.

[0337] As indicated at Block E, the cathode-anode input terminal configuration subsystem **91** automatically configures the input terminals of each recharging head arranged about the path-length extended metal-fuel tape, and then the system controller **18**' controls the Metal-Fuel Card Recharging Subsystem **7** so that electrical power is supplied to the path-length extended metal-fuel tape at the required recharging voltages and currents, and metal-oxide formations on the tape are converted into the primary metal. When all or a substantial portion of the metal-fuel tape has been recharged, then the Cartridge Loading/Unloading Subsystem **2** can be programmed to automatically eject the metal-fuel tape cartridge for replacement with a cartridge containing recharged metal-fuel tape.

[0338] Managing Metal-Fuel Availability and Metal-Oxide Presence Within the First Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0339] In the FCB system of the first illustrative embodiment, means are provided for automatically managing the availability of metal-fuel within the Metal-Fuel Tape Discharging Subsystem **6** during discharging operations, and metal-oxide presence within the Metal-Fuel Tape Recharging Subsystem **7** during recharging operations. Such system capabilities will be described in greater detail hereinbelow.

[0340] During The Discharging Mode:

[0341] As shown in **FIG. 2B17**, data signals representative of discharge parameters (e.g., i_{acd}, v_{acd}, . . . , pO_{2d}, H_2O_d, T_{acd}, V_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **277** within the Metal-Fuel Tape Discharging Subsystem **6**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **285** as shown, for example, in **FIG. 2A16**. Each information structure **285** comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel zone identifier **80 (83,86)**, associated with a particular metal-fuel tape supply (e.g. reel-to-reel, cassette, etc.). The unique metal-fuel zone identifier is determined by data reading head **38 (38', 38")** shown in **FIG. 2A6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **275** for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[0342] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **277** during the discharging mode. Such information types include, for example: (1) the amount of electrical current (i_{acd}) discharged across particular cathode-anode structures within particular discharge heads; (2) the voltage (v_{acd}) generated across each such cathode-anode structure; (3) the velocity (v_d) of the metal-fuel zone being transported through the discharging head assembly; (4) the oxygen concentration (pO_{2d}) level in each subchamber within each discharging head; (5) the moisture level $\{H_2O\}_d$ near each cathode-electrolyte interface within each discharging head; and (6) the temperature (T_{acd}) within each channel of each discharging head. From such collected information, the Data Capture and Processing Subsystem **277** can readily compute (i) the time (Δt) duration that electrical current was discharged across a particular cathode-anode structure within a particular discharge head.

[0343] The information structures produced and stored within the Metal-Fuel Database Management Subsystem **275** on a real-time basis can be used in a variety of ways during discharging operations. For example, the above-described current (i_{avg}) and time information (Δt) is conventionally measured in Amperes and Hours, respectively. The product of these measures (AH) provides an approximate measure of the electrical charge (−Q) discharged from the metal-air fuel cell battery structures along the metal-fuel tape. Thus the computed "AH" product provides an approximate amount of metal-oxide that one can expect to have been formed on the identified (i.e. labeled) zone of metal-fuel, at a particular instant in time, during discharging operations.

[0344] When information relating to the instantaneous velocity (v_t) of each metal-fuel zone is used in combination with the AH product, it is possible to compute a more accurate measure of electrical discharge across a cathode-anode structure in a particular discharge head. From this more accurately computed discharged amount, the Data Capture and Processing Subsystem **277** can compute a very accurate estimate of the amount of metal-oxide produced as each metal-fuel zone is transported through a discharge head at a particular tape velocity and given set of discharging conditions determined by the detected recharging parameters.

[0345] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database

Management Subsystem **275** can be used to account for or determine how much metal-fuel (e.g. zinc) should be available for discharging (i.e. producing electrical power) from zinc-fuel tape, or how much metal-oxide is present for reducing along the zinc-fuel tape. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-fuel amounts available along a particular metal-fuel zone.

[**0346**] In the illustrative embodiment, metal-fuel availability is managed within the Metal-Fuel Tape Discharging Subsystem **6**, using one of two different methods for managing metal-fuel availability described hereinbelow.

[**0347**] First Method of Metal-Fuel Availability Management

[**0348**] During Discharging Operations

[**0349**] According to the first method of metal-fuel availability management, (i) the data reading head **38** (**38'**, **38"**) is used to identify each metal-fuel zone passing under the metal-oxide sensing head assembly **23** and produce zone identification data indicative thereof, while (ii) the metal-oxide sensing head assembly **23** measures the amount of metal-oxide present along each identified metal-fuel zone. As mentioned hereinabove, each metal-oxide measurement is carried out by applying a test voltage across a particular track of metal fuel, and detecting the electrical which flows across the section of metal-fuel track in response the applied test voltage. The data signals representative of the applied voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem **277** and processed to produce a data element representative of the ratio of the applied voltage to response current ($v_{applied}/(i_{response})$. This data element is automatically recorded within an information structure linked to the identified metal-fuel zone maintained in the Metal-Fuel Data Management Subsystem **275**. As this data element (v/i) provides a direct measure of electrical resistance across the subsection of metal-fuel tape under measurement, it can be accurately correlated to a measured amount of metal-oxide present on the identified metal-fuel zone. As shown in **FIG. 2A16**, this metal-oxide measure (MOM) is recorded in the information structure shown linked to the identified metal-fuel zone upon which the response current measurements were taken.

[**0350**] The Data Capturing and Processing Subsystem **277** can then compute the amount of metal-fuel (MFA_t) remaining on the identified metal-fuel zone at time "t" using (i) the measured amount of metal-oxide on the identified fuel zone at time instant "t" (MOM_t), and (ii) a priori information recorded in the Metal-Fuel Database Management Subsystem **275** regarding the maximum amount of metal-fuel ($MFA_{maximum}$) that is potentially available over each metal-fuel zone when the zone is disposed in its fully charged state, with no metal-oxide formation thereon. This computation can be mathematically expressed as: $MFA_t=MFA_{maximum}-MOM_t$. As illustrated in **FIG. 2A16**, each such data element is automatically recorded within an information storage structure in the Metal-Fuel Database Management Subsystem **275**. The address of each such recorded information structure is linked to the identification data of the identified metal-fuel zone ID data read during discharging operations.

[**0351**] During discharging operations, the above-described metal-fuel availability update procedure is carried out every t_1-t_{i+1} seconds for each metal-fuel zone that is automatically identified by the data reading head **38** (**38'**, **38"**), over which the metal-fuel tape is transported. This ensures that for each metal-fuel zone along each track along a supply of metal-fuel tape there is an up-to-date information structure containing information on the discharging parameters, the metal-fuel availability state, metal-oxide presence state, and the like.

[**0352**] Second Method of Metal-Fuel Availability Management

[**0353**] During Discharging Operations

[**0354**] According to the second method of metal-fuel availability management, (i) the data reading head **38** (**38'**, **38"**) is used to identify each metal-fuel zone passing under the discharging head assembly and produce zone identification data indicative thereof, while (ii) the Data Capturing and Processing Subsystem **277** automatically collects information relating to the various discharging parameters and computes parameters pertaining to the availability of metal-fuel and metal-oxide presence along each metal-fuel zone along a particular supply of metal-fuel tape. In accordance with the principles of the present invention, this method of metal-fuel management is realized as a three-step procedure cyclically carried out within the Metal-Fuel Database Management Subsystem **275** of the Discharging Subsystem **6**. After each cycle of computations, the Metal-Fuel Database Management Subsystem **275** contains current (up-to-date) information on the amount of metal-fuel disposed along each metal-fuel zone (disposed along any particular fuel track). Such information on each identifiable zone of the metal-fuel tape can be used to: manage the availability of metal-fuel to meet the electrical power demands of the electrical load connected to the FCB system; as well as set the discharging parameters in an optimal manner during discharging operations.

[**0355**] As shown in **FIG. 2A16**, information structures **285** are recorded for each identified metal-fuel zone (MFZ_k) along each metal-fuel track (MFT_j), at each sampled instant of time t_i. Initially, the metal-fuel tape has been either fully charged or recharged and loaded into the FCB system hereof, and in this fully charged state, each metal-fuel zone has an initial amount of metal-fuel present along its surface. This initial metal-fuel amount can be determined in a variety of different ways, including for example: by encoding such initialization information on the metal-fuel tape itself; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem **275** at the factory and automatically initialized upon reading a code applied along the metal-fuel tape by data reading head **38** (**38'**, **38"**); by actually measuring the initial amount of metal-fuel by sampling values at a number of metal-fuel zones using the metal-oxide sensing assembly **23**; or by any other suitable technique.

[**0356**] As part of the first step of the procedure, this initial metal-fuel amount available at initial time instant to, and designated as MFA_0, is quantified by the Data Capture and Processing Subsystem **277** and recorded within the information structure of **FIG. 2A16** maintained within the Metal-Fuel Database Management Subsystem **275**. While this initial metal-fuel measure (MFA_0) can be determined empirically through metal-oxide sensing techniques, in many applications it may be more expedient to use theoretical principles to compute this measure after the tape has been subjected to a known course of treatment (e.g. complete recharging).

[**0357**] The second step of the procedure involves subtracting from the initial metal-fuel amount MFA_0, the computed metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during discharging operations conducted between time interval t_0-t_i. The during the discharging operation, metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected—electrical discharge current i_{acd}, time duration Δt_d, and the average tape zone velocity v_{0-1} over time duration Δt_d.

[**0358**] The third step of the procedure involves adding to the computed measure (MFA_0–MOE_{0-1}), the metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during any recharging operations conducted between time interval t_0-t_i. Notably, the metal-fuel estimate MFE_{0-1} is computed using the following recharging parameters collected—electrical recharge current i_{acr}, time duration Δt, and tape zone velocity v_{0-1} during the discharging operation. As this metal-fuel measure MFE_{0-1} will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem **280** within the Metal-Fuel Tape Recharging Subsystem **7**, it will be necessary for the system controller **18** to read this prerecorded information element from the Database Subsystem **280** within the Recharging Subsystem **7** during discharging operations.

[**0359**] The computed result of the above-described procedure (i.e. MFA_0–MOE_{0-1}+MFE_{0-1}) is then posted within the Metal-Fuel Database Management Subsystem **275** within Discharging Subsystem **6** as the new current metal-fuel amount (MFA_1) which will be used in the next metal-fuel availability update procedure.

[**0360**] During discharging operations, the above-described accounting update procedure is carried out for every t_i-t_{i+1} seconds for each metal-fuel zone that is automatically identified by the data reading head **38** (**38**', **38**"), by which the metal-fuel tape is transported. Notably, each element of metal-fuel zone identification data (zone ID data) collected by the data reading head **38** (**38**', **38**") during discharging operations is used to address memory storage locations within the Metal-Fuel Database Management Subsystems **275** and **280** where correlated information structures are to be recorded during database updating operations. While such database updating operations are carried out at the same time that discharging operations are carried out, it may be convenient in some applications to perform such updating operations after the occurrence of some predetermined delay period.

[**0361**] Uses for Metal-Fuel Availability Management During the Discharging Mode of Operation

[**0362**] During discharging operations, the computed estimates of metal-fuel present over any particular metal-fuel zone (i.e. MFE_{t1-t2}), along any particular fuel track, determined at the j-th discharging head, can be used to compute in real-time the availability of metal-fuel at the (j+1)th, (j+2)th, or (j+n)th discharging head downstream from the j-th discharging head. Using such computed measures, the system controller **18** within the Metal-Fuel Tape Discharging Subsystem **6** can determine (i.e. anticipate) in real-time, which metal-fuel zones along a supply of metal-fuel tape contain metal-fuel (e.g. zinc) in quantities sufficient to satisfy instantaneous electrical-loading conditions imposed upon the Metal-Fuel Tape Discharging Subsystem **6** during the discharging operations, and selectively advance the metal-fuel tape to zones where metal-fuel is known to exist. In the event that gaps of fuel-depletion exist along any particular section of tape, the tape transport control subsystem can rapidly "skip over" such tape sections to where metal-fuel exists. Such tape advancement (or skipping) operations can be carried out by the system controller **18** temporarily increasing the instantaneous velocity of the metal-fuel tape so that tape supporting metal-fuel content (e.g. deposits) along particular tracks are readily available for producing electrical power required by the electrical load **12**. During such brief time periods when depleted sections of tape are transported through the discharging head assembly **9**, the discharging power regulation subsystem **40**, equipped with storage capacitors or the like, can serve to regulate the output power as required by electrical load conditions.

[**0363**] Another advantage derived from such metal-fuel management capabilities is that the system controller **18** within the Metal-Fuel Tape Discharging Subsystem **6** can control discharge parameters during discharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystem **275** during the immediately prior discharging and recharging operations.

[**0364**] Means for Controlling Discharging Parameters During the Discharging Mode Using Information Recorded During the Prior Modes of Operation

[**0365**] In the FCB system of the first illustrative embodiment, the system controller **18** within the Metal-Fuel Tape Discharging Subsystem **6** can automatically control discharge parameters using information collected during prior recharging and discharging operations and recorded within the Metal-Fuel Database Management Subsystems of the FCB system of **FIG. 1**.

[**0366**] As shown in **FIG. 2B17**, the subsystem architecture and buses **276**, **279** and **281** provided within and between the Discharging and Recharging Subsystems **6** and **7** enable system controller **18** within the Metal-Fuel Tape Discharging Subsystem **6** to access and use information recorded within the Metal-Fuel Database Management Subsystem **280** within the Metal-Fuel Tape Recharging Subsystem **7**. Similarly, the subsystem architecture and buses provided within and between the Discharging and Recharging Subsystems **6** and **7** enable system controller **18**' within the Metal-Fuel Tape Recharging Subsystem **7** to access and use information recorded within the Metal-Fuel Database Management Subsystem **275** within the Metal-Fuel Tape Discharging Subsystem **6**. The advantages of such information file and sub-file sharing capabilities will be explained hereinbelow.

[**0367**] During the discharging operations, the system controller **18** can access various types of information stored within the Metal-Fuel Database Management Subsystems of Discharging and Recharging Subsystems **6** and **7**. One important information element will relate to the amount of metal-fuel currently available at each metal-fuel zone along a particular fuel track at a particular instant of time (i.e. MFE_t). Using this information, the system controller **18** can determine if there will be sufficient metal-fuel along a particular section of tape to satisfy current electrical power demands. The zones along one or more or all of the fuel tracks along a supply of metal-fuel tape may be substantially consumed as a result of prior discharging operations, and not having been recharged since the last discharging operation. The system controller **18** can anticipate such metal-fuel conditions prior to the section of tape being transported over the discharging heads. Depending on the metal-fuel condition of "upstream" sections of tape, the system controller **18** may respond as follows: (i) increase the tape speed when the fuel is thinly present on identified zones, and decrease the tape speed when the fuel is thickly present on identified zones being transported through the discharging heads, to satisfy the demands of the electrical load; (ii) connect the cathode-anode structures of metal-fuel "rich" tracks into the discharging power regulation subsystem **40** when high loading conditions are detected at load **12**, and connect the cathode-anode structures of metal-fuel "depleted" tracks from this subsystem when low loading conditions are detected at load **12**; (iii) increase the amount of oxygen being injected within the corresponding cathode support structures (i.e. increase the pO_2 therewithin) when the thinly formed metal-fuel is present on identified metal-fuel zones, and decrease the amount of oxygen being injected within the corresponding cathode support structures when thickly formed metal-fuel is present on identified metal-fuel zones being transported through the discharging heads; (iv) control the temperature of the discharging heads when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments of the present invention, the system controller **18** may operate in different ways in response to the detected condition of particular tracks on an identified fuel zone.

[0368] During the Recharging Mode:

[0369] As shown in **FIG. 2B17**, data signals representative of recharge parameters (e.g. i_{acr}, v_{acr}, . . . , pO_{2r}, H_2O_r, T_r, v_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **275** within the Metal-Fuel Tape Recharging Subsystem **7**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **286** as shown, for example, in **FIG. 2B16**. As in the case of discharge parameter collection, each information structure **286** for recharging parameters comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel zone identifier **80** (**83**, **86**), associated with the metal-fuel tape supply (e.g. reel-to-reel, cassette, etc.) being recharged. The unique metal-fuel zone identifier is determined by data reading head **60** (**60'**, **60"**) shown in **FIG. 2B6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **280** of the Metal-Fuel Tape Recharging Subsystem **7**, shown in **FIG. 2B17**, for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[0370] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **282** during the recharging mode. Such information types include, for example: (1) the recharging voltage applied across each such cathode-anode structure within each recharging head; (2) the amount of electrical current (i_{ac}) supplied across each cathode-anode structures within each recharge head; (3) the velocity of the metal-fuel tape being transported through the recharging head assembly; (4) the oxygen concentration (pO_2) level in each subchamber within each recharging head; (5) the moisture level (H_2O) near each cathode-electrolyte interface within each recharging head; and (6) the temperature (T_{ac}) within each channel of each recharging head. From such collected information, the Data Capture and Processing Subsystem **282** can readily compute various parameters of the system including, for example, the time duration (Δt) that electrical current was supplied to a particular cathode-anode structure within a particular recharging head.

[0371] The information structures produced and stored within the Metal-Fuel Database Management Subsystem **280** of the Metal-Fuel Tape Recharging Subsystem **7** on a real-time basis can be used in a variety of ways during recharging operations. For example, the above-described current (i_{avg}) and time duration (Δt) information acquired during the recharging mode is conventionally measured in Amperes and Hours, respectively. The product of these measures (AH) provides an approximate measure of the electrical charge (−Q) supplied to the metal-air fuel cell battery structures along the metal-fuel tape during recharging operations. Thus the computed "AH" product provides an approximate amount of metal-fuel that one can expect to have been produced on the identified (i.e. labeled) zone of metal-fuel, at a particular instant in time, during recharging operations.

[0372] When information relating to the instantaneous velocity (v_t) of each metal-fuel zone is used in combination with the AH product, it is possible to compute a more accurate measure of electrical charge (Q) supplied to a particular cathode-anode structure in a particular recharging head. From this accurately computed "recharge" amount, the Data Capture and Processing Subsystem **282** can compute a very accurate estimate of the amount of metal-fuel produced as each identified metal-fuel zone is transported through each recharging head at a particular tape velocity, and given set of recharging conditions determined by the detected recharging parameters.

[0373] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database Management Subsystems within the Metal-Fuel Tape Discharging and Recharging Subsystems **6** and **7** respectively can be used to account for or determine how much metal-oxide (e.g. zinc-oxide) should be present for recharging (i.e. conversion back into zinc from zinc-oxide) along the zinc-fuel tape. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-oxide amounts present along each metal-fuel zone during recharging operations.

[0374] In the illustrative embodiment, the metal-oxide presence process may be managed within the Metal-Fuel Tape Recharging Subsystem **7** using one or two different methods which will be described hereinbelow.

[0375] First Method of Metal-Oxide Presence Management

[0376] During Recharging Operations

[0377] According to the first method of metal-oxide presence management, (i) the data reading head **60** (**60'**, **60"**) is used to identify each metal-fuel zone passing under the metal-oxide sensing head assembly **23'** and produce zone identification data indicative thereof, while (ii) the metal-oxide sensing head assembly **23'** measures the amount of metal-oxide present along each identified metal-fuel zone. As mentioned hereinabove, each metal-oxide measurement is carried out by applying a test voltage across a particular track of metal fuel, and detecting the electrical current which flows across the section of metal-fuel track in response the applied test voltage. The data signals representative of the applied voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem **282** and processed to produce a data element representative of the ratio of the applied voltage to response current ($v_{applied}/(i_{response})$. This data element is automatically recorded within an information structure linked to the identified metal-fuel zone, maintained in the Metal-Fuel Data Management Subsystem **282** of the Metal-Fuel Tape Recharging Subsystem **7**. As this data element (v/i) provides a direct measure of electrical resistance across the subsection of metal-fuel tape under measurement, it can be accurately correlated to a measured amount of metal-oxide present on the identified metal-fuel zone. As shown in **FIG. 2B16**, this metal-oxide measure (MOM) is recorded in the information structure shown linked to the identified metal-fuel zone upon which the response current measurements were taken during a particular recharging operation.

[**0378**] The Data Capturing and Processing Subsystem **282** within the Metal-Fuel Tape Recharging Subsystem **7** can then compute the amount of metal-oxide (MOAT) existing on the identified metal-fuel zone at time "t". As illustrated in **FIG.** 2B16, each such data element is automatically recorded within an information storage structure in the Metal-Fuel Database Management Subsystem **282** of the Metal-Fuel Tape Recharging Subsystem **7**. The address of each such recorded information structure is linked to the identification data of the identified metal-fuel zone ID data read during recharging operations.

[**0379**] During recharging operations, the above-described metal-oxide presence update procedure is carried out every t_i-t_{i+1} seconds for each metal-fuel zone that is automatically identified by the data reading head **60** (**60**', **60**"), over which the metal-fuel tape is transported.

[**0380**] Second Method of Metal-Fuel Presence Management

[**0381**] During Recharging Operations

[**0382**] According to the second method of metal-fuel presence management, (i) the data reading head **60** (**60**', **60**") is used to identify each metal-fuel zone passing under the recharging head assembly and produce zone identification data indicative thereof, while (ii) the Data Capturing and Processing Subsystem **282** automatically collects information relating to the various recharging parameters and computes parameters pertaining to the availability of metal-fuel and metal-oxide presence along each metal-fuel zone along a particular supply of metal-fuel tape. As will be described in greater detail hereinafter, this method of metal-oxide management is realized as a three-step procedure cyclically carried out within the Metal-Fuel Database Management Subsystem **280** of the Recharging Subsystem **7**. After each cycle of computation, the Metal-Fuel Database Management Subsystem **280** contains current (up-to-date) information on the amount of metal-fuel disposed along each metal-fuel zone (disposed along any particular fuel track). Such information on each identifiable zone of the metal-fuel tape can be used to: manage the presence of metal-oxide for efficient conversion into its primary metal; as well as set the recharging parameters in an optimal manner during recharging operations.

[**0383**] As shown in **FIG.** 2B16, information structures **286** are recorded for each identified metal-fuel zone (MFZ_k) along each metal-fuel track (MFT_j), at each sampled instant of time t_1. Typically, the metal-fuel tape has been completely or partially discharged and loaded into the FCB system hereof, and in this discharged state, each metal-fuel zone has an initial amount of metal-oxide present along its surface which cannot be used to produced electrical power within the FCB system. This initial metal-fuel amount can be determined in a variety of different ways, including for example: by encoding such initialization information on the metal-fuel tape itself; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem **282** at the factory and automatically initialized upon reading a code applied along the metal-fuel tape by data reading head **60** (**60**', **60**"); by actually measuring the initial amount of metal-oxide by sampling values at a number of metal-fuel zones using the metal-oxide sensing assembly **23**'; or by any other suitable technique.

[**0384**] As part of the first step of the metal-oxide management procedure, this initial metal-oxide amount available at initial time instant to, and designated as MOA_0, is quantified by the Data Capture and Processing Subsystem **282** and recorded within the information structure of **FIG.** 2B16 maintained within the Metal-Fuel Database Management Subsystem **282** of the Metal-Fuel Tape Recharging Subsystem **7**. While this initial metal-oxide measure (MOA_0) can be determined empirically through metal-oxide sensing techniques, in many applications it may be more expedient to use theoretical principles to compute this measure after the tape has been subjected to a known course of treatment (e.g. complete discharging).

[**0385**] The second step of the procedure involves subtracting from the initial metal-oxide amount MOA_0, the computed metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during recharging operations conducted between time interval t_0-t_1. During the recharging operation, metal-oxide estimate MOE_{0-1} is computed using the following recharging parameters collected—electrical recharge current i_{acr}, time duration thereof Δt, and tape zone velocity v_{0-1}.

[**0386**] The third step of the procedure involves adding to the computed measure (MOA_0–MFE_{0-1}), the metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during any discharging operations conducted between time interval t_0-t_1. Notably, the metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected-electrical discharge current i_{acd}, time duration thereof Δt_r and average tape zone velocity v_{0-1} over this time duration during recharging operations. As this metal-oxide estimate MOE_{0-1} will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem within the Metal-Fuel Tape Discharging Subsystem **6**, it will be necessary to read this prerecorded information element from the database within the Metal-Fuel Tape Discharging Subsystem **6** during recharging operations.

[0387] The computed result of the above-described accounting procedure (i.e. $MOA_0-MFE_{0-1}+MOE_{0-1}$) is then posted within the Metal-Fuel Database Management Subsystem **280** within Recharging Subsystem **7** as the new current metal-oxide amount (MOA_1) which will be used in the next metal-oxide presence update procedure.

[0388] During recharging operations, the above-described accounting update procedure is carried out for every t_i-t_{i+1} seconds for each metal-fuel zone that is automatically identified by the data reading head **60** (**60'**, **60"**), by which the metal-fuel tape is transported. Notably, each element of metal-fuel zone identification data (zone ID data) is collected by the data reading head **60** (**60'**, **60"**) during recharging operations and is used to address memory storage locations within the Metal-Fuel Database Management Subsystem **280** where correlated information structures are to be recorded during database updating operations. While such database updating operations are carried out at the same time that recharging operations are carried out, it may be convenient in some applications to perform such updating operations after the occurrence of some predetermined delay period.

[0389] Uses for Metal-Oxide Presence Management During the Recharging Mode of Operation

[0390] During recharging operations, the computed amounts of metal-oxide present over any particular metal-fuel zone (i.e. MOA_{t1-t2}), along any particular fuel track, determined at the j-th recharging head, can be used to compute in real-time the presence of metal-fuel at the (j+1)th, (j+2)th, or (j+n)th recharging head downstream from the j-th recharging head. Using such computed measures, the system controller **18'** within the Metal-Fuel Tape Recharging Subsystem **7** can determine (i.e. anticipate) in real-time, which metal-fuel zones along a supply of metal-fuel tape contain metal-oxide (e.g. zinc-oxide) requiring recharging, and which contain metal-fuel not requiring recharging. For those metal-fuel zones requiring recharging, the system controller **18'** can temporarily increasing the instantaneous velocity of the metal-fuel tape so that tape supporting metal-oxide content (e.g. deposits) along particular tracks are readily available for conversion into metal-fuel within the recharging head assembly.

[0391] Another advantage derived from such metal-oxide management capabilities is that the system controller **18'** within the Metal-Fuel Tape Recharging Subsystem **7** can control recharge parameters during recharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystem **280** during the immediately prior discharging operations, and vice versa. Such advantages will be described in greater detail hereinafter.

[0392] During Recharging operations, information collected can be used to compute an accurate measure of the amount of metal-oxide that exists along each metal-fuel zone at any instant in time. Such information, stored within information storage structures maintained within the Metal-Fuel Database Subsystem **280**, can be accessed and used by the system controller **18'** within the Metal-Fuel Tape Discharging Subsystem **7** to control the amount of electrical current supplied across the cathode-anode structures of each recharging head **11**. Ideally, the magnitude of electrical current will be selected to ensure complete conversion of the estimated amount of metal-oxide (present at each such zone) into its source metal (e.g. zinc).

[0393] Means for Controlling Recharging Parameters During the Recharging Mode Using Information Recorded During the Prior Modes of Operation

[0394] In the FCB system of the first illustrative embodiment, the system controller **18'** within the Metal-Fuel Tape Recharging Subsystem **7** can automatically control recharge parameters using information collected during prior discharging and recharging operations and recorded within the Metal-Fuel Database Management Subsystems of the FCB system of **FIG. 1**.

[0395] During the recharging operations, the system controller **18'** within the Metal-Fuel Tape Recharging Subsystem **7** can access various types of information stored within the Metal-Fuel Database Management Subsystem **275**. One important information element stored therein will relate to the amount of metal-oxide currently present at each metal-fuel zone along a particular fuel track at a particular instant of time (i.e. MOE_t). Using this information, the system controller **18'** can determine exactly where metal-oxide deposits are present along particular sections of tape, and thus can advance the metal fuel tape thereto in order to efficiently and quickly carry out recharging operations therealong. The system controller **18'** can anticipate such metal-fuel conditions prior to the section of tape being transported over the recharging heads. Depending on the metal-fuel condition of "upstream" sections of tape, the system controller **18'** of the illustrative embodiment may respond as follows: (i) increase the tape speed when the metal-oxide is thinly present on identified zones, and decrease the tape speed when the metal-oxide is thickly present thereon; (ii) connect cathode-anode structures of metal-oxide "rich" tracks into the recharging power regulation subsystem **92** for longer periods of recharging, and connect metal-oxide "depleted" tracks from this subsystem for shorter periods of recharging; (iii) increase the rate of oxygen evacuation from cathode-anode structures having thickly formed metal-oxide formations present on identified metal-fuel zones, and decrease the rate of oxygen evacuation from cathode-anode structures having thinly formed metal-oxide formations present on identified metal-fuel zones being transported through the recharging heads; (iv) control the temperature of the recharging heads when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments of the present invention, the system controller **18'** may operate in different ways in response to the detected condition of particular track on an identified fuel zone.

The Second Illustrative Embodiment of the Metal-Fuel Tape FCB System of the Present Invention

[0396] The second illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIG. 3A**. As shown therein, this FCB system **100** comprises a number of subsystems, namely: a Metal-Fuel Tape Cassette Cartridge Loading/Unloading Subsystem **2** as described hereinabove for loading and unloading of a metal-fuel tape cassette device **3** into the FCB system during its Cartridge Loading and Unloading Modes of operation, respectively; a Metal-Fuel Tape Transport Subsystem **4** as described hereinabove for transporting the metal-fuel tape through the system during its Discharging and Recharging Modes of operation; and Metal-Fuel Tape Recharging Subsystem **7** as described hereinabove for electro-chemically recharging (i.e. reducing) sections of oxidized metal-fuel tape during the Recharging Mode of operation. Details concerning each of these subsystems have been described hereinabove in connection with the first illustrative embodiment of the FCB system shown in **FIG. 1**. The primary difference between the systems shown in **FIGS. 1 and 3** is that the system of **FIG. 3** does not have a Metal-Fuel Discharging Subsystem **6**, and thus functions as a recharger and not a discharging (i.e. power generating) device.

The Third Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[**0397**] The third illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIG. 3B**. As shown therein, this FCB system **101** comprises a number of subsystems, namely: a Metal-Fuel Tape Cassette Cartridge Loading/Unloading Subsystem **2** for loading and unloading of a metal-fuel tape cassette device **4** into the FCB system; a Metal-Fuel Tape Transport Subsystem **7** for transporting the metal-fuel tape through the system during its Discharging and Recharging Modes of operation; and Metal-Fuel Tape Recharging Subsystem **7** for electrochemically recharging (i.e. reducing) sections of oxidized metal-fuel tape during the Recharging Mode of operation. Details concerning each of these subsystems have been described hereinabove in connection with the first illustrative embodiment of the FCB system shown in **FIG. 1**. The primary difference between the systems shown in **FIGS. 3A and 3B** is that the system of **FIG. 3B** is capable of recharging metal-fuel cassette devices **3** that may incorporate a component or two of a discharging head, as well as other components associated with Metal-Fuel Tape Discharging Subsystem **6**.

The Fourth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[**0398**] The fourth illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIGS. 4 through 5**B**15**. As shown in FIGS. **4**, **5**A**1** and **5**A**2**, this FCB system **110** comprises a number of subsystems, namely: a Metal-Fuel Card Loading/Unloading Subsystem **111** for semi-manually loading one or more metal-fuel cards **112** into the discharging ports **114** of the FCB system, and semi-manually unloading metal-fuel cards therefrom; a Metal-Fuel Card Discharging (i.e. Power Generation) Subsystem **115** for generating electrical power across an electrical load **116** from the metal-fuel cards during the Discharging Mode of operation; and Metal-Fuel Card Recharging Subsystem **117** for electro-chemically recharging (i.e. reducing) sections of oxidized metal-fuel cards during the Recharging Mode of operation. Details concerning each of these subsystems and how they cooperate will be described below.

[**0399**] As shown in **FIG. 5**A**9**, the metal-fuel material consumed by this FCB System is provided in the form of metal fuel cards **112** which are manually loaded into the card storage bay of the system. In the illustrative embodiment, the card storage bay is divided into two sections: a discharging bay **113** for loading (re)charged metal-fuel cards for discharge (i.e. power generation); and a recharging bay **114** for loading discharged metal-fuel cards for recharging purposes. As shown in FIGS. **4**, **5**A**3**, **5**A**9**, each metal-fuel card **112** has a rectangular-shaped housing containing a plurality of electrically isolated metal-fuel strips **119**A through **119**E adapted to contact the cathode elements **120**A through **120**E of each "multi-track" discharging head in the Metal-Fuel Tape Discharging Subsystem when the fuel card is moved into properly aligned position between cathode support plate **121** and anode contacting structure **122** during the Discharging Mode, as shown in **FIG. 5**A**4**.

[**0400**] In the illustrative embodiment, the fuel card of the present invention is "multi-tracked" in order to enable the simultaneous production of multiple supply voltages (e.g. 1.2 Volts) from the "multi-track" discharging heads employed therein. As will be described in greater detail hereinafter, the purpose of this novel generating head design is to enable the generating and delivery of a wide range of output voltages from the system, suitable to the electrical load connected to the FCB system.

[**0401**] Brief Summary of Modes of Operation of the FCB System

[**0402**] Of the Fourth Illustrative Embodiment of the Present Invention

[**0403**] The FCB system of the fourth illustrative embodiment has several modes of operation, namely: a Card Loading Mode during which metal-fuel cards are semi-manually loaded within the system; a Discharging Mode during which electrical power is produced from the output terminal of the system and supplied to the electrical loaded connected thereto; a Recharging Mode during which metal-fuel cards are recharged; and a Card Unloading Mode during which metal-fuel cards are semi-manually unloaded from the system. These modes will be described in greater detail hereinafter with reference to FIGS. **5**A**1** and **5**A**2** in particular.

[**0404**] During the Card Loading Mode, one or more metal-fuel cards **112** are loaded into the FCB system by the Card Loading/Unloading Subsystem **111**. During the Discharging Mode, the charged metal-fuel cards are discharged in order to electro-chemically generate electrical power therefrom for supply to the electrical load **116** connected thereto. During the Recharging Mode, the oxidized metal-fuel cards are electro-chemically reduced in order to convert oxide formations on the metal-fuel cards into its primary metal during recharging operations. During the Card Unloading Mode, the metal-fuel cards are unloaded (e.g. ejected) from the FCB system by the Card Loading/Unloading Subsystem **111**.

[**0405**] While it may be desirable in some applications to suspend tape recharging operations while carryout tape discharging operations, the FCB system of the fourth illustrative embodiment enables concurrent operation of the Discharging and Recharging Modes. Notably, this feature of the present invention enables simultaneous discharging and recharging of metal-fuel tape during power generation operations.

[**0406**] Multi-Track Metal-Fuel Card Used in the FCB System of the First Illustrative Embodiment

[**0407**] In the FCB system shown in FIGS. **4**, **5**A**3** and **5**A**4** each metal-fuel card **112** has multiple fuel-tracks (e.g. five tracks) as taught in copending application Ser. No. 08/944,507, supra. When using such a metal-fuel card design, it is desirable to design each discharging head **124** within the Metal-Fuel Card Discharging Subsystem **115** as a "multi-track" discharging head. Similarly, each recharging head **125** within the Metal-Fuel Card Recharging Subsystem **117** hereof shown in FIGS. **5B3** and **5B4** should be designed as a multi-track recharging head in accordance with the principles of the present invention. As taught in great detail in copending application Ser. No. 08/944,507, the use of "multi-tracked" metal-fuel cards **112** and multi-track discharging heads **124** enables the simultaneous production of multiple output voltages {**V1**, **V2**, . . . , Vn} selectable by the end user. Such output voltages can be used for driving various types of electrical loads **116** connected to the output power terminals **125** of the Metal-Fuel Card Discharging Subsystem. This is achieved by configuring the individual output voltages produced across anode-cathode structures within each discharging head during metal-fuel card discharging operations. This system functionality will be described in greater detail hereinbelow.

[**0408**] In general, multi-track and single-track metal-fuel cards alike can be made using several different techniques. Preferably, the metal-fuel contained with each card-like device **112** is made from zinc as this metal is inexpensive, environmentally safe, and easy to work. Several different techniques will be described below for making zinc-fuel cards according to the present invention.

[**0409**] For example, in accordance with a first fabrication technique, an thin metal layer (e.g. nickel or brass) of about 0.1 to about 5.0 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of a card-like structure). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of the thin metal layer is to provide efficient current collection at the anode surface. Thereafter, zinc powder is mixed with a binder material and then applied as a coating (e.g. 1 to about 500 microns thick) upon the surface thin metal layer. The zinc layer should have a uniform porosity of about 50% to allow the ionically-conducting medium (e.g. electrolyte ions) to flow with minimum electrical resistance between the cathode and anode structure. As will be explained in greater detail hereinafter, the resulting structure can be mounted within an electrically insulating casing of thin dimensions to improve the structural integrity of the metal-fuel card, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay. Optionally, the casing of the metal-fuel card can be provided with slidable panels that enable access to the metal-fuel strips when the card is received in the discharging bay **113** and the discharging head is transported into position for discharging operations, or when the card is received in the recharging bay **114** and the recharging head is transported into position for recharging operations.

[**0410**] In accordance with a second fabrication technique, a thin metal layer (e.g. nickel or brass) of about 0.1 to about 5 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of card). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of the thin metal layer is to provide efficient current collection at the anode surface. Thereafter zinc is electroplated onto the surface of the thin layer of metal. The zinc layer should have a uniform porosity of about 50% to allow the ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the cathode and anode structures. As will be explained in greater detail hereinafter, the resulting structures can be mounted within an electrically-insulating casing of ultra-thin dimensions to provide a metal-fuel card having suitable structural integrity, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay. Optionally, the casing of the metal-fuel card can be provided with slidable panels that enable access to the metal-fuel strips when the card is received in the discharging bay **113** and the discharging head is transported into position for discharging operations, or when the card is received in the recharging bay and the recharging head is transported into position for recharging operations.

[**0411**] in accordance with a third fabrication technique, zinc powder is mixed with a low-density plastic material and draw into the form of thin electrically-conductive plastic tape. The low-density plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The zinc impregnated tape should have a uniform porosity of about 50% to allow the ions within an ionically-conducting medium (e.g. electrolyte ions) to flow with minimum electrical resistance between the cathode and anode structure. Thereafter, a thin metal layer (e.g. nickel or brass) of about 0.1 to about 5.0 microns thickness is applied to the surface of electrically-conductive tape. The function of the thin metal layer is to provide efficient current collection at the anode surface. As will be explained in greater detail hereinafter, the resulting structure can be mounted within an electrically insulating casing of thin dimensions to improve the structural integrity of the metal-fuel card, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay.

[**0412**] In any of the above-described embodiments, the card housing can be made from any suitable material designed to withstand heat and corrosion. Preferably, the housing material is electrically non-conducting to provide an added measure of user-safety during card discharging and recharging operations.

[**0413**] Also, each of the above-described manufacturing techniques can be readily modified to produce "double-sided" metal-fuel cards, in which single track or multi-track metal-fuel layers are provided on both sides of the flexible base (i.e. substrate) material employed therein. Such embodiments of metal-fuel tape will be useful in applications where discharging heads are to be arranged on both sides of a metal-fuel card loaded within the FCB system. When making double-sided metal-fuel cards, it will be necessary in most embodiments to form a current collecting layer (of thin metal material) on both sides of the plastic substrate so that current can be collected from both sides of the metal-fuel card, associated with different cathode structures. When making double-sided multi-tracked fuel cards, it may be desirable or necessary to laminate together two multi-track metal-fuel sheets, as described hereinabove, with the substrates of each sheet in physical contact. Adaptation of the above-described methods to produce double-sided metal-fuel cards will readily apparent to those skilled in the art having had the benefit of the present disclosure. In such illustrative embodiments of the present invention, the anode-contacting structures will be modified so that electrical contact is established with each electrically-isolated current collecting layer formed within the metal-fuel card structure being employed therein.

[0414] Card Loading/Unloading Subsystem for the Fourth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0415] As schematically illustrated in FIGS. 4, 5A3 and 5A4, and shown in detail in copending U.S. application Ser. No. 08/944,507, the Card Loading/Unloading Transport Subsystem 111 in the FCB system of FIG. 4 comprises a number of cooperating mechanisms, namely: a card receiving mechanism 111A for automatically (i) receiving the metal-fuel card 112 at a card insertion port formed in the front or top panel of the system housing 126, and (ii) withdrawing the metal-fuel card into the card discharge bay provided therewithin; optionally, an automatic door opening mechanism 111B for opening the (optional) door formed in the card (for metal-fuel card access) when the metal-fuel card is received within the card discharge bay of the FCB system; and an automatic card ejection mechanism 111C for ejecting the metal-fuel card from the card discharge bay through the card insertion port in response to a predetermined condition. Such predetermined conditions may include, for example, the depression of an "ejection" button provided on the front panel of the system housing 126, automatic sensing of the end of the metal-fuel card, etc.).

[0416] In the illustrative embodiment of FIG. 4, the card receiving mechanism 111A can be realized as a platform-like carriage structure that surrounds the exterior of the housing of each card received in its discharging bay. The platform-like carriage structure can be supported on a pair of parallel rails, by way of rollers, and translatable therealong by way of an electric motor and cam mechanism, operably connected to system controller 130. The function of the cam mechanism is to convert rotational movement of the motor shaft into a rectilinear motion necessary for translating the platform-like carriage structure along the rails when a card is inserted within the platform-like carriage structure. A proximity sensor, mounted within the system housing, can be used to detect the presence of a metal-fuel card being inserted through the insertion port in the system housing and placed within the platform-like carriage structure. The signal produced from the proximity sensor can be provided to the system controller in order to initiate the card withdrawal process in an automated manner.

[0417] With the system housing, the automatic door opening mechanism 111B can be realized by any suitable mechanism that can slide the card door into its open position when the metal-fuel card is completely withdrawn into the card discharge bay. In the illustrative embodiment, the automatic card ejection mechanism 111C employs the same basic structures and functionalities of the card receiving mechanism described above. The primary difference is the automatic card ejection mechanism responds to the depression of an "ejection" button 127A or 127B provided on the front panel of the system housing, or functionally equivalent triggering condition or event. When the button is depressed, the discharging heads are automatically transported away from the metal-fuel card, the metal-fuel card is automatically ejected from the card discharge bay, through the card insertion port.

[0418] Notably, the control functions required by the Card Loading/Unloading Subsystem 111, as well as all other subsystems within the FCB system of the first illustrative embodiment, are carried out by the system controller 130, shown in FIGS. 5A3 and 5A4. In the illustrative embodiments hereof, the system controller 130 is realized by a programmed microcontroller (i.e. microcomputer) having program storage memory (ROM), data storage memory (RAM) and the like operably connected by one or more system buses well known in the microcomputing and control arts. The additional functions performed by the system controller of the Metal-Fuel Card Discharging Subsystem will be described in greater detail hereinafter.

[0419] The Metal-Fuel Card Discharging Subsystem for the Fourth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0420] As shown in FIGS. 5A3 and 5A4, the metal-fuel card discharging subsystem 115 of the first illustrative embodiment comprises a number of subsystems, namely: an assembly of multi-track discharging (i.e. discharging) heads 124, each having multi-element cathode structures 121 and anode-contacting structures 122 with electrically-conductive output terminals connectable in a manner to be described hereinbelow; a discharging head transport subsystem 131 for transporting the subcomponents of the discharging head assembly 124 to and from the metal-fuel cards loaded into the subsystem; a cathode-anode output terminal configuration subsystem 132 for configuring the output terminals of the cathode and anode-contacting structures of the discharging heads under the control of the system controller 130 so as to maintain the output voltage required by a particular electrical load 116 connected to the Metal-Fuel Card Discharging Subsystem 115; a cathode-anode voltage monitoring subsystem 133, connected to the cathode-anode output terminal configuration subsystem 132 for monitoring (i.e. sampling) voltages produced across cathode and anode structures of each discharging head, and producing (digital) data representative of the sensed voltage level; a cathode-anode current monitoring subsystem 134, connected to the cathode-anode output terminal configuration subsystem 132, for monitoring (e.g. sampling) the electrical current flowing across the cathode-electrolyte interface of each discharging head during the Discharging Mode, and producing a digital data signal representative of the sensed current levels; a cathode oxygen pressure control subsystem comprising the system controller 130, solid-state pO_2 sensors 135, vacuum chamber (structure) 136 shown in FIGS. 5A7 and 5A8, air-compressor or oxygen supply means (e.g O_2 tank or cartridge) 137, airflow control device 138, manifold structure 139, and multi-lumen tubing 140 shown in FIGS. 5A3 and 5A4, arranged together for sensing and controlling the pO2 level within the cathode structure of each discharging head 124; an ion transport control subsystem comprising the system controller 130, solid-state moisture sensor (hydrometer) 142, moisturizing (e.g. micro-sprinklering element) 143 realized as a micro-sprinkler embodied within the walls structures of the cathode support plate 121 (having water expressing holes 144 disposed along each wall surface as shown in FIG. A6), a water pump 145, a water reservoir 146, a water flow control valve 147, a manifold structure 148 and conduits 149 extending into moisture delivery structure 143, arranged together as shown for sensing and modifying conditions within the FCB system (e.g. the moisture or humidity level at the cathode-electrolyte interface of the discharging heads) so that the ion-concentration at the cathode-electrolyte interface is maintained within an optimal range during the Discharge Mode of operation; discharge head temperature control subsystem comprising the system controller **130**, solid-state temperature sensors (e.g. thermistors) **290** embedded within each channel of the multi-cathode support structure **121** hereof, and a discharge head cooling device **291**, responsive to control signals produced by the system controller **130**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations; a relational-type Metal-Fuel Database Management Subsystem (MFDMS) **293** operably connected to system controller **130** by way of local bus **299**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Tape Discharging Subsystem **115**; a Data Capture and Processing Subsystem (DCPS) **295**, comprising data reading head **150** (**150'**, **150"**) embedded within or mounted closely to the cathode support structure of each discharging head **124**, and a programmed microprocessor-based data processor adapted to receive data signals produced from cathode-anode voltage monitoring subsystem **133**, cathode-anode current monitoring subsystem **134**, the cathode oxygen pressure control subsystem and the ion-concentration control subsystem hereof, and enable (i) the reading metal-fuel card identification data from the loaded metal-fuel card, (ii) the recording sensed discharge parameters and computed metal-oxide indicative data derived therefrom in the Metal-Fuel Database Management Subsystem **293** using local system bus **296**, and (iii) the reading prerecorded recharge parameters and prerecorded metal-fuel indicative data stored in the Metal-Fuel Database Management Subsystem **293** using local system bus **294**; a discharging (i.e. output) power regulation subsystem **151** connected between the output terminals of the cathode-anode output terminal configuration subsystem **132** and the input terminals of the electrical load **116** connected to the Metal-Fuel Card Discharging Subsystem **115**, for regulating the output power delivered across the electrical load (and regulate the voltage and/or current characteristics as required by the Discharge Control Method carried out by the system controller **130**); an input/output control subsystem **152**, interfaced with the system controller **130**, for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **130** for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[**0421**] Multi-Track Discharging Head Assembly within the Metal-Fuel Card Discharging Subsystem

[**0422**] The function of the assembly of multi-track discharging heads **124** is to generate electrical power across the electrical load as each metal-fuel card is discharged during the Discharging Mode of operation. In the illustrative embodiment, each discharging (i.e. discharging) head **124** comprises: a cathode element support plate **121** having a plurality of isolated channels **155**A through **155**E permitting the free passage of oxygen (O_2) through the bottom portion of each such channel; plurality of electrically-conductive cathode elements (e.g. strips) **120**A through **120**E for insertion within the lower portion of these channels, respectively; a plurality of electrolyte-impregnated strips **155**A through **155**E for placement over the cathode strips, and support within the channels **154**A through **154**E, respectively, as shown in **FIG. 5A9**; and an oxygen-injection chamber **136** mounted over the upper (back) surface of the cathode element support plate **121**, in a sealed manner.

[**0423**] As shown in **FIG. 5A7**, **5A8** and **5A14**, each oxygen-injection chamber **136** has a plurality of subchambers **136**A through **136**E, physically associated within channels **154**A through **154**E, respectively. Together, each vacuum subchamber is isolated from all other subchambers and is in fluid communication within one channel supporting a cathode element and electrolyte impregnated element. As shown, each subchamber is arranged in fluid communication with air compressor (or O_2 supply) **137** via one lumen of multi-lumen tubing **140**, one channel of manifold assembly **139** and one channel of air-flow switch **138**, each of whose operation is controlled by system controller **130**. This arrangement enables the system controller **130** to independently control the pO_2 level in each oxygen-injection subchambers **136**A through **136**E within an optimal range during discharging operations by selectively pumping pressurized air through the corresponding air flow channel in the manifold assembly **139**. The optimal range for the pO_2 level can be empirically determined through experimentation using techniques known in the art.

[**0424**] In the illustrative embodiment, electrolyte-impregnated strips are realized by impregnating an electrolyte-absorbing carrier medium with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for each discharging cell is made from a formula consisting of an alkali solution (e.g. KOH), a gelatin material, water, and additives known in the art.

[**0425**] In the illustrative embodiment, each cathode strip **120**A through **120**E is made from a sheet of nickel wire mesh **156** coated with porous carbon material and granulated platinum or other catalysts **157** shown in **FIG. 5A7** to form a cathode suitable for use in the discharging heads in the metal-air FCB system. Details of cathode construction are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor **40** is soldered to the underlying wire mesh sheet of each cathode strip. As shown in **FIG. 5A7**, each electrical conductor **158** is passed through a hole **159** formed in the bottom surface of each channel **154** of the cathode support plate, and is connected to the input terminals of the cathode-anode output terminal configuration subsystem **132**. As shown, each cathode strip is pressed into the lower portion of its channel **1564** in the cathode support plate **121** to secure the same therein. As shown in **FIG. 5A7**, the bottom surface of each channel has numerous perforations **160** formed therein to allow the free passage of oxygen to the cathode strip during the Discharge Mode. In the illustrative embodiment, electrolyte-impregnated strips **155**A through **155**E are placed over cathode strips **120**A through **120**E respectively, and is secured within the upper portions of the corresponding cathode supporting channels. As best shown in FIGS. **5A8**, **5A13** and **5A14**, when the cathode strips and thin electrolyte strip are mounted in their respective channels in the cathode support plate **121**, the outer surface of each electrolyte-impregnated strip is disposed flush with the upper surface of the plate defining the channels.

[**0426**] Hydrophobic agents are added to the carbon material constituting the oxygen-pervious cathode elements to ensure the expulsion of water therefrom. Also, the interior surfaces of the cathode support channels are coated with a hydrophobic film (e.g. Teflon®) **161** to repel water from penetrating electrolyte-impregnated strips **155**A through **155**E and thus achieve optimum oxygen transport across the cathode strips during the Discharging Mode. Preferably, the cathode support plate is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate and oxygen-injection chamber can be fabricated using injection molding technology also well known in the art.

[**0427**] In order to sense the partial oxygen pressure pO_2 within the cathode structure during the Discharging Mode, for use in effective control of electrical power generated from discharging heads, solid-state PO2 sensor **135** is embedded within each channel of the cathode support plate **121**, as illustrated in **FIG. 5**A7, and operably connected to the system controller **130** as an information input device thereto. In the illustrative embodiment, the pO_2 sensor can be realized using well-known pO_2 sensing technology employed to measure (in vivo) pO_2 levels in the blood of humans. Such prior art sensors employ miniature diodes which emit electromagnetic radiation at two or more different wavelengths that are absorbed at different levels in the presence of oxygen in the blood, and such information can be processed and analyzed to produce a computed measure of pO_2 in a reliable manner, as taught in U.S. Pat. No. 5,190,038 and references cited therein, each being incorporated herein by reference. In the present invention, the characteristic wavelengths of the light emitting diodes can be selected so that similar sensing functions can be carried out within the structure of the cathode in each discharging head, in a straightforward manner.

[**0428**] The multi-tracked fuel card of **FIG. 4** is shown in greater structural detail in **FIG. 5**D**1**. As shown, the metal-fuel card **120** comprises: an electrically non-conductive base layer **165** of flexible construction (i.e. made from a plastic material stable in the presence of the electrolyte); plurality of parallel extending, spatially separated strips of metal (e.g. zinc) **119**A through **119**E disposed upon the ultra-thin metallic current-collecting layer (not shown) itself disposed upon the base layer **165**; a plurality of electrically non-conductive strips **166**A through **166**E disposed upon the base layer **165**, between pairs of fuel strips **119**A through **119**E; and a plurality of parallel extending channels (e.g. grooves) **167**A through **167**E formed in the underside of the base layer, opposite the metal fuel strips thereabove, for allowing electrical contact with the metal-fuel tracks **119**A through **119**E through the grooved base layer. Notably, the spacing and width of each metal fuel strip is designed so that it is spatially registered with a corresponding cathode strip in the discharging head of the Metal-Fuel Card Discharging Subsystem in which the metal-fuel card **112** is intended to be used. The metal fuel card described above can be made by applying zinc strips onto a layer of base plastic material in the form of a card, using any of the fabrication techniques described hereinabove. The metal strips can be physically spaced apart, or separated by Teflon®, in order to ensure electrical isolation therebetween. Then, the gaps between the metal strips can be filled in by applying a coating of electrically insulating material, and thereafter, the base layer can be machined, laser etched or otherwise treated to form fine channels therein for allowing electrical contact with the individual metal fuel strips through the base layer. Finally, the upper surface of the multi-tracked fuel card can be polished to remove any electrical insulation material from the surface of the metal fuel strips which are to come in contact with the cathode structures during discharging.

[**0429**] In **FIG. 5**A**10**, an exemplary metal-fuel (anode) contacting structure **122** is disclosed for use with the multi-tracked cathode structure shown in FIGS. **5**A**7** and **5**A**8**. As shown, a plurality of electrically conductive elements **168**A through **168**E are supported from an platform **169** disposed adjacent the travel of the fuel card within the card. Each conductive element **168**A through **168**E has a smooth surface adapted for slidable engagement with one track of metal-fuel through the fine groove formed in the base layer of the metal-fuel card. Each conductive element is connected to an electrical conductor which is connected to the cathode-anode output terminal configuration subsystem **132** under the management of the system controller **130**. The platform **169** is operably associated with the discharging head transport subsystem **131** and can be designed to be moved into position with the fuel card **112** during the Discharging Mode of the system, under the control of the system controller **130**.

[**0430**] Notably, the use of multiple discharging heads, as in the illustrative embodiments hereof, rather than a single discharging head, allows more power to be produced from the discharging head assembly **124** for delivery to the electrical load while minimizing heat build-up across the individual discharging heads. This feature of the Metal-Fuel Card Discharging Subsystem **115** extends the service life of the cathodes employed within the discharging heads thereof.

[**0431**] Discharging Head Transport Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0432**] The primary function of the discharging head transport subsystem **131** is to transport the assembly of discharging heads **124** about the metal-fuel cards **112** that have been loaded into the FCB system, as shown in **FIG. 5**A3. When properly transported, the cathode and anode-contacting structures of the discharging heads are brought into "ionically-conductive" and "electrically-conductive" contact with the metal-fuel tracks of loaded metal-fuel cards during the Discharging Mode of operation.

[**0433**] Discharging head transport subsystem **131** can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode supporting structure **121** and anode-contacting structure **122** of each discharging head away from the metal-fuel card **112**, as shown in **FIG. 5**A3, and about the metal-fuel card as shown in **FIG. 5**A4. As shown, these transport mechanisms are operably connected to system controller **130** and controlled by the same in accordance with the system control program carried out thereby.

[**0434**] Cathode-Anode Output Terminal Configuration Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0435**] As shown in FIGS. **5**A**3** and **5**A**4**, the cathode-anode output terminal configuration subsystem **132** is connected between the input terminals of the discharging power regulation subsystem **151** and the output terminals of the cathode-anode pairs within the assembly of discharging heads **124**. The system controller **130** is operably connected to cathode-anode output terminal configuration subsystem **132** in order to supply control signals for carrying out its functions during the Discharging Mode of operation.

[**0436**] The function of the cathode-anode output terminal configuration subsystem **132** is to automatically configure (in series or parallel) the output terminals of selected cathode-anode pairs within the discharging heads of the Metal-Fuel Card Discharging Subsystem **115** so that the required output voltage level is produced across the electrical load connected to the FCB system during card discharging operations. In the illustrative embodiment of the present invention, the cathode-anode output terminal configuration mechanism **132** can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the discharging heads **124** are connected to the input terminals of the output power regulating subsystem **151**. Such switching operations are carried out under the control of the system controller **130** so that the required output voltage is produced across the electrical load connected to the discharging power regulating subsystem **151** of the FCB system.

[**0437**] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0438**] As shown in FIGS. **5A3** and **5A4**, the cathode-anode voltage monitoring subsystem **133** is operably connected to the cathode-anode output terminal configuration subsystem **132** for sensing voltage levels and the like therewithin. This subsystem is also operably connected to the system controller for receiving control signals required to carry out its functions. In the first illustrative embodiment, the cathode-anode voltage monitoring subsystem **133** has two primary functions: to automatically sense the instantaneous voltage level produced across the cathode-anode structures associated with each metal-fuel track being transported through each discharging head during the Discharging Mode; and to produce a (digital) data signal indicative of the sensed voltages for detection, analysis and response by Data Capture and Processing Subsystem **295**.

[**0439**] In the first illustrative embodiment of the present invention, the Cathode-Anode Voltage Monitoring Subsystem **133** can be realized using electronic circuitry adapted for sensing voltage levels produced across the cathode-anode structures associated with each metal-fuel track disposed within each discharging head in the Metal-Fuel Card Discharging Subsystem **115**. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels for detection and analysis by Data Capture and Processing Subsystem **295**.

[**0440**] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0441**] As shown in FIGS. **5A3** and **5A4**, the cathode-anode current monitoring subsystem **134** is operably connected to the cathode-anode output terminal configuration subsystem **132**. The cathode-anode current monitoring subsystem **134** has two primary functions: to automatically sense the magnitude of electrical currents flowing through the cathode-anode pair of each metal-fuel track along each discharging head assembly within the Metal-Fuel Card Discharging Subsystem **115** during the Discharging Mode; and to produce a digital data signal indicative of the sensed current for detection and analysis by Data Capture and Processing Subsystem **295**. In the first illustrative embodiment of the present invention, the cathode-anode current monitoring subsystem **134** can be realized using current sensing circuitry for sensing electrical currents flowing through the cathode-anode pairs of each metal-fuel track along each discharging head assembly, and producing digital data signals indicative of the sensed currents. As will be explained in greater detail hereinafter, these detected current levels are used by the system controller in carrying out its discharging power regulation method, and well as creating a "discharging condition history" and metal-fuel availability records for each zone or subsection of discharged metal-fuel card.

[**0442**] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0443**] The function of the cathode oxygen pressure control subsystem is to sense the oxygen pressure (pO_2) within each channel of the cathode structure of the discharging heads **124**, and in response thereto, control (i.e. increase or decrease) the same by regulating the air (O_2) pressure within such cathode structures. In accordance with the present invention, partial oxygen pressure (PO_2) within each channel of the cathode structure of each discharging head is maintained at an optimal level in order to allow optimal oxygen consumption within the discharging heads during the Discharging Mode. By maintaining the pO2 level within the cathode structure, power output produced from the discharging heads can be increased in a controllable manner. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by the system controller, the system controller is provided with a controllable variable for use in regulating the electrical power supplied to the electrical load during the Discharging Mode.

[**0444**] Ion-Concentration Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0445**] In order to achieve high-energy efficiency during the Discharging Mode, it is necessary to maintain an optimal concentration of (charge-carrying) ions at the cathode-electrolyte interface of each discharging head within the Metal-Fuel card Discharging Subsystem **115**. Thus it is the primary function of the ion-concentration control subsystem to sense and modify conditions within the FCB system so that the ion-concentration at the cathode-electrolyte interface within the discharging head is maintained within an optimal range during the Discharge Mode of operation.

[**0446**] In the case where the ionically-conducting medium between the cathode and anode of each track in the discharging head is an electrolyte containing potassium hydroxide (KOH), it will be desirable to maintain its concentration at 6N (~6M) during the Discharging Mode of operation. As the moisture level or relative humidity (RH %) within the cathode structure can significantly affect the concentration of KOH in the electrolyte, it is desirable to regulate the relative humidity at the cathode-electrolyte-anode interface within each discharging head. In the illustrative embodiment, ion-concentration control is achieved in a variety of ways by embedding a miniature solid-state humidity (or moisture) sensor **142** within the cathode support structure (or as close as possible to the anode-cathode interfaces) in order to sense moisture conditions and produce a digital data signal indicative thereof. This digital data signal is supplied to the Data Capture and Processing Subsystem **295** for detection and analysis. In the event that the moisture level drops below the predetermined threshold value set in memory (ROM) within the system controller **130**, the system controller automatically generate a control signal supplied to a moisturizing element **143** realizable as a micro-sprinkler structure **143** embodied within the walls of the cathode support structure **121**. In the illustrative embodiment, the walls function as water carrying conduits which express water droplets out of holes **144** adjacent the particular cathode elements when water-flow valve **147** and pump **145** are activated by the system controller **130**. Under such conditions, water is pumped from reservoir **146** through manifold **148** along conduit **149** and is expressed from holes **144** adjacent the cathode element requiring an increase in moisture level, as sensed by moisture sensor **142**. Such moisture-level sensing and control operations ensure that the concentration of KOH within the electrolyte within electrolyte-impregnated strips **155A** through **155E** is optimally maintained for ion transport and thus power generation.

[**0447**] Discharge Head Temperature Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0448**] As shown in FIGS. **5A3**, **5A4**, and **5A7**, the discharge head temperature control subsystem incorporated within the Metal-Fuel Card Discharging Subsystem **115** of the fourth illustrative embodiment comprises a number of subcomponents, namely: the system controller **130**; solid-state temperature sensors (e.g. thermistors) **290** embedded within each channel of the multi-cathode support structure hereof, as shown in **FIG. 2A7**; and discharge head cooling device **291**, responsive to control signals produced by the system controller **130**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations. The discharge head cooling device **291** can be realized using a wide variety of heat-exchanging techniques, including forced-air cooling, water-cooling, and/or refrigerant cooling, each well known in the heat exchanging art. In some embodiments of the present invention, where high levels of electrical power are being generated, it may be desirable to provide a jacket-like structure about each discharge head in order to circulate air, water or refrigerant for temperature control purposes.

[**0449**] Data Capture and Processing Subsystem within the Metal-Fuel Tape Discharging Subsystem

[**0450**] In the illustrative embodiment of **FIG. 4**, Data Capture And Processing Subsystem (DCPS) **295** shown in FIGS. **5A3** and **5A4** carries out a number of functions, including, for example: (1) identifying each metal-fuel card immediately before it is loaded within a particular discharging head within the discharging head assembly and producing metal-fuel card identification data representative thereof; (2) sensing (i.e. detecting) various "discharge parameters" within the Metal-Fuel Card Discharging Subsystem existing during the time period that the identified metal-fuel card is loaded within the discharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-oxide produced during card discharging operations, and producing "metal-oxide indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **293** (accessible by system controller **130**), sensed discharge parameter data as well as computed metal-oxide indicative data both correlated to its respective metal-fuel track/card identified during the Discharging Mode of operation. As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **293** by Data Capture and Processing Subsystem **295** can be used by the system controller **130** in various ways including, for example: optimally discharging (i.e. producing electrical power from) partially or completely oxidized metal-fuel cards in an efficient manner during the Discharging Mode of operation; and optimally recharging partially or completely oxidized metal-fuel cards in a rapid manner during the Recharging Mode of operation.

[**0451**] During discharging operations, the Data Capture and Processing Subsystem **295** automatically samples (or captures) data signals representative of "discharge parameters" associated with the various subsystems constituting the Metal-Fuel Card Discharging Subsystem **115** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Discharging Mode. In accordance with the principles of the present invention, card-type "discharge parameters" shall include, but are not limited to: the voltages produced across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte voltage monitoring subsystem **133**; the electrical currents flowing across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte current monitoring subsystem **134**; the oxygen saturation level (pO_2) within the cathode structure of each discharging head **124**, monitored by the cathode oxygen pressure control subsystem (**130, 135, 136, 137, 138, 140**); the moisture (H_2O) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular discharging heads monitored, for example, by the ion-concentration control subsystem (**130,142, 145, 146, 147, 148, 149**); the temperature (T) of the discharging heads during card discharging operations; and the time duration (Δt) of the state of any of the above-identified discharge parameters.

[**0452**] In general, there a number of different ways in which the Data Capture and Processing Subsystem can record card-type "discharge parameters" during the Discharging Mode of operation. These different methods will be detailed hereinbelow.

[**0453**] According to a first method of data recording shown in **FIG. 5A9**, a unique card identifying code or indicia **171** (e.g. miniature bar code symbol encoded with zone identifying information) is graphically printed on an "optical" data track **172** realized, for example, as a strip of transparent of reflective film material affixed or otherwise attached along the edge of the metal-fuel card, as shown in **FIG. 5A9**. This optical data track **172**, with its card identifying code recorded therein by printing or photographic techniques, can be formed at the time of manufacture of the multi-track metal-fuel card hereof. The metal-fuel card identifying indicia **171** along the edge of the card is then read by an optical data reader **150** realized using optical techniques (e.g. laser scanning bar code symbol readers, or optical decoders). In the illustrative embodiment, information representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **295**, and subsequently recorded within the Metal-Fuel Database Management Subsystem **293** during discharging operations.

[**0454**] According to a second method of data recording shown in **FIG. 5A9'**, a unique digital "card identifying" code **171'** is magnetically recorded in a magnetic data track **172'** disposed along the edge of the metal-fuel card **112'**. This magnetic data track, with card identifying code recorded therein, can be formed at the time of manufacture of the multi-track metal-fuel card hereof. The card identifying indicia along the edge of the card is then read by a magnetic reading head **150'** realized using magnetic information reading techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **295**, and subsequently recorded within the Metal-Fuel Database Management Subsystem **293** during discharging operations.

[**0455**] According to a third method of data recording shown in **FIG. 5A9"**, a unique digital "card identifying" code is recorded as a sequence of light transmission apertures **171"** formed in an optically opaque data track **172"** disposed along the edge the metal-fuel card **112"**. In this aperturing technique, information is encoded in the form of light transmission apertures whose relative spacing and/or width is the means by which information encoding is achieved. This optical data track, with card identifying codes recorded therein, can be formed at the time of manufacture of the multi-track metal-fuel card hereof. The zone identifying indicia **171"** along the edge of the card is then read by an optical sensing head **150"** realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **295**, and subsequently recorded within the Metal-Fuel Database Management Subsystem **293** during discharging operations.

[**0456**] According to a fourth alternative method of data recording, both unique digital "card identifying" code and set of discharge parameters for each track on the identified metal-fuel card are recorded in a magnetic, optical, or apertured data track, realized as a strip attached to the surface of the metal-fuel card of the present invention. The block of information pertaining to a particular metal-fuel card can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information during the Recharging Mode of operation. Typically, the block of information will include the metal-fuel card identification number and a set of discharge parameters, as schematically indicated in **FIG. 5A15**, which are automatically detected by the Data Capture and Processing Subsystem **295** as the metal-fuel card is loaded within the discharging head assembly **124**.

[**0457**] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel card can have a very low information capacity. This is because very little information needs to be recorded to tag each metal-fuel card with a unique identifier (i.e. address number or card identification number), to which sensed discharge parameters are recorded in the Metal-Fuel Database Management Subsystem **293**. Also, formation of a data track in accordance with the first and second methods should be very inexpensive, as well as providing apparatus for reading card identifying information recorded along such data tracks.

[**0458**] Discharging Power Regulation Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0459**] As shown in FIGS. **5A3** and **5A4**, the input port of the discharging power regulation subsystem **151** is operably connected to the output port of the cathode-electrolyte output terminal configuration subsystem **132**, whereas the output port of the discharging power regulation subsystem **151** is operably connected to the input port of the electrical load **116**. While the primary function of the discharging power regulation subsystem is to regulate the electrical power delivered the electrical load during its Discharging Mode of operation (i.e. produced from discharged metal-fuel cards loaded within the discharging heads hereof), the discharging power regulation subsystem **151** has a mode of programmed operation, wherein the output voltage across the electrical load as well as the electrical current flowing across the cathode-electrolyte interface are regulated during discharging operations. Such control functions are managed by the system controller **130** and can be programmably selected in a variety of ways in order to achieve optimal discharging of multi-tracked and single-tracked metal-fuel card according to the present invention while satisfying dynamic loading requirements.

[**0460**] The discharging power regulating subsystem **151** of the third illustrative embodiment can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistor-controlled technology, in which a current-controlled source is connectable in electrical series with electrical load **116** in order to control the electrical current therethrough in response to control signals produced by the system controller **130** carrying out a particular Discharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which a voltage-controlled source is connectable in electrical parallel with the electrical load in order to control the output voltage therethrough in response to control signals produced by the system controller **130**. Such circuitry can be combined and controlled by the system controller **130** in order to provide constant power control across the electrical load.

[**0461**] In the illustrative embodiments of the present invention, the primary function of the discharging power regulation subsystem **151** is to carry out real-time power regulation to the electrical load using any one of the following Discharge Power Control Methods, namely: (1) a Constant Output Voltage/Variable Output Current Method, wherein the output voltage across the electrical load is maintained constant while the current is permitted to vary in response to loading conditions; (2) a Constant Output Current/Variable Output Voltage Method, wherein the current into the electrical load is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Output Voltage/Constant Output Current Method, wherein the voltage across and current into the load are both maintained constant in response to loading conditions; (4) a Constant Output Power Method, wherein the output power across the electrical load is maintained constant in response to loading conditions; (5) a Pulsed Output Power Method, wherein the output power across the electrical load is pulsed with the duty cycle of each power pulse being maintained in accordance with preset conditions; (6) a Constant Output Voltage/Pulsed Output Current Method, wherein the output current into the electrical load is maintained constant while the current into the load is pulsed with a particular duty cycle; and (7) a Pulsed Output Voltage/Constant Output Current Method, wherein the output power into the load is pulsed while the current thereinto is maintained constant.

[**0462**] In the preferred embodiment of the present invention, each of the seven (7) Discharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **130**. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic or optical condition established or detected at the interface between the electrical load and the Metal-Fuel Card Discharging Subsystem **115**.

[**0463**] Input/Output Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0464**] In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Card Discharging Subsystems **115** in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Card Discharging Subsystem **115** hereof includes Input/Output Control Subsystem **152** which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Card Discharging Subsystem as if its system controller were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **152** is realized as a standard IEEE I/O bus architecture which provides an external or remote computer system with a way and means of directly interfacing with the system controller **130** of the Metal-Fuel Card Discharging Subsystem **115** and managing various aspects of system and subsystem operation in a straightforward manner.

[**0465**] System Controller within the Metal-Fuel Card Discharging Subsystem

[**0466**] As illustrated in the detailed description set forth above, the system controller **130** performs numerous operations in order to carry out the diverse functions of the FCB system within its Discharging Mode. In the preferred embodiment of the FCB system of **FIG. 4**, the system controller **130** is realized using a programmed microcontroller having program and data storage memory (e.g. ROM, EPROM, RAM and the like) and a system bus structure well known in the microcomputing and control arts. In any particular embodiment of the present invention, it is understood that two or more microcontrollers may be combined in order to carry out the diverse set of functions performed by the FCB system hereof. All such embodiments are contemplated embodiments of the system of the present invention.

[**0467**] Discharging Metal-Fuel Cards Within The Metal-Fuel Card Discharging Subsystem

[**0468**] **FIG. 5A5** sets forth a high-level flow chart describing the basic steps of discharging metal-fuel cards (i.e. generating electrical power therefrom) using the Metal-Fuel Card Discharging Subsystem shown in FIGS. **5A3** through **5A4**.

[**0469**] As indicated at Block A, the Card Loading/Unloading Subsystem **111** transports up to four metal-fuel cards **112** from the card receiving port of the system housing into the card discharging bay of the Metal-Fuel Card Discharging Subsystem. This card transport process is schematically illustrated in FIGS. **5A1** and **5A2**. **FIG. 5A3** illustrates the state of the subsystem when the metal-fuel cards are loaded within the discharging bay thereof.

[**0470**] As indicated at Block B, the Discharge Head Transport Subsystem **131** arranges the discharging heads about the metal-fuel cards loaded into the discharging bay of the Metal-Fuel Card Discharging Subsystem so that the ionically-conducting medium is disposed between each cathode structure and loaded metal-fuel card.

[**0471**] As indicated at Block C, the Discharge Head Transport Subsystem **131** then configures each discharging head so that its cathode structure is in ionic contact with a loaded metal-fuel card and its anode contacting structure is in electrical contact therewith, as indicated in **FIG. 5A4**.

[**0472**] As indicated at Block D, the cathode-electrolyte output terminal configuration subsystem **132** automatically configures the output terminals of each discharging head arranged about a loaded metal-fuel card, and then the system controller controls the Metal-Fuel Card Discharging Subsystem so that electrical power is generated and supplied to the electrical load **116** at the required output voltage and current levels. When one or more of the loaded metal-fuel cards are discharged, then the Card Loading/Unloading Subsystem **111** automatically ejects the discharged metal-fuel cards out through the discharging bay for replacement with recharged metal-fuel cards.

[**0473**] Metal-Fuel Card Recharging Subsystem for the Fourth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[**0474**] As shown in FIGS. **5B3** and **5B4**, the Metal-Fuel Card Recharging Subsystem **117** of the first illustrative embodiment comprises a number of subsystems, namely: an assembly of multi-zoned metal-oxide reducing (i.e. recharging) heads **175**, each having multi-element cathode structures **121**' and anode-contacting structures **124**' with electrically-conductive input terminals connectable in a manner to be described hereinbelow; a recharging head transport subsystem **131**' for transporting the subcomponents of the recharging head assembly **175** to and from loaded metal-fuel cards; an input power supply subsystem **176** for converting externally supplied AC power signals applied to its input terminal **177** into DC power supply signals having voltages suitable for recharging metal-fuel cards arranged about the recharging heads of the Metal-Fuel Card Recharging Subsystem; a cathode-electrolyte input terminal configuration subsystem **178**, for connecting the output terminals (port) of the input power supply subsystem to the input terminals (port) of the cathode and anode-contacting structures of the recharging heads **175**, under the control of the system controller **130'** so as to supply input voltages thereto for electro-chemically converting metal-oxide formations into its primary metal during the Recharging Mode; a cathode-electrolyte voltage monitoring subsystem **133'**, connected to the cathode-electrolyte input terminal configuration subsystem **178**, for monitoring (i.e. sampling) the voltage applied across cathode and anode of each recharging head **175**, and producing (digital) data representative of the sensed voltage level; a cathode-electrolyte current monitoring subsystem **134'**, connected to the cathode-electrolyte input terminal configuration subsystem **178**, for monitoring (e.g. sampling) the current flowing across the cathode-electrolyte interface of each recharging head during the Recharging Mode, and producing digital data representative of the sensed current level; a cathode oxygen pressure control subsystem comprising the system controller **130'**, solid-state pO_2 sensors **135'**, vacuum chamber (structure) **136'** shown in FIGS. **5B7** and **5B8**, vacuum pump **137'**, airflow control device **138'**, manifold structure **139'**, and multi-lumen tubing **140'** shown in FIGS. **5B3** and **5B4**, arranged together as shown for sensing and controlling the pO2 level within the cathode structure of each recharging head; an ion-concentration control subsystem comprising system controller **130'**, solid-state moisture sensor (hydrometer) **142'**, moisturizing (e.g. micro-sprinklering element) **143'** realized as a micro-sprinkler embodied within the walls structures of the cathode support plate **121'** (having water expressing holes **144'** disposed along each wall surface as shown in **FIG. 5**B6), a water pump **145'**, a water reservoir **146'**, an electronically-controlled water flow control valve **147'**, a manifold structure **148'** and conduits **149'** extending into moisture delivery structure **143'**, arranged together as shown for sensing and modifying conditions within the FCB system (e.g. the relative humidity at the cathode-electrolyte interface of the recharging heads) so that the ion-concentration at the cathode-electrolyte interface is maintained within an optimal range during the Recharge Mode of operation; recharge head temperature control subsystem comprising the system controller **130'**, solid-state temperature sensors (e.g. thermistors) **290'** embedded within each channel of the multi-cathode support structure **121'** hereof, and a recharge head cooling device **291'**, responsive to control signals produced by the system controller **130'**, for lowering the temperature of each recharging channel to within an optimal temperature range during recharging operations; a relational-type Metal-Fuel Database Management Subsystem (MFDMS) **297** operably connected to system controller **130'** by way of local system bus **298**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Tape Recharging Subsystem **115**; a Data Capture and Processing Subsystem (DCPS) **299**, comprising data reading head **180** (**180'**, **180''**) embedded within or mounted closely to the cathode support structure of each recharging head **175**, and a programmed microprocessor-based data processor adapted to receive data signals produced from cathode-electrolyte voltage monitoring subsystem **133'**, cathode-electrolyte current monitoring subsystem **134'**, the cathode oxygen pressure control subsystem, the recharge head temperature control subsystem and the ion-concentration control subsystem hereof, and enable (i) the reading metal-fuel card identification data from the loaded metal-fuel card, (ii) the recording sensed recharge parameters and computed metal-fuel indicative data derived therefrom in the Metal-Fuel Database Management Subsystem (MFDMS) **297** using local system bus **300**, and (iii) the reading prerecorded discharge parameters and prerecorded metal-oxide indicative data stored in the Metal-Fuel Database Management Subsystem (MFDMS) **297** using local system bus **298**; an input (i.e. recharging) power regulation subsystem **181** connected between the output terminals (i.e. port) of the input power supply subsystem **176** and the input terminal (i.e. port) of the cathode-electrolyte input terminal configuration subsystem **178**, for regulating the input power (and voltage and/or current characteristics) delivered across the cathode and anode structures of each metal-fuel track being recharged during the Recharging Mode; an input/output control subsystem **152'**, interfaced with the system controller **130'**, for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **130'**, interfaced with system controller **130'** within the Metal-Fuel Card Recharging Subsystem **117** by way of a global system bus **303** as shown in **FIG. 5B16**, and having various means for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[**0475**] Multi-Track Recharging Head Assembly within the Metal-Fuel Card Recharging Subsystem

[**0476**] The function of the assembly of multi-track recharging heads **175** is to electro-chemically reduced metal-oxide formations on the tracks of metal-fuel cards loaded into the recharging bay of the system during the Recharging Mode of operation. In the illustrative embodiment shown in **FIG. 5**B7 and **5**B8, each recharging head **175** comprises: a cathode element support plate **121'** having a plurality of isolated channels **154**A' through **154**E' permitting the free passage of oxygen (O2) through the bottom portion of each such channel; a plurality of electrically-conductive cathode elements (e.g. strips) **120**A' through **120**E' for insertion within the lower portion of these channels, respectively; a plurality of electrolyte-impregnated strips **155**A' through **155**E' for placement over the cathode strips **36**, and support within the channels **154**A' through **154**E', respectively, as shown in **FIG. 5**B6; and an oxygen-evacuation chamber **136'** mounted over the upper (back) surface of the cathode element support plate **121'**, in a sealed manner, as shown in **FIG. 5**B7.

[**0477**] As shown in FIGS. **5B3**, **5B4** and **5B14**, each oxygen-evacuation chamber **136'** has a plurality of subchambers **136**A' through **136**E' being physically associated with channels **154**A' through **154**E', respectively. Together, each vacuum subchamber is isolated from all other subchambers and is in fluid communication with one channel supporting a cathode element and electrolyte-impregnated element therein. As shown in FIGS. **5B3**, **5B4** and **5B8**, each subchamber is arranged in fluid communication with vacuum pump **137'** via one lumen of multi-lumen tubing **140'**, one channel of manifold assembly **139'** and one channel of air-flow switch **138'**, each of whose operation is controlled by system controller **130'**. This arrangement enables the system controller **130'** to independently control the pO2 level in each of the oxygen-evacuation subchambers

136A' through 136E' within an optimal range during recharging operations within the recharging head assembly. This operation is carried out by selectively evacuating air from the subchambers through the corresponding air flow channels in the manifold assembly 139'. This arrangement allows the system controller 130' to maintain the pO_2 level within an optimal range during recharging operations.

[0478] In the illustrative embodiment, electrolyte-impregnated strips 155A' within the discharging head assembly through 155E' are realized by impregnating an electrolyte-absorbing carrier medium with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for each discharging cell is made from a formula consisting of an alkali solution (e.g. KOH), a gelatin material, water, and additives known in the art.

[0479] In the illustrative embodiment, each cathode strip is made from a sheet of nickel wire mesh 156' coated with porous carbon material and granulated platinum or other catalysts 157' to form a cathode suitable for use in the recharging heads in metal-air FCB system. Details of cathode construction are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor 158' is soldered to the underlying wire mesh sheet 156' of each cathode strip. As shown in **FIG.** 5B7, each electrical conductor 158' is passed through a hole 159' formed in the bottom surface of each channel 154A1 through 154E' of the cathode support plate 121', and is connected to the input terminals of the cathode-electrolyte input terminal configuration subsystem 178. As shown, the cathode strip pressed into the lower portion of the channel to secure the same therein. As shown in **FIG.** 5B7, the bottom surface of each channel has numerous perforations 160' formed therein to allow the evacuation of oxygen away from the cathode-electrolyte interface, and out towards the vacuum pump 137' during recharging operations. In the illustrative embodiment, an electrolyte-impregnated strips 155A' through 155E' are placed over cathode strips 120A' through 120E', respectively, and are secured within the upper portions of the corresponding cathode supporting channels. As best shown in FIGS. 5B13 and 5B14, when the cathode strips and thin electrolyte strips are mounted in their respective channels in the cathode support plate 121', the outer surface of each electrolyte-impregnated strip is disposed flush with the upper surface of the plate defining the channels.

[0480] Hydrophobic agents are added to the carbon material constituting the oxygen-pervious cathode elements in order to repel water therefrom. Also, the interior surfaces of the cathode support channels are coated with a hydrophobic film (e.g. Teflon®) 161 to ensure the expulsion of water within electrolyte-impregnated strips 155A' through 155E' and thus achieve optimum oxygen transport across the cathode strips during the Recharging Mode. Preferably, the cathode support plate 121' is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate 121' and evacuation chamber 136' can be fabricated using injection molding technology also well known in the art.

[0481] In order to sense the partial oxygen pressure (pO_2) within the cathode structure during the Recharging Mode, for use in effective control of metal-oxide reduction within the recharging heads, a solid-state pO_2 sensor 135' is embedded within each channel of the cathode support plate 121', as illustrated in **FIG.** 5B7, and operably connected to the system controller as an information input devices thereto. In the illustrative embodiment, each pO_2 sensor can be realized using well-known pO_2 sensing technology employed to measure (in vivo) pO_2 levels in the blood of humans. Such prior art sensors employ miniature diodes which emit electromagnetic radiation at different wavelengths that are absorbed at different levels in the presence of oxygen in the blood, and such information can be processed and analyzed to produce a computed measure of pO2 in a reliable manner, as taught in U.S. Pat. No. 5,190,038 and references cited therein, each being incorporated herein by reference. In the present invention, the characteristic wavelengths of the light emitting diodes can be selected so that similar sensing functions are carried out within the structure of the cathode in each recharging head, in a straightforward manner.

[0482] **FIG.** 5B9 shows a section of multi-tracked fuel card 112 which has undergone partial discharge and thus has metal-oxide formations along the metal-fuel tracks thereof. Notably, this partially-discharged metal-fuel card shown in **FIG.** 5A9 and described above requires recharging within the Metal-Fuel Card Recharging Subsystem 117 of the FCB system of **FIG. 4**.

[0483] In **FIG.** 5B10, an exemplary metal-fuel (anode) contacting structure 122' is disclosed for use with the cathode structure shown in FIGS. 5B7 and 5B8. As shown, a plurality of electrically conductive elements 168A' through 168E' are supported from an platform 169' disposed adjacent the travel of the fuel card within the card. Each conductive element 168A' through 168E' has a smooth surface adapted for slidable engagement with one track of metal-fuel through the fine grooves formed in the base layer of the fuel card. Each conductive element is connected to an electrical conductor which is connected to the output port of the cathode-electrolyte input terminal configuration subsystem 178. The platform 169' is operably associated with the recharging head transport subsystem 131' and can be designed to be moved into position with the metal-fuel card during the Recharging Mode of the system, under the control of the system controller 130'.

[0484] Notably, the use of multiple recharging heads 175, as shown in the illustrative embodiments hereof, rather than a single recharging head, allows discharged metal-fuel cards to be recharged more quickly using lower recharging currents, thereby minimizing heat build-up across the individual recharging heads. This feature of the Metal-Fuel Card Recharging Subsystem 117 extends the service life of the cathodes employed within the recharging heads thereof.

[0485] Recharging Head Transport Subsystem within the Metal-Fuel Card Recharging Subsystem

[0486] The primary function of the recharging head transport subsystem 131' is to transport the assembly of recharging heads 175 to and from the metal-fuel cards 112 loaded into the recharging bay of the subsystem as shown in FIGS. 5B3 and 5B4. When properly transported, the cathode and anode-contacting structures of the recharging heads are brought into “ionically-conductive” and “electrically-conductive” contact with the metal-fuel tracks of loaded metal-fuel card during the Recharging Mode.

[0487] The recharging head transport subsystem **131**' can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode supporting structure **121**' and anode-contacting structure **124**' of each recharging head away from the metal-fuel card **112**, as shown in **FIG. 5**B3, and about the metal-fuel card as shown in **FIG. 5**B4. As shown, these transport mechanisms are operably connected to system controller **130**' and controlled by the same in accordance with the system control program carried out thereby.

[0488] Input Power Supply Subsystem within the Metal-Fuel Card Recharging Subsystem

[0489] In the illustrative embodiment, the primary function of the Input Power Supply Subsystem **176** is to receive as input, standard alternating current (AC) electrical power (e.g. at 120 or 220 Volts) through an insulated power cord, and to convert such electrical power into regulated direct current (DC) electrical power at a regulated voltage required at the recharging heads **175** of the Metal-Fuel Card Recharging Subsystem **117** during the recharging mode of operation. For zinc anodes and carbon cathodes, the required "open-cell" voltage v_{acr} across each anode-cathode structure during recharging is about 2.2-2.3 Volts in order to sustain electrochemical reduction. This subsystem can be realized in various ways using power conversion and regulation circuitry well known in the art.

[0490] Cathode-Anode Input Terminal Configuration Subsystem within the Metal-Fuel Card Recharging Subsystem

[0491] As shown in FIGS. **5**B3 and **5**B4, the cathode-electrolyte input terminal configuration subsystem **178** is connected between the output terminals of the recharging power regulation subsystem **181** and the input terminals of the cathode-electrolyte pairs associated with multiple tracks of the recharging heads **175**. The system controller **130**' is operably connected to cathode-electrolyte input terminal configuration subsystem **178** in order to supply control signals thereto for carrying out its functions during the Recharge Mode of operation.

[0492] The function of the cathode-electrolyte input terminal configuration subsystem **178** is to automatically configure (in series or parallel) the input terminals of selected cathode-electrolyte pairs within the recharging heads of the Metal-Fuel Card Recharging Subsystem **117** so that the required input (recharging) voltage level is applied across cathode-electrolyte structures of metal-fuel tracks requiring recharging. In the illustrative embodiment of the present invention, the cathode-electrolyte input terminal configuration mechanism **178** can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the recharging heads **175** are connected to the output terminals of the input power regulating subsystem **181**. Such switching operations are carried out under the control of the system controller **130**' so that the required output voltage produced by the input power regulating subsystem **181** is applied across the cathode-electrolyte structures of metal-fuel tracks requiring recharging.

[0493] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Card Recharging Subsystem

[0494] As shown in FIGS. **5**B3 and **5**B4, the cathode-electrolyte voltage monitoring subsystem **133**' is operably connected to the cathode-electrolyte input terminal configuration subsystem **178** for sensing voltage levels across the cathode and anode structures connected thereto. This subsystem is also operably connected to the system controller **130**' for receiving control signals therefrom required to carry out its functions. In the first illustrative embodiment, the cathode-electrolyte voltage monitoring subsystem **133**' has two primary functions: to automatically sense the instantaneous voltage levels applied across the cathode-electrolyte structures associated with each metal-fuel track being transported through each recharging head during the Recharging Mode; and to produce (digital) data signals indicative of the sensed voltages for detection and analysis by the Data Capture and Processing Subsystem **299**.

[0495] In the first illustrative embodiment of the present invention, the cathode-electrolyte voltage monitoring subsystem **133**' can be realized using electronic circuitry adapted for sensing voltage levels applied across the cathode-electrolyte structures associated with each metal-fuel track transported through each recharging head within the Metal-Fuel Card Recharging Subsystem **117**. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels for detection and analysis by the Data Capture and Processing Subsystem **299**. As will be described in greater detail hereinafter, such data signals can be used by the system controller to carry out its recharging power regulation method during the Recharging Mode of operation.

[0496] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Card Recharging Subsystem

[0497] As shown in FIGS. **5**B3 and **5**B4, the cathode-electrolyte current monitoring subsystem **134**' is operably connected to the cathode-electrolyte input terminal configuration subsystem **178**. The cathode-electrolyte current monitoring subsystem **134**' has two primary functions: to automatically sense the magnitude of electrical current flowing through the cathode-electrolyte pair of each metal-fuel track along each recharging head assembly within the Metal-Fuel Card Recharging Subsystem **117** during the discharging mode; and to produce digital data signal indicative of the sensed currents for detection and analysis by Data Capture and Processing Subsystem **299**.

[0498] In the first illustrative embodiment of the present invention, the cathode-electrolyte current monitoring subsystem **134**' can be realized using current sensing circuitry for sensing the electrical current passed through the cathode-electrolyte pair of each metal-fuel track (i.e. strip) along each recharging head assembly, and producing digital data signals indicative of the sensed current levels. As will be explained in greater detail hereinafter, these detected current levels can be used by the system controller in carrying out its recharging power regulation method, and well as creating a "recharging condition history" information file for each zone or subsection of recharged metal-fuel card.

[0499] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Card Recharging Subsystem

[0500] The function of the cathode oxygen pressure (pO_2) control subsystem is to sense the oxygen pressure (pO_2) within each subchannel of the cathode structure of the recharging heads **175**, and in response thereto, control (i.e.

increase or decrease) the same by regulating the air (O_2) pressure within the subchannels of such cathode structures. In accordance with the present invention, partial oxygen pressure (pO_2) within each subchannel of the cathode structure of each recharging head is maintained at an optimal level in order to allow optimal oxygen evacuation from the recharging heads during the Recharging Mode. By lowering the pO_2 level within each channel of the cathode structure (by evacuation), metal-oxide along metal-fuel cards can be completely recovered with optimal use of input power supplied to the recharging heads during the Recharging Mode. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by Data Capture and Processing Subsystem **299** and ultimate response the system controller **130'**. Thus the system controller **130'** is provided with a controllable variable for use in regulating the electrical power supplied to the discharged fuel tracks during the Recharging Mode.

[0501] Ion-Concentration Control Subsystem within the Metal-Fuel Card Recharging Subsystem

[0502] To achieve high-energy efficiency during the Recharging Mode, it is necessary to maintain an optimal concentration of (charge-carrying) ions at the cathode-electrolyte interface of each recharging head **175** within the Metal-Fuel Card Recharging Subsystem **117**. Also, the optimal ion-concentration within the Metal-Fuel Card Recharging Subsystem **117** may be different than that required within the Metal-Fuel Card Discharging Subsystem **115**. For this reason, in particular applications of the FCB system hereof, it may be desirable and/or necessary to provide a separate ion-concentration control subsystem within the Metal-Fuel Card Recharging Subsystem **117**. The primary function of such an ion-concentration control subsystem within the Metal-Fuel Card Recharging Subsystem **117** would be to sense and modify conditions therewithin so that the ion-concentration at the cathode-electrolyte interface of the recharging heads is maintained within an optimal range during the Recharging Mode of operation.

[0503] In the illustrative embodiment of such a subsystem, ion-concentration control is achieved by embedding a miniature solid-state humidity (or moisture) sensor **142'** within the cathode support structure **121'** as shown in **FIG. 5**B7 (or as close as possible to the anode-cathode interfaces) in order to sense moisture or humidity conditions therein and produce a digital data signal indicative thereof. This digital data signal is supplied to the Data Capture and Processing Subsystem **299** for detection and analysis. In the event that the moisture level or relative humidity drops below the predetermined threshold value set in memory (ROM) within the system controller, the system controller **130'**, monitoring information in the Metal-Fuel Database Management Subsystem **297** automatically generates a control signal supplied to a moisturizing element, realizable as a micro-sprinkling structure **143'** embodied within the walls of the cathode support structure **121'**. In the illustrative embodiment, the walls function as water carrying conduits which express fine water droplets out of micro-sized holes **144** in a manner similar to that carried out in the cathode support structure **121** in the discharge heads. Thus the function of the pump **145'**, reservoir **146'**, flow-control valve **147'**, manifold **148'** and multi-lumen tubing **149'** is similar to pump **145**, reservoir **146**, flow-control valve **147**, manifold **148** and multi-lumen tubing **149**, respectively.

[0504] Such operations will increase the moisture level or relative humidity within the interior of the cathode support structure channels and thus ensure that the concentration of KOH within the electrolyte within electrolyte-impregnated strips supported therewithin is optimally maintained for ion transport and thus metal-oxide reduction during card recharging operations.

[0505] Data Capture and Processing Subsystem within the Metal-Fuel Tape Recharging Subsystem

[0506] In the illustrative embodiment of **FIG. 4**, Data Capture And Processing Subsystem (DCPS) **299** shown in FIGS. **5B3** and **5B4** carries out a number of functions, including, for example: (1) identifying each metal-fuel card immediately before it is loaded within a particular recharging head within the recharging head assembly and producing metal-fuel card identification data representative thereof; (2) sensing (i.e. detecting) various "recharge parameters" within the Metal-Fuel Card Recharging Subsystem existing during the time period that the identified metal-fuel card is loaded within the recharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-fuel produced during card recharging operations, and producing "metal-fuel indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **297** (accessible by system controller **130'**), sensed recharge parameter data as well as computed metal-fuel indicative data both correlated to its respective metal-fuel track/card identified during the Recharging Mode of operation. As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **297** by Data Capture and Processing Subsystem **299** can be used by the system controller **130'** in various ways including, for example: optimally recharging partially or completely oxidized metal-fuel cards in a rapid manner during the Recharging Mode of operation.

[0507] During recharging operations, the Data Capture and Processing Subsystem **299** automatically samples (or captures) data signals representative of "recharge parameters" associated with the various subsystems constituting the Metal-Fuel Card Recharging Subsystem **117** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Recharging Mode. In accordance with the principles of the present invention, card-type "recharge parameters" shall include, but are not limited to: the voltages produced across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte voltage monitoring subsystem **133'**; the electrical currents flowing through the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte current monitoring subsystem **134'**; the oxygen saturation level (pO_2) within the cathode structure of each recharging head **175**, monitored by the cathode oxygen pressure control subsystem (**130'**, **135'**, **136'**, **137'**, **138'**, **140'**); the moisture (H_2O) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular recharging heads monitored, for example, by the ion-concentration control subsystem (**130'**,**142'**, **145'**, **146'**, **147'**, **148'**, **149'**); the temperature (T_r) of the recharging heads during card recharging operations; and the time duration (Δt_r) of the state of any of the above-identified recharge parameters.

[0508] In general, there a number of different ways in which the Data Capture and Processing Subsystem **299** can record card-type "recharge parameters" during the Recharging Mode of operation. These different methods will be detailed hereinbelow.

[0509] According to a first method of data recording shown in **FIG.** 5B9, card identifying code or indicia (e.g. miniature bar code symbol encoded with zone identifying information) **171** graphically printed on "optical" data track **172**, can be read by optical data reader **180** realized using optical techniques (e.g. laser scanning bar code symbol readers, or optical decoders) well known in the art. In the illustrative embodiment, information representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **299**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **297** during recharging operations.

[0510] According to a second method of data recording shown in **FIG.** 5B9', digital "card identifying" code **171**' magnetically recorded in a magnetic data track **172**', can be read by magnetic reading head **180**' realized using magnetic information reading techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **299**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **297** during recharging operations.

[0511] According to a third method of data recording shown in **FIG.** 5A9", digital "card identifying" code **171**" (recorded as a sequence of light transmission apertures in an optically opaque data track **172**"), can be read by an optical sensing head **180**" realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **299**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **297** during recharging operations.

[0512] According to a fourth alternative method of data recording, both unique digital "card identifying" code and set of recharge parameters for each track on the identified metal-fuel card are recorded in a magnetic, optical, or apertured data track, realized as a strip attached to the surface of the metal-fuel card of the present invention. The block of information pertaining to a particular metal-fuel card can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information during the Recharging Mode of operation. Typically, the block of information will include the metal-fuel card identification number and a set of recharge parameters, as schematically indicated in **FIG.** 5B16, which are automatically detected by the Data Capture and Processing Subsystem **299** as the metal-fuel card is loaded within the recharging head assembly **175**.

[0513] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel card can have a very low information capacity. This is because very little information needs to be recorded to tag each metal fuel card with a unique identifier (i.e. address number or card identification number), to which sensed recharge parameters are recorded in the Metal-Fuel Database Management Subsystem **297**. Also, formation of a data track in accordance with the first and second methods should be very inexpensive, as well as providing apparatus for reading card identifying information recorded along such data tracks. Input/Output Control Subsystem within the Metal-Fuel Card Recharging Subsystem In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Card Recharging Subsystems in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Card Recharging Subsystem **117** hereof includes an Input/Output Control Subsystem **117** which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Card Recharging Subsystem as if its system controller **130**' were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **152**' is realized as a standard IEEE I/O bus architecture which provides an external or remote computer system with a way and means of directly interfacing with the system controller **130**' of the Metal-Fuel Card Recharging Subsystem **117** and managing various aspects of system and subsystem operation in a straightforward manner.

[0514] Recharging Power Regulation Subsystem within the Metal-Fuel Card Recharging Subsystem

[0515] As shown in FIGS. **5B3** and 5B4, the output port of the recharging power regulation subsystem **181** is operably connected to the input port of the cathode-electrolyte input terminal configuration subsystem **178**, whereas the input port of the recharging power regulation subsystem **181** is operably connected to the output port of the input power supply **176**. While the primary function of the recharging power regulation subsystem **181** is to regulate the electrical power supplied to metal-fuel card during the Recharging Mode of operation, the recharging power regulation subsystem **181** can also regulate the voltage applied across the cathode-electrolyte structures of the metal-fuel tracks, as well as the electrical currents flowing through the cathode-electrolyte interfaces thereof during recharging operations. Such control functions are managed by the system controller **130**' and can be programmably selected in a variety of ways in order to achieve optimal recharging of multi-tracked and single-tracked metal-fuel cards according to the present invention.

[0516] The recharging power regulating subsystem **181** can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistorcontrolled technology, in which one or more current-controlled sources are connectable in electrical series with the cathode and anode structures in order to control the electrical currents therethrough in response to control signals produced by the system controller carrying out a particular Recharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which one or more voltage-controlled sources are connectable in electrical parallel with the cathode and anode structures in order to control the voltage thereacross in response to control signals produced by the system controller. Such circuitry can be combined and controlled by the system controller **130'** in order to provide constant power (and/or voltage and/or current) control across the cathode-electrolyte structures of the metal-fuel card **112**.

[**0517**] In the illustrative embodiments of the present invention, the primary function of the recharging power regulation subsystem **181** is to carry out real-time power regulation to the cathode/anode structures of metal-fuel card using any one of the following Recharge Power Control Methods, namely: (1) a Constant Input Voltage/Variable Input Current Method, wherein the input voltage applied across each cathode-electrolyte structure is maintained constant while the current therethrough is permitted to vary in response to loading conditions presented by metal-oxide formations on the recharging card; (2) a Constant Input Current/Variable Input Voltage Method, wherein the current into each cathode-electrolyte structure is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Input Voltage/Constant Input Current Method, wherein the voltage applied across and current into each cathode-electrolyte structure during recharging are both maintained constant in response to loading conditions; (4) a Constant Input Power Method, wherein the input power applied across each cathode-electrolyte structure during recharging is maintained constant in response to loading conditions; (5) a Pulsed Input Power Method, wherein the input power applied across each cathode-electrolyte structure during recharging pulsed with the duty cycle of each power pulse being maintained in accordance with preset or dynamic conditions; (6) a Constant Input Voltage/Pulsed Input Current Method, wherein the input current into each cathode-electrolyte structure during recharging is maintained constant while the current into the cathode-electrolyte structure is pulsed with a particular duty cycle; and (7) a Pulsed Input Voltage/ Constant Input Current Method, wherein the input power supplied to each cathode-electrolyte structure during recharging is pulsed while the current thereinto is maintained constant.

[**0518**] In the preferred embodiment of the present invention, each of the seven (7) Recharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **130'**. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic and/or optical condition established or detected at the interface between the metal-fuel card device and the Metal-Fuel Card Recharging Subsystem **117**.

[**0519**] System Controller within the Metal-Fuel Card Recharging Subsystem

[**0520**] As illustrated in the detailed description set forth above, the system controller **130'** performs numerous operations in order to carry out the diverse functions of the FCB system within its Recharging Mode. In the preferred embodiment of the FCB system of **FIG. 4**, the subsystem used to realize the system controller **130'** in the Metal-Fuel Card Recharging Subsystem **117** is the same subsystem used to realize the system controller **130** in the Metal-Fuel Card Discharging Subsystem **115**. It is understood, however, the system controllers employed in the Discharging and Recharging Subsystems can be realized as separate subsystems, each employing one or more programmed micro-controllers in order to carry out the diverse set of functions performed by the FCB system hereof. In either case, the input/output control subsystem of one of these subsystems can be designed to be the primary input/output control subsystem, with which one or more external subsystems (e.g. a management subsystem) can be interfaced to enable external and/or remote management of the functions carried out within FCB system hereof.

[**0521**] Recharging Metal-Fuel Cards Within the Metal-Fuel Card Recharging Subsystem

[**0522**] **FIG. 5B5** sets forth a high-level flow chart describing the basic steps of recharging metal-fuel cards within the Metal-Fuel Card Recharging Subsystem **117** shown in FIGS. **5B3** through **5B4**.

[**0523**] As indicated at Block A, the Card Loading/Unloading Subsystem **111** transports four metal-fuel cards into the card recharging bays of the Metal-Fuel Card Recharging Subsystem **117**.

[**0524**] As indicated at Block B, the Recharge Head Transport Subsystem **131'** arranges the recharging heads about the metal-fuel cards loaded into the recharging bay of the Metal-Fuel Card Recharging Subsystem **117** so that the ionically-conducting medium is disposed between each cathode structure and loaded metal-fuel card.

[**0525**] As indicated at Block C, the Recharge Head Transport Subsystem **131'** then configures each recharging head **175** so that its cathode structure is in ionic contact with a loaded metal-fuel card **112** and its anode contacting structure is in electrical contact therewith.

[**0526**] As indicated at Block D, the cathode-electrolyte input terminal configuration subsystem **178** automatically configures the input terminals of each recharging head arranged about a loaded metal-fuel card, and then the system controller controls the Metal-Fuel Card Recharging Subsystem **117** so that electrical power is supplied to the cathode-electrolyte structures of the recharging heads loaded with metal-fuel cards, at the required recharging voltages and currents. When one or more of the loaded metal-fuel cards are recharged, then the Card Loading/Unloading Subsystem **111** automatically ejects the recharged metal-fuel cards out through the recharging bay for replacement with discharged metal-fuel cards.

[**0527**] Managing Metal-Fuel Availability and Metal-Oxide Presence Within the Fourth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[**0528**] During The Discharging Mode:

[**0529**] In the FCB system of the fourth illustrative embodiment shown in **FIG. 4**, means are provided for automatically managing the metal-fuel availability within the Metal-Fuel Card Discharging Subsystem **115** during discharging operations. Such system capabilities will be described in greater detail hereinbelow.

[**0530**] As shown in **FIG. 5B17**, data signals representative of discharge parameters (e.g., i_{acd}, v_{acd}, . . . , pO_{2d},

H_2O_d, T_{acd}, v_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **295** within the Metal-Fuel Card Discharging Subsystem **115**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **301** as shown, for example, in **FIG. 5A15**. Each information structure **301** comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel card identifier **171** (**171'**, **171"**), associated with a particular metal-fuel card. The unique metal-fuel card identifier is determined by data reading head **150** (**150'**, **150"**) shown in **FIG. 5A6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **293** within the Metal-Fuel Card Discharging Subsystem **115**, for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[**0531**] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **295** during the discharging mode. Such information types include, for example: (1) the amount of electrical current (i_{acd}) discharged across particular cathode-electrolyte structures within particular discharge heads; (2) the voltage generated across each such cathode-electrolyte structure; (3) the oxygen concentration (pO_{2d}) level in each subchamber within each discharging head; (4) the moisture level (H_2O_d) near each cathode-electrolyte interface within each discharging head; and (5) the temperature (T_{acd}) within each channel of each discharging head. From such collected information, the Data Capture and Processing Subsystem **295** can readily compute (i) the time (Δt_d) duration that electrical current was discharged across a particular cathode-electrolyte structure within a particular discharge head.

[**0532**] The information structures produced by the Data Capture and Processing Subsystem **295** are stored within the Metal-Fuel Database Management Subsystem **293** on a real-time basis and can be used in a variety of ways during discharging operations. For example, the above-described current (i_{acd}) and time (Δt_d) information is conventionally measured in Amperes and Hours, respectively. The product of these measures, denoted by "AH", provides an approximate measure of the electrical charge (−Q) that has been "discharged" from the metal-air fuel cell battery structures along the metal-fuel card. Thus the computed "AH" product provides an accurate amount of metal-oxide that one can expect to have been formed on a particular track of an identified (i.e. labeled) metal-fuel card at a particular instant in time, during discharging operations.

[**0533**] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database Management Subsystems **293** and **297** within the Metal-Fuel Card Discharging and Recharging Subsystems **115** and **117**, respectively, can account for or determine how much metal-fuel (e.g. zinc) should be available for discharging (i.e. producing electrical power) from a particular zinc-fuel card, or how much metal-oxide is present for reducing therealong. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-fuel amounts available along a particular metal-fuel zone.

[**0534**] In the illustrative embodiment, metal-fuel availability is managed within the Metal-Fuel Card Discharging Subsystem **115**, using the method of metal-fuel availability management described hereinbelow.

[**0535**] Preferred Method of Metal-Fuel Availability Management During Discharging Operations

[**0536**] In accordance with the principles of the present invention, the data reading head **150** (**150'**, **150'**) automatically identifies each metal-fuel card as it is loaded within the discharging assembly and produces card identification data indicative thereof which is supplied to the Data Capture and Processing Subsystem within the Metal-Fuel Card Discharging Subsystem **115**. Upon receiving card identification data on the loaded metal-fuel card, the Data Capture and Processing Subsystem automatically creates an information structure (i.e. data file) on the card, for storage within the Metal-Fuel Database Management Subsystem **293**. The function of the information structure is to record current (up-to-date) information on sensed discharging parameters, the metal-fuel availability state, metal-oxide presence state, and the like, as shown in **FIG. 5A15**. In the event that an information storage structure has been previously created for this particular metal-fuel card within the Metal-Fuel Database Management Subsystem, this information file is accessed from Database Subsystem **293** for updating. As shown in **FIG. 5A15**, for each identified metal-fuel card, an information structure **285** is maintained for each metal-fuel track (MFT_j), at each sampled instant of time t_i.

[**0537**] Once an information structure has been created (or found) for a particular metal-fuel card, the initial state or condition of each metal-fuel track thereon must be determined and entered within the information structure maintained within the Metal-Fuel Database Management Subsystem **293**. Typically, the metal-fuel card loaded within the discharging head assembly will be partially or fully charged, and thus containing a particular amount of metal-fuel along its tracks. For accurate metal-fuel management, these initial metal-fuel amounts in the loaded card must be determined and then information representative stored with the Metal-Fuel Database Management Subsystems of the Discharging and Recharging Subsystems **115** and **117**, respectively. In general, initial states of information can be acquired in a number of different ways, including for example: by encoding such initialization information on the metal-fuel card prior to completing a discharging operation on a different FCB system; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem **293** during the most recent discharging operation carried out in the same FCB system; by recording within the Metal-Fuel Database Management Subsystem **293** (at the factory), the actual (known) amount of metal-fuel present on each track of a particular type metal-fuel card, and automatically initializing such information within a particular information structure upon reading a code on the metal-fuel card using data reading head **150** (**150'**, **150"**); by actually measuring the initial amount of metal-fuel on each metal-fuel track using the metal-oxide sensing assembly described above in conjunction with the cathode-electrolyte output terminal configuration subsystem **132**; or by any other suitable technique.

[**0538**] Prior to conducting discharging operations on the loaded fuel card, the actual measurement technique mentioned above can be carried out by configuring metal-oxide sensing drive circuitry (shown in **FIG. 2A15**) with the cathode-electrolyte output terminal configuration subsystem **132** and Data Capture and Processing Subsystem **295** within the Discharging Subsystem **115**. Using this arrangement, the metal-oxide sensing heads can automatically acquire information on the "initial" state of each metal-fuel track on each identified metal-fuel card loaded within the discharging head assembly. Such information would include the initial amount of metal-oxide and metal-fuel present on each track at the time of loading, denoted by "t_0".

[**0539**] In a manner similar to that described in connection with the FCB system of **FIG. 1**, such metal-fuel/metal-oxide measurements are carried out on each metal-fuel track of the loaded card by automatically applying a test voltage across a particular track of metal fuel, and detecting the electrical which flows across the section of metal-fuel track in response the applied test voltage. The data signals representative of the applied voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem **295** and processed to produce a data element representative of the ratio of the applied test voltage to response current with appropriate numerical scaling. This data element is proportional to $V_{applied}/i_{response}$ automatically recorded within the information structure (i.e. file) linked to the identified metal-fuel card maintained in the Metal-Fuel Data Management Subsystem **293**. As this data element (v/i) provides a direct measure of electrical resistance across the metal-fuel track under measurement, it can be accurately correlated to a measured amount of metal-oxide present on the identified metal-fuel track.

[**0540**] Data Capture and Processing Subsystem **295** then quantifies the measured initial metal-oxide amount (available at initial time instant t_0), and designates it as MOA_0 for recording within the information structure (shown in **FIG. 5A15**). Then using a priori information about the maximum metal-fuel available on each track when fully (re)charged, the Data Capture and Processing Subsystem **295** computes an accurate measure of metal-fuel available on each track at time "t_0", for each fuel track, designates each measures as MFA_0 and records these initial metal-fuel measures (MFA_0) for the identified fuel card within the Metal-Fuel Database Management Subsystems **293** and **297** of both the Metal-Fuel Card Discharging and Recharging Subsystems. While this initialization procedure is simple to carry out, it is understood that in some applications it may be more desirable to empirically determine these initial metal-fuel measures using theoretically-based computations premised on the metal-fuel cards having been subjected to a known course of treatment, for example: (1) momentarily subjecting the loaded fuel card to electrical-shorting conditions at the power output terminals of the FCB system; (2) automatically detecting the response characteristics thereof; and (3) correlating such detected response characteristics within a known initial state of oxidation stored in a Table as a function of shorting current; while maintaining all other (re)charging parameters constant (hereinafter referred to as the "Short-Circuit Resistance Test").

[**0541**] After the initialization procedure is completed, the Metal-Fuel Card Discharging Subsystem **115** is ready to carry out its metal-fuel management functions along the lines to be described hereinbelow. In the illustrative embodiment, this method involves two basic steps that are carried out in a cyclical manner during discharging operations.

[**0542**] The first step of the procedure involves subtracting from the initial metal-fuel amount MFA_O, the computed metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during discharging operations conducted between time interval t_0-t_1. The during the discharging operation, metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected—electrical discharge current i_{acd}, and time duration Δt_d.

[**0543**] The second step of the procedure involves adding to the computed measure (MFA_0-MOE_{0-1}), the metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during any recharging operations that may have been conducted between time interval t_0-t_1. Notably, metal-fuel estimate MFE_{0-1} is computed using: electrical recharge current i_{acr}; and the time duration thereof Δt_d during the discharging operation. Notably, this metal-fuel measure MFE0-1 will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem **293** within the Metal-Fuel Card Recharging Subsystem **115** during the immediately previous recharging operation (if one such operation was carried out). Thus, in the illustrative embodiment, it will be necessary to read this prerecorded information element from the Database Subsystem **297** within the Recharging Subsystem **117** during current discharging operations.

[**0544**] The computed result of the above-described accounting procedure (i.e. $MFA_0-MOE_{0-1}+MFE_{0-1}$) is then posted within the Metal-Fuel Database Management Subsystem **293** within Metal-Fuel Card Discharging Subsystem **115** as the new current metal-fuel amount (MFA_1) which will be used in the next metal-fuel availability update procedure. During discharging operations, the above-described update procedure is carried out every t_i-t_{i+1} seconds for each metal-fuel track that is being discharged.

[**0545**] Such information maintained on each metal-fuel track can be used in a variety of ways, for example: managing the availability of metal-fuel to meet the electrical power demands of the electrical load connected to the FCB system; as well as setting the discharging parameters in an optimal manner during discharging operations. The details pertaining to this metal-fuel management techniques will be described in greater detail hereinbelow.

[**0546**] Uses for Metal-Fuel Availability Management During the Discharging Mode of Operation

[**0547**] During discharging operations, the computed estimates of metal-fuel present over any particular metal-fuel track at time t_2 (i.e. MFT_{t1-t2}), determined at the j-th discharging head, can be used to compute the availability of metal-fuel at the (j+1)th, (j+2)th, or (J+n)th discharging head downstream from the j-th discharging head. Using such computed measures, the system controller **130** within the Metal-Fuel Card Discharging Subsystem **115** can determine (i.e. anticipate) in real-time, which metal-fuel track along a metal-fuel card contains metal-fuel (e.g. zinc) in quantities sufficient to satisfy instantaneous electrical-loading conditions imposed upon the Metal-Fuel Card Discharging Subsystem **115** during the discharging operations, and selectively "switch-in" the metal-fuel track(s) along which metal-fuel is known to exist. Such track switching operations may involve the system controller **130** temporarily connecting the output terminals of the cathode-electrolyte structures thereof to the input terminals of the cathode-electrolyte output terminal configuration subsystem **132** so that tracks supporting metal-fuel content (e.g. deposits) are made readily available for producing electrical power required by the electrical load **116**.

[**0548**] Another advantage derived from such metal-fuel management capabilities is that the system controller **130** within the Metal-Fuel Card Discharging Subsystem **115** can control discharge parameters during discharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystems **293** and **297** during the immediately prior recharging and discharging operations.

[**0549**] Means for Controlling Discharging Parameters During the Discharging Mode Using Information Recorded During the Prior Modes of Operation

[**0550**] In the FCB system of the fourth illustrative embodiment, the system controller **130** within the Metal-Fuel Card Discharging Subsystem **115** can automatically control discharge parameters using information collected during prior recharging and discharging operations and recorded within the Metal-Fuel Database Management Subsystems **293** and **297** of the FCB system of **FIG. 4**.

[**0551**] As shown in **FIG. 5**B**16**, the subsystem architecture and buses provided within and between the Discharging and Recharging Subsystems **115** and **117** enable system controller **130** within the Metal-Fuel Card Discharging Subsystem **115** to access and use information recorded within the Metal-Fuel Database Management Subsystem **297** within the Metal-Fuel Card Recharging Subsystem **117**. Similarly, the subsystem architecture and buses provided within and between the Discharging and Recharging Subsystems **115** and **117** enable system controller **130**' within the Metal-Fuel Card Recharging Subsystem **117** to access and use information recorded within the Metal-Fuel Database Management Subsystem **293** within the Metal-Fuel Card Discharging Subsystem **115**. The advantages of such information file and sub-file sharing capabilities will be explained hereinbelow.

[**0552**] During the discharging operations, the system controller **130** can access various types of information stored within the Metal-Fuel Database Management Subsystems within the Discharging and Recharging Subsystems **115** and **117**. One important information element will relate to the amount of metal-fuel currently available at each metal-fuel track along at a particular instant of time (i.e. MFE_t). Using this information, the system controller **130** can determine if there will be sufficient metal-fuel along a particular track to satisfy electrical power demands of the connected load **116**. The metal-fuel along one or more or all of the fuel tracks along a metal-fuel card may be substantially consumed as a result of prior discharging operations, and not having been recharged since the last discharging operation. The system controller **130** can anticipate such metal-fuel conditions within the discharging heads. Depending on the metal-fuel condition of "upstream" fuel cards, the system controller **130** may respond as follows: (i) connect the cathode-electrolyte structures of metal-fuel "rich" tracks into the discharge power regulation subsystem **151** when high electrical loading conditions are detected at load **116**, and connect cathode-electrolyte structures of metal-fuel "depleted" tracks into this subsystem when low loading conditions are detected at electrical load **116**; (ii) increase the rate of oxygen being injected within the corresponding cathode support structures (i.e. by increasing the air pressure therewithin) when the metal-fuel is thinly present on identified metal-fuel tracks, and decrease the rate of oxygen being injected within the corresponding cathode support structures (i.e. by decreasing the air pressure therewithin) when the metal-fuel is thickly present on identified metal-fuel zones, in order to maintain power produced from the discharging heads; (iii) control the temperature of the discharging heads when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments of the present invention, the system controller **130** may operate in different ways in response to the detected condition of particular tracks on an identified metal-fuel card.

[**0553**] During the Recharging Mode

[**0554**] In the FCB system of the fourth illustrative embodiment shown in **FIG. 4**, means are provided for automatically managing the metal-oxide presence within the Metal-Fuel Card Recharging Subsystem **117** during recharging operations. Such system capabilities will be described in greater detail hereinbelow.

[**0555**] As shown in **FIG. 5**B**16**, data signals representative of recharge parameters (e.g., i_{acr}, v_{acr}, . . . , pO_{2r}, $\{H_2O\}_f$, T_r, v_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **299** within the Metal-Fuel Card Recharging Subsystem **117**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **302** as shown, for example, in **FIG. 5**B**15**. As in the case of discharge parameter collection, each information structure **302** for recharging parameters comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel card identifier **171** (**171**', **171**"), associated with the metal-fuel card being recharged. The unique metal-fuel card identifier is determined by data reading head **180** (**180**', **180**") shown in **FIG. 5**B**6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **297** of the Metal-Fuel Card Recharging Subsystem **117**, shown in **FIG. 5B16**, for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[**0556**] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **299** during the recharging mode. Such information types include, for example: (1) the recharging voltage applied across each such cathode-electrolyte structure within each recharging head; (2) the amount of electrical current (i_{acr}) supplied across each cathode-electrolyte structures within each recharge head; (3) the oxygen concentration (pO_{2r}) level in each subchamber within each recharging head; (4) the moisture level ($\{H_2O\}_r$) near each cathode-electrolyte interface within each recharging head; and (5) the temperature (T_{acr}) within each channel of each recharging head. From such collected information, the Data Capture and Processing Subsystem **299** can readily compute various parameters of the system including, for example, the time duration (Δt_r) that electrical current (i_r) was supplied to a particular cathode-electrolyte structure within a particular recharging head.

[0557] The information structures produced and stored within the Metal-Fuel Database Management Subsystem 297 of the Metal-Fuel Card Recharging Subsystem 117 on a real-time basis can be used in a variety of ways during recharging operations.

[0558] For example, the above-described current (i_{acr}) and time duration (Δt_r) information acquired during the recharging mode is conventionally measured in Amperes and Hours, respectively. The product of these measures (AH) provides an accurate measure of the electrical charge (−Q) supplied to the metal-air fuel cell battery structures along the metal-fuel card during recharging operations. Thus the computed "AH" product provides an accurate amount of metal-fuel that one can expect to have been produced on the identified track of metal-fuel, at a particular instant in time, during recharging operations.

[0559] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database Management Subsystems 293 and 297 within the Metal-Fuel Card Discharging and Recharging Subsystems 115 and 117 respectively can be used to account for or determine how much metal-oxide (e.g. zinc-oxide) should be present for recharging (i.e. conversion back into zinc from zinc-oxide) along the zinc-fuel card. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-oxide amounts present along each metal-fuel track during recharging operations.

[0560] In the illustrative embodiment, metal-oxide presence may be managed within the Metal-Fuel Card Recharging Subsystem 7 using the method described hereinbelow.

[0561] Preferred Method of Metal-Oxide Presence Management

[0562] During Recharging Operations

[0563] In accordance with the principles of the present invention, the data reading head 180 (180', 180') automatically identifies each metal-fuel card as it is loaded within the recharging assembly 175 and produces card identification data indicative thereof which is supplied to the Data Capture and Processing Subsystem 299 within the Metal-Fuel Card Discharging Subsystem 117. Upon receiving card identification data on the loaded metal-fuel card, the Data Capture and Processing Subsystem 299 automatically creates an information structure (i.e. data file) on the card, for storage within the Metal-Fuel Database Management Subsystem 297. The function of the information structure is to record current (up-to-date) information on sensed recharging parameters, the metal-fuel availability state, metal-oxide presence state, and the like, as shown in FIG. 5B15. In the event that an information storage structure has been previously created for this particular metal-fuel card within the Metal-Fuel Database Management Subsystem, this information file is accessed from Database Management Subsystem 297 for updating. As shown in FIG. 5B15, for each identified metal-fuel card, an information structure 302 is maintained for each metal-fuel track (MFT_j), at each sampled instant of time t_1.

[0564] Once an information structure has been created (or found) for a particular metal-fuel card, the initial state or condition of each metal-fuel track thereon must be determined and entered within the information structure maintained within the Metal-Fuel Database Management Subsystem 297. Typically, the metal-fuel card loaded within the recharging head assembly 175 will be partially or fully discharged, and thus containing a particular amount of metal-oxide along its tracks for conversion back into its primary metal. For accurate metal-fuel management, these initial metal-oxide amounts in the loaded card(s) must be determined and then information representative stored with the Metal-Fuel Database Management Subsystems 293 and 297 of the Discharging and Recharging Subsystems 115 and 117, respectively. In general, initial states of information can be acquired in a number of different ways, including for example: by encoding such initialization information on the metal-fuel card prior to completing a discharging operation on a different FCB system; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem 297 during the most recent recharging operation carried out in the same FCB system; by recording within the Metal-Fuel Database Management Subsystem 297 (at the factory), the amount of metal-oxide normally expected on each track of a particular type metal-fuel card, and automatically initializing such information within a particular information structure upon reading a code on the metal-fuel card using data reading head 180 (180', 180"); by actually measuring the initial amount of metal-oxide on each metal-fuel track using the metal-oxide sensing assembly described above in conjunction with the cathode-electrolyte input terminal configuration subsystem 178; or by any other suitable technique.

[0565] Prior to conducting recharging operations on the loaded fuel card(s), the "actual" measurement technique mentioned above can be carried out by configuring metal-oxide sensing ($V_{applied}/i_{response}$) drive circuitry (shown in FIG. 2A15) with the cathode-electrolyte input terminal configuration subsystem 178 and Data Capture and Processing Subsystem 299 within the Recharging Subsystem 117. Using this arrangement, the metal-oxide sensing heads can automatically acquire information on the "initial" state of each metal-fuel track on each identified metal-fuel card loaded within the recharging head assembly. Such information would include the initial amount of metal-oxide and metal-fuel present on each track at the time of loading, denoted by "t_0".

[0566] In a manner similar to that described in connection with the FCB system of FIG. 1, such metal-fuel/metal-oxide measurements are carried out on each metal-fuel track of the loaded card by automatically applying a test voltage across a particular track of metal fuel, and detecting the electrical which flows across the section of metal-fuel track in response the applied test voltage. The data signals representative of the applied voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem 299 and processed to produce a data element representative of the ratio of the applied voltage to response current (v applied/i response) with appropriate numerical scaling. This data element is automatically recorded within an information structure linked to the identified metal-fuel card maintained in the Metal-Fuel Data Management Subsystem 297. As this data element (v/i) provides a direct measure of electrical resistance across the metal-fuel track under measurement, it can be accurately correlated to a measured "initial" amount of metal-oxide present on the identified metal-fuel track.

[0567] Data Capture and Processing Subsystem **299** then quantifies the measured initial metal-oxide amount (available at initial time instant to), and designates it as MOA_0 for recording in the information structures maintained within the Metal-Fuel Database Management Subsystems of both the Metal-Fuel Card Discharging and Recharging Subsystems **115** and **117**. While this initialization procedure is simple to carry out, it is understood that in some applications it may be more desirable to empirically determine these initial metal-oxide measures using theoretically-based computations premised on the metal-fuel cards having been subjected to a known course of treatment (e.g. the Short-Circuit Resistance Test described hereinabove).

[0568] After completing the initialization procedure, the Metal-Fuel Card Recharging Subsystem **117** is ready to carry out its metal-fuel management functions along the lines to be described hereinbelow. In the illustrative embodiment, this method involves two basic steps that are carried out in a cyclical manner during recharging operations.

[0569] The first step of the procedure involves subtracting from the initial metal-oxide amount MOA_0, the computed metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during recharging operations conducted between time interval t_0-t_1. During the recharging operation, metal-fuel estimate MFE_{0-1} is computed using the following recharging parameters collected—electrical recharge current i_{acr} and the time duration Δt_R thereof.

[0570] The second step of the procedure involves adding to the computed measure (MOA_0−MFE_{0-1}), the metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during any discharging operations that may have been conducted between time interval t_0-t_1. Notably, the metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected—electrical recharge current i_{acd} and time duration Δt_{0-1}, during the discharging operation. Notably, metal-oxide measure MOE_{0-1} will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem within the Metal-Fuel Card Recharging Subsystem **115** during the immediately previous discharging operation (if one such operation has been carried out since t_0). Thus, in the illustrative embodiment, it will be necessary to read this prerecorded information element from the Database Management Subsystem **293** within the Discharging Subsystem **115** during the current recharging operations.

[0571] The computed result of the above-described procedure (i.e. MOA_0−MFE_{0-1}+MOE_{0-1}) is then posted within the Metal-Fuel Database Management Subsystem **297** within Metal-Fuel Card Recharging Subsystem **117** as the new "current" metal-fuel amount (MOA_1) which will be used in the next metal-oxide presence update procedure. During recharging operations, the above-described update procedure is carried out every t_i-t_{i+1} seconds for each metal-fuel track that is being recharged.

[0572] Such information maintained on each metal-fuel track can be used in a variety of ways, for example: managing the presence of metal-oxide formations along the track of metal-fuel cards; as well as setting the recharging parameters in an optimal manner during recharging operations. The details pertaining to such metal-oxide presence management techniques will be described in greater detail hereinbelow.

[0573] Uses for Metal-Oxide Presence Management During the Recharging Mode of Operation

[0574] During recharging operations, the computed amounts of metal-oxide present along any particular metal-fuel track (i.e. MFT), determined at the i-th recharging head, can be used to compute the presence of metal-oxide at the (i+1)th, (i+2)th, or (i+n)th recharging head downstream from the i-th recharging head. Using such computed measures, the system controller **130'** within the Metal-Fuel Card Recharging Subsystem **117** can determine (i.e. anticipate) in real-time, which metal-fuel tracks along a metal-fuel card contain metal-oxide (e.g. zinc-oxide) requiring recharging, and which contain significant amounts of metal-fuel and not requiring recharging. For those metal-fuel tracks requiring recharging, the system controller **130'** can electronically switch-in the cathode-electrolyte structures of those metal-fuel tracks having significant metal-oxide content (e.g. deposits) for conversion into metal-fuel within the recharging head assembly **175**.

[0575] Another advantage derived from such metal-oxide management capabilities is that the system controller **130'** within the Metal-Fuel Card Recharging Subsystem **117** can control recharge parameters during recharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystems **293** and **297** during the immediately prior recharging and discharging operations.

[0576] During Recharging operations, information collected can be used to compute an accurate measure of the amount of metal-oxide that exists along each metal-fuel track at any instant in time. Such information, stored within information storage structures maintained within the Metal-Fuel Database Subsystem **297**, can be accessed and used by the system controller **130'** within the Metal-Fuel Card Discharging Subsystem **117** to control the amount of electrical current supplied across the cathode-electrolyte structures of each recharging head **175**. Ideally, the magnitude of electrical current will be selected to ensure complete conversion of the estimated amount of metal-oxide (e.g. zinc-oxide) along each such track, into its primary source metal (e.g. zinc) without destroying the structural integrity and porosity characteristics of the metal-fuel tape.

[0577] Means for Controlling Recharging Parameters During the Recharging Mode Using Information Recorded During Prior Modes of Operation

[0578] In the FCB system of the fourth illustrative embodiment, the system controller **130'** within the Metal-Fuel Card Recharging Subsystem **117** can automatically control recharge parameters using information collected during prior discharging and recharging operations and recorded within the Metal-Fuel Database Management Subsystems **293** and **297** of the FCB system of **FIG. 4**.

[0579] During the recharging operations, the system controller **130'** within the Metal-Fuel Card Recharging Subsystem **117** can access various types of information stored within the Metal-Fuel Database Management Subsystem **297**. One important information element stored therein will relate to the amount of metal-oxide currently present along each metal-fuel track at a particular instant of time (i.e. MOAT). Using this information, the system controller **130'** can determine on which tracks metal-oxide deposits are present, and thus can connect the input terminal of the corresponding cathode-electrolyte structures (within the recharging heads) to the recharging power control subsystem **181** by way of the cathode-electrolyte input terminal configuration subsystem **178**, to efficiently and quickly carry out recharging operations therealong. The system controller **130'** can anticipate such metal-oxide conditions prior to conducting recharging operations. Depending on the metal-oxide condition of "upstream" fuel cards loaded within the discharging head assembly, the system controller **130'** of the illustrative embodiment may respond as follows: (i) connect cathode-electrolyte structures of metal-oxide "rich" tracks into the recharging power regulation subsystem **181** for long recharging durations, and connect cathode-electrolyte structures of metal-oxide "depleted" tracks from this subsystem for relatively shorter recharging operations; (ii) increase rate of oxygen evacuation from about the cathode support structures corresponding to tracks having thickly formed metal-oxide formations therealong during recharging operations, and decrease the rare of oxygen evacuation from about the cathode support structures corresponding to tracks having thinly formed metal-oxide formations therealong during recharging operations; (iii) control the temperature of the recharging heads when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments, the system controller **130'** may operate in different ways in response to the detected condition of particular track on identified fuel card.

The Fifth Illustrative Embodiment of the Air-Metal FCB System of the Present Invention

[**0580**] The fifth illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIGS. 6 through** 7B13. As shown in FIGS. **6**, **7A1** and **7A2** this FCB system **185** comprises a number of subsystems, namely: a Metal-Fuel Card Discharging (i.e. Power Generation) Subsystem **186** for generating electrical power from the recharged metal-fuel cards **187** during the Discharging Mode of operation; Metal-Fuel Card Recharging Subsystem **191** for electrochemically recharging (i.e. reducing) sections of oxidized metal-fuel cards **187** during the Recharging Mode of operation; a Recharged Card Loading Subsystem **189** for automatically loading one or more metal-fuel cards **187** from recharged storage bin **188**A into the discharging bay of the FCB system; a Discharged Card Unloading Subsystem **192** for automatically unloading one or more discharged metal-fuel cards **187** from the discharging bay of the FCB system into the discharged metal-fuel card storage bin **188**B; Discharged Card Loading Subsystem **192** for automatically loading one or more discharged metal-fuel cards from the discharged metal-fuel card storage bin **188**B, into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**; and a Recharged Card Unloading Subsystem **193** for automatically unloading recharged metal-fuel cards from the recharging bay of the Recharging Subsystem into the recharged metal-fuel card storage bin **188**A. Details concerning each of these subsystems and how they cooperate will be described below.

[**0581**] As shown in **FIG. 6**, the metal fuel consumed by this FCB System is provided in the form of metal fuel cards **187**, slightly different in construction from the card **112** used in the system of **FIG. 4**. As shown in **FIGS. 6 and 7A12**, each metal-fuel card **178** has a rectangular-shaped housing containing a plurality of electrically isolated metal-fuel elements (e.g. squares) **195**A through **195**D. As will be illustrated in greater detail hereinafter, these elements are adapted to contact the cathode elements **196**A through **196**D of the "multi-zoned" discharging head **197** in the Metal-Fuel Card Discharging Subsystem **186** when the metal-fuel card **178** is moved into properly aligned position between cathode support plate **198** and anode contacting structure **199** thereof during the Discharging Mode, as shown in **FIG. 7A4**, and also contact the cathode elements **196A'** through **196**D' of the recharging head **197'** in the Metal-Fuel Card Recharging Subsystem **191** when the fuel card is moved into properly aligned position between the cathode support plate **198'** and the anode contacting support structure **199'** during the recharging mode as shown in **FIG.** 7B4.

[**0582**] In the illustrative embodiment, the fuel card of the present invention is "multi-zoned" in order to enable the simultaneous production of multiple supply voltages (e.g. 1.2 Volts) from the "multi-zone" discharging head **197**. As described in connection with the other embodiments of the present invention, this enable the generation and delivery of a wide range of output voltages from the system, suitable to the requirements of the particular electrical load connected to the FCB system.

[**0583**] Brief Summary of Modes of Operation of the FCB System of the Fourth Illustrative Embodiment of the Present Invention

[**0584**] The FCB system of the fifth illustrative embodiment has several modes of operation, namely: a Recharge Card Loading Mode during which one or more metal-fuel cards are automatically loaded from the recharged metal-fuel card storage bin **188**A into the discharging bay of the Metal-Fuel Card Discharging Subsystem **186**, Discharged Card Loading Mode during which one or more metal-fuel cards are automatically loaded from the discharged metal-fuel card storage bin into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**; a Discharging Mode during which electrical power is produced from metal-fuel cards **187** loaded into the Metal-Fuel Card Discharging Subsystem **186** by electrochemical oxidation, and supplied to the electrical load connected to the output of the subsystem; a Recharging Mode during which metal-fuel cards loaded into the Metal-Fuel Card Recharging Subsystem **191** are recharged by electrochemical reduction; and a Discharged Card Unloading Mode during which one or more metal-fuel cards are automatically unloaded from the discharging bay of the system into the discharged metal-fuel card storage bin **188**B thereof; and a Recharged Card Unloading Mode, during which one or more recharged metal-fuel cards are automatically unloaded from the recharging bay of the Metal-Fuel Card Recharging Subsystem **191** into the recharged metal-fuel card storage bin **188**A. These modes will be described in greater detail hereinafter.

[**0585**] Multi-Zone Metal-Fuel Card Used in the FCB System of the Fifth Illustrative Embodiment

[**0586**] In the FCB system of **FIG. 6**, each metal-fuel card **187** has multiple fuel-tracks (e.g. five zones) as taught in copending application Ser. No. 08/944,507, supra. When using such a metal-fuel card design, it is desirable to design each discharging head **197** within the Metal-Fuel Card Discharging Subsystem **186** as a "multi-zoned" discharging head. Similarly, each recharging head **197'** within the Metal-

Fuel Card Recharging Subsystem **191** hereof should be designed as a multi-zoned recharging head in accordance with the principles of the present invention. As taught in great detail in copending application Ser. No. 08/944,507, the use of "multi-zoned" metal-fuel cards **187** and multi-zoned discharging heads **197** enables the simultaneous production of multiple output voltages {V1, V2, . . . , Vn} selectable by the end user. Such output voltages can be used for driving various types of electrical loads **200** connected to the output power terminals **201** of the Metal-Fuel Card Discharging Subsystem. This is achieved by selectively configuring the individual output voltages produced across each anode-cathode structure within the discharging heads during card discharging operations. This system functionality will be described in greater detail hereinbelow.

[0587] In general, multi-zone and single-zone metal-fuel cards **187** alike can be made using several different techniques. Preferably, the metal-fuel elements contained with each card-like device **187** is made from zinc as this metal is inexpensive, environmentally safe, and easy to work. Several different techniques will be described below for making zinc-fuel elements according to this embodiment of the present invention.

[0588] For example, in accordance with a first fabrication technique, a thin metal layer (e.g. nickel or brass) of about 0.1 to about 5 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of a card-like structure). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of the thin metal layer is to provide efficient current collection at the anode surface. Thereafter, zinc powder is mixed with a binder material and then applied as a coating (e.g. 1-500 microns thick) upon the surface of the thin metal layer. The zinc layer should have a uniform porosity of about 50% to allow the ions within the ionically-conducting medium (e.g. electrolyte ions) to flow with minimum electrical resistance between the cathode and anode structures. As will be explained in greater detail hereinafter, the resulting metal-fuel structure can be mounted within an electrically insulating casing of thin dimensions to improve the structural integrity of the metal-fuel card **187**, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay. The casing of the metal-fuel card can be provided with a slidable panel that enables access to the metal-fuel strips when the card is received in the storage bay and the discharging head is transported into position for discharging operations.

[0589] In accordance with a second fabrication technique, a thin metal layer (e.g. nickel or brass) of about 0.1 to about 5 microns thickness is applied to the surface of low-density plastic material (drawn and cut in the form of card). The plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. The function of the thin metal layer is to provide efficient current collection at the anode surface. Thereafter zinc is electroplated onto the surface of the thin layer of metal. The zinc layer should have a uniform porosity of about 50% to allow ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the cathode and anode structures. As will be explained in greater detail hereinafter, the resulting metal-fuel structures can be mounted within an electrically insulating casing of thin dimensions to provide a metal-fuel card having suitable structural integrity, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay. The casing of the metal-fuel card can be provided with slidable panels that enable access to the metal-fuel strips when the card is received in the storage bay and the discharging head is transported into position for discharging operations.

[0590] In accordance with a third fabrication technique, zinc power is mixed with a low-density plastic base material and drawn into electrically-conductive sheets. The low-density plastic material should be selected so that it is stable in the presence of an electrolyte such as KOH. Each electrically-conductive sheet should have a uniform porosity of about 50% to allow ions within the ionically-conducting medium (e.g. electrolyte) to flow with minimum electrical resistance between the current collecting elements of the cathode and anode structures. Then a thin metal layer (e.g. nickel or brass) of about 1 to 10 microns thickness is applied to the surface of the electrically-conductive sheet. The function of the thin metal layer is to provide efficient current collection at the anode surface. As will be explained in greater detail hereinafter, the resulting metal-fuel structures can be mounted within an electrically insulating casing of thin dimensions to provide a metal-fuel card having suitable structural integrity, while providing the discharging heads access to the anode structure when the card is loaded within its card storage bay. The card housing can be made from any suitable material designed to withstand heat and corrosion. Preferably, the housing material is electrically non-conducting to provide an added measure of user-safety during card discharging and recharging operations.

[0591] Each of the above-described techniques for manufacturing metal-fuel elements can be ready modified to produce "double-sided" metal-fuel cards, in which single track or multi-track metal-fuel layers are provided on both sides of the base (i.e. substrate) material. Such embodiments of metal-fuel cards will be useful in applications where discharging heads are to be arranged on both sides of metal-fuel tape loaded within the FCB system. When making double-sided metal-fuel tape, it will be necessary in most embodiments to form a current collecting layer (of thin metal material) on both sides of the plastic substrate so that current can be collected from both sides of the metal-fuel tape, associated with different cathode structures. When making double-sided multi-tracked fuel cards, it may be desirable or necessary to laminate together two metal-fuel sheets together, as described hereinabove, with the substrates of each sheet in physical contact. Adaptation of the above-described methods to produce double-sided metal-fuel cards will be readily apparent to those skilled in the art having had the benefit of the present disclosure. In such illustrative embodiments of the present invention, the anode-contacting structures within the each discharging head will be modified so that electrical contact is established with each electrically-isolated current collecting layer formed within the metal-fuel card structure being employed therewith.

[0592] Card Loading/Unloading Subsystem for the Fifth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0593] As schematically illustrated in **FIG. 7A1**, the function of the Recharge Card Loading Subsystem **189** is to automatically transport a plurality of recharged metal-fuel cards from the bottom of the stack of recharged metal-fuel cards **187** in the recharged metal-fuel card storage bin **188**A into the discharging bay of the Metal-Fuel Card Discharging Subsystem **182**. As shown in **FIG. 7**A**2**, the function of the Discharged Card Unloading Subsystem **190** is to automatically transport a plurality of oxidized metal-fuel cards **187**' from the discharging bay of the Metal-Fuel Card Discharging Subsystem **186**, to the top of the stack of discharged metal-fuel cards in the discharged metal-fuel card storage bin **188**B. As shown in **FIG. 7**B**1**, the function of the Discharged Card Loading Subsystem **192** is to automatically transport a plurality of oxidized metal-fuel cards from the bottom of the stack of discharged metal-fuel cards **187**' in the discharged metal-fuel card storage bin **191** into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**. As shown in **FIG. 7**B**2**, the function of the Recharged Card Unloading Subsystem **193** is to automatically transport a plurality of recharged metal-fuel cards **197** from the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**, to the top of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage bin **188**A.

[**0594**] As shown in **FIG. 7**A**1**, the Recharged Card Loading Subsystem **189** can be realized by any electro-mechanism mechanism comprising, for example, an electric motor, rollers, guides and other components arranged in such a manner as to enable the sequential transport of a recharged metal-fuel card from the bottom of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage bin **188**A, into the discharging bay of the Metal-Fuel Card Discharging Subsystem, where the cathode and anode structures of the discharging heads **197** are arranged. This electromechanical card transport mechanism is operably connected to the system controller **203**.

[**0595**] As shown in **FIG. 7**A**2**, the Discharged Card Unloading Subsystem **190** can be realized by any electro-mechanism mechanism comprising, for example, an electric motor, rollers, guides and other components arranged in such a manner as to enable the sequential transport of discharged metal-fuel cards from the discharging bay of the Metal-Fuel Card Discharging Subsystem to the top of the stack of discharged metal-fuel cards in the discharged metal-fuel card storage bin **188**B, where the cathode and anode structures of the discharging heads **197** are arranged. This electromechanical card transport mechanism is operably connected to the system controller **203**.

[**0596**] As shown in **FIG. 7**B**1**, the Discharged Card Loading Subsystem **190** can be realized by any electro-mechanism mechanism comprising, for example, an electric motor, rollers, guides and other components arranged in such a manner as to enable the sequential transport of discharged metal-fuel cards from the bottom of the stack of discharged metal-fuel cards in the discharged metal-fuel card storage bin **188**B, into the recharging bay of the Metal-Fuel Card Recharging Subsystem, where the cathode and anode structures of the discharging heads are arranged. This electromechanical card transport mechanism is operably connected to the system controller **203**.

[**0597**] As shown in **FIG. 7**B**2**, the Recharged Card Unloading Subsystem **193** can be realized by any electro-mechanism mechanism comprising, for example, an electric motor, rollers, guides and other components arranged in such a manner as to enable the sequential transport of recharged metal-fuel cards from the recharging bay of the Metal-Fuel Card Recharging Subsystem, to the top of the stack of recharged metal-fuel cards in the recharged metal-fuel card storage bin **188**A, where the cathode and anode structures of the discharging heads are arranged. This electromechanical card transport mechanism is operably connected to the system controller **203**.

[**0598**] The Metal-Fuel Card Discharging Subsystem for the Fifth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[**0599**] As shown in FIGS. **7**A**3** and **7**A**4**, the metal-fuel card discharging subsystem **182** of the fifth illustrative embodiment of the present invention comprises a number of subsystems, namely: an assembly of multi-track discharging (i.e. discharging) heads **197**, each having multi-element cathode structures **198** and anode-contacting structures **199** with electrically-conductive output terminals connectable in a manner to be described hereinbelow; a discharging head transport subsystem **204** for transporting the subcomponents of the discharging head assembly **197** to and from metal-fuel cards **197** loaded within the system; a cathode-electrolyte output terminal configuration subsystem **205** for configuring the output terminals of the cathode and anode-contacting structures of the discharging heads under the control of system controller **203** so as to maintain the output voltage required by a particular electrical load connected to the Metal-Fuel Card Discharging Subsystem **186**; a cathode-electrolyte voltage monitoring subsystem **206**A, connected to the cathode-electrolyte output terminal configuration subsystem **205** for monitoring (i.e. sampling) the voltages produced across cathode and anode structures of each discharging head, and producing (digital) data representative of the sensed voltage levels; a cathode-electrolyte current monitoring subsystem **206**B, connected to the cathode-electrolyte output terminal configuration subsystem **205**, for monitoring (e.g. sampling) the currents flowing through the cathode-electrolyte interfaces of each discharging head during the Discharging Mode, and producing digital data representative of the sensed current levels; a cathode oxygen pressure control subsystem comprising the system controller **203**, solid-state pO_2 sensors **250**, vacuum chamber (structure) **207** shown in FIGS. **7**A**7** and **7**A**8**, vacuum pump **208**, electronically-controlled airflow control device **209**, manifold structure **210**, and multi-lumen tubing **211** shown in FIGS. **7**A**3** and **7**A**4**, arranged together as shown for sensing and controlling the pO2 level within the cathode structure of each discharging head **197**; an ion transport control subsystem comprising the system controller **203**, solid-state moisture sensor (hydrometer) **212**, moisturizing (e.g. micro-sprinklering element) **213** realized as a micro-sprinkler embodied within the walls structures of the cathode support plate **198** (having water expressing holes **214** disposed along each wall surface as shown in **FIG. 7**A**6**), a water pump **215**, a water reservoir **216**, an electronically-controlled water-flow control valve **217**, a manifold structure **28** and multi-lumen conduits **219** extending into moisture delivery structure **213**, arranged together as shown for sensing and modifying conditions within the FCB system (e.g. the moisture level or relative humidity level at the cathode-electrolyte interface of the discharging heads) so that the ion-concentration at the cathode-electrolyte interface is maintained within an optimal range during the Discharging Mode of operation; discharge head temperature control subsystem comprising the system controller **203**, solid-state temperature sensors (e.g. thermistors) **305** embedded within each channel of the multi-cathode support plate **198** hereof, and a discharge head cooling device **306**, responsive to control signals produced by the system controller **203**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations; a relational-type Metal-Fuel Database Management Subsystem (MFDMS) **308** operably connected to system controller **203** by way of local system bus **309**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Card Discharging Subsystem **186**; a Data Capture and Processing Subsystem (DCPS) **400**, comprising data reading head **260** (**260**', **260**") embedded within or mounted closely to the cathode support structure of each discharging head **197**, and a programmed microprocessor-based data processor adapted to receive data signals produced from cathode-electrolyte voltage monitoring subsystem **206**A, cathode-electrolyte current monitoring subsystem **206**B, the cathode oxygen pressure control subsystem and the ion-concentration control subsystem hereof, and enable (i) the reading metal-fuel card identification data from the loaded metal-fuel card, (ii) the recording sensed discharge parameters and computed metal-oxide indicative data derived therefrom in the Metal-Fuel Database Management Subsystem **308** using local system bus **401**, and (iii) the reading prerecorded recharge parameters and prerecorded metal-fuel indicative data stored in the Metal-Fuel Database Management Subsystem (MFDMS) **308** using local system bus **309**; a discharging (i.e. output) power regulation subsystem **223** connected between the output terminals of the cathode-electrolyte output terminal configuration subsystem **205** and the input terminals of the electrical load **200** connected to the Metal-Fuel Card Discharging Subsystem **186**, for regulating the output power delivered across the electrical load (and regulate the voltage and/or current characteristics as required by the Discharge Power Control Method carried out by the system controller **203**); an input/output control subsystem **224**, interfaced with the system controller **203**, interfaced with system controller **203**' within the Metal-Fuel Card Recharging Subsystem **117** by way of global system bus **402** as shown in **FIG. 7**B**14**, and having various means for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **203** for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[0600] Multi-Zone Discharging Head Assembly within the Metal-Fuel Card Discharging Subsystem

[0601] The function of the assembly of multi-zone discharging heads **197** is to generate electrical power across the electrical load **200** as one or more metal-fuel cards **187** are discharged during the Discharging Mode of operation. In the illustrative embodiment, each discharging (i.e. discharging) head **197** comprises: a cathode element support plate **34** having a plurality of isolated recesses **224**A through **224**D permitting the free flow of oxygen (**02**) through perforations **225** formed in the bottom portion thereof; a plurality of electrically-conductive cathode elements (e.g. strips) **196**A through **196**D for insertion within the lower portion of these recesses **224**A through **224**D, respectively; a plurality of electrolyte impregnated strips **226**A through **226**D for placement over the cathode strips **196**A through **196**D, and support within the recesses **225**A through **225**D, respectively, as shown in **FIG. 7**A**12**; and oxygen-injection chamber **207** shown in **FIG. 7**A**7** mounted over the upper (back) surface of the cathode element support plate **198**, in a sealed manner as shown in **FIG. 7**A**12**.

[0602] As shown in **FIG. 7**A**3** and **7**A**4**, each oxygen-injection chamber **207** has a plurality of subchambers **207**A through **207**D, being physically associated with recesses **224**A through **224**D, respectively. Each vacuum subchamber is isolated from all other subchambers and is in fluid communication with one channel supporting a cathode element and electrolyte-impregnated element. As shown, each subchamber is arranged in fluid communication with vacuum pump **208** via one lumen of multi-lumen tubing **211**, one channel of manifold assembly **210** and one channel of air-flow switch **209**, each of whose operation is managed by system controller **203**. This arrangement enables the system controller **203** to independently control the pO2 level in each oxygen-injection subchamber **207**A through **207**D by selectively pumping pressurized air through the corresponding air flow channel in the manifold assembly **210**.

[0603] As shown in **FIG. 7**A**8**A, each electrolyte-impregnated strip **226**A through **226**D is realized by impregnating an electrolyte-absorbing carrier strip with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for the discharging cell is made from a formula consisting of alkali solution, a gelatin material, water, and additives well known in the art.

[0604] As shown in **FIG. 7**A**8**A, each cathode strip **196**A through **196**D is made from a sheet of nickel wire mesh **228** coated with porous carbon material and granulated platinum or other catalysts **229** to form a cathode element that is suitable for use in metal-air FCB systems. Details of cathode construction for use in air-metal FCB systems are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor (nickel) **230** is soldered to the underlying wire mesh sheet **228** of each cathode strip. As shown in **FIG. 7**A**12**, each electrical conductor **230**, attached to its cathode strip is passed through a hole **231** formed in the bottom surface of a recess of the cathode support plate **198**, and is connected to an electrical conductor (e.g. wire) which extends out from its respective subchamber and terminates at a conventional conductor **235**A. During assembly, the cathode strip pressed into the lower portion of the recess to secure the same therein.

[0605] As shown in **FIG. 7**A**6**, the bottom surface of each recess **224**A through **224**D has numerous perforations **225** formed therein to allow the free passage of air and oxygen therethrough to the cathode strip **196**A through **196**D (at atmospheric temperature and pressure). In the illustrative embodiment, an electrolyte-impregnated strip **226**A through **226**D are placed over cathode strips **196**A through **196**D, respectively, and secured within the upper portion of the cathode supporting recess by adhesive, retaining structures or the like. As shown in **FIG. 7**A**12**, when the cathode strips and thin electrolyte strips are mounted in their respective recesses in the cathode support plate **198**, the outer surface of each electrolyte-impregnated strip is disposed flush with the upper surface of the plate defining the recesses.

[0606] The interior surfaces of the cathode support recesses **224**A through **224**D are coated with a hydrophobic material (e.g. Teflon®) to ensure the expulsion of water within electrolyte-impregnated strips **226**A through **226**D and thus optimum oxygen transport across the cathode strips. Hydrophobic agents are added to the carbon material constituting the oxygen-pervious cathode elements in order to repel water therefrom. Preferably, the cathode support plate is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate can be fabricated using injection molding technology also well known in the art.

[0607] In **FIG.** 7A7, the oxygen-injection chamber **207** is shown realized as a plate-like structure having dimensions similar to that of the cathode support plate **198**. As shown in **FIG.** 7A7, the oxygen-injection chamber has four (4) recesses **207**A through **207**D which spatially correspond to and are in spatial registration with cathode recesses **224**A through **224**D, respectively, when oxygen-injection chamber **207** is mounted upon the top surface of the cathode support plate **198**, as shown in **FIG.** 7A**12**. Four small conduits are formed within the recessed plate **207**, namely: between inlet opening **207**E1 and outlet opening **207**A1; between inlet opening **207**E2 and outlet opening **207**B1; between inlet opening **207**E3 and outlet opening **207**C1; and between inlet opening **207**E4 and outlet opening **207**D1. When recessed plate **207** is mounted upon the cathode support plate **198**, subchambers **207**A through **207**D are formed between recesses **207**A through **207**D and the back portion of the perforated cathode support plate **198**. Each lumen of the multi-lumen conduit **211** is connected to one of the four inlet openings **207**E1 through **207**E4, and thereby arranges the subchambers **207**A through **207**D in fluid communication with the four controlled O_2-flow channels within the pO_2 control subsystem in the Discharging Subsystem **186**.

[0608] The structure of the multi-tracked fuel card **187** loaded into the FCB system of **FIG. 6** is illustrated in FIGS. **7**A**9** and **7**A**10**. As shown, the metal fuel card comprises: electrically nonconductive anode support plate **228** of rigid construction, having a plurality of recesses **231**A through **231**D formed therein and a central hole **230** formed through the bottom surface of each recess; and the plurality of strips of metal (e.g. zinc fuel) **195**A through **195**D, each being disposed within a recess within the anode support plate **228**. Notably, the spacing and width of each metal fuel strip is designed so that it is spatially registered with a corresponding cathode strip in the discharging head of the system in which the fuel card is intended to be used. The metal-fuel card described above can be made by forming zinc strips in the shape of recesses in the anode support plate, and then inserting a metal fuel strip into each of the recesses. When inserted within its respective recess in the cathode-electrolyte support plate **228**, each metal fuel strip is electrically isolated from all other metal fuel strips.

[0609] In **FIG.** 7A**11**, an exemplary metal-fuel (anode) contacting structure (assembly) **199** is disclosed for use with the multi-tracked fuel card **187** having cathode support structure **228** shown in **FIG.** 7A6. As shown in **FIG.** 7A**11**, a plurality of electrically conductive elements **232**A through **232**D in the form of conductive posts are supported from a metal-fuel contacting support platform **233**. The position of these electrically conductive posts spatially coincide with the holes **230** formed in the bottom surfaces of recesses **229**A through **229**D in the anode supporting plate **228**. As shown, electrical conductors **234**A through **234**D are electrically connected to conductive posts **232**A through **232**D respectively, and anchored along the surface of the anode support plate (e.g. within a recessed groove) and terminate in a conventional connector **235**B similar to conductors terminating at electrical connector **235**A. This connector is electrically connected to the output cathode-electrolyte terminal configuration subsystem **205** as shown in FIGS. **7**A**3** and **7**A**4**. The width and length dimensions of the anode-contacting support plate **233** are substantially similar to the width and length dimensions of the cathode support plate **198** as well as the anode (metal-fuel) support plate **228**.

[0610] **FIG.** 7A**12** illustrates the spatial relationship between the anode contacting support plate **199**, cathode support plate **198**, oxygen-injection chamber plate **207**, and anode (metal-fuel) support plate (i.e. fuel card) **228** when the fuel card **187** is loaded therebetween. In this loaded configuration, each cathode element **196**A through **196**D along the cathode support plate establishes ionic contact with the front exposed surface of the corresponding metal fuel strip (i.e. zone) **195**A through **195**D by way of the electrolyte-impregnated pad **226**A through **226**D disposed therebetween Also, in this loaded configuration, each anode-contacting element (e.g. conductive post) **232**A through **232**D projects from the anode contacting support plate **233** through the central hole **230** in the bottom panel of each recess formed in the anode contacting support plate **199** and establishes electrical contact with the corresponding metal fuel strip **195**A through **195**D mounted therein, completing an electrical circuit through a single air-metal fuel cell of the present invention.

[0611] Discharging Head Transport Subsystem within the Metal-Fuel Card Discharging Subsystem

[0612] The primary function of the discharging head transport subsystem **204** is to transport the assembly of discharging heads **197** about the metal-fuel cards **187** that have been loaded into the FCB system, as shown in **FIG.** 7A3. When properly transported, the cathode and anode-contacting structures of the discharging heads are brought into "ionically-conductive" and "electrically-conductive" contact with the metal-fuel tracks (i.e. zones) of loaded metal-fuel cards loaded within the system during the Discharging Mode of operation.

[0613] Discharging head transport subsystem **204** can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode supporting and anode-contacting structures of each discharging head **197** away from the metal-fuel card **112**, as shown in **FIG.** 7A3, and about the metal-fuel card **187** as shown in **FIG.** 7A4. As shown, these transport mechanisms are operably connected to system controller **203** and controlled by the same in accordance with the system control program carried out thereby.

[0614] Cathode-Anode Output Terminal Configuration Subsystem within the Metal-Fuel Card Discharging Subsystem

[0615] As shown in FIGS. **7**A**3** and **7**A**4**, the cathode-electrolyte output terminal configuration subsystem **205** is connected between the input terminals of the discharging power regulation subsystem **233** and the output terminals of the cathode-electrolyte pairs within the assembly of discharging heads **197**. The system controller **203** is operably connected to cathode-electrolyte output terminal configuration subsystem **205** in order to supply control signals for carrying out its functions during the Discharging Mode of operation.

[**0616**] The function of the cathode-electrolyte output terminal configuration subsystem **205** is to automatically configure (in series or parallel) the output terminals of selected cathode-electrolyte pairs within the discharging heads **197** of the Metal-Fuel Card Discharging Subsystem **186** so that the required output voltage level is produced across the electrical load **200** connected to the FCB system during card discharging operations. In the illustrative embodiment of the present invention, the cathode-electrolyte output terminal configuration mechanism **205** can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the discharging heads **197** are connected to the input terminals of the discharging power regulating subsystem **223**. Such switching operations are carried out under the control of the system controller **203** so that the required output voltage is produced across the electrical load connected to the discharging power regulating subsystem **151** of the FCB system.

[**0617**] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0618**] As shown in FIGS. **7A3** and **7A4**, the cathode-electrolyte voltage monitoring subsystem **206**A is operably connected to the cathode-electrolyte output terminal configuration subsystem **205** for sensing voltage levels and the like therewithin. This subsystem is also operably connected to the system controller for receiving control signals required to carry out its functions. In the first illustrative embodiment, the cathode-electrolyte voltage monitoring subsystem **206**A has two primary functions: to automatically sense the instantaneous voltage level produced across the cathode-electrolyte structures associated with each metal-fuel zone within each discharging head **197** during the Discharging Mode; and to produce a (digital) data signal indicative of the sensed voltages for detection, analysis and response by Data Capture and Processing Subsystem **400**.

[**0619**] In the first illustrative embodiment of the present invention, the Cathode-Anode Voltage Monitoring Subsystem **206A** can be realized using electronic circuitry adapted for sensing voltage levels produced across the cathode-electrolyte structures associated with each metal-fuel zone disposed within each discharging head **197** in the Metal-Fuel Card Discharging Subsystem **186**. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels for detection and analysis by Data Capture and Processing Subsystem **400**.

[**0620**] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0621**] As shown in FIGS. **7A3** and **7A4**, the cathode-electrolyte current monitoring subsystem **206**B is operably connected to the cathode-electrolyte output terminal configuration subsystem **205**. The cathode-electrolyte current monitoring subsystem **206**B has two primary functions: to automatically sense the magnitude of electrical currents flowing through the cathode-electrolyte pair of each metal-fuel zone within each discharging head **197** in the Metal-Fuel Card Discharging Subsystem **186** during the Discharging Mode; and to produce digital data signals indicative of the sensed currents for detection and analysis by Data Capture and Processing Subsystem **400**. In the first illustrative embodiment of the present invention, the cathode-electrolyte current monitoring subsystem **206**B can be realized using current sensing circuitry for sensing electrical currents flowing through the cathode-electrolyte pairs of each metal-fuel zone within each discharging head **197**, and producing digital data signals indicative of the sensed currents. As will be explained in greater detail hereinafter, these detected current levels are used by the system controller **203** in carrying out its discharging power regulation method, and well as creating a "discharging condition history" and metal-fuel availability records for each fuel zone on the discharged metal-fuel card.

[**0622**] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0623**] The function of the cathode oxygen pressure control subsystem is to sense the oxygen pressure (pO_2) within each channel of the cathode structure of each discharging head **197**, and in response thereto, control (i.e. increase or decrease) the same by regulating the air (O_2) pressure within the chambers of such cathode structures. In accordance with the present invention, partial oxygen pressure (PO_2) within each channel of the cathode structure of each discharging head is maintained at an optimal level in order to allow optimal oxygen consumption within the discharging heads during the Discharging Mode. By maintaining the pO2 level within the cathode structure, power output produced from the discharging heads can be increased in a controllable manner. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by the Data Capture and Processing Subsystem **400**, the system controller **203** is provided with a controllable variable for use in regulating the electrical power supplied to the electrical load **200** during the Discharging Mode.

[**0624**] Ion-Concentration Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0625**] In order to achieve high-energy efficiency during the Discharging Mode, it is necessary to maintain an optimal concentration of (charge-carrying) ions at the cathode-electrolyte interface of each discharging head **197** within the Metal-Fuel card Discharging Subsystem **186**. Thus it is the primary function of the ion-concentration control subsystem to sense and modify conditions within the FCB system so that the ion concentration at the cathode-electrolyte interface within the discharging head is maintained within an optimal range during the Discharge Mode of operation.

[**0626**] In the illustrative embodiment, ion-concentration control is achieved in a variety of ways by embedding a miniature solid-state humidity (or moisture) sensor **212** within each recess of the cathode support structure **198** (or as close as possible to the anode-cathode interfaces) in order to sense moisture conditions and produce a digital data signal indicative thereof. This digital data signal is supplied to the Data Capture and Processing Subsystem **400** for detection and analysis. In the event that the moisture level drops below the predetermined threshold value set in memory (ROM) within the system controller **203**, the system controller automatically generates a control signal supplied to a moisturizing element **213** realizable as a micro-sprinkler structure **143** embodied within the walls of the cathode support structure **198**. In the illustrative embodiment, the walls of the cathode support structure **198** function as water carrying conduits which express water droplets out of holes **214** adjacent the particular cathode elements when water-flow valve **217** and pump **215** are activated by the system controller **203**. Under such conditions, water is pumped from reservoir **216** through manifold **218** along multi-lumen conduit **219** and is expressed from holes **214** adjacent the cathode element requiring an increase in moisture level, as sensed by moisture sensor **212**. Such moisture-level sensing and control operations ensure that the concentration of KOH within the electrolyte within electrolyte-impregnated strips **226**A through **226**E is optimally maintained for ion transport and thus power generation.

[**0627**] Discharge Head Temperature Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[**0628**] As shown in FIGS. **7A3**, **7A4**, and **7A7**, the discharge head temperature control subsystem incorporated within the Metal-Fuel Card Discharging Subsystem **186** of the first illustrative embodiment comprises a number of subcomponents, namely: the system controller **203**; solid-state temperature sensors (e.g. thermistors) **305** embedded within each channel of the multi-cathode support structure hereof **198**, as shown in **FIG. 7A6**; and a discharge head cooling device **306**, responsive to control signals produced by the system controller **203**, for lowering the temperature of each discharging channel to within an optimal temperature range during discharging operations. The discharge head cooling device **306** can be realized using a wide variety of heat-exchanging techniques, including forced-air cooling, water-cooling, and/or refrigerant cooling, each well known in the heat exchanging art. In some embodiments of the present invention, where high levels of electrical power are being generated, it may be desirable to provide a jacket-like structure about each discharge head in order to circulate air, water or refrigerant for temperature control purposes.

[**0629**] Data Capture and Processing Subsystem within the Metal-Fuel Tape Discharging Subsystem

[**0630**] In the illustrative embodiment of **FIG. 6**, Data Capture And Processing Subsystem (DCPS) **400** shown in FIGS. **7A3** and **7A4** carries out a number of functions, including, for example: (1) identifying each metal-fuel card immediately before it is loaded within a particular discharging head **197** within the discharging head assembly and producing metal-fuel card identification data representative thereof; (2) sensing (i.e. detecting) various "discharge parameters" within the Metal-Fuel Card Discharging Subsystem **186** existing during the time period that the identified metal-fuel card is loaded within the discharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-oxide produced during card discharging operations, and producing "metal-oxide indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **400** (accessible by system controllers **203** and **203**'), sensed discharge parameter data as well as computed metal-fuel indicative data both correlated to its respective metal-fuel zone/card identified during the Discharging Mode of operation. As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **308** by Data Capture and Processing Subsystem **400** can be used by the system controller **203** in various ways including, for example: optimally discharging (i.e. producing electrical power from) partially or completely oxidized metal-fuel cards in an efficient manner during the Discharging Mode of operation; and optimally recharging partially or completely oxidized metal-fuel cards in a rapid manner during the Recharging Mode of operation.

[**0631**] During discharging operations, the Data Capture and Processing Subsystem **400** automatically samples (or captures) data signals representative of "discharge parameters" associated with the various subsystems constituting the Metal-Fuel Card Discharging Subsystem **186** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Discharging Mode. In accordance with the principles of the present invention, card-type "discharge parameters" shall include, but are not limited to: the discharging voltages produced across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte voltage monitoring subsystem **206**A; the electrical (discharging) currents flowing across the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte current monitoring subsystem **206**B; the oxygen saturation level (pO_{2d}) within the cathode structure of each discharging head **197**, monitored by the cathode oxygen pressure control subsystem (**203, 270, 207, 208, 209, 210, 211**); the moisture (H_2O_d) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular discharging heads monitored, for example, by the ion-concentration control subsystem (**203, 212, 213, 214, 215, 216, 217, 218** and **219**); the temperature (T_r) of the discharging heads during card discharging operations; and the time duration (Δt_d) of the state of any of the above-identified discharge parameters.

[**0632**] In general, there a number of different ways in which the Data Capture and Processing Subsystem **400** can record card-type "discharge parameters" during the Recharging Mode of operation. These different methods will be detailed hereinbelow.

[**0633**] According to a first method of data recording shown in **FIG. 7B9**, card identifying code or indicia (e.g. miniature bar code symbol encoded with zone identifying information) **240** can be graphically printed on "optical" data track **241** during card manufacture, and can be read by an optical data reader **260** embodied within or adjacent each discharging head. The optical data reading head **260** can be realized using optical scanning/decoding techniques (e.g. laser scanning bar code symbol readers, or optical decoders) well known in the art. In the illustrative embodiment, information representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **400**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **308** during discharging operations.

[**0634**] According to a second method of data recording illustrated in **FIG. 7B9**, a digital "card identifying" code

240' is magnetically recorded in magnetic data track 241' during card manufacture, and can be read during discharging operations using a magnetic reading head 270' embodied within or supported adjacent each discharging head. Each magnetic reading head 260' can be realized using magnetic information reading techniques (e.g. magstripe reading apparatus) well known in the art. In the illustrative embodiment, the digital data representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem 400, and subsequent recorded within the Metal-Fuel Database Management Subsystem 308 during discharging operations.

[0635] According to a third method of data recording shown in FIG. 7B9, a unique digital "card identifying" code 240" is recorded as a sequence of light transmission apertures formed in an optically opaque data track 241" during card manufacture, and can be read during discharging operations by an optical sensing head 260" realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem 400, and subsequent recorded within the Metal-Fuel Database Management Subsystem 308 during discharging operations.

[0636] According to a fourth alternative method of data recording, both unique digital "card identifying" code and set of discharge parameters for each track on the identified metal-fuel card are recorded in a magnetic, optical, or apertured data track, realized as a strip attached to the surface of the metal-fuel card of the present invention. The block of information pertaining to a particular metal-fuel card can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information during the Discharging Mode of operation. Typically, the block of information will include the metal-fuel card identification number and a set of discharge parameters, as schematically indicated in FIG. 7B13, which are automatically detected by the Data Capture and Processing Subsystem 400 as the metal-fuel card is loaded within the discharging head assembly 197.

[0637] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel card can have a very low information capacity. This is because very little information needs to be recorded to tag each metal fuel card with a unique identifier (i.e. address number or card identification number), to which sensed discharge parameters are recorded in the Metal-Fuel Database Management Subsystem 308. Also, formation of a data track in accordance with the first and second methods should be very inexpensive, as well as providing apparatus for reading card identifying information recorded along such data tracks.

[0638] Discharging Power Regulation Subsystem within the Metal-Fuel Card Discharging Subsystem

[0639] As shown in FIGS. 7A3 and 7B4, the input port of the recharging power regulation subsystem 223 is operably connected to the output port of the cathode-electrolyte input terminal configuration subsystem 205, whereas the output port of the recharging power regulation subsystem 223 is operably connected to the input port of the electrical load 200. While the primary function of the discharging power regulation subsystem 223 is to regulate the electrical power delivered the electrical load 200 during its Discharging Mode of operation (i.e. produced from discharged metal-fuel cards loaded within the discharging heads hereof), the discharging power regulation subsystem 223 has a mode of programmed operation, wherein the output voltage across the electrical load as well as the electrical current flowing across the cathode-electrolyte interface are regulated during discharging operations. Such control functions are managed by the system controller 203 and can be programmably selected in a variety of ways in order to achieve optimal regulation to the electrical load 200 as multi-tracked and single-tracked metal-fuel cards are discharged in accordance with the principles of the present invention.

[0640] The discharging power regulating subsystem 223 can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistor-controlled technology, in which one or more current-controlled sources are connectable in electrical series with the cathode and anode structures in order to control the electrical currents therethrough in response to control signals produced by the system controller 203 carrying out a particular Discharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which one or more voltage-controlled sources are connectable in electrical parallel with the cathode and anode structures in order to control the voltage thereacross in response to control signals produced by the system controller. Such circuitry can be combined and controlled by the system controller 203 in order to provide constant power (and/or voltage and/or current) control across the electrical load 200.

[0641] In the illustrative embodiments of the present invention, the primary function of the discharging power regulation subsystem 223 is to carry out real-time power regulation to the electrical load 200 using any one of the following Discharge Power Control Methods, namely: (1) a Constant Output Voltage/Variable Output Current Method, wherein the output voltage across the electrical load is maintained constant while the current is permitted to vary in response to loading conditions; (2) a Constant Output Current/Variable Output Voltage Method, wherein the current into the electrical load is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Output Voltage/Constant Output Current Method, wherein the voltage across and current into the load are both maintained constant in response to loading conditions; (4) a Constant Output Power Method, wherein the output power across the electrical load is maintained constant in response to loading conditions; (5) a Pulsed Output Power Method, wherein the output power across the electrical load is pulsed with the duty cycle of each power pulse being maintained in accordance with preset conditions; (6) a Constant Output Voltage/Pulsed Output Current Method, wherein the output current into the electrical load is maintained constant while the current into the load is pulsed with a particular duty cycle; and (7) a Pulsed Output Voltage/Constant Output Current Method, wherein the output power into the load is pulsed while the current thereinto is maintained constant.

[0642] In the preferred embodiment of the present invention, each of the seven (7) Discharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **203**. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic or optical condition established or detected at the interface between the electrical load and the Metal-Fuel Card Discharging Subsystem **186**.

[0643] Input/Output Control Subsystem within the Metal-Fuel Card Discharging Subsystem

[0644] In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Card Discharging Subsystems **186** in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Card Discharging Subsystem **186** hereof includes Input/Output Control Subsystem **224** which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Card Discharging Subsystem **186** as if its system controller were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **224** is realized as a standard IEEE I/O bus architecture which provides an external or remote computer system with a way and means of directly interfacing with the system controller **203** of the Metal-Fuel Card Discharging Subsystem **186** and managing various aspects of system and subsystem operation in a straightforward manner.

[0645] System Controller within the Metal-Fuel Card Discharging Subsystem

[0646] As illustrated in the detailed description set forth above, the system controller **203** performs numerous operations in order to carry out the diverse functions of the FCB system within its Discharging Mode. In the preferred embodiment of the FCB system of **FIG. 6**, the system controller **203** is realized using a programmed microcontroller having program and data storage memory (e.g. ROM, EPROM, RAM and the like) and a system bus structure well known in the microcomputing and control arts. In any particular embodiment of the present invention, it is understood that two or more microcontrollers may be combined in order to carry out the diverse set of functions performed by the FCB system hereof. All such embodiments are contemplated embodiments of the system of the present invention.

[0647] Discharging Metal-Fuel Cards Using The Metal-Fuel Card Discharging Subsystem

[0648] FIGS. **7A51** and **7A52** set forth a high-level flow chart describing the basic steps of discharging metal-fuel cards using the Metal-Fuel Card Discharging Subsystem shown in FIGS. **7A3** through **7A4**.

[0649] As indicated at Block A of **FIG. 7A51**, the Recharged Card Loading Subsystem **189** transports four recharged metal-fuel cards **187** from the bottom of the recharged metal-fuel card storage bin **188A** into the card discharging bay of the Metal-Fuel Card Discharging Subsystem **186**, as illustrated in **FIG. 7A1**.

[0650] As indicated at Block B, the Discharge Head Transport Subsystem **204** arranges the recharging heads **197** about the metal-fuel cards loaded into the discharging bay of the Metal-Fuel Card Discharging Subsystem **186** so that the ionically-conducting medium is disposed between each cathode structure and loaded metal-fuel card, as shown in **FIG. 7A2**.

[0651] As indicated at Block C, the Discharge Head Transport Subsystem **204** then configures each discharging head so that its cathode structure is in ionic contact with a loaded metal-fuel card and its anode contacting structure is in electrical contact therewith.

[0652] As indicated at Block D in **FIG. 7A51**, the cathode-electrolyte input terminal configuration subsystem **205** automatically configures the output terminals of each discharging head **197** arranged about a loaded metal-fuel card, and then the system controller **203** controls the Metal-Fuel Card Discharging Subsystem **186** so that electrical power is generated and supplied to the electrical load **200** at the required output voltage and current levels.

[0653] As indicated at Block E in **FIG. 7A52**, when one or more of the metal-fuel cards are discharged, then the Discharged Card Unloading Subsystem **190** transports the discharged metal-fuel cards to the top of the discharged metal-fuel cards in the discharged metal-fuel card storage bin **188B**. Thereafter, as indicated at Block F, the operations recited at Blocks A through E are repeated in order to load additional recharged metal-fuel cards into the discharge bay for discharging.

[0654] Metal-Fuel Card Recharging Subsystem for the Fifth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0655] As shown in FIGS. **7B3** and **7B4**, the Metal-Fuel Card Recharging Subsystem **191** of the fifth illustrative embodiment comprises a number of subsystems, namely: an assembly of multi-track metal-oxide reducing (i.e. recharging) heads **197'**, each having multi-element cathode structures **198'** and anode-contacting structures **199'** with electrically-conductive input terminals connectable in a manner to be described hereinbelow; a recharging head transport subsystem **204'** for transporting the subcomponents of the recharging head assembly **197'**; an input power supply subsystem **243** for converting externally supplied AC power signals into DC power supply signals having voltages suitable for recharging metal-fuel tracks along fuel cards loaded within the recharging heads of the Metal-Fuel Card Recharging Subsystem **191**; a cathode-electrolyte input terminal configuration subsystem **244**, for connecting the output terminals (port) of the input power supply subsystem **243** to the input terminals (port) of the cathode and anode-contacting structures of the recharging heads **197'**, under the control of the system controller **203'** so as to supply input voltages thereto for electro-chemically converting metal-oxide formations into its primary metal during the Recharging Mode; a cathode-electrolyte voltage monitoring subsystem **206A'**, connected to the cathode-electrolyte input terminal configuration subsystem **244**, for monitoring (i.e. sampling) the voltage applied across the cathode and anode structure of each track in each recharging head, and producing (digital) data representative of the sensed voltage levels; a cathode-electrolyte current monitoring subsystem **206B'**, connected to the cathode-electrolyte input terminal configuration subsystem **244**, for monitoring (i.e. sampling) the electrical currents flowing through the cathode and anode structure of each track in each recharging head, and producing (digital) data representative of the sensed current levels; a cathode oxygen pressure control subsystem comprising the system controller **203**', solid-state pO_2 sensors **250**', a vacuum chamber (structure) **207**' as shown in FIGS. **7B7** and **7B8**, a vacuum pump **208**', an electronically-controlled airflow control device **209**', a manifold structure **210**', and multi-lumen tubing **211**' shown in FIGS. **7B3** and **7B4**, arranged together as shown for sensing and controlling the pO_2 level within each channel of the cathode support structure of each recharging head **197**'; an ion-concentration control subsystem comprising system controller **203**', solid-state moisture sensors (hydrometer) **212**', a moisturizing (e.g. micro-sprinklering element) **213**' realized as a micro-sprinkler embodied within the walls structures of the cathode support plate **198**' (having water expressing holes **214**" disposed along each wall surface as shown in **FIG. 7B6**), a water pump **215**', a water reservoir **216**', a water flow control valve **217**', a manifold structure **218**' and multi-lumen conduits **219**' extending into moisture delivery structure **213**', arranged together as shown for sensing and modifying conditions within the FCB system (e.g. the moisture level or relative humidity at the cathode-electrolyte interface of the recharging heads **197**') so that the ion-concentration at the cathode-electrolyte interfaces thereof is maintained within an optimal range during the Recharge Mode of operation to facilitate optimal ion transport threreacross; recharge head temperature control subsystem comprising the system controller **203**', solid-state temperature sensors (e.g. thermistors) **305**' embedded within each channel of the multi-cathode support structure **198**' hereof, and a recharge head cooling device **306**', responsive to control signals produced by the system controller **203**', for lowering the temperature of each recharging channel to within an optimal temperature range during recharging operations; a relational-type metal-fuel database management subsystem (MFDMS) **404** operably connected to system controller **203**' by way of local system bus **405**, and designed for receiving particular types of information derived from the output of various subsystems within the Metal-Fuel Card Recharging Subsystem **191**; a Data Capture and Processing Subsystem (DCPS) **406**, comprising data reading head **270** (**270**', **270**") embedded within or mounted closely to the cathode support structure of each recharging head **197**', and a programmed microprocessor-based data processor adapted to receive data signals produced from cathode-electrolyte voltage monitoring subsystem **206**A', cathode-electrolyte current monitoring subsystem **206**B', the cathode oxygen pressure control subsystem, the recharge head temperature control subsystem and the ion-concentration control subsystem hereof, and enable (i) the reading metal-fuel card identification data from the loaded metal-fuel card, (ii) the recording sensed recharge parameters and computed metal-fuel indicative data derived therefrom in the Metal-Fuel Database Management Subsystem **404** using local system bus **407**, and (iii) the reading prerecorded discharge parameters and prerecorded metal-oxide indicative data stored in the Metal-Fuel Database Management Subsystem **404** using local system bus **405**; an input/output control subsystem **224**', interfaced with the system controller **203**', for controlling all functionalities of the FCB system by way of a remote system or resultant system, within which the FCB system is embedded; and system controller **203**' for managing the operation of the above mentioned subsystems during the various modes of system operation. These subsystems will be described in greater technical detail below.

[0656] Multi-Zone Recharging Head Assembly within the Metal-Fuel Card Recharging Subsystem

[0657] The function of the assembly of multi-zone recharging heads **197**' is to electrochemically reduce metal-oxide formations along the zones of metal-fuel cards loaded within the recharging head assembly during the Recharging Mode of operation. In the illustrative embodiment, each recharging head **197**' comprises: a cathode element support plate **198**' having a plurality of isolated recesses **231**A' through **231**D' with perforated bottom panels permitting the free flow of oxygen (O_2) therethrough; a plurality of electrically-conductive cathode elements (e.g. strips) **196**A' through **196**D' for insertion within the lower portion of these recesses **231**A' through **231**D', respectively; a plurality of electrolyte-impregnated strips **226**A' through **226**D' for placement over the cathode strips **196**A' through **196**D', and support within the recesses, respectively, as shown in **FIG. 7B6**; and oxygen-evacuation chamber **207**' mounted over the upper (back) surface of the cathode element support plate **198**', in a sealed manner, as shown in **FIG. 7B12**.

[0658] As shown in FIGS. **7B3** and **7B4**, the oxygen-evacuation chamber **207**' has a plurality of subchambers **207**A' through **207**D' physically associated with recesses **231**A' through **231**D', respectively. Each vacuum subchamber **207**A' through **207**D' is isolated from all other subchambers and is in fluid communication with one channel supporting a cathode element and an electrolyte-impregnated element. As shown, each with vacuum pump **208**' via one lumen of multi-lumen tubing **211**', one channel of manifold assembly **210**' and one channel of air-flow switch **209**', each of whose operation is controlled by system controller **203**'. This arrangement enables the system controller **203**' to independently control the pO_2 level in each oxygen-evacuation subchamber **207**A' through **207**D' by selectively evacuating air from the chamber through the corresponding air flow channel in the manifold assembly **210**.

[0659] As shown in **FIG. 4**, electrolyte-impregnated strips **226**A' through **226**D' are realized by impregnating an electrolyte-absorbing carrier strip with a gel-type electrolyte. Preferably, the electrolyte-absorbing carrier strip is realized as a strip of low-density, open-cell foam material made from PET plastic. The gel-electrolyte for the discharging cell is made from a formula consisting of alkali solution, a gelatin material, water, and additives well known in the art.

[0660] As shown in **FIG. 7A8A**, each cathode strip **196**A' through **196**D' is made from a sheet of nickel wire mesh **228**' coated with porous carbon material and granulated platinum or other catalysts **229**' to form a cathode element that is suitable for use in metal-air FCB systems. Details of cathode construction for use in air-metal FCB systems are disclosed in U.S. Pat. Nos. 4,894,296 and 4,129,633, incorporated herein by reference. To form a current collection pathway, an electrical conductor (nickel) **230**' is soldered to the underlying wire mesh sheet **228**' of each cathode strip. As shown in **FIG. 7B6**, each electrical conductor **230** attached to its cathode strip is passed through a hole **231**' formed in the bottom surface of a recess of the cathode support plate, and is connected to the cathode-electrolyte input terminal configuration subsystem **244**' shown in FIGS. **7B3** and **7B4**. During assembly, the cathode strip pressed into the lower portion of the recess to secure the same therein.

[0661] As shown in **FIG. 7**B6, the bottom surface of each recess **224**A' through **224**D' has numerous perforations **225**' formed therein to allow the free passage of air and oxygen therethrough to the cathode strip **196**A' through **196**D', respectively, (at atmospheric temperature and pressure). In the illustrative embodiment, electrolyte-impregnated strips **226**A' through **226**D' are placed over cathode strips **196**A' through **196**D', respectively, and are secured within the upper portion of the cathode supporting recesses by adhesive, retaining structures or the like. As shown in **FIG. 7**B12, when the cathode strips and thin electrolyte strips are mounted in their respective recesses in the cathode support plate **198**', the outer surface of each electrolyte-impregnated strip is disposed flush with the upper surface of the cathode support plate **198**'.

[0662] The interior surfaces of the cathode support recesses **224**A' through **224**D' are coated with a hydrophobic material (e.g. Teflon®) **45**" to ensure the expulsion of water within electrolyte-impregnated strips **226**A' through **226**D' and thus optimum oxygen transport across the cathode strips. Hydrophobic agents are added to the carbon material constituting the oxygen-pervious cathode elements in order to repel water therefrom. Preferably, the cathode support plate is made from an electrically non-conductive material, such as polyvinyl chloride (PVC) plastic material well known in the art. The cathode support plate can be fabricated using injection molding technology also well known in the art.

[0663] In **FIG. 7**B7, the oxygen-injection chamber **207**' is shown realized as a plate-like structure having dimensions similar to that of the cathode support plate **198**'. As shown, the oxygen-injection chamber has four (4) recesses **207**A' through **207**D' which spatially correspond to and are in spatial registration with cathode recesses **224**A' through **224**D', respectively, when oxygen-injection chamber **207**' is mounted upon the top surface of the cathode support plate **198**', as shown in **FIG. 7**B12. Four small conduits are formed within the recessed plate **207**', namely: between inlet opening **207**E1' and outlet opening **207**A1'; between inlet opening **207**E2' and outlet opening **207**B1'; between inlet opening **207**E3' and outlet opening **207**C 1'; and between inlet opening **207**E4' and outlet opening **207**D1'. When recessed plate **207**' is mounted upon the cathode support plate **198**', subchambers **207**A' through **207**D' are formed between recesses **207**A' through **207**D' and the back portion of the perforated cathode support plate **198**'. Each lumen of the multi-lumen conduit **211**' is connected to one of the four inlet openings **207**E1' through **207**E4', and thereby arranges the subchambers **207**A' through **207**D' in fluid communication with the four controlled O_2-flow channels within the pO_2 control subsystem in the Recharging Subsystem **191**.

[0664] The structure of an assembled multi-tracked fuel card **187** partially oxidized is illustrated in **FIG. 7**B9. While not shown, metal-oxide patterns are formed along each anode fuel strip **195**A' through **195**D' in response to electrical loading conditions during discharging operations.

[0665] In **FIG. 7**B11, an exemplary metal-fuel (anode) contacting structure (assembly) **199**' is disclosed for use with the multi-tracked fuel card **187** having cathode support structure **228**' shown in **FIG. 7**B6. As shown, a plurality of electrically conductive elements **232**A' through **232**D' in the form of conductive posts are supported from a metal-fuel contacting support platform **233**'. The position of these electrically conductive posts spatially coincide with the holes **230**' formed in the bottom surfaces of recesses **229**A' through **229**D' in the anode supporting plate **228**'. As shown, electrical conductors **234**A' through **234**D' are electrically connected to conductive posts **232**A' through **232**D', respectively, and anchored along the surface of the anode support plate (e.g. within a recessed groove) and terminate in a conventional connector **235**B, similar to conductor terminations at electrical connector **235**A'. This connector is electrically connected to the cathode-electrolyte input terminal configuration subsystem **244** as shown in **FIG. 7**B3 and 7B4. The width and length dimensions of the anode contacting support plate **233** are substantially similar to the width and length dimensions of the cathode support plate **198**' as well as the anode (metal-fuel) support plate **228**'.

[0666] **FIG. 7D** illustrates the spatial relationship between the anode contacting support plate **233**', cathode support plate **198**', oxygen-injection chamber plate **207**', and anode (metal-fuel) support plate (i.e. fuel card) **228** when the fuel card is loaded therebetween. In this loaded configuration, each cathode element **196**A' through **196**D' along the cathode support plate establishes ionic contact with the front exposed surface of the corresponding metal fuel strip (i.e. zone) **195**A' through **195**D' by way of the electrolyte-impregnated pad **226**A' through **226**D' disposed therebetween Also, in this loaded configuration, each anode-contacting element (e.g. conductive post) **232**A'-**232**D' projects from the anode contacting support plate **233**' through the central hole **230**' in the bottom panel of a recess formed in the anode contacting support plate **199**' and establishes electrical contact with the corresponding metal fuel strip mounted therein, completing an electrical circuit through a single air-metal fuel cell of the present invention.

[0667] Recharging Head Transport Subsystem within the Metal-Fuel Card Recharging Subsystem

[0668] The primary function of the recharging head transport subsystem **204**' is to transport the assembly of recharging heads **197**' about the metal-fuel cards that have been loaded into the recharging bay of the subsystem as shown in FIGS. 7B3 and 7B4. When properly transported, the cathode and anode-contacting structures of the recharging heads are brought into "ionically-conductive" and "electrically-conductive" contact with the metal-fuel zones of loaded metal-fuel cards during the Recharging Mode.

[0669] The recharging head transport subsystem **204**' can be realized using any one of a variety of electromechanical mechanisms capable of transporting the cathode supporting and anode-contacting structures of each recharging head **197**' away from the metal-fuel card **187**, as shown in **FIG. 7**B3, and about the metal-fuel card as shown in **FIG. 7**B4. As shown, these transport mechanisms are operably connected to system controller **203**' and controlled by the same in accordance with the system control program carried out thereby.

[0670] Input Power Supply Subsystem within the Metal-Fuel Card Recharging Subsystem

[0671] In the illustrative embodiment, the primary function of the Input Power Supply Subsystem **243** is to receive as input, standard alternating current (AC) electrical power (e.g. at 120 or 220 Volts) through an insulated power cord, and to convert such electrical power into regulated direct current (DC) electrical power at a regulated voltage required at the recharging heads **197**' of the Metal-Fuel Card Recharging Subsystem **191** during the recharging mode of operation. For zinc anodes and carbon cathodes, the required "open-cell" voltage v_{acr} across each anode-cathode structure during recharging is about 2.2-2.3 Volts in order to sustain electro-chemical reduction. This subsystem can be realized in various ways using power conversion and regulation circuitry well known in the art.

[**0672**] Cathode-Anode Input Terminal Configuration Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0673**] As shown in FIGS. **7B3** and **7B4**, the cathode-electrolyte input terminal configuration subsystem **244** is connected between the input terminals of the recharging power regulation subsystem **245** and the input terminals of the cathode-electrolyte pairs associated with multiple tracks of the recharging heads **197**'. The system controller **203**' is operably connected to cathode-electrolyte input terminal configuration subsystem **244** in order to supply control signals thereto for carrying out its functions during the Recharge Mode of operation.

[**0674**] The function of the cathode-electrolyte input terminal configuration subsystem **244** is to automatically configure (in series or parallel) the input terminals of selected cathode-electrolyte pairs within the recharging heads of the Metal-Fuel Card Recharging Subsystem **191** so that the required input (recharging) voltage level is applied across cathode-electrolyte structures of metal-fuel tracks requiring recharging. In the illustrative embodiment of the present invention, the cathode-electrolyte input terminal configuration mechanism **244** can be realized as one or more electrically-programmable power switching circuits using transistor-controlled technology, wherein the cathode and anode-contacting elements within the recharging heads **197**' are connected to the output terminals of the input power regulating subsystem **245**. Such switching operations are carried out under the control of the system controller **203**' so that the required output voltage produced by the recharging power regulating subsystem **245** is applied across the cathode-electrolyte structures of metal-fuel tracks requiring recharging.

[**0675**] Cathode-Anode Voltage Monitoring Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0676**] As shown in FIGS. **7B3** and **7B4**, the cathode-electrolyte voltage monitoring subsystem **206A**' is operably connected to the cathode-electrolyte input terminal configuration subsystem **244** for sensing voltage levels across the cathode and anode structures connected thereto. This subsystem is also operably connected to the system controller **203**' for receiving control signals therefrom required to carry out its functions. In the first illustrative embodiment, the cathode-electrolyte voltage monitoring subsystem **206A**' has two primary functions: to automatically sense the instantaneous voltage levels applied across the cathode-electrolyte structures associated with each metal-fuel zone loaded within each recharging head during the Recharging Mode; and to produce (digital) data signals indicative of the sensed voltages for detection and analysis by the Data Capture and Processing Subsystem **406** within the Metal-Fuel Card Recharging Subsystem **191**.

[**0677**] In the first illustrative embodiment of the present invention, the cathode-electrolyte voltage monitoring subsystem **206A**' can be realized using electronic circuitry adapted for sensing voltage levels applied across the cathode-electrolyte structures associated with each metal-fuel zone within each recharging head within the Metal-Fuel Card Recharging Subsystem **191**. In response to such detected voltage levels, the electronic circuitry can be designed to produce a digital data signals indicative of the sensed voltage levels for detection and analysis by the Data Capture and Processing Subsystem **406**. As will be described in greater detail hereinafter, such data signals can be used by the system controller **203**' to carry out its Recharging Power Regulation Method during the Recharging Mode of operation.

[**0678**] Cathode-Anode Current Monitoring Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0679**] As shown in FIGS. **7B3** and **7B4**, the cathode-electrolyte current monitoring subsystem **206B**' is operably connected to the cathode-electrolyte input terminal configuration subsystem **244**. The cathode-electrolyte current monitoring subsystem **206B**' has two primary functions: to automatically sense the magnitude of electrical current flowing through the cathode-electrolyte pair of each metal-fuel track along each recharging head assembly within the Metal-Fuel Card Recharging Subsystem **191** during the discharging mode; and to produce digital data signals indicative of the sensed currents for detection and analysis by Data Capture and Processing Subsystem **406** within the Metal-Fuel Card Recharging Subsystem **191**.

[**0680**] In the first illustrative embodiment of the present invention, the cathode-electrolyte current monitoring subsystem **206B**' can be realized using current sensing circuitry for sensing the electrical current passed through the cathode-electrolyte pair of each metal-fuel track (i.e. strip) along each recharging head assembly, and producing digital data signals indicative of the sensed current levels. As will be explained in greater detail hereinafter, these detected current levels can be used by the system controller in carrying out its recharging power regulation method, and well as creating a "recharging condition history" information file for each zone or subsection of recharged metal-fuel card.

[**0681**] Cathode Oxygen Pressure Control Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0682**] The function of the cathode oxygen pressure control subsystem is to sense the oxygen pressure (pO_2) within each subchannel of the cathode structure of the recharging heads **175**, and in response thereto, control (i.e. increase or decrease) the same by regulating the air (O_2) pressure within the subchannels of such cathode structures within each recharging head **197**'. In accordance with the present invention, partial oxygen pressure (pO_2) within each subchannel of the cathode structure of each recharging head is maintained at an optimal level in order to allow optimal oxygen evacuation from the recharging heads during the Recharging Mode. By lowering the pO_2 level within each channel of the cathode structure (by evacuation), metal-oxide along metal-fuel cards can be completely recovered with optimal use of input power supplied to the recharging heads during the Recharging Mode. Also, by monitoring changes in pO_2 and producing digital data signals representative thereof for detection and analysis by Data Capture and Processing Subsystem **406** and ultimate response the system controller **203**'. Thus the system controller **203**' is provided with a controllable variable for use in regulating the electrical power supplied to the discharged fuel tracks during the Recharging Mode.

[0683] Ion-Concentration Control Subsystem within the Metal-Fuel Card Recharging Subsystem

[0684] In the illustrative embodiment of **FIG. 6**, ion-concentration control within each recharging head **197**' is achieved by embedding a miniature solid-state humidity (or moisture) sensor **212**' within the cathode support structure **121**' as shown in **FIG. 7**B6 (or as close as possible to the anode-cathode interfaces) in order to sense moisture or humidity conditions therein and produce a digital data signal indicative thereof. This digital data signal is supplied to the Data Capture and Processing Subsystem **406** for detection and analysis. In the event that the moisture level or relative humidity drops below the predetermined threshold value set in memory (ROM) within the system controller, the system controller **203**', monitoring information in the Metal-Fuel Database Management Subsystem **404** automatically generates a control signal supplied to a moisturizing element **213**', realizable as a micro-sprinkling structure embodied within the walls of the cathode support structure **198**'. In the illustrative embodiment, the walls function as water-carrying conduits which express fine water droplets out of micro-sized holes **214**' in a manner similar to that carried out in the cathode support structure **198** in the discharge head **197**. Thus the function of the water pump **215**', water reservoir **216**', water flow-control valve **217**', manifold assembly **218**' and multi-lumen tubing **219**' is similar to water pump **215**, water reservoir **216**, water flow-control valve **217**, manifold assembly **218** and multi-lumen tubing **219**, respectively.

[0685] Such operations will increase (or decrease) the moisture level or relative humidity within the interior of the cathode support structure channels and thus ensure that the concentration of KOH within the electrolyte within electrolyte-impregnated strips supported therewithin is optimally maintained for ion transport and thus metal-oxide reduction during card recharging operations.

[0686] Data Capture and Processing Subsystem within the Metal-Fuel Card Recharging Subsystem

[0687] In the illustrative embodiment of **FIG. 6**, Data Capture And Processing Subsystem (DCPS) **406** shown in FIGS. **7**B3 and **7**B4 carries out a number of functions, including, for example: (1) identifying each metal-fuel card immediately before it is loaded within a particular recharging head within the recharging head assembly **197**' and producing metal-fuel card identification data representative thereof; (2) sensing (i.e. detecting) various "recharge parameters" within the Metal-Fuel Card Recharging Subsystem **191** existing during the time period that the identified metal-fuel card is loaded within the recharging head assembly thereof; (3) computing one or more parameters, estimates or measures indicative of the amount of metal-fuel produced during card recharging operations, and producing "metal-fuel indicative data" representative of such computed parameters, estimates and/or measures; and (4) recording in the Metal-Fuel Database Management Subsystem **404** (accessible by system controller **203**'), sensed recharge parameter data as well as computed metal-fuel indicative data both correlated to its respective metal-fuel track/card identified during the Recharging Mode of operation. As will become apparent hereinafter, such recorded information maintained within the Metal-Fuel Database Management Subsystem **404** by Data Capture and Processing Subsystem **406** can be used by the system controller **203**' in various ways including, for example: optimally recharging partially or completely oxidized metal-fuel cards in a rapid manner during the Recharging Mode of operation.

[0688] During recharging operations, the Data Capture and Processing Subsystem **406** automatically samples (or captures) data signals representative of "recharge parameters" associated with the various subsystems constituting the Metal-Fuel Card Recharging Subsystem **191** described above. These sampled values are encoded as information within the data signals produced by such subsystems during the Recharging Mode. In accordance with the principles of the present invention, card-type "recharge parameters" shall include, but are not limited to: the voltages produced across the cathode and anode structures along particular metal-fuel zones monitored, for example, by the cathode anode voltage monitoring subsystem **206**A'; the electrical currents flowing through the cathode and anode structures along particular metal-fuel tracks monitored, for example, by the cathode-electrolyte current monitoring subsystem **206**B'; the oxygen saturation level (pO_2) within the cathode structure of each recharging head **197**', monitored by the cathode oxygen pressure control subsystem (**203**', **250**', **208**', **209**', **210**', **211**'); the moisture (H_2O) level (or relative humidity) level across or near the cathode-electrolyte interface along particular metal-fuel tracks in particular recharging heads monitored, for example, by the ion-concentration control subsystem (**203**', **212**', **214**', **215**', **216**', **217**', **218**', **219**'); the temperature (T_r) of the recharging heads **197**' during card recharging operations; and the time duration (Δt_r) of the state of any of the above-identified recharge parameters.

[0689] In general, there a number of different ways in which the Data Capture and Processing Subsystem can record card-type "recharge parameters" during the Recharging Mode of operation. These different methods will be detailed hereinbelow.

[0690] According to a first method of data recording shown in **FIG. 7**B9, card identifying code or indicia (e.g. miniature bar code symbol encoded with zone identifying information) **240** graphically printed on an "optical" data track **241**, can be read by optical data reader **270** realized using optical techniques (e.g. laser scanning bar code symbol readers, or optical decoders). In the illustrative embodiment, information representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **406**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **404** during recharging operations.

[0691] According to a second method of data recording shown in **FIG. 7**B9, digital "card identifying" code **240**' magnetically recorded in a magnetic data track **241**', can be read by magnetic reading head **270**' realized using magnetic information reading techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique card identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **406**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **404** during recharging operations.

[0692] According to a third method of data recording shown in **FIG. 7**B9, digital "card identifying" code recorded as a sequence of light transmission apertures **240**" in an optically opaque data track **241**", can be read by optical sensing head **270**" realized using optical sensing techniques well known in the art. In the illustrative embodiment, the digital data representative of these unique zone identifying codes is encoded within data signals provided to the Data Capture and Processing Subsystem **406**, and subsequent recorded within the Metal-Fuel Database Management Subsystem **404** during recharging operations.

[**0693**] According to a fourth alternative method of data recording, both unique digital "card identifying" code and set of recharge parameters for each track on the identified metal-fuel card are recorded in a magnetic, optical, or apertured data track, realized as a strip attached to the surface of the metal-fuel card of the present invention. The block of information pertaining to a particular metal-fuel card can be recorded in the data track physically adjacent the related metal-fuel zone facilitating easily access of such recorded information during the Recharging Mode of operation. Typically, the block of information will include the metal-fuel card identification number and a set of recharge parameters, as schematically indicated in **FIG. 7B13**, which are automatically detected by the Data Capture and Processing Subsystem **406** as the metal-fuel card is loaded within the recharging head assembly **197**'.

[**0694**] The first and second data recording methods described above have several advantages over the third method described above. In particular, when using the first and second methods, the data track provided along the metal-fuel card can have a very low information capacity. This is because very little information needs to be recorded to tag each metal-fuel card with a unique identifier (i.e. address number or card identification number), to which sensed recharge parameters are recorded in the Metal-Fuel Database Management Subsystem **404**. Also, formation of a data track in accordance with the first and second methods should be very inexpensive, as well as providing apparatus for reading card identifying information recorded along such data tracks.

[**0695**] Input/Output Control Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0696**] In some applications, it may be desirable or necessary to combine two or more FCB systems or their Metal-Fuel Card Recharging Subsystems **191** in order to form a resultant system with functionalities not provided by the such subsystems operating alone. Contemplating such applications, the Metal-Fuel Card Recharging Subsystem **191** hereof includes an Input/Output Control Subsystem **224**' which allows an external system (e.g. microcomputer or microcontroller) to override and control aspects of the Metal-Fuel Card Recharging Subsystem as if its system controller **203**' were carrying out such control functions. In the illustrative embodiment, the Input/Output Control Subsystem **224**' is realized as a standard IEEE I/O bus architecture which provides an external or remote computer system with a way and means of directly interfacing with the system controller **203**' of the Metal-Fuel Card Recharging Subsystem **191** and managing various aspects of system and subsystem operation in a straightforward manner.

[**0697**] Recharging Power Regulation Subsystem within the Metal-Fuel Card Recharging Subsystem

[**0698**] As shown in FIGS. **7B3** and **5B4**, the output port of the recharging power regulation subsystem **244** is operably connected to the input port of the cathode-electrolyte input terminal configuration subsystem **244**, whereas the input port of the recharging power regulation subsystem **245** is operably connected to the output port of the input power supply **243**. While the primary function of the recharging power regulation subsystem **245** is to regulate the electrical power supplied to metal-fuel card during the Recharging Mode of operation, the recharging power regulation subsystem **245** can also regulate the voltage applied across the cathode-electrolyte structures of the metal-fuel tracks, as well as the electrical currents flowing through the cathode-electrolyte interfaces thereof during recharging operations. Such control functions are managed by the system controller **203**' and can be programmably selected in a variety of ways in order to achieve optimal recharging of multi-tracked and single-tracked metal-fuel card according to the present invention.

[**0699**] The input power regulating subsystem **245** can be realized using solid-state power, voltage and current control circuitry well known in the power, voltage and current control arts. Such circuitry can include electrically-programmable power switching circuits using transistor-controlled technology, in which one or more current-controlled sources are connectable in electrical series with the cathode and anode structures in order to control the electrical currents therethrough in response to control signals produced by the system controller carrying out a particular Recharging Power Control Method. Such electrically-programmable power switching circuits can also include transistor-controlled technology, in which one or more voltage-controlled sources are connectable in electrical parallel with the cathode and anode structures in order to control the voltage thereacross in response to control signals produced by the system controller. Such circuitry can be combined and controlled by the system controller **203**' in order to provide constant power (and/or voltage and/or current) control across the cathode-electrolyte structures of the metal-fuel card **187**.

[**0700**] In the illustrative embodiments of the present invention, the primary function of the recharging power regulation subsystem **245** is to carry out real-time power regulation to the cathode/anode structures of metal-fuel card **187** using any one of the following methods, namely: (1) a Constant Input Voltage/Variable Input Current Method, wherein the input voltage applied across each cathode-electrolyte structure is maintained constant while the current therethrough is permitted to vary in response to loading conditions presented by metal-oxide formations on the recharging card; (2) a Constant Input Current/Variable Input Voltage Method, wherein the current into each cathode-electrolyte structure is maintained constant while the output voltage thereacross is permitted to vary in response to loading conditions; (3) a Constant Input Voltage/Constant Input Current Method, wherein the voltage applied across and current into each cathode-electrolyte structure during recharging are both maintained constant in response to loading conditions; (4) a Constant Input Power Method, wherein the input power applied across each cathode-electrolyte structure during recharging is maintained constant in response to loading conditions; (5) a Pulsed Input Power Method, wherein the input power applied across each cathode-electrolyte structure during recharging pulsed with the duty cycle of each power pulse being maintained in accordance with preset or dynamic conditions; (6) a Constant

Input Voltage/Pulsed Input Current Method, wherein the input current into each cathode-electrolyte structure during recharging is maintained constant while the current into the cathode-electrolyte structure is pulsed with a particular duty cycle; and (7) a Pulsed Input Voltage/Constant Input Current Method, wherein the input power supplied to each cathode-electrolyte structure during recharging is pulsed while the current thereinto is maintained constant.

[0701] In the preferred embodiment of the present invention, each of the seven (7) Recharging Power Regulation Methods are preprogrammed into ROM associated with the system controller **203**'. Such power regulation methods can be selected in a variety of different ways, including, for example, by manually activating a switch or button on the system housing, by automatically detection of a physical, electrical, magnetic an/or optical condition established or detected at the interface between the metal-fuel card device and the Metal-Fuel Card Recharging Subsystem **191**.

[0702] System Controller within the Metal-Fuel Card Recharging Subsystem

[0703] As illustrated in the detailed description set forth above, the system controller **203**' performs numerous operations in order to carry out the diverse functions of the FCB system within its Recharging Mode. In the preferred embodiment of the FCB system of **FIG. 6**, the subsystem used to realize the system controller **203**' in the Metal-Fuel Card Recharging Subsystem **191** is the same subsystem used to realize the system controller **203** in the Metal-Fuel Card Discharging Subsystem **186**. It is understood, however, the system controllers employed in the Discharging and Recharging Subsystems **186** and **191** can be realized as separate subsystems, each employing one or more programmed microcontrollers in order to carry out the diverse set of functions performed by the FCB system hereof. In either case, the input/output control subsystem of one of these subsystems can be designed to be the primary input/output control subsystem, with which one or more external subsystems (e.g. a management subsystem) can be interfaced to enable external or remote management of the functions carried out within FCB system hereof.

[0704] Recharging Metal-Fuel Cards Using The Metal-Fuel Card Recharging Subsystem

[0705] FIGS. **7B51** and **7B52** set forth a high-level flow chart describing the basic steps of recharging metal-fuel cards using the Metal-Fuel Card Recharging Subsystem **191** shown in FIGS. **7B3** through **7B4**. As indicated at Block A in **FIG. 7B51**, the Discharge Card Loading Subsystem **192** transports four discharged metal-fuel cards **187** from the bottom of the discharged metal-fuel card storage bin **188**B into the card recharging bay of the Metal-Fuel Card Recharging Subsystem **191**, as illustrated in **FIG. 7**B1.

[0706] As indicated at Block B, the Recharge Head Transport Subsystem **204**' arranges the recharging heads **197**' about the metal-fuel cards loaded into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191** so that the ionically-conducting medium is disposed between each cathode structure and loaded metal-fuel card.

[0707] As indicated at Block C, the Recharge Head Transport Subsystem **204**' then configures each recharging head **197**' so that its cathode structure is in ionic contact with a loaded metal-fuel card and its anode contacting structure is in electrical contact therewith.

[0708] As indicated at Block D in **FIG. 7B51**, the cathode-electrolyte input terminal configuration subsystem **244** automatically configures the input terminals of each recharging head **197**' arranged about a loaded metal-fuel card, and then the system controller **203**' controls the Metal-Fuel Card Recharging Subsystem **191** so that electrical power is supplied to the metal fuel zones of the metal-fuel cards at the voltage and current level required for optimal recharging.

[0709] As indicated at Block E in **FIG. 7B52**, when one or more of the metal-fuel cards are recharged, then the Recharge Card Unloading Subsystem **193** transports the recharged metal-fuel card(s) to the top of the recharged metal-fuel cards in the recharged metal-fuel card storage bin **188**B, as shown in **FIG. 7B2**. Thereafter, as indicated at Block F, the operations recited at Blocks A through E are repeated in order to load additional discharged metal-fuel cards into the recharge bay for recharging.

[0710] Managing Metal-Fuel Availability and Metal-Oxide Presence Within the Fifth Illustrative Embodiment of the Metal-Air FCB System of the Present Invention

[0711] During The Discharging Mode:

[0712] In the FCB system of the fifth illustrative embodiment shown in **FIG. 6**, means are provided for automatically managing the metal-fuel availability within the Metal-Fuel Card Discharging Subsystem **186** during discharging operations. Such system capabilities will be described in greater detail hereinbelow.

[0713] As shown in **FIG. 7B14**, data signals representative of discharge parameters (e.g., i_{acd}, v_{acd}, . . . , pO_{2d}, H_2O_d, T_{acd}, v_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **400** within the Metal-Fuel Card Discharging Subsystem **186**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **409** as shown, for example, in **FIG. 7A13**. Each information structure **409** comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel card identifier **240 (240', 240")**, associated with a particular metal-fuel card. The unique metal-fuel card identifier is determined by data reading head **260 (260', 260")** shown in **FIG. 7A6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **308** within the Metal-Fuel Card Discharging Subsystem **186**, for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[0714] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **400** during the discharging mode. Such information types include, for example: (1) the amount of electrical current (i_{acd}) discharged across particular cathode-electrolyte structures within particular discharge heads; (2) the voltage generated across each such cathode-electrolyte structure; (3) the oxygen concentration (pO_{2d}) level in each subchamber within each discharging head; (4) the moisture level (H_2O_d) near each cathode-electrolyte interface within each discharging head; and (5) the temperature (T_{acd}) within each channel of each discharging head. From such collected information, the Data Capture and Processing

Subsystem **400** can readily compute (i) the time (Δt_d) duration that electrical current was discharged across a particular cathode-electrolyte structure within a particular discharge head.

[**0715**] The information structures produced by the Data Capture and Processing Subsystem **400** are stored within the Metal-Fuel Database Management Subsystem **308** within the Metal-Fuel Card Discharging Subsystem **186** on a real-time basis and can be used in a variety of ways during discharging operations.

[**0716**] For example, the above-described current (i_{acd}) and time (Δt_d) information is conventionally measured in Amperes and Hours, respectively. The product of these measures, denoted by "AH", provides an approximate measure of the electrical charge (−Q) that has been "discharged" from the metal-air fuel cell battery structures along the metal-fuel tape. Thus the computed "AH" product provides an accurate amount of metal-oxide that one can expect to have been formed on a particular track of an identified (i.e. labeled) metal-fuel card at a particular instant in time, during discharging operations.

[**0717**] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database Management Subsystems **308** and **404** within the Metal-Fuel Card Discharging and Recharging Subsystems **186** and **191**, respectively, can account for or determine how much metal-fuel (e.g. zinc) should be available for discharging (i.e. producing electrical power) from a particular zinc-fuel card, or how much metal-oxide is present for reducing therealong. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-fuel amounts available along a particular metal-fuel zone.

[**0718**] In the illustrative embodiment, metal-fuel availability is managed within the Metal-Fuel Card Discharging Subsystem **186**, using the method of metal-fuel availability management described hereinbelow.

[**0719**] Preferred Method of Metal-Fuel Availability Management

[**0720**] During Discharging Operations

[**0721**] In accordance with the principles of the present invention, the data reading head **260** (**260**', **260**') automatically identifies each metal-fuel card as it is loaded within the discharging assembly **197** and produces card identification data indicative thereof which is supplied to the Data Capture and Processing Subsystem within the Metal-Fuel Card Discharging Subsystem **186**. Upon receiving card identification data on the loaded metal-fuel card, the Data Capture and Processing Subsystem automatically creates an information structure (i.e. data file) on the card within the Metal-Fuel Database Management Subsystem. The function of the information structure, shown in **FIG. 7A13**, is to record current (up-to-date) information on sensed discharging parameters, the metal-fuel availability state, metal-oxide presence state, and the like. In the event that an information storage structure has been previously created for this particular metal-fuel card within the Metal-Fuel Database Management Subsystem, this information file is then accessed for updating. As shown in **FIG. 7A13**, for each identified metal-fuel card, an information structure **409** is maintained for each metal-fuel zone (MFZ_j), at each i-th sampled instant of time t_i.

[**0722**] Once an information structure has been created (or found) for a particular metal-fuel card **187**, the initial state or condition of each metal-fuel zone thereon **195**A through **195**D must be determined and entered within the information structure maintained within the Metal-Fuel Database Management Subsystem **308** of the Metal-Fuel Card Discharging Subsystem **186**.

[**0723**] Typically, the metal-fuel card loaded within the discharging head assembly **197** will be partially or fully charged, and thus containing a particular amount of metal-fuel along its support surface. For accurate metal-fuel management, these initial metal-fuel amounts (MFAs) in the loaded card must be determined and then information representative thereof stored with the Metal-Fuel Database Management Subsystems **308** and **404** of the Discharging and Recharging Subsystems **186** and **191**, respectively. In general, initial states of information can be acquired in a number of different ways, including for example: by encoding such initialization information on the metal-fuel card prior to completing a discharging operation on a different FCB system; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem **308** during the most recent discharging operation carried out in the same FCB system; by recording within the Metal-Fuel Database Management Subsystem **308** (at the factory), the amount of metal-fuel present on each track of a particular type metal-fuel card, and automatically initializing such information within a particular information structure upon reading a code on the metal-fuel card using data reading head **260** (**260**', **260**"); by actually measuring the initial amount of metal-fuel on each metal-fuel track using the metal-oxide sensing assembly described above in conjunction with the cathode-electrolyte output terminal configuration subsystem **205**; or by any other suitable technique.

[**0724**] The actual measurement technique mentioned above can be carried out by configuring metal-oxide sensing ($v_{applied}/i_{response}$) drive circuitry (shown in **FIG. 2A15**) with the cathode-electrolyte output terminal configuration subsystem **205** and Data Capture and Processing Subsystem **400** within the Metal-Fuel Card Discharging Subsystem **186**. Using this arrangement, the metal-oxide sensing heads can automatically acquire information on the "initial" state of each metal-fuel track on each identified metal-fuel card loaded within the discharging head assembly **197**. Such information would include the initial amount of metal-oxide and metal-fuel present on each zone (**195**A through **195**D) at the time of loading, denoted by "t_0" In a manner similar to that described in connection with the FCB systems of **FIGS. 1 and 4**, such metal-fuel/metal-oxide measurements are carried out on each metal-fuel zone (MFZ) of the loaded card **187** by automatically applying a test voltage across a particular metal fuel zone **195**A through **195**D, and detecting the electrical which flows thereacross in response the applied electrical test voltage. The data signals representative of the applied test voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem **400** and processed to produce a data element representative of the ratio of the applied voltage to response current (i.e., $V_{applied}/(i_{response})$ with appropriate numerical scaling. This data element is automatically recorded within an information structure linked to the identified metal-fuel card maintained in the Metal-Fuel Data Management Subsystem **308**. As this data element (v/i) provides a direct measure of electrical resistance across the metal-fuel zone under measurement, it can be accurately correlated to a measured amount of metal-oxide present on the identified metal-fuel zone.

[0725] Data Capture and Processing Subsystem **400** then quantifies the measured initial metal-oxide amount (available at initial time instant to), and designates it as MOA_0 for recording within the information structure (shown in **FIG. 7A13**). Then using a priori information about the maximum metal-fuel available on each track when fully (re)charged, the Data Capture and Processing Subsystem **400** computes an accurate measure of metal-fuel available on each track at time "t_0", for each fuel track, designates each measures as NFA_0 and records these initial metal-fuel measures $\{MFA_0\}$ for the identified fuel card within the Metal-Fuel Database Management Subsystems of both the Metal-Fuel Card Discharging and Recharging Subsystems **186** and **191**, respectively. While this initialization procedure is simple to carry out, it is understood that in some applications it may be more desirable to empirically determine these initial metal-fuel measures using theoretically-based computations premised on the metal-fuel cards having been subjected to a known course of treatment (e.g. the Short Circuit Resistance Test described hereinabove).

[0726] After the initialization procedure is completed, the Metal-Fuel Card Discharging Subsystem **186** is ready to carry out its metal-fuel management functions along the lines to be described hereinbelow. In the illustrative embodiment, this method involves two basic steps that are carried out in a cyclical manner during discharging operations.

[0727] The first step of the procedure involves subtracting from the initial metal-fuel amount MFA_0, the computed metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during discharging operations conducted between time interval t_0-t_1. The during the discharging operation, metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected—electrical discharge current i_{acd}, and time duration Δt_d.

[0728] The second step of the procedure involves adding to the computed measure (MFA_0–MOE_{0-1}), the metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during any recharging operations that may have been conducted between time interval t_0-t_1. Notably, the metal-fuel estimate MFE_{0-1} is computed using: the electrical recharge current i_{acr}; and time duration Δt, during the discharging operation. Notably, metal-fuel measure MFE_{0-1} will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem within the Metal-Fuel Card Recharging Subsystem **186** during the immediately previous recharging operation (if one such operation was carried out). Thus, it will be necessary to read this prerecorded information element from the database within the Recharging Subsystem **191** during current discharging operations.

[0729] The computed result of the above-described accounting procedure (i.e. MFA_0–MOE_{0-1}+MFE_{0-1}) is then posted within the Metal-Fuel Database Management Subsystem **400** within Metal-Fuel Card Discharging Subsystem **186** as the new current metal-fuel amount (MFA_1) which will be used in the next metal-fuel availability update procedure. During discharging operations, the above-described update procedure is carried out for every t_i-t_{i+1} seconds for each metal-fuel track that is being discharged.

[0730] Such information maintained on each metal-fuel track can be used in a variety of ways, for example: manage the availability of metal-fuel to meet the electrical power demands of the electrical load connected to the FCB system; as well as setting the discharging parameters in an optimal manner during discharging operations. The details pertaining to this metal-fuel management techniques will be described in greater detail hereinbelow.

[0731] Uses for Metal-Fuel Availability Management During the Discharging Mode of Operation

[0732] During discharging operations, the computed estimates of metal-fuel present over any particular metal-fuel zone **195**A through **195**D at time t_2 (i.e. MFZ_{t1-t2}), determined at the J-th discharging head, can be used to compute the availability of metal-fuel at the (j+1)th, (j+2)th, or (j+n)th discharging head downstream from the j-th discharging head. Using such computed measures, the system controller **203** within the Metal-Fuel Card Discharging Subsystem **186** can determine (i.e. anticipate) in real-time, which metal-fuel zone on a metal-fuel card contains metal-fuel (e.g. zinc) in quantities sufficient to satisfy instantaneous electrical-loading conditions imposed upon the Metal-Fuel Card Discharging Subsystem **186** during the discharging operations, and selectively switch-in the metal-fuel zones(s) across which metal-fuel is known to be present. Such track switching operations may involve the system controller **203** temporarily connecting the output terminals of the cathode-electrolyte structures thereof to the input terminals of the cathode-electrolyte output terminal configuration subsystem **205** so that zones supporting metal-fuel content (e.g. deposits) are made readily available for producing electrical power required by the electrical load **200**.

[0733] Another advantage derived from such metal-fuel management capabilities is that the system controller **203** within the Metal-Fuel Card Discharging Subsystem **115** can control discharge parameters during discharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystem **308** during the immediately prior recharging and discharging operations.

[0734] Means for Controlling Discharging Parameters During the Discharging Mode Using Information Recorded During the Prior Modes of Operation

[0735] In the FCB system of the fourth illustrative embodiment, the system controller **203** within the Metal-Fuel Card Discharging Subsystem **186** can automatically control discharge parameters using information collected during prior recharging and discharging operations and recorded within the Metal-Fuel Database Management Subsystems of the FCB system of **FIG. 6**.

[0736] As shown in **FIG. 7B14**, the subsystem architecture and buses provided within and between the Discharging and Recharging Subsystems **186** and **191** enable system controller **203** within the Metal-Fuel Card Discharging Subsystem **186** to access and use information recorded within the Metal-Fuel Database Management Subsystem **404** within the Metal-Fuel Card Recharging Subsystem **191**. Similarly, the subsystem architecture and buses provided within and between the Discharging and Recharging Subsystems **186** and **191** enable system controller **103'** within the Metal-Fuel Card Recharging Subsystem **191** to access and use information recorded within the Metal-Fuel Database Management Subsystem **308** within the Metal-Fuel Card Discharging Subsystem **186**. The advantages of such information and sub-file sharing capabilities will be explained hereinbelow.

[0737] During the discharging operations, the system controller **203** can access various types of information stored within the Metal-Fuel Database Management Subsystems with the Discharging and Recharging Subsystems **186** and **191**. One important information element will relate to the amount of metal-fuel currently available at each metal-fuel zone **195**A through **195**D along at a particular instant of time (i.e. MFE_t). Using this information, the system controller **203** can determine if there will be sufficient metal-fuel along a particular track to satisfy current electrical power demands. The metal-fuel along one or more or all of the fuel zones **195**A through **195**D along a metal-fuel card may be substantially consumed as a result of prior discharging operations, and not having been recharged since the last discharging operation. The system controller **203** can anticipate such metal-fuel conditions within the discharging heads. Depending on the metal-fuel condition of "upstream" fuel cards, the system controller **203** may respond as follows: (i) connect the cathode-electrolyte structures of metal-fuel "rich" tracks into the discharge power regulation subsystem **223** when high electrical loading conditions are detected at electrical load **200**, and connect cathode-electrolyte structures of metal-fuel "depleted" zones into this subsystem when low loading conditions are detected at electrical load **200**; (ii) increase the amount of oxygen being injected within the corresponding cathode support structures when the metal-fuel is thinly present on identified metal-fuel zones, and decrease the amount of oxygen being injected within the corresponding cathode support structures when the metal-fuel is thickly present on identified metal-fuel zones, in order to maintain power produced from the discharging heads **197**; (iii) control the temperature of the discharging heads **197** when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments of the present invention, the system controller **203** may operate in different ways in response to the detected condition of particular zone on identified fuel card.

[0738] During the Recharging Mode

[0739] In the FCB system of the fifth illustrative embodiment shown in **FIG. 6**, means are provided for automatically managing the metal-oxide presence within the Metal-Fuel Card Recharging Subsystem **191** during recharging operations. Such system capabilities will be described in greater detail hereinbelow.

[0740] As shown in **FIG. 7B14**, data signals representative of recharge parameters (e.g., i_{acr}, v_{acr}, . . . , pO_{2r}, H_2O_r, T_r, v_{acr}/i_{acr}) are automatically provided as input to the Data Capture and Processing Subsystem **406** within the Metal-Fuel Card Recharging Subsystem **191**. After sampling and capturing, these data signals are processed and converted into corresponding data elements and then written into an information structure **410** as shown, for example, in **FIG. 7B13**. As in the case of discharge parameter collection, each information structure **410** for recharging parameters comprises a set of data elements which are "time-stamped" and related (i.e. linked) to a unique metal-fuel card identifier **240** (**240'**, **240"**), associated with the metal-fuel card being recharged. The unique metal-fuel card identifier is determined by data reading head **270** (**270'**, **270"** respectively) shown in **FIG. 7B6**. Each time-stamped information structure is then recorded within the Metal-Fuel Database Management Subsystem **404** of the Metal-Fuel Card Recharging Subsystem **191**, shown in **FIG. 7B14**, for maintenance, subsequent processing and/or access during future recharging and/or discharging operations.

[0741] As mentioned hereinabove, various types of information are sampled and collected by the Data Capture and Processing Subsystem **406** during the recharging mode. Such information types include, for example: (1) the recharging voltage applied across each such cathode-electrolyte structure within each recharging head **197'**; (2) the amount of electrical current (i_{acr}) supplied across each cathode-electrolyte structures within each recharge head **197'**; (3) the oxygen concentration (pO_{2r}) level in each subchamber within each recharging head; (4) the moisture level (H_2O_r) near each cathode-electrolyte interface within each recharging head; and (5) the temperature (T_{acr}) within each channel of each recharging head **197'**. From such collected information, the Data Capture and Processing Subsystem **406** can readily compute various parameters of the system including, for example, the time duration (Δt_r) that electrical current was supplied to a particular cathode-electrolyte structure within a particular recharging head.

[0742] The information structures produced and stored within the Metal-Fuel Database Management Subsystem **404** of the Metal-Fuel Card Recharging Subsystem **191** on a real-time basis can be used in a variety of ways during recharging operations. For example, the above-described current (i_{acr}) and time duration (Δt_r) information acquired during the recharging mode is conventionally measured in Amperes and Hours, respectively. The product of these measures (AH) provides an accurate measure of the electrical charge (−Q) supplied to the metal-air fuel cell battery structures along the metal-fuel tape during recharging operations. Thus the computed "AH" product provides an accurate amount of metal-fuel that one can expect to have been produced on the identified metal-fuel zone, at a particular instant in time, during recharging operations.

[0743] When used with historical information about metal oxidation and reduction processes, the Metal-Fuel Database Management Subsystems **308** and **404** within the Metal-Fuel Card Discharging and Recharging Subsystems **186** and **191**, respectively, can be used to account for or determine how much metal-oxide (e.g. zinc-oxide) should be present for recharging (i.e. conversion back into zinc from zinc-oxide) along the zinc-fuel card. Thus such information can be very useful in carrying out metal-fuel management functions including, for example, determination of metal-oxide amounts present along each metal-fuel zone **195**A through **195**D during recharging operations.

[0744] In the illustrative embodiment, the metal-oxide presence process may be managed within the Metal-Fuel Card Recharging Subsystem **191** using method described hereinbelow.

[0745] Preferred Method of Metal-Oxide Presence Management During Recharging Operations

[0746] In accordance with the principles of the present invention, the data reading head **270** (**270'**, **270'**) automatically identifies each metal-fuel card as it is loaded within the recharging assembly 197' and produces card identification data indicative thereof which is supplied to the Data Capture and Processing Subsystem within the Metal-Fuel Card Discharging Subsystem **191**. Upon receiving card identification data on the loaded metal-fuel card, the Data Capture and Processing Subsystem automatically creates an information structure (i.e. data file) on the card within the Metal-Fuel Database Management Subsystem. The function of this information structure, shown in **FIG. 7B13**, is to record current (up-to-date) information on sensed recharging parameters, the metal-fuel availability state, metal-oxide presence state, and the like. In the event that an information storage structure (i.e. data file) has been previously created for this particular metal-fuel card within the Metal-Fuel Database Management Subsystem **404**, this information file is accessed therefrom for updating. As shown in **FIG. 7B13**, for each identified metal-fuel card, an information structure **410** is maintained for each metal-fuel zone (MFZ_j) **195A** through **195D**, at each sampled instant of time t_1. Once an information structure has been created (or found) for a particular metal fuel card, the initial state or condition of each metal-fuel zone thereon must be determined and entered within the information structure maintained within the Metal-Fuel Database Management Subsystems **308** and **404** of the Discharging and Recharging Subsystems **186** and **191**, respectively.

[0747] Typically, the metal-fuel card loaded within the recharging head assembly **197** will be partially or fully discharged, and thus containing a particular amount of metal-oxide along its fuel zones for conversion back into its primary metal. For accurate metal-fuel management, these initial metal-oxide amounts (MOAs) in the loaded card(s) must be determined and then information representative thereof stored with the Metal-Fuel Database Management Subsystem of the Discharging and Recharging Subsystems **186** and **191**, respectively. In general, initial states of information can be acquired in a number of different ways, including for example: by encoding such initialization information on the metal-fuel card prior to completing a discharging operation on a different FCB system; by prerecording such initialization information within the Metal-Fuel Database Management Subsystem **404** during the most recent recharging operation carried out in the same FCB system; by recording within the Metal-Fuel Database Management Subsystem **404** (at the factory), the amount of metal-oxide normally expected on each zone of a particular type metal-fuel card, and automatically initializing such information within a particular information structure upon reading a code on the metal-fuel card using data reading head **270** (**270'**, **270"**); by actually measuring the initial amount of metal-oxide on each metal-fuel zone using the metal-oxide sensing assembly described above in conjunction with the cathode-electrolyte input terminal configuration subsystem **244**; or by any other suitable technique.

[0748] The "actual" measurement technique mentioned above can be carried out by configuring metal-oxide sensing drive circuitry (shown in **FIG. 2A15**) with the cathode-electrolyte input terminal configuration subsystem **244** and Data Capture and Processing Subsystem **406** within the Recharging Subsystem **191**. Using this arrangement, the metal-oxide sensing heads can automatically acquire information on the "initial" state of each metal-fuel track on each identified metal-fuel card loaded within the recharging head assembly **197'**. Such information would include the initial amount of metal-oxide and metal-fuel present on each track at the time of loading, denoted by "t_0".

[0749] In a manner similar to that described in connection with the FCB system of **FIGS. 1 and 4**, such metal-fuel/metal-oxide measurements are carried out on each metal-fuel zone of the loaded card by automatically applying a test voltage across a particular zone of metal fuel, and detecting the electrical which flows thereacross in response the applied test voltage. The data signals representative of the applied voltage ($v_{applied}$) and response current ($i_{response}$) at a particular sampling period are automatically detected by the Data Capture and Processing Subsystem **406** and processed to produce a data element representative of the ratio of the applied voltage to response current ($v_{applied}/(i_{response})$ with appropriate numerical scaling. This data element is automatically recorded within an information structure linked to the identified metal-fuel card maintained in the Metal-Fuel Data Management Subsystem **404**. As this data element (v/i) provides a direct measure of electrical resistance across the metal-fuel zone under measurement, it can be accurately correlated to a measured "initial" amount of metal-oxide present on the identified metal-fuel zone.

[0750] Data Capture and Processing Subsystem **406** then quantifies the measured initial metal-oxide amount (available at initial time instant to), and designates it as MOA_0 for recording in the information structures maintained within the Metal-Fuel Database Management Subsystems **308** and **404** of both the Metal-Fuel Card Discharging and Recharging Subsystems **186** and **191**, respectively. While this initialization procedure is simple to carry out, it is understood that in some applications it may be more desirable to empirically determine these initial metal-oxide measures using theoretically-based computations premised on the metal-fuel cards having been subjected to a known course of treatment (e.g. The Short-Circuit Resistance Test described hereinabove).

[0751] After completing the initialization procedure, the Metal-Fuel Card Recharging Subsystem **191** is ready to carry out its metal-fuel management functions along the lines to be described hereinbelow. In the illustrative embodiment, this method involves two basic steps that are carried out in a cyclical manner during discharging operations.

[0752] The first step of the procedure involves subtracting from the initial metal-oxide amount MOA_0, the computed metal-fuel estimate MFE_{0-1} which corresponds to the amount of metal-fuel produced during recharging operations conducted between time interval t_0-t_1. The during the recharging operation, metal-fuel estimate MFE_{0-1} is computed using the following recharging parameters: electrical recharge current i_{acr}; and time duration Δt_r.

[0753] The second step of the procedure involves adding to the computed measure (MOA_0–MFE_{0-1}), the metal-oxide estimate MOE_{0-1} which corresponds to the amount of metal-oxide produced during any discharging operations that may have been conducted between time interval t_0-t_1. Notably, the metal-oxide estimate MOE_{0-1} is computed using the following discharging parameters collected—electrical recharge current i_{acd} and time duration Δt_{0-1}, during the discharging operation. Notably, metal-oxide measure MOE_{0-1} will have been previously computed and recorded within the Metal-Fuel Database Management Subsystem

308 within the Metal-Fuel Card Discharging Subsystem 186 during the immediately previous discharging operation (if one such operation carried out since to). Thus, it will be necessary to read this prerecorded information element from Database Management Subsystem 308 within the Discharging Subsystem 186 during the current recharging operations.

[0754] The computed result of the above-described accounting procedure (i.e. $MOA_0-MFE_{0-1}+MOE_{0-1}$) is then posted within the Metal-Fuel Database Management Subsystem 404 within Metal-Fuel Card Recharging Subsystem 191 as the new current metal-fuel amount (MOA_1) which will be used in the next metal-oxide presence update procedure. During recharging operations, the above-described update procedure is carried out for every t_i-t_{i+1} seconds for each metal-fuel zone that is being recharged.

[0755] Such information maintained on each metal-fuel zone can be used in a variety of ways, for example: manage the presence of metal-oxide formations along the zones of metal-fuel cards; as well as setting the recharging parameters in an optimal manner during recharging operations. The details pertaining to such metal-oxide presence management techniques will be described in greater detail hereinbelow.

[0756] Uses for Metal-Oxide Presence Management During the Recharging Mode of Operation

[0757] During recharging operations, the computed amounts of metal-oxide present along any particular metal-fuel zone (i.e. MFZ), determined at the i-th recharging head 197', can be used to compute the presence of metal-oxide at the (i+1)th, (i+2)th, or (i+n)th recharging head downstream from the i-th recharging head 197'. Using such computed measures, the system controller 203' within the Metal-Fuel Card Recharging Subsystem 191 can determine (i.e. anticipate) in real-time, which metal-fuel tracks along a metal-fuel card contain metal-oxide (e.g. zinc-oxide) requiring recharging, and which contain metal-fuel not requiring recharging. For those metal-fuel zones requiring recharging, the system controller 203' can electronically switch-in the cathode-electrolyte structures of those metal-fuel zones having significant metal-oxide content (e.g. deposits) for conversion into metal-fuel within the recharging head assembly 197'.

[0758] Another advantage derived from such metal-oxide management capabilities is that the system controller 203' within the Metal-Fuel Card Recharging Subsystem 191 can control recharge parameters during recharging operations using information collected and recorded within the Metal-Fuel Database Management Subsystem 404 during the immediately prior recharging and discharging operations.

[0759] During Recharging operations, information collected can be used to compute an accurate measure of the amount of metal-oxide that exists along each metal-fuel zone 195A through 195D at any instant in time. Such information, stored within information storage structures maintained within the Metal-Fuel Database Subsystem 404, can be accessed and used by the system controller 203' within the Metal-Fuel Card Discharging Subsystem 186 to control the amount of electrical current supplied across the cathode-electrolyte structures of each recharging head 197'. Ideally, the magnitude of electrical current will be selected to ensure complete conversion of the estimated amount of metal-oxide (e.g. zinc-oxide) along each such zone, into its primary source metal (e.g. zinc).

[0760] Means for Controlling Recharging Parameters During the Recharging Mode Using Information Recorded During Prior Modes of Operation

[0761] In the FCB system of the fifth illustrative embodiment, the system controller 203' within the Metal-Fuel Card Recharging Subsystem 191 can automatically control recharge parameters using information collected during prior discharging and recharging operations and recorded within the Metal-Fuel Database Management Subsystems 308 and 404 of the FCB system of **FIG. 6**.

[0762] During the recharging operations, the system controller 203' within the Metal-Fuel Tape Recharging Subsystem 191 can access various types of information stored within the Metal-Fuel Database Management Subsystem 404. One important information element stored therein will relate to the amount of metal-oxide currently present along each metal-fuel zone at a particular instant of time (i.e. MOA_t). Using this information, the system controller 203' can determine on which zones significant metal-oxide deposits are present, and thus can connect the input terminal of the corresponding cathode-electrolyte structures (within the recharging heads) to the recharging power control subsystem 245 by way of the cathode-electrolyte input terminal configuration subsystem 244, to efficiently and quickly carry out recharging operations therealong. The system controller 203' can anticipate such metal-oxide conditions prior to conducting recharging operations. Depending on the metal-oxide condition of "upstream" fuel cards loaded within the discharging head assembly, the system controller 203' of the illustrative embodiment may respond as follows: (i) connect cathode-electrolyte structures of metal-oxide "rich" zones into the recharging power regulation subsystem 245 for long recharging durations, and connect cathode-electrolyte structures of metal-oxide "depleted" zones from this subsystem for relatively shorter recharging operations; (ii) increase the rate of oxygen evacuation from the cathode support structures corresponding to zones having thickly formed metal-oxide formations therealong during recharging operations, and decrease the rate of oxygen evacuation from the cathode support structures corresponding to zones having thinly formed metal-oxide formations therealong during recharging operations; (iii) control the temperature of the recharging heads 197' when the sensed temperature thereof exceeds predetermined thresholds; etc. It is understood that in alternative embodiments, the system controller 203' may operate in different ways in response to the detected condition of particular zones on an identified fuel card.

[0763] The Sixth Illustrative Embodiment of the Air-Metal FCB System of the Present Invention

[0764] In **FIGS. 8 through** 9A2, a sixth embodiment of the FCB system hereof is disclosed. This system 420 is a hybrid of the system of **FIG. 1**, wherein the discharging and recharging head assembly are combined into a single assembly enabling simultaneous discharge and recharge operations. As shown in **FIG. 8**, FCB system 420 comprises a tape transport subsystem 2, a cassette tape loading/unloading subsystem 2, and a hybrid-type metal-fuel tape discharging/recharging subsystem 425. The tape transport subsystem 4 and cassette tape loading/unloading subsystem 2 are substantially similar as the subsystems disclosed in connection with the first, second and third illustrative embodiments shown in **FIGS. 1, 3A** and 3B and thus will not be redescribed to avoid obfuscation of the present invention. The hybrid-type metal-fuel tape discharging/recharging subsystem **425** employed in the system of **FIG. 8** is sufficiently different from the subsystems described hereinabove to warrant further description below.

[0765] As shown in FIGS. **9A1** and **9A2**, the metal-fuel tape discharging/recharging subsystem **425** comprises a discharging head subassembly **9'**, a recharging head subassembly **11'**, discharging power regulation subsystem **40**, and recharging power regulation subsystem of the type employed in the FCB system of **FIG. 1**.

[0766] As shown, the discharging and recharging head subassemblies **9'** and **11'** are mounted upon a common discharge/recharge transport subsystem **424** which is functionally equivalent to the discharging head transport subsystem **24** and recharging head transport subsystem **24'** disclosed in **FIG. 2A3** and **2A4**. The discharging power regulation subsystem and recharging power regulation subsystem having functionalities similar to those described hereinabove.

[0767] In the illustrative embodiment shown in FIGS. **9A1** and **9A2**, the recharging surface area of the recharging head subassembly **11'** is substantially greater than the discharging surface area of the discharging head subassembly **9'**, in order to ensure rapid recharging operations. The terminals of each cathode-electrolyte structure of heads **9'** and **11'** are connected to a cathode-electrolyte terminal configuration subsystem **426** which can be programmed to configure the terminals of the heads **9'** and **11'** to function as either a discharging head or recharging head as required by any particular application at hand. Programmable cathode-electrolyte terminal configuration Subsystem **426** is controlled by system controller **18** and is surrounded by many of the supporting subsystems employed in the Discharging and Recharging Subsystems **6** and **7** of the FCB system of **FIG. 1**.

[0768] In the event that a particular head within the metal-fuel tape discharging/recharging subsystem **425** is configured to function as a discharging head, then pressurized air will be pumped into the cathode structure thereof to increase the pO_2 therewithin during the Discharge Mode while the output terminals thereof are connected to the input terminals of the discharging power regulation subsystem **40**, shown in FIGS. **9A1** and **9A2**. In the event that a particular head within the metal-fuel tape discharging/recharging subsystem **425** is configured to function as a recharging head, then pressurized air will be evacuated from the cathode structure thereof to lower the pO_2 therewithin during the Recharging Mode while the input terminals thereof are connected to the output terminals of the recharging power regulation subsystem **92**, shown in FIGS. **9A1** and **9A2**. This hybrid architecture has a number of advantages, namely: it enables multiple discharging heads in applications where long-term high power generation is required; it enables multiple recharging heads where ultra-fast recharging operations are required; and it enables simultaneous discharging and recharging operations where moderate electrical loading requirements must be satisfied.

[0769] The Seventh Illustrative Embodiment of the Air-Metal FCB System of the Present Invention

[0770] The seventh illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIGS. 10 through 10A**. In this embodiment, the FCB system is provided with metal-fuel in the form of metal-fuel cards (or sheets) contained within a cassette cartridge-like device having a partitioned interior volume for storing (re)charged and discharged metal-fuel cards in separate storage compartments. A number of advantages are provided by this metal-fuel supply design, namely: the amount of physical space required for storing the (re)charged and discharged metal-fuel cards is substantially reduced; a new supply of pre-charged metal fuel cards can be quickly supplied to the system by simply sliding a prefilled tray-like cartridge into the tray receiving port of the system housing; and an old supply of discharged cards can be quickly removed from the system by withdrawing a single cartridge tray from the housing and inserting a new one therein.

[0771] As shown in **FIGS. 10 through 10A**, this FCB system **500** comprises a number of subsystems, namely: a Metal-Fuel Card Discharging (i.e. Power Generation) Subsystem **186** for generating electrical power from recharged metal-fuel cards **187** during the Discharging Mode of operation; Metal-Fuel Card Recharging Subsystem **191** for electro-chemically recharging (i.e. reducing) sections of oxidized metal-fuel cards **187** during the Recharging Mode of operation; a Recharged Card Loading Subsystem **189'** for automatically loading one or more charged (recharged) metal-fuel cards **187** from recharged card storage compartment **501A** within cassette tray/cartridge **502**, into the discharging bay of the Discharging Subsystem **186**; Discharged Card Unloading Subsystem **190'** for automatically unloading one or more discharged metal-fuel cards **187** from the discharging bay of Discharging Subsystem **186**, into the discharged metal-fuel card storage compartment **501B**, located above card storage compartment **501A** and separated by platform **503** arranged within cartridge housing **504** to divide its interior volume into approximately equal subvolumes; Discharged Card Loading Subsystem **192'** for automatically loading one or more discharged metal-fuel cards from the discharged metal-fuel card storage bin **501B**, into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**; and a Recharged Card Unloading Subsystem **193'** for automatically unloading recharged metal fuel cards from the recharging bay of the Recharging Subsystem into the recharged metal-fuel card storage compartment **501A**.

[0772] The metal fuel consumed by this FCB System is provided in the form of metal fuel cards **187** which can be similar in construction to cards **112** used in the system of **FIG. 4** or cards **187** used in the system of **FIG. 6**. In either case, the discharging and recharging heads will be designed and constructed to accommodate the physical placement of metal fuel on the card or sheet-like structure. Preferably, each metal-fuel card used in this FCB system will be "multizoned" or "multi-tracked" in order to enable the simultaneous production of multiple supply voltages (e.g. 1.2 Volts) from the "multi-zoned" or "multi-tracked" discharging heads. As described in detail hereinabove, this inventive feature enables the generation and delivery of a wide range of output voltages from the system, suitable to the requirements of the particular electrical load connected to the FCB system.

[0773] While the metal-fuel delivery mechanism of the above-described illustrative embodiment is different from the other described embodiments of the present invention, the Metal-Fuel Card Discharging Subsystem **186** and the Metal-Fuel Card Recharging Subsystem **191** can be substantially the same or modified as required to satisfy the requirements of any particular embodiment of this FCB system design.

[0774] The Eighth Illustrative Embodiment of the Air-Metal FCB System of the Present Invention

[0775] The eighth illustrative embodiment of the metal-air FCB system hereof is illustrated in **FIGS. 11 through 11**A. In this embodiment, the FCB system is provided with a Metal-Fuel Card Discharging Subsystem, but not a Metal-Fuel Card recharging Subsystem, thereby providing a simpler design. metal-fuel in the form of metal-fuel cards (or sheets) contained within a cassette cartridge-like device having a partitioned interior volume for storing (re)charged and discharged metal-fuel cards in separate storage compartments. The A number of advantages are provided by this metal-fuel supply design, namely: the amount of physical space required for storing the (re)charged and discharged metal-fuel cards is substantially reduced; a new supply of pre-charged metal-fuel cards can be quickly supplied to the system by simply sliding a prefilled tray-like cartridge into the tray receiving port of the system housing; and an old supply of discharged cards can be quickly removed from the system by withdrawing a single cartridge tray from the housing and inserting a new one therein.

[0776] As shown therein, this FCB system **600** comprises a number of subsystems, namely: a Metal-Fuel Card Discharging (i.e. Power Generation) Subsystem **186** for generating electrical power from recharged metal-fuel cards **187** during the Discharging Mode of operation; Metal-Fuel Card Recharging Subsystem **191** for electro-chemically recharging (i.e. reducing) sections of oxidized metal-fuel cards **187** during the Recharging Mode of operation; a Recharged Card Loading Subsystem **189**' for automatically loading one or more charged (recharged) metal-fuel cards **187** from recharged card storage compartment **501**A within cassette tray/cartridge **502**, into the discharging bay of the Discharging Subsystem **186**; Discharged Card Unloading Subsystem **190**' for automatically unloading one or more discharged metal-fuel cards **187** from the discharging bay of Discharging Subsystem **186**, into the discharged metal-fuel card storage compartment **501**B, located above card storage compartment **501**A and separated by platform **503** arranged within cartridge housing **504** to divide its interior volume into approximately equal subvolumes; Discharged Card Loading Subsystem **192**' for automatically loading one or more discharged metal-fuel cards from the discharged metal-fuel card storage bin **501**B, into the recharging bay of the Metal-Fuel Card Recharging Subsystem **191**; and a Recharged Card Unloading Subsystem **193**' for automatically unloading recharged metal-fuel cards from the recharging bay of the Recharging Subsystem into the recharged metal-fuel card storage compartment **501**A.

[0777] The metal fuel consumed by this FCB System is provided in the form of metal fuel cards **187** which can be similar in construction to cards **112** used in the system of **FIG. 4** or cards **187** used in the system of **FIG. 6**. In either case, the discharging and recharging heads will be designed and constructed to accommodate the physical placement of metal fuel on the card or sheet-like structure. Preferably, each metal-fuel card used in this FCB system will be "multizoned" or "multi-tracked" in order to enable the simultaneous production of multiple supply voltages (e.g. 1.2 Volts) from the "multi-zoned" or "multi-tracked" discharging heads. As described in detail hereinabove, this inventive feature enables the generation and delivery of a wide range of output voltages from the system, suitable to the requirements of the particular electrical load connected to the FCB system.

[0778] While the metal-fuel delivery mechanism of the above-described illustrative embodiment is different from the other described embodiments of the present invention, the Metal-Fuel Card Discharging Subsystem **186** and the Metal-Fuel Card Recharging Subsystem **191** can be substantially the same or modified as required to satisfy the requirements of any particular embodiment of this FCB system design.

[0779] Additional Embodiments of Metal-Air FCB Systems According to the Present Invention

[0780] In the FCB systems described hereinabove, multiple discharging heads and multiple recharging heads have been provided for the noted advantages that such features provide. It is understood, however, that FCB systems of the present invention can be made with a single discharging head alone or in combination with one or more recharging heads, as well as, with a single discharging head alone or in combination with one or more discharging heads.

[0781] In the FCB systems described hereinabove, the cathode structures of the discharging heads and the recharging heads are shown as being planar or substantially planar structures which are substantially stationary relative to the anode-contacting electrodes or elements, while the metal-fuel (i.e. the anode) material is either: (i) stationary relative to the cathode structures in the metal-fuel card embodiments of the present invention shown in **FIGS. 4 and 6**; or (ii) moving relative to the cathode structures in the metal-fuel tape embodiments of the present invention shown in **FIGS. 1, 2, 3** and **8**.

[0782] It is understood, however, the metal-air FCB system designs of the present invention are not limited to the use of planar stationary cathode structures, but can be alternatively constructed using one or more cylindrically-shaped cathode structures adapted to rotate relative to, and come into ionic contact with metal-fuel tape or metal-fuel cards during discharging and/or recharging operations, while carrying out all of the electrochemical functions that cathode structures must enable in metal-air FCB systems. Notably, the same techniques that are used to construct planar stationary cathodes structures described hereinabove can be readily adapted to fashion cylindrically-shaped cathode structures realized about hollow, air-pervious support tubes driven by electric motors and bearing the same charge collecting substructure that the cathode structures typically are provided with, as taught in detail hereinabove.

[0783] In such alternative embodiments of the present invention, the ionically-conducting medium disposed between the cylindrically-shaped rotating cathode structure(s) and transported metal-fuel tape can be realized in a number of different ways, for example, as: (1) a solid-state electrolyte-impregnated gel or other medium affixed to the outer surface of the rotating cathode; (2) a solid-state electrolyte-impregnated gel or other medium affixed to the surface of the transported metal-fuel tape arranged in ionic-contact with the rotating cylindrically-shaped cathode structure; (3) a belt-like structure comprising a flexible porous substrate embodying a solid-state ionically conducting medium, transportable relative to both the rotating cylidindrically-shaped cathode structure and the moving metal-fuel tape or (card) during discharging and/or recharging operations; or (4) a liquid-type ionically conducting medium (e.g. such as an electrolyte) disposed between the rotating cathode structure and transported metal-fuel tape (or card) to enable ionic charge transport between the cathode and anode structures during discharging and recharging operations.

[0784] One particular advantage in using a solid-state ionically-conducting belt like structure of the type-described above is that it provides "frictionless" contact between transported metal-fuel tape and its rotating cylindrical cathode structure, thereby minimizing wear and tear of metal-fuel tape that is expected to be discharged and recharged over a large number of cycles without replacement.

[0785] In embodiments where multiple cylindrical cathodes are mounted within an array-like structure, and each cathode support tube being synchronously driven by meshing gears and metal-fuel tape being transported over the surfaces thereof in accordance with a predefined tape pathway using a tape transport similar to the subsystem shown in **FIG. 1**, it is possible to generate very high electrical power output from physical structures occupying relatively small volumes of space, thereby providing numerous advantages over prior art FCB systems.

[0786] The above-described FCB systems of the present invention can be used to power various types of electrical circuits, devices and systems, including, but not limited to, lawn mowers, stand-alone portable generators, vehicular systems, and a nominal 200 kW discharging system.

[0787] Having described in detail the various aspects of the present invention described above, it is understood that modifications to the illustrative embodiments will readily occur to persons with ordinary skill in the art having had the benefit of the present disclosure. All such modifications and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying claims to Invention.

What is claimed is:

1. A metal-air fuel cell battery (FCB) system, wherein one or more recharge parameters are automatically controlled in order to optimally recharge oxidized metal-fuel material (i.e. anodes) for reuse in metal-air FCB systems.

2. A metal-air fuel cell battery (FCB) system, wherein one or more discharge parameters are automatically controlled in order to optimally discharge metal-fuel material (i.e. anodes) for use in generating electrical power within metal-air FCB systems.

3. A metal-air fuel cell battery system comprising:

a subsystem for controlling the recharging of metal-oxide along oxidized metal-fuel tape so as to completely reduce metal-oxide on said metal-fuel tape without destroying the porous structure of the metal-fuel tape.

4. The metal-air fuel cell battery system of claim 3, wherein said metal-fuel anodes to be recharged (i.e. electrochemically reduced) are either stationary and/or moving cathode structures.

5. A metal-air fuel cell battery system, wherein metal-fuel structures to be recharged are realized in the form of oxidized metal-fuel tape which, during discharging operations, is transported across a cathode structure associated with the discharging head of a metal-air FCB system.

6. A metal-air fuel cell battery system, wherein the path-length of oxidized metal-fuel tape is substantially extended during recharging operations in order that a supply of oxidized metal-fuel tape contained within a cassette device or on a supply reel can be rapidly recharged.

7. A metal-air fuel cell battery system, wherein oxidized metal-fuel tape to be recharged is contained within a cassette-type device insertable in the storage bay of a compact FCB discharging unit.

8. A metal-air fuel cell battery system, wherein oxidized metal-fuel tape to be recharged comprises multiple metal-fuel tracks for use in generating different output voltages from a metal-air FCB system.

9. A metal-air fuel cell battery system, wherein the path-length of oxidized metal-fuel tape is significantly extended within the recharging bay of the system using a tape path-length extension mechanism.

10. A metal-air fuel cell battery system, wherein the recharging head assembly comprises a plurality of cathode and anode structures which are selectively arranged about the extended path-length of oxidized metal-fuel tape during recharging operations.

11. A metal-air fuel cell battery system, wherein a system, wherein a recharging power regulating subsystem is provided for regulating operating parameters during recharging of metal-oxide during recharging operations.

12. A metal-air fuel cell battery system, wherein oxygen, generated from within cathode elements with the recharging head of the system during recharging, is evacuated under the control of the recharging power regulation subsystem thereof.

13. A metal-air fuel cell battery system, wherein the relative humidity within the cathode elements of the recharging head of the system is controlled by the recharging power regulation subsystem thereof.

14. A metal-air fuel cell battery system, wherein the speed of the oxidized fuel tape transported over the recharging heads is regulated under the control of the recharging power regulation subsystem thereof.

15. A metal-air fuel cell battery system, wherein the voltage applied across and current driven through oxidized metal-fuel tape during recharging operations is regulated under the control of the recharging power control subsystem thereof.

16. A metal-air fuel cell battery system, wherein an metal-oxide sensing head is provided upstream for sensing which fuel tracks along a length of multi-tracked metal-fuel tape have been discharged (i.e. oxidized), and a recharging head is disposed downstream having multiple pairs of electrically-isolated cathode and anode structures for selectively recharging only those metal-fuel tracks that have been sufficiently oxidized (i.e. consumed).

17. A metal-air fuel cell battery system, wherein supply of metal-fuel cards or plates is contained within a cassette storage cartridge.

18. A metal-air fuel cell battery system, wherein each metal-fuel card or plate is automatically loaded from the cassette cartridge into the recharging bay of the system.

19. A metal-air fuel cell battery system, comprising a subsystem for recharging metal-fuel cards or plates that have been oxidized during the discharging mode of operation.

20. A metal-air fuel cell battery system, wherein each oxidized metal-fuel card or plate is manually loaded into the recharging bay of the system, and after recharging (i.e. reducing) is completed, the card is ejected from the recharging bay in a semi-automatic manner.

21. A metal-air fuel cell battery system, wherein each oxidized metal-fuel card or plate is automatically loaded into the recharging bay of the system, and after recharging is completed, the card is automatically ejected from the recharging bay, and another oxidized metal-fuel card is automatically loaded thereinto for recharging.

22. A metal-air fuel cell battery system, wherein each zone or subsection of metal fuel along the length of metal-fuel tape track is labelled with a digital code, through optical or magnetic means, for enabling the recording of discharging-related data during discharging mode of operation, for future access and use in carrying out various types of managment operations, including rapid and efficient recharging operations.

23. A metal-air fuel cell battery system, wherein metal-fuel tape can be transported through its discharging head assembly and recharging head assemmbly in a bi-directional manner while the availablity of metal-fuel therealong is automatically managed in order to improve the performance of the system.

24. A metal-air fuel cell battery system, wherein the recharging bay contains an assembly of recharging heads, each of which comprises an electrically conductive cathode structure, an ionically conductive medium, and an anode contacting structure.

25. A metal-air fuel cell battery system, wherein a plurality of oxidized metal-fuel cards or plates are automatically transported into the system for high-speed recharging.

26. A metal-air fuel cell battery system, wherein during discharging cycles, multiple discharging heads are employed to discharge metal-fuel tape at controlled anode-cathode current levels in order to control the formation of optimally-reducible metal-oxide patterns therealong during discharge cycles.

27. A metal-air fuel cell battery system, wherein during discharging cycles, the use of multiple discharging heads enables each discharging head to be "lightly loaded", thus permitting improved control over the formation of metal oxide during discharging cycles so that complete conversion thereof into its primary metal can be achieved in an optimal manner.

28. A metal-air fuel cell battery system, wherein information regarding the instantaneous loading conditions along each zone (i.e. frame) of the metal-fuel tape are recorded in memory by the system controller.

29. A metal-air fuel cell battery system, comprising:

means for acquiring idenitification data for each metal-fuel zone along a spool of metal-fuel tape to determine the indentity thereof;

means for sensing loading condition data associated with each said identified metal-fuel zone; and

means for recording said loading condition data for future use during subsequent tape recharging operations.

30. A metal-air fuel cell battery system, wherein during tape recharging operations, such recorded loading condition information is read from memory and used to set current and voltage levels maintained at the recharging heads of the system.

31. A metal-air fuel cell battery system, wherein metal-fuel tape discharging conditions are recorded at the time of discharge and used to optimally recharge discharged metal-fuel tape during tape recharging operations.

32. A metal-air fuel cell battery system, wherein during tape discharging operations, optical sensing of bar code data along each zone of metal-fuel tape is carried out using a minaturized bar code symbol reader embedded with the cathode structure of each discharging head of the system.

33. A metal-air fuel cell battery system, wherein during tape recharging operations, optical sensing of bar code data along each zone of discharged metal-fuel tape is carried out using a minaturized bar code symbol reader embedded with the cathode structure of each recharging head of the system.

34. A metal-air fuel cell battery system, wherein the subsystems thereof are remotely controllable through an input/output subsystem operably connected to a system controller.

35. A metal-air fuel cell battery system, wherein a plurality of metal-fuel cards can be loaded within a metal-fuel card discharging bay and simultaneously discharged within its metal-fuel card discharging subsystem in order to generate and deliver electrical power across an electrical load connected thereto.

36. A metal-air fuel cell battery system, wherein a plurality of metal-fuel cards can be loaded within a metal-fuel card recharging bay and simultaneously recharged within its Metal-Fuel Card Recharging Subsystem in order to convert metal-oxide along the metal-fuel card into its primary metal fuel for reuse in discharging operations.

37. A metal-air fuel cell battery system, comprising metal-fuel card discharging and recharging subsystems which can be operated simultaneously as well as under the management of a system controller associated with a resultant system, such as an electrical power management system.

38. A metal-air fuel cell battery system comprising:

a Metal-Fuel Tape Discharging Subsystem;

a Metal-Fuel Tape Recharging Subsystem integrated with said Metal-Fuel Tape Discharging Subsystem; and

a tape path-length extension mechanism employed in said Metal-Fuel Tape Recharging Subsystem for extending oxidized metal-fuel tape over a path-length which is substantially greater than the path-length maintained by the tape path-length extension mechanism in said Metal-Fuel Tape Discharging Subsystem (i.e. $A_{Recharge} >> A_{discharge}$).

39. A metal-air fuel cell battery system comprising:

means for discharging and recharging metal-fuel tape in a single hybrid-type subsystem, wherein a tape path-length extension mechanism is employed therein for extending metal-fuel tape to be recharged over a path which is substantially greater than the path maintained for metal-fuel tape to be discharged.

40. A metal-air fuel cell battery system comprising:

means for discharging and recharging metal-fuel tape in a single hybrid-type subsystem, wherein the discharging heads and recharging heads of said subsystem are arranged about the extended path-length of metal-fuel tape to enable simultaneous discharging and recharging operations.

41. A metal-air fuel cell battery system comprising:

a number of subsystems for enabling data capture, processing and storage of discharge and recharge parameters as well as metal-fuel and metal-oxide indicative data for use during discharging and recharging modes of operation.

42. A metal-air fuel cell battery system comprising:

means for storing a supply of metal-fuel cards (or sheets) within a cassette cartridge-like device having a partitioned interior volume for storing (re)charged and discharged metal-fuel cards in seperate storage compartments formed within the same cassette cartridge-like device.

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