United States Patent

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[73] Assignee **The United States of America as represented by the United States Atomic Energy Commission**

[54] **REACTOR CORE WITH REMOVABLE CORE ELEMENTS**
3 Claims, 18 Drawing Figs.

[52] **U.S. Cl.** **176/84,** 176/71
[51] **Int. Cl.** **G21c 5/00**
[50] **Field of Search** 176/84, 85, 71, 41

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Attorney—Roland A. Anderson

ABSTRACT: In the top layer of a lattice of core elements, keys interlock the core elements and provide geometric stability for a reactor core. Mores specifically, the core elements are interlocked by loose, shared keys extending between keyways in a pair of adjacent core elements. These loose shared keys are readily slideable from the keyways with removal of either of the core elements whereby the cavity is left clear to receive new replacement core elements. Fixed keys may also be attached to the core elements to facilitate alignment and keying of core elements to each other.

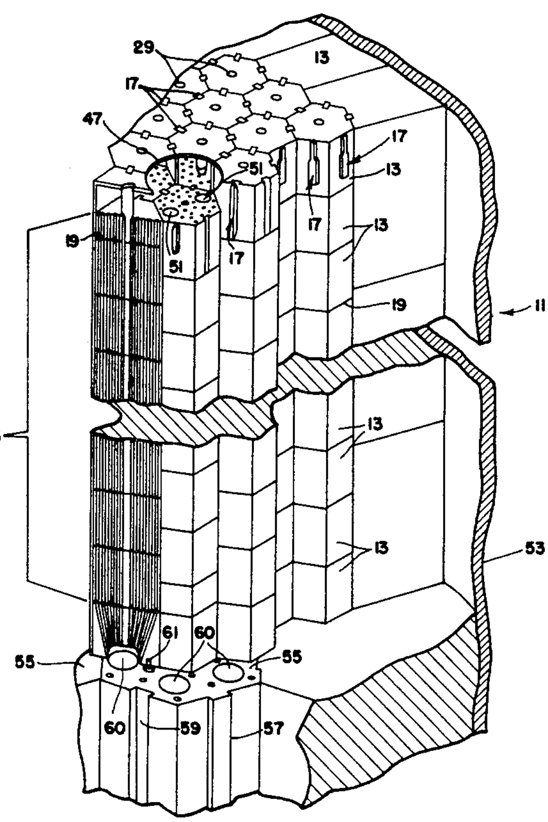

FIG. 1

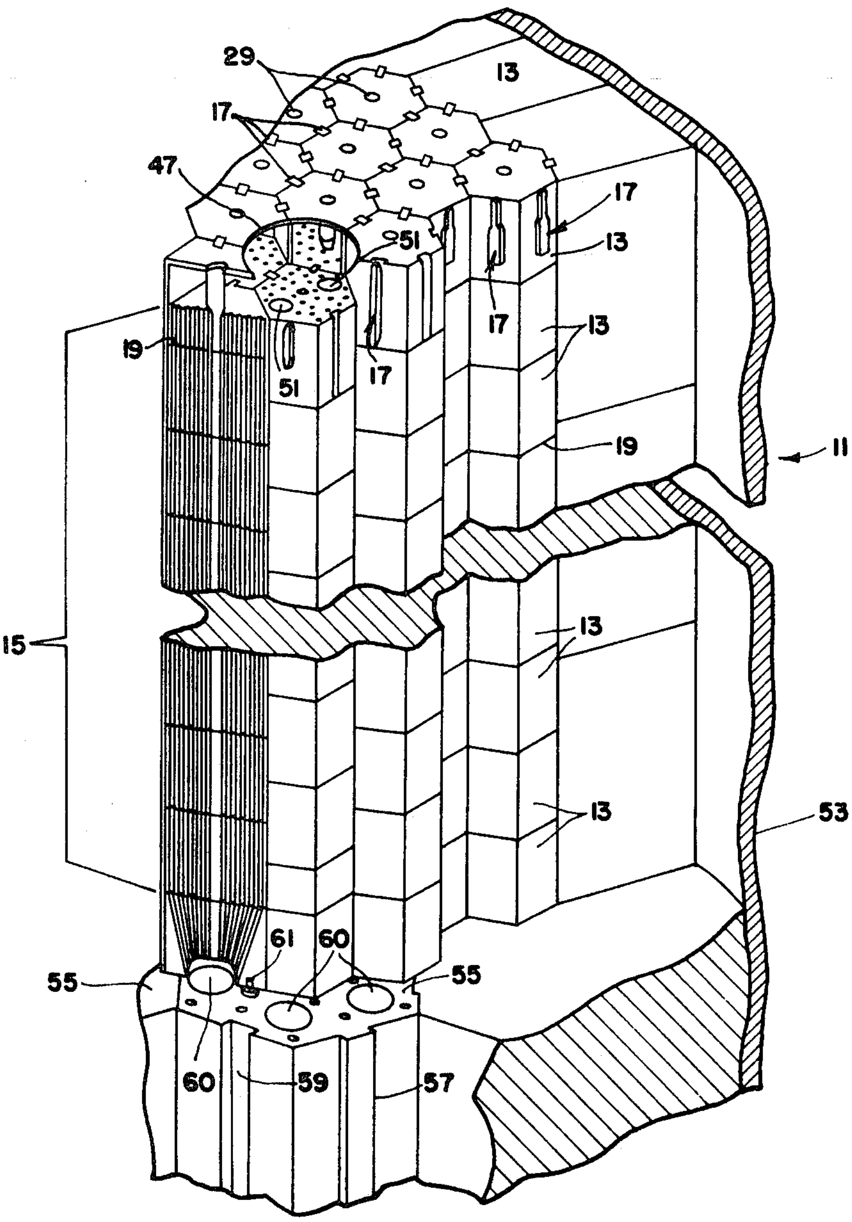

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FIG.2

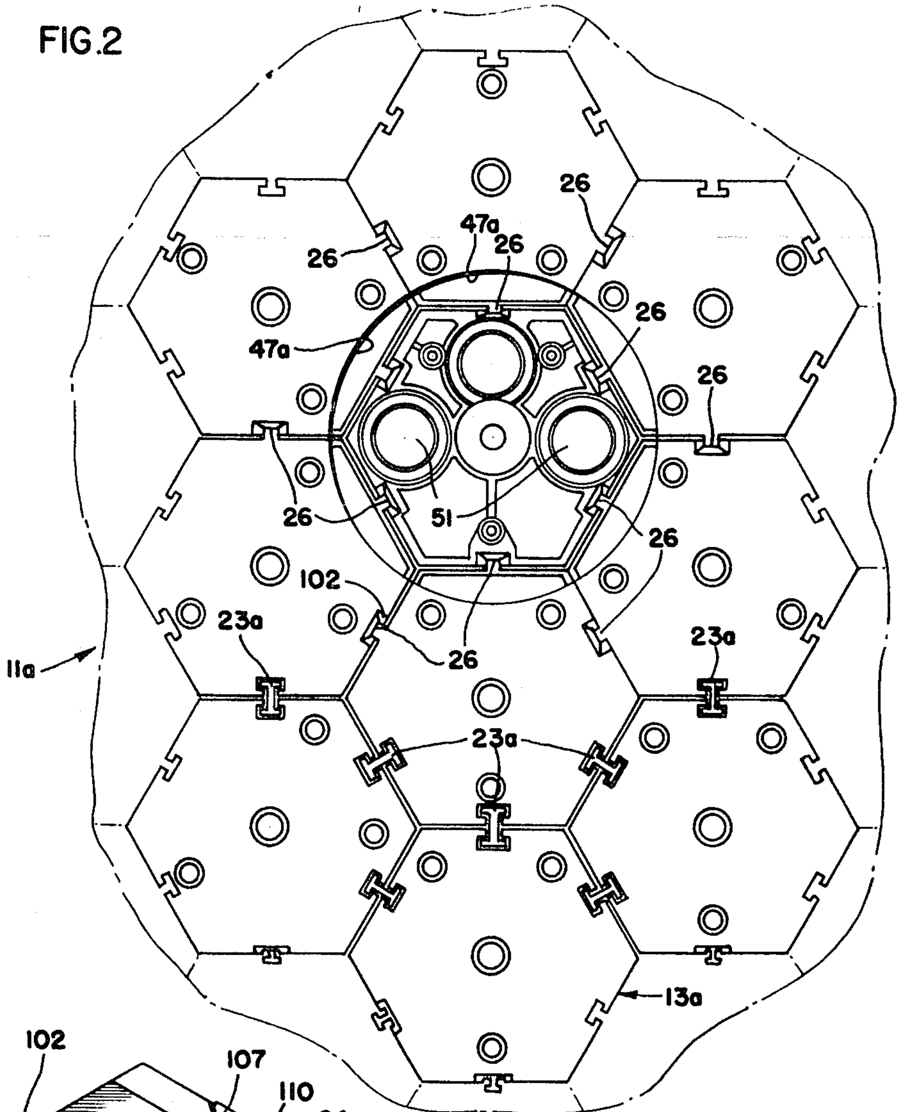

FIG.3

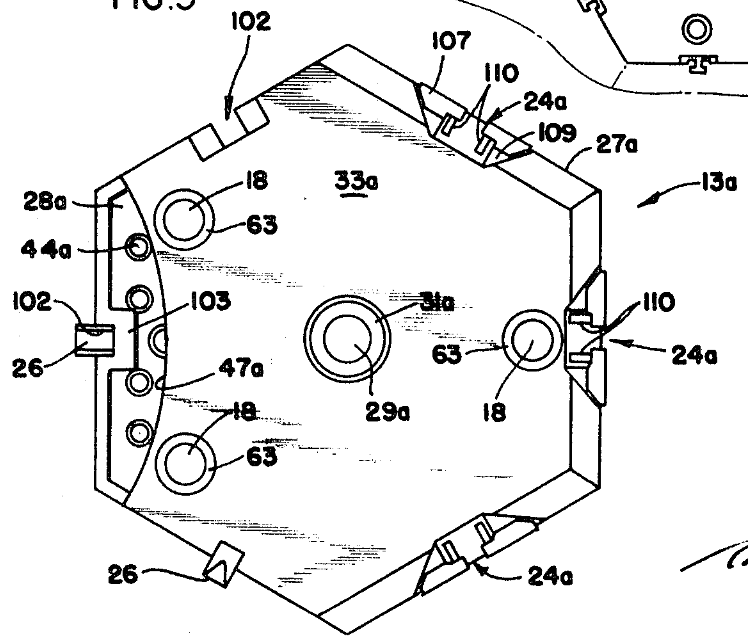

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FIG.4

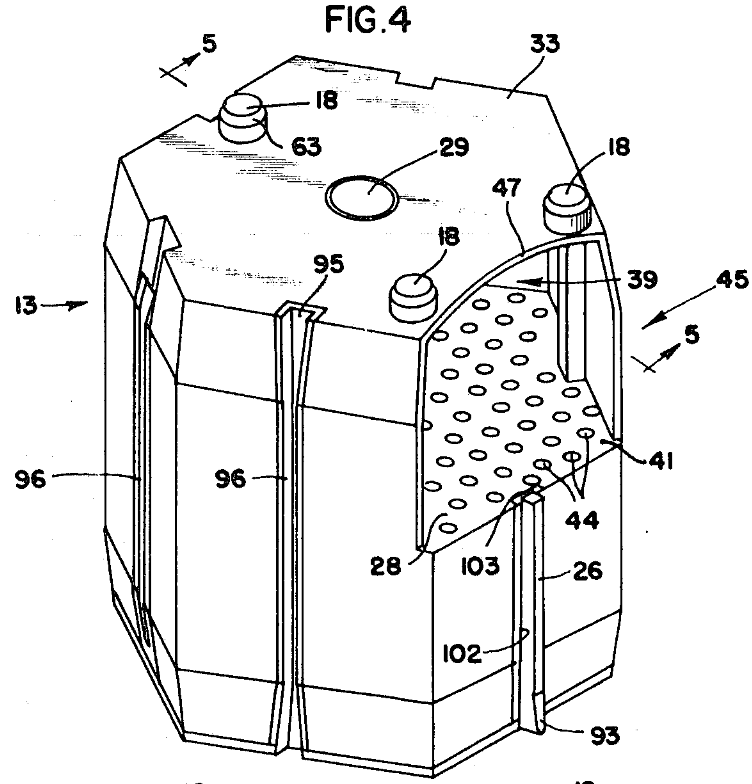

FIG.5

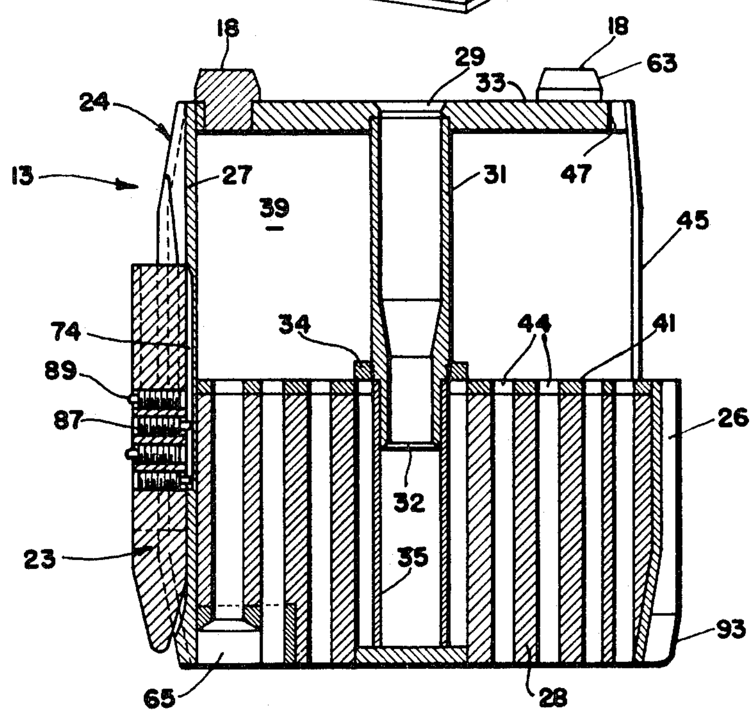

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FIG.6

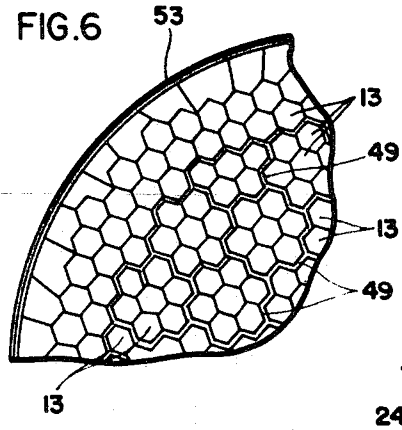


FIG.7

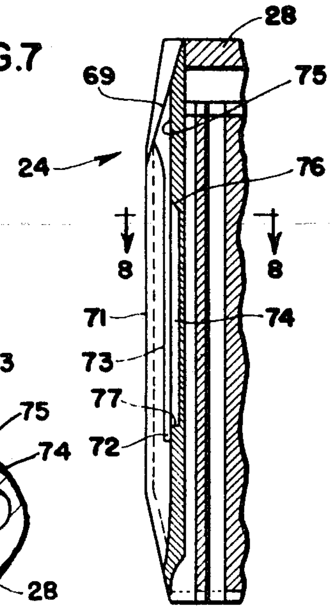
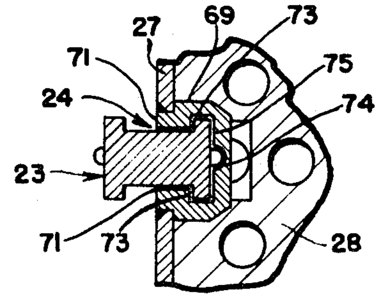


FIG.8



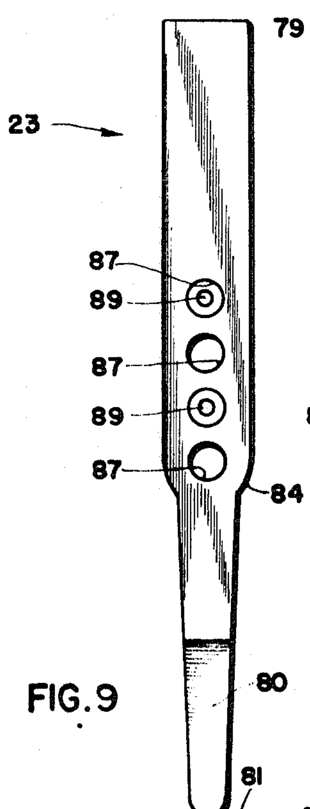


FIG.9

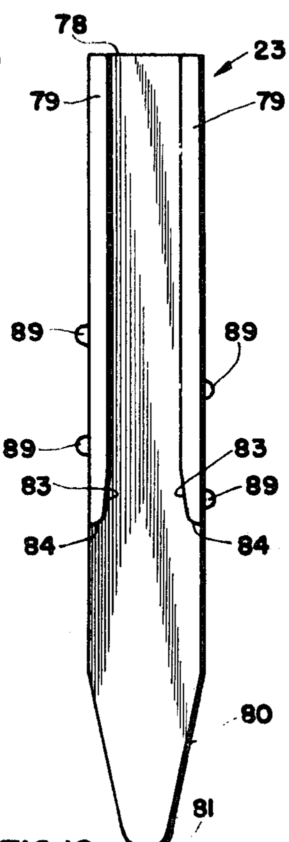


FIG.10

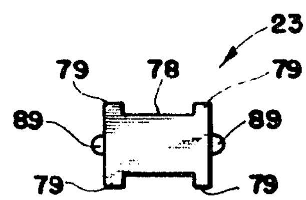


FIG.11

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FIG.12

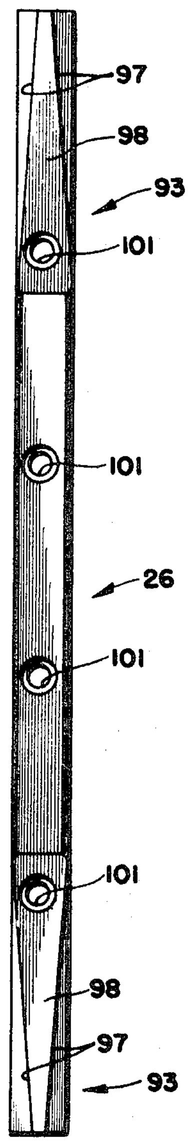

FIG.13

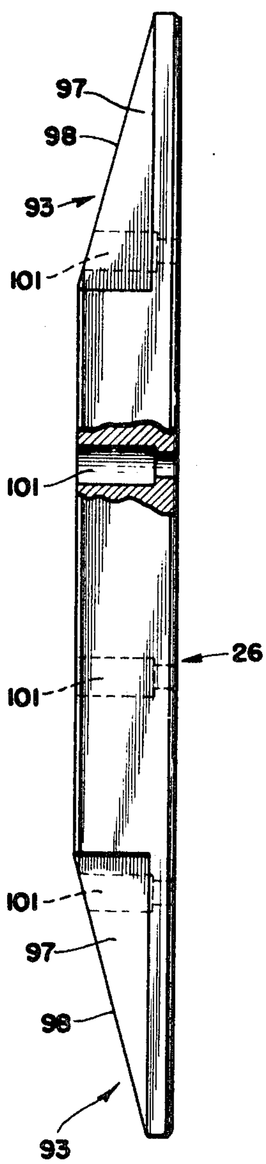

FIG.14

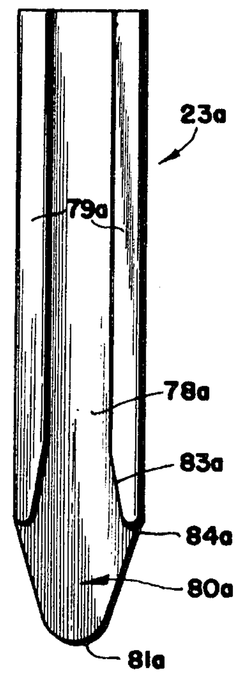

FIG.15

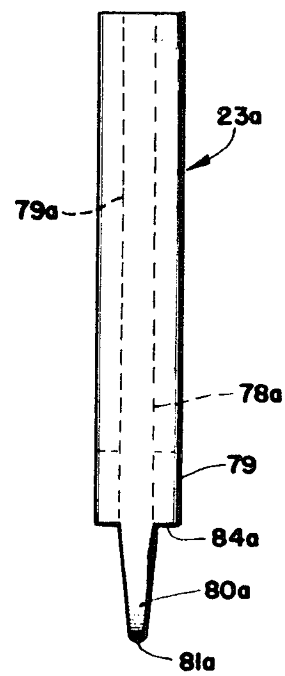

FIG.16

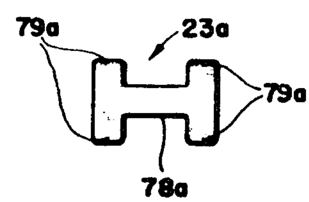

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FIG.17

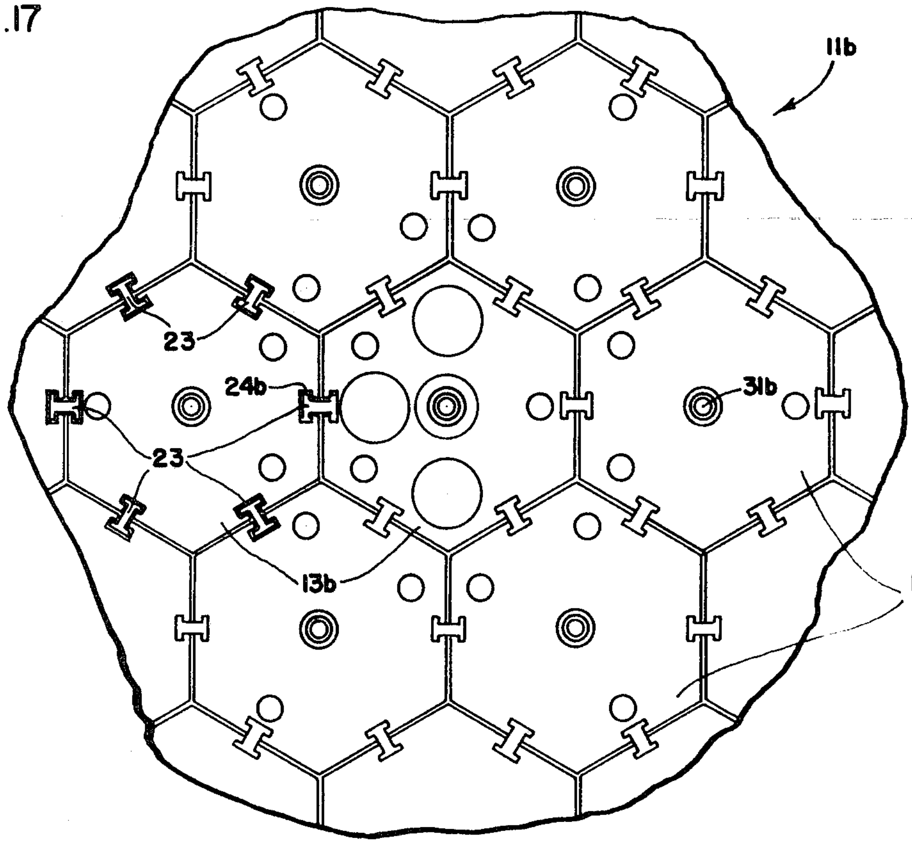
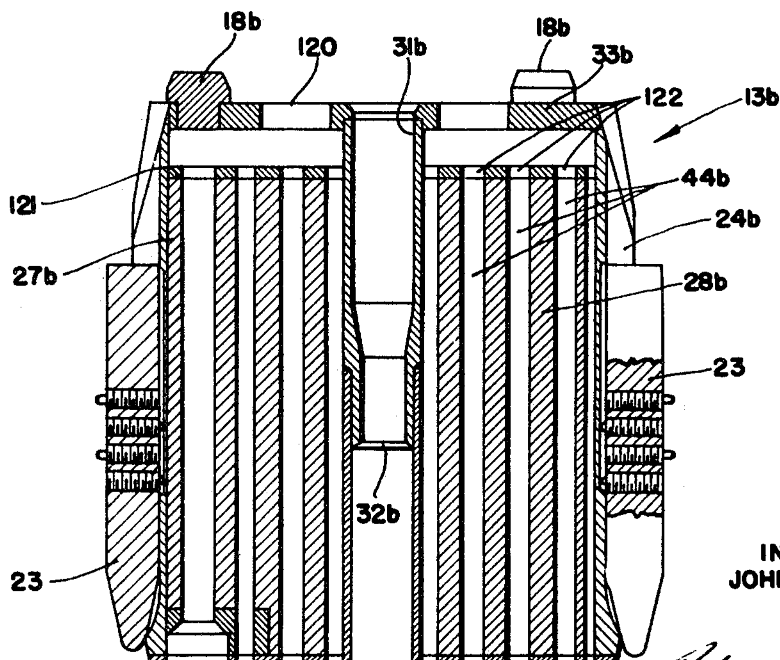


FIG.18



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REACTOR CORE WITH REMOVABLE CORE ELEMENTS

This invention relates to a nuclear reactor and, more particularly, to a reactor core having a lattice of core elements including fuel elements, reflector elements and the like.

The lattice of core elements is, in this instance, formed of blocked-shaped core elements stacked in vertical columns and arranged in substantially horizontal layers. The core elements have vertical passageways therein which are aligned to accept control rods or to allow the flow of coolant through a column of core elements. To prevent misalignment of these passageways and to maintain the geometric alignment of the lattice, the core elements need to be restrained and stabilized against lateral shifting due to pressure loads or to unusual loads, such as may be induced by an earthquake. Also, misalignment of the core elements is possible as a result of dimensional changes due to growth or shrinkage caused by thermal changes or neutronic conditions.

While it has been proposed heretofore to provide mechanical keying of core elements to stabilize such core elements against lateral displacement and vertical misalignment within reactor cores, the latter had fixed stationary graphite elements to which the core elements were keyed or interlocked. The removal of keys and core elements from such reactor cores is a time-consuming and difficult operation. Such techniques are unsatisfactory for nuclear reactor cores where the fuel elements, moderator elements or reflector elements are removed and replaced at quite frequent intervals, and particularly where the refueling is an "online" continuing kind of operation.

With the present invention, the lattice of core elements are aligned and stabilized by keys, but yet the core may be inspected and/or refueled by literally digging a hole in the core to remove core elements with automatically operated equipment. In such reactor cores, it is particularly important that the core elements surrounding the hole be interlocked against lateral shifting which would diminish the hole dimensions and also that the walls of the core elements defining the hole be free of interferring keys so that deeper core elements may be freely moved through the hole.

Accordingly, an object of the present invention is to stabilize the core elements against lateral shifting ore misalignment in a manner which does not interfere with removal or insertion of interior core elements.

Other objects and advantages of the invention will become apparent from the detailed description taken in connection with the accompanying drawings in which:

FIG. 1 is a fragmentary perspective view of a reactor core embodying the invention;

FIG. 2 is an enlarged plan view of a portion of the reactor core;

FIG. 3 is an enlarged, plan view of a core element;

FIG. 4 is a perspective view of another core element for use in a top layer of core elements;

FIG. 5 is a cross-sectional view taken along the line 5—5 of FIG. 4;

FIG. 6 is a fragmentary plan view showing several adjacent refueling zones;

FIG. 7 is a cross-sectional view of a keyway on a core element;

FIG. 8 is a cross-sectional view taken along the line 8—8 of FIG. 7 but with a key inserted in the keyway;

FIG. 9 is a front, elevational view of a removable key;

FIG. 10 is a side view of the key of FIG. 9;

FIG. 11 is a plan view of the key of FIG. 9;

FIG. 12 and 13 are front and side elevational views of a fixed key;

FIGS. 14, 15 and 16 are side, front and plan views, respectively, of a removable key constructed in accordance with another embodiment of the invention;

FIG. 17 is a plan view of a reactor core constructed in accordance with another embodiment of the invention; and

FIG. 18 is a vertical cross-sectional view of a core element for use in the reactor core of FIG. 17.

As shown in the drawings for purposes of illustration, the invention is embodied in a nuclear reactor core **11** (FIG. **1**) having a lattice of core elements **13** stacked vertically in columns **15** and horizontally in layers **16**. In the upper layer, the core elements **13** are keyed to each other by suitable keying means generally designated at **17**, which stabilizes the core elements from shifting laterally and becoming misaligned and displaced due to forces such as lateral pressures or forces from earthquakes. The keying means **17** is of particular importance from the standpoint of stabilizing the core elements during a refueling process in which a refueling machine automatically removes spent core elements **13** and replaces the same, i.e., refills the hole, with new core elements. As will be explained, the keying means are constructed to release automatically from the surrounding and associated core elements during lifting of a top layer core element from the reactor core in a refueling operation. In this instance, only the core elements **13** in the top layer have the keying means, and the core elements in the lower layers are interlocked to each other and to the top layer core elements by locating dowels **18** (FIG. **4**) projecting across horizontal interfaces **19** between adjacent core elements and into sockets therefor. Thus, the individual core elements are restrained against shifting laterally and closing in the hole formed by removal of core elements during a refueling process.

As will be explained in greater detail, the keying means **17** for the core elements in the upper layer includes loose, shared removable keys **23** which span a pair of facing keyways **24** in the vertical sides of core elements in adjacent columns, the loose keys **23** being removable or shared keys in the sense that the loose keys **23** extend into and slide in a pair of keyways and remove from the keyway in the stationary core element with lifting of the other associated core element. This is in contrast to fixed keys **26** which are securely fastened to one core element against movement relative to it. As will be explained in detail, a combination of loose keys **23** and fixed keys **26** may be used for refueling reactor cores, such as shown in FIG. **1**, in an "offline" operation in which the reactor core is shut down and a group of core elements in the top layer are removed prior to removing any core elements from the next lower layer. On the other hand, only loose keys **23** are used when refueling the reactor core **11*b***, which is illustrated in FIG. **17**, by an "online" operation which involves removing each one of a vertical column of core elements before removing another to top layer core element in another column.

Referring now in greater detail to the elements of the embodiment of the invention illustrated in FIG. **1–5**, the topmost core elements **13** in each column are formed of metal clad blocks **28** of nuclear grade graphite which are parallepipedic blocks having a hexagonal, horizontal cross section. Each of the topmost core elements has an outer metal cladding or jacket **27** substantially covering the sides and top of the graphite blocks **28** leaving the topmost blocks **28** with a graphite to graphite interface with next lower core element, it being understood that only the topmost core elements are metal clad. The reflector core elements are generally formed of solid blocks of graphite while the fuel-bearing core elements have coated carbide particles packed in vertical bores in the graphite blocks.

The core elements **13** are formed with a central, vertically extending, receiver opening **29** (FIG. **5**) to receive a grapple (not shown) of a refueling machine for lifting the core element vertically for removing it from the reactor core or for lowering it into position in the core. In the metal clad core elements of the top layer, the receiver opening **29** is encompassed by a metallic, cylindrically shaped handling tube **31** which will receive laterally directed, gripping forces from the expansible grapple and also the lifting forces at an annular shoulder **32** in the interior of the handling tube. The handling tube is suitably fastened as by welding to a top wall **33** of the metal cladding **27** and a holddown ring **34** (FIG. **5**) is threaded on the exterior of the handling tube **31** to bear against the top surface of the graphite block **28**. A lower end **35** of the handling tube **31** projects through a central bore in the graphite block and has an annular bottom plate welded thereto to hold the graphite block against downward sliding movement relative to the cladding 27. The lower, unclad core elements likewise have grapple-receiving openings 29 to accept the grapple for lifting them.

The uppermost core elements, illustrated in FIG. 4, are the plenum kind having an interior, hollow chamber 39 extending vertically between the top cladding wall 33 and an upper side 41 of the graphite block 28 and circumferentially between the vertical sides of the cladding 27 except at inlet opening 45 in the latter. Cooling gas flows into the chamber through the opening 45 and then flows down through a series of vertically disposed passageways 44 in this top block which are aligned with other similar passageways in the lower core element blocks. The top edge of the opening 45 is formed with a scalloped, arcuate edge 47 formed in the top wall 33; and, as best seen in FIG. 1, the arcuate edges 47 of adjacent core elements are arranged to define a circular-shaped opening admitting the cooling gas into each of the core element chambers of a region.

The illustrated reactor core is formed with a large number of columns, e.g., several hundred or more columns, with about six or more core elements in each column. The core elements are arranged in refueling regions (FIG. 6), as outlined by heavy lines 49 of seven columns each, except at the outer boundaries of the core where six columns constitute a fuel region. In these seven-column regions, six columns are clustered in an outer ring about a center column which has a pair of vertically oriented control rod channels 51 (FIG. 2) through which may be projected control rods (not shown). The control rod elements are displaced vertically from the planes of the interfaces 19 of the other core elements 13.

The columns of core elements 13 are arranged in a cylindrical formation in a right circular cylinder core barrel 53 and are supported in a suitable manner such as on large core support blocks 55 FIG. 1) which are sufficiently large to support and entire refueling region, e.g., seven columns of core elements. The core support blocks 55 are interlocked to one another by key-shaped projections 57 integrally formed in the vertical sides of the support block and projecting into a corresponding slot 59 in an adjacent support block. The core support blocks have large, vertical extending coolant passageways 60 to receive cooling gas from the converging coolant passages in the lower reflector core elements on it. These lowermost reflector core elements are positioned on and stabilized against lateral shifting on the support blocks by dowels 61 extending downwardly therefrom and projected into aligned similar-shaped openings in the top faces of the core support block. The core elements 13 are formed with three upstanding locating dowels 18 of generally cylindrical shape with a beveled upper edge 63 (FIG. 4) to guide the dowels into the cylindrical-shaped openings or sockets 65 formed in the bottom wall of the core elements and spaded to correspond with the spacing of the dowels. When the dowels are seated in sockets 65 in the respective internal core elements 13, the latter are held against lateral shifting relative to one another except for a slight movement which might result from clearance tolerances or an accumulation of clearance tolerances between the dowels 18 and the sockets 65.

It will be appreciated that a slight clearance exists between the core elements in adjacent columns and that the keying means 17 limits the lateral movement of a column or core elements to this clearance so that the hole will not be closed in to replacement core elements. The use of the metal cladding 27 and accurately dimensioned keyways 24 therein provides good dimensional control and accurate positioning of each column location in the core when the keys 23 and 26 are interlocking the columns. In the embodiment of FIGS. 4–8, the keyways 24 for the loose shared keys 23 are formed in vertical bars 69 (FIG. 8) welded at locations centrally in vertical sidewalls of the cladding and serving as part of the cladding which is of thinner cross section. Preferably, the keyways 24 for the removable keys 23 have an opening of substantially T-shaped horizontal cross section formed by a pair of spaced, vertically extending throat-defining walls 71 which extend the full length of the keyway. The throat-defining walls 71 intersect a pair of transversely intersecting slots, which extend from a lower end wall 72 upwardly to the top of the keyway. These transverse slots are defined between shoulders 73, which extend at right angles to the throat walls 71 and to a rear keyway 75, to define a laterally extending slot normal to the keyway throat. Formed centrally within the rear wall 75 is a narrow groove 74 which, as will be explained, receives a detent and extends vertically from an arcuate upper end 76 to a lower end 77 (FIG. 7) which is spaced slightly above the lower end 72 of the flange-receiving slots. At the upper end of the keyways 24, the throat walls 71 are beveled outwardly at about 30° to provide an enlarged guide slot to facilitate entry of a removable key therein. As best seen in FIG. 7, the upper and lower ends of the keyways are beveled also to conform to the beveled top and lower rims of the cladding 27.

The removable key 23 is formed to span and fit within a pair of opposite keyways 24 with a free sliding fit in each of the keyways. More specifically, the key 23 has central body 78 of a substantially rectangular cross section of sufficient length to bridge the core elements and extend through the throats of keyways. A pair of outwardly extending flanges 79 are formed at each end of the body 78 of the key, the flanges being dimensioned to fit between the keyway shoulder walls 73 and rear walls 75. The flanges are dimensioned to slide in the keyways and have sufficient strength to withstand and transfer laterally directed forces between its associated core elements.

To assist insertion of a removable key 23 into a keyway 24 and to accommodate any slight turning or lateral misalignments between an inserting key and a keyway, the lower end of the removable key is formed with a tapered nose 80 leading to a rounded, lower end 81, as best seen in FIG. 9. Also, the tapered nose 80 is made with a reduced cross-sectional thickness to facilitate entry of the body into the throat of the keyway slot. Key insertion is also aided by having the nose free of flanges 79 and having the lower inward facing ends 83, as best seen in FIG. 10, of the flanges 79 tapered and formed with a reduced cross-sectional thickness. The flange ends 83 are rounded at 84 (FIG. 9) to guide the flanges 79 into the portions of the keyway receiving the same. Thus, the tapered nose 80 of the key will insert into the enlarged slot at the top of keyway 24 and will be guided and will guide itself down into the keyway.

In this embodiment of the invention, the removable shared keys 23 are detented within each of its receiving keyways 24 by detent mechanisms 87 (FIG. 5) which have a spring-biased plunger with a rounded nose 89 for projecting into the narrow detent groove 74. In this instance, the detent mechanisms are threaded into tapped, horizontal bores, and an internal spring (not shown) within each detent mechanism is disposed behind each plunger to force the same outwardly to project its nose into groove 74.

When the removable shared key 23 is being lifted with one of its core elements, the lower ends 84 of its flanges may bottom on the lower ends or shoulders 72 of the flange-receiving slots in the rising core element to overcome any resistance of the key to sliding upwardly in the keyway of the adjacent stationary core element. When the rising key brings its detent noses 89 into engagement with the top end 76 of the detent groove 74 in the stationary core element, the detent nose is cammed back into the key until the key is lifted clear of the stationary core element 13. On the other hand, when core elements are being inserted into the core, the detent noses 89 on its keys are cammed inwardly by the rear keyway wall 75 until carried down into a position for expanding into detent grooves 74 whereupon the detent noses 89 may snap back into the grooves.

As explained previously, core elements illustrated in FIGS. 1–5 may also be provided a number of fixed keys such as the fixed key 26 illustrated in FIGS. 4 and 5. The fixed key 26 is generally rectangular in cross section with a lower pointed nose **93** for insertion into an enlarged, flared slot **95** of a keyway **96** having a similar rectangular cross section. Where the plenum opening **45** is formed, the fixed key **26** is shortened. A suitable shape for the longer fixed keys **26** is illustrated in FIGS. **12** and **13** wherein a generally rectangular cross-sectional bar is provided with both upper and lower pointed noses **93** formed by inwardly inclined sidewalls **97** and an outer wall **98**. A series of horizontal bores **101** are provided in the fixed keys to receive screws for fastening the keys rigidly to and within a groove **102** in a bar portion **103** of the cladding for an upper core element.

An alternative form of a loose, shared, removable key **23*a*** (FIGS. **14, 15** and **16**) without the detent mechanisms may be used with a core element **13*a*** (FIG. 3). As this key **23*a*** is substantially similar to the key **23**, reference characters with a suffix "*a*" are used to identify elements previously described in connection with the key **23**. This key has a thinner body **78*a*** but thicker flanges **79*a***. The key **23*a*** is particularly suited for use with the core elements **13*a*** which are substantially similar to the core elements **13** except for keyways **24*a*** which are formed by a pair of flat machined bars **107** fastened to machine bosses **109** on the cladding. The lower ends **84*a*** of the flanges **79*a*** will bottom on a pair of pins **110** disposed near the bottom of the keyways.

One suitable arrangement of core elements using both removable shared keys **23*a*** and fixed keys **26** is illustrated in FIG. **2**, wherein each of the six clustered core elements **13*a*** has a shared key **23*a*** projecting across its refueling boundary line and inserted into a keyway **24*a*** in a core element in another refueling zone. Fixed keys **26** are provided on the other interiorly directed faces of the clustered core elements for keying to an adjacent core element in its refueling zone. The reactor core **11*a*** is refueled "offline" and each of the seven core elements in the top layer for the region are first removed. This leaves a very large hole having the sidewalls thereof free of inwardly projecting keys as the shared keys **23*a*** at the boundary of the region were removed with the lifted core elements. Thus, the second and subsequent layers of core elements may be lifted through this hole for replacement.

In contrast to the above-described "offline" refueling operation for the reactor core **11** described hereinbefore in connection with FIGS. **1** and **2**, a reactor core **11*b*** constructed in accordance with a further embodiment of the invention and illustrated in FIG. **17** permits an "online" refueling operation in which a single column of core elements **13*b*** is removed and replaced prior to the removal of any other core elements of the region. The core elements **13*b*** are substantially similar to the above-described core elements **13** or **13*a*** except that the core elements **13*b*** lack any fixed keys **26** and lack the large plenum chambers and scalloped opening **45** leading thereto. To simplify the description, reference characters with a suffix "b" are used to identify parts for the core element **13*b*** similar to the parts described in connection with core elements **13** and **13*a***.

The core elements **13*b*** used for the online refueling kind of reactor are provided with fixed circular orifices **120**, as best seen in FIG. **18**, in the top plate **33*b*** of the metal cladding **27*b*** for the core element. In this fixed orifice core element, the cooling gas may flow through the fixed orifices **120** into a small space between a top plate **33*b*** and a flat apertured plate **121** on top of the graphite block. Apertures **122** in the plate **121** are aligned with cooling passageways **44*b*** in the graphite block **28*b*** which has a substantially greater height than the graphite block height for the core elements **13** or **13*a***. The illustrated core element has a handling tube **31*b*** welded at its upper end to the top plate **33*b*** and to the apertured plate **121**. At its lower end, the handling tube is welded to a bottom apertured plate **124** which is welded to the surrounding vertical sidewalls of the cladding. A lifting grapple (not shown) will abut the underside of an annular shoulder **32*b*** in the handling tube **31*b*** to lift the core element.

As each core element **13*b*** has six loose keys **23** or **23*a***, the lifting of a core element **13*b*** causes the removal of its six keys from the keyways in the six surrounding core elements. Thus, the sidewalls defining the hole in the top layer are free of keys and allow a lower core element in the same column to be lifted subsequently from through the hole.

A brief description of a typical "online" refueling operation will be described as an aid to under standing the invention. The refueling machine disposed on the exterior of the core pressure vessel has a fuel chute which penetrates the pressure vessel through a nozzle opening in which is normally positioned the control-rod-driving mechanism for the control rods used in the region to be refueled. With the fuel chute in position, a grapple head is lowered through the chute and projected into the handling tube **31*b*** of an outer core element **13*b*** in one column of core elements. The grappling head is expanded in the tube to grip the shoulder **32*b*** on the handling tube and then a lifting mechanism begins to lift the core element upwardly. The shared removable keys **23** or **23*a*** bottom at the lower ends **72** of the keyway slots of the core element being lifted. The key flanges **79** slide upwardly in the keyways **24*b*** of the stationary core elements surrounding the rising core element. Even though the topmost core element **13*b*** of a column is removed, the remaining core elements in the top layer are held by the shared keys **23** or **23*a*** against shifting laterally and closing in on the hole formed with removal of the top core element.

After the top core element is removed from a column and stored, the grapple head is again lowered and inserted into an opening **29** of the core element in the second layer of the same column. The grapple is connected to and lifts the second core element through the hole left by the upper core element. As the second layer core elements in the surrounding columns are connected by dowels **18*b*** to their respective upper layer core elements, these surrounding core elements are held against closing in the hole which would prevent insertion of new replacement core elements for the column. The dowels hold the interior core elements against any large lateral shifting movement tending to interfere with passage of a core element in the cavity, and, if there is any slight lateral shifting of a core element allowed by the clearance between dowel pins and dowel sockets, rollers (not shown) may be provided on the grapple head frame (not shown) to force the core elements laterally outward during its traverse in the hole. The supplementary use of reversible driven rollers on the hexagonal boundaries of the grapple head frame for spreading adjacent columns and enforcing the clearances is a feature of one embodiment. In this instance, each of the spent core elements of the column are removed and then the new core elements are inserted one by one into the hole until it is again filled. The dowels **18*b*** of each interior core element project into the sockets of the core element superimposed thereon. The top layer core element **13*b*** fills the hole and its loose shared keys **23** or **23*a*** insert into the keyways of the surrounding top layer core elements to interlock this core element with the others.

In the "offline" refueling operation, each of the seven core elements **13** or **13*a*** in the top layer are removed by lifting with the grapple leaving a hole which is seven columns in area before any of the second layer core elements are removed. As the top layer core elements **13** or **13*a*** each have a loose shared key **23** or **23*a*** at and extending across the region boundary line **49**, the boundary of the hole along this line will be free of fixed keys which would prevent removal of the subsequent layers or core elements.

From the foregoing, it will be seen that a lattice of core elements is restrained and interlocked against lateral shifting which would misalign passageways therein or close in on a hole formed during a refueling operation. The core elements and columns thereof are interlocked to each other, and a novel keying arrangement permits lifting of the keyed blocks for a refueling of the reactor core.

While a preferred embodiment has been shown and described, it will be understood that there is no intent to limit the invention by such disclosure but, rather, it is intended to cover all modifications and alternate constructions falling within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. In a reactor core, means defining a support for said core; core elements stacked one upon another in columns on said support and arranged in substantially parallel layers; means for interlocking said core elements to each other within a column; and means for keying said core element in one column to another associated core element in an immediately adjacent column in at least one of said layers to stabilize said core to withstand laterally directed forces, said keying means including keyways in opposing sides of said core elements and further including removable keys spanning a pair of said keyways, said keyways for said removable keys having an inlet throat and slots extending transversely to said throat, and said removable keys having a central body and pairs of transversely extending flanges for a sliding fit in each of its pair of keyways and for sliding from the keyway of one core element when its other associated core element is lifted for removal from the core, and said removable keys having a releasable detent means for detenting said removable keys in position within said keyways.

2. In a reactor core, hexagonally cross-sectioned core elements stacked in a plurality of adjacent, vertical columns, said uppermost core elements in each column having an outer metal jacket and an inner block of moderator material, said core elements having vertically extending projections on a horizontally disposed face thereof and having sockets on another horizontally disposed face, said sockets in one core element receiving said projections in another core element and aligning said core elements within said columns, keyways formed in some of the vertically disposed sides of said metal jackets and aligned with similar keyways in core elements in adjacent columns, removable keys projecting into pairs of aligned keyways to interlock adjacent columns to each other, said removable keys being fitted in said keyways for sliding vertically from the keyway of an adjacent core element with removal of an associated core element, and fixed keys secured to other sides of the core elements and projecting in other keyways formed in core elements of adjacent columns, said fixed keys being removed only with removal of the core element to which it is secured.

3. A reactor core in accordance with claim 2 in which said removable keys have a body for spanning adjacent core elements and flanges extending transversely of said body and inserted into said keyways.