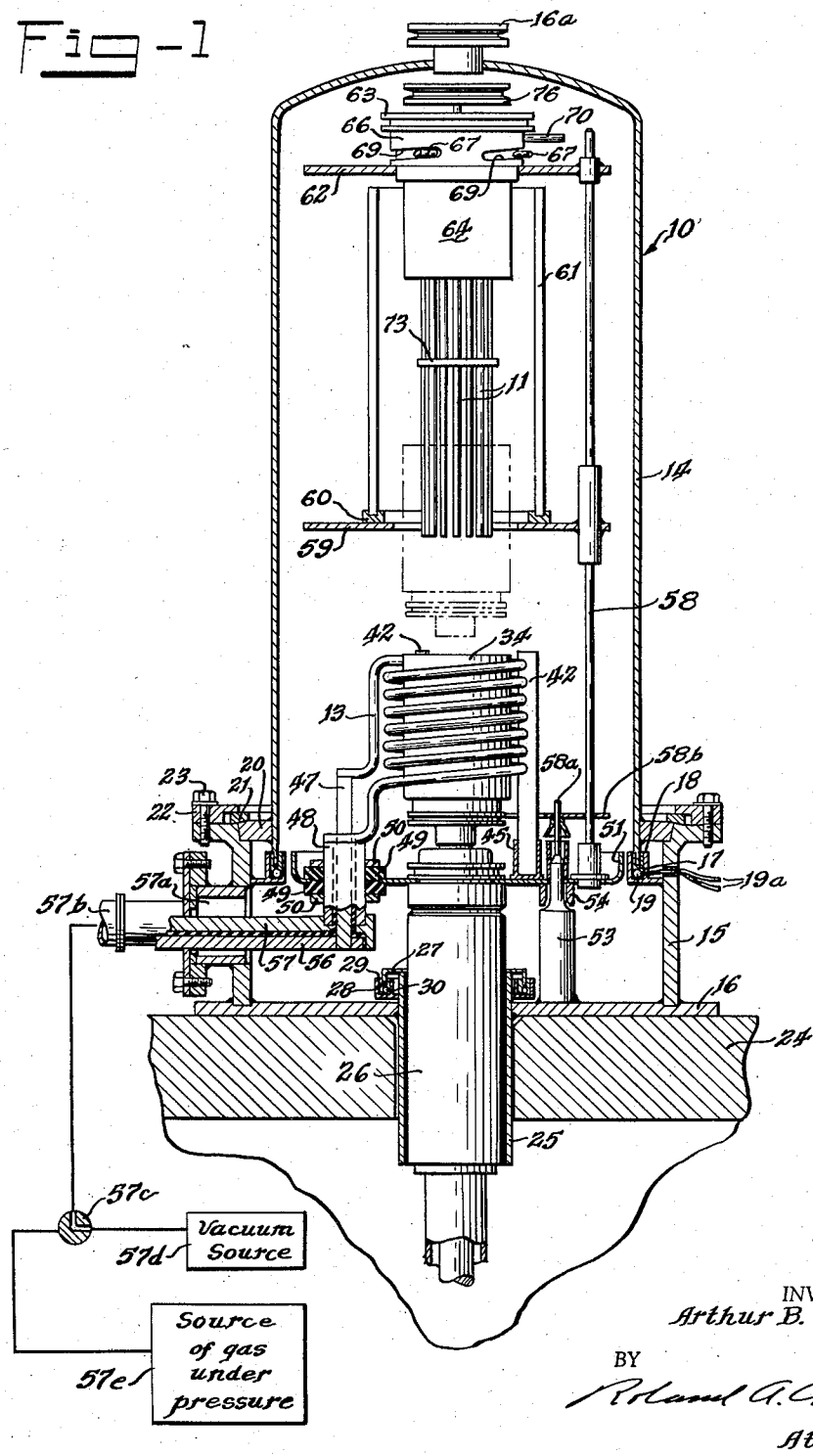
Sept. 13, 1960 A. B. SHUCK 2,952,056

APPARATUS AND METHOD FOR INJECTION CASTING

Filed Oct. 10, 1957 3 Sheets-Sheet 1

Fig-1



INVENTOR.
Arthur B. Shuck

BY
Roland A. Anderson
Attorney

Sept. 13, 1960 A. B. SHUCK 2,952,056

APPARATUS AND METHOD FOR INJECTION CASTING

Filed Oct. 10, 1957

3 Sheets-Sheet 2

Fig-2

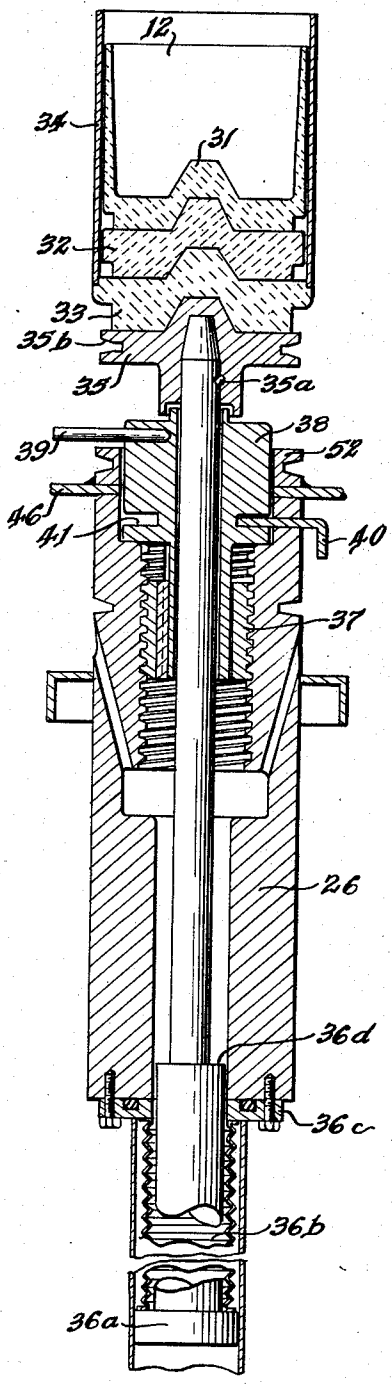
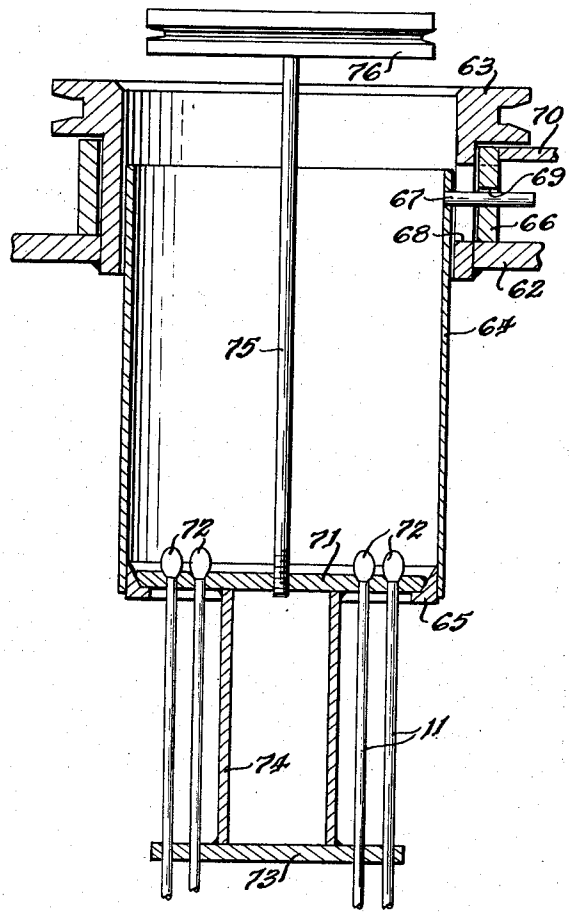


Fig-3



INVENTOR.
Arthur B. Shuck

BY

Roland A. Anderson

Attorney

Sept. 13, 1960 A. B. SHUCK 2,952,056

APPARATUS AND METHOD FOR INJECTION CASTING

Filed Oct. 10, 1957 3 Sheets-Sheet 3

Fig - 4

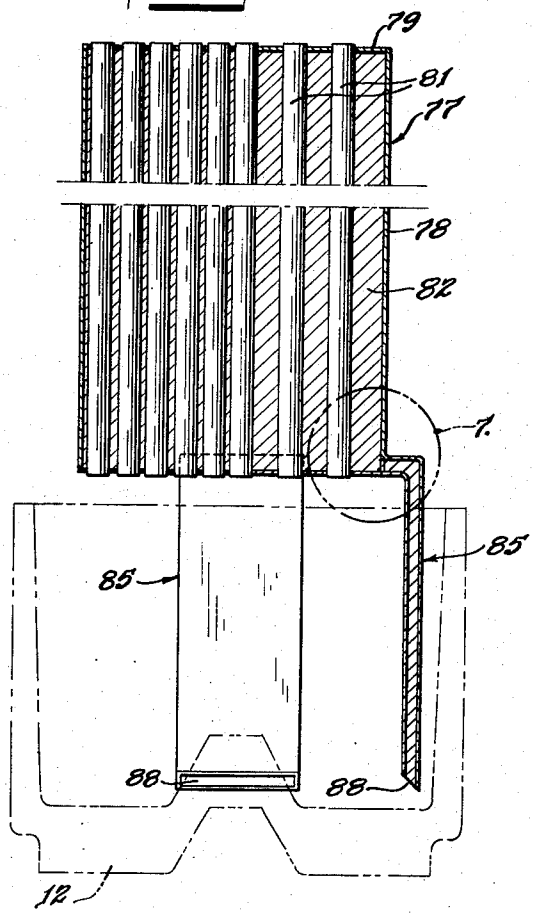


Fig - 6

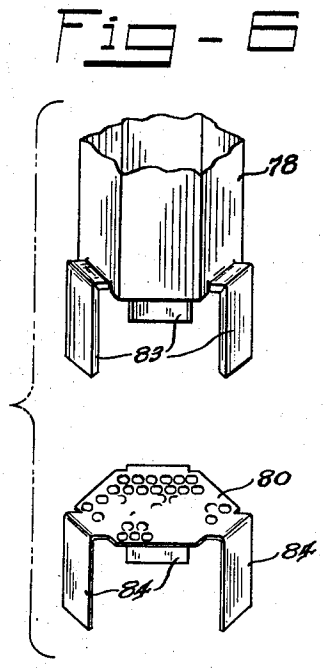


Fig - 5

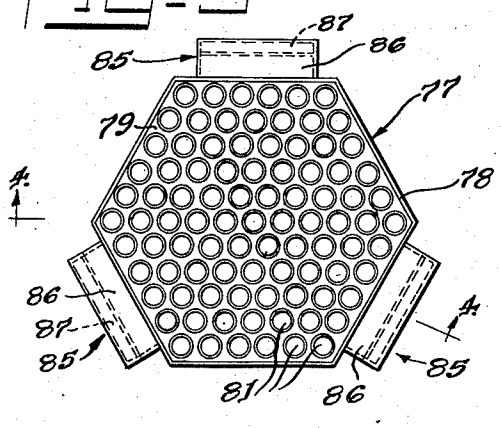
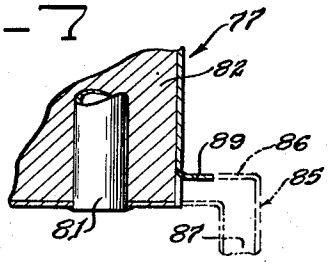


Fig - 7



INVENTOR.
Arthur B. Shuck

BY
Roland A. Anderson
Attorney

United States Patent Office 2,952,056
Patented Sept. 13, 1960

2,952,056

APPARATUS AND METHOD FOR INJECTION CASTING

Arthur B. Shuck, Wheaton, Ill., assignor to the United States of America as represented by the United States Atomic Energy Commission

Filed Oct. 10, 1957, Ser. No. 689,459

4 Claims. (Cl. 22—210)

This invention relates to injection casting and, more particularly, to vacuum casting of long members with narrow sections.

When molten metal moves by gravity from a crucible to a mold, the metal must be poured or valved. In either event difficulties may arise, particularly if the mold cavity is thin or narrow. Pouring of the metal may result in spilling. In valving, contact of the valve with the molten metal may interfere with the effectiveness of the valve, or the fitting of the mold to the valve may be difficult and inconvenient. Similar difficulties have been encountered with valves in vacuum casting.

When the metal being cast contains irradiated uranium or some other highly radioactive material, the casting operation may have to be remotely controlled, and the cleaning up of spilled metal and the replacement or adjustment of valves will be very difficult. Moreover, the unworkability of the metal or the need for remote control of working operations will make impossible or difficult the reduction of large radioactive castings to long objects of narrow section.

An object of the present invention is to provide a method and apparatus for casting that avoid spilling by doing away with pouring and that eliminate the need to replace and adjust valves by keeping them away from molten metal and molds. These desirable results are achieved by a novel scheme of vacuum casting.

A further object is to cast a long object with narrow sections. Such an object may be a long slender rod.

Another object is to cast a long narrow object free from surface imperfections so that the need for sizing operations is obviated.

According to the present invention, a long tubular mold open at one end and closed at the other, and a crucible containing a charge are placed in a sealed vessel, the vessel is evacuated, the charge is melted, the open end of the mold is dipped into the melted charge, and gas under pressure is admitted to the vessel to drive the melted charge into the mold to the closed end thereof.

In the drawings:

Fig. 1 is a sectional elevation, partly schematic, of the novel casting apparatus of the present invention;

Fig. 2 is a fragmentary sectional view of the crucible of the present casting apparatus and the means for elevating the crucible;

Fig. 3 is a fragmentary sectional view of the molds of the present apparatus and the means for supporting the molds;

Fig. 4 is a sectional view taken on the line 4—4 of Fig. 5 and showing the application of the present casting method to the making of a composite article having many passages;

Fig. 5 is a plan view of the composite article;

Fig. 6 is an exploded view showing parts of the composite article; and

Fig. 7 is a fragmentary sectional view of the portion in

circle 7 of Fig. 4, illustrating a step in the making of the composite article.

The apparatus of the present invention comprises essentially a sealed vessel **10**, a plurality of tubular molds **11** therein, a crucible **12** (Fig. 2) vertically movable in the vessel, a heater **13** surrounding the crucible **12**, and connections to the vessel **10** for vacuum and gas under pressure. The vessel **10**, with the molds **11** and crucible **12** therein is evacuated; a charge in the crucible **12** is melted, the crucible **12** is moved upwards to submerge the lower open ends of the molds **11** in the melted charge; and gas under pressure is admitted to the vessel **10** to drive the melted charge into the molds **11** as far as the closed upper ends thereof.

The vessel **10** comprises a bell **14**, a ring **15**, and a base **16**. The bell **14** has a lifting member **16***a*. The lower open end of the bell **14** extends into the ring **15** and is sealed thereto by dipping into a body of solder **17** which is contained in a channeled annulus **18**, connected to the inside of the ring **15** by a seal weld. A resistance heater **19** in the annulus **18** melts the solder **17** when the bell **14** is to be removed. Leads to the heater **19** are designated by **19***a*. The bell **14** is clamped to the ring **15** by a flange **20** on the bell **14**, a ring **21**, seated on the flange **20** and the ring **15**, an annular retainer **22** holding the ring **21** in place, and screws **23** going through the annular retainer **22** and threaded into the ring **15**. The ring is welded to the base **16**.

The base **16** rests on a support **24** and carries a tubular extension **25** which is welded to the base **16** at a central opening therein and extends through the support **24**. In the tubular extension **25** there is positioned a body **26** carried thereby by means of a flanged ring **27** secured to the body **26** in a seal weld and resting on the upper end of the tubular extension **25**. The flanged ring **27** dips into a body of solder **28** which is carried in an annulus **29** and acts as a seal between the tubular extension **25** and the body **26**. A resistance heater **30** in the annulus **29** melts the solder **28** when the body **26** is to be removed from the tubular extension **25**.

The parts of the vessel **10**, the annuli **18** and **29**, the extension **25**, the body **26**, and the ring **27** are formed of mild steel. The portions that the bodies of solder **17** and **28** contact are coated with copper.

As shown in Fig. 2, the crucible **12** is a cup having an internal hollow conical protrusion **31** in its base. The crucible **12** is of graphite and is coated inside and outside by thoria, which may be applied by spraying over an initial coating of magnesium carbonate. The crucible **12** rests on a stabilized-zirconia disk **32**, which rests on a stabilized-zirconia base **33**, to which is attached a cylindrical heater **34** of tantalum surrounding the crucible **12**. The base **33** rests on a steel pedestal **35** attached by a pin **35***a* to the upper end of a rod **36**. The pedestal **35** has a circumferential groove **35***b* which is engageable by a tool, not shown, for removing the pedestal **35**, base **33**, heater **34**, disk **32**, and crucible **12** together. The rod **36** carries at its lower end a piston **36***a* which is pneumatically or hydraulically actuated to raise or lower the rod **36** and the crucible **12** with respect to the molds **11**. A bellows seal **36***b* is connected at its lower end in the piston **36***a* and its upper end to a ring **36***c* attached to the body **26**.

The height to which the crucible **12** may rise in submerging the lower open ends of the molds **11** in the melted metal in the crucible is determined by engagement of a shoulder **36***d* on the rod **36** with an adjustable stop **37**. As shown in Fig. 2, this stop has threaded engagement with the interior of the body **26** and is slidably keyed to an adjusting member **38**, and so rotation of this member causes the stop **37** to rotate and to move up or down. The adjusting member **38**, which is rotated

by a tool 39 inserted therein, is rotatably supported in the body 26 and is held therein by a removable retainer 40 extending through the body 26 and into a circumferential groove 41 in the adjusting member 38. As a practical matter, the stop 37 will be adjusted only downwards from the position shown in Fig. 2, since the shoulder 36*d* on the rod 36 would contact the lower end of the member 38, not the stop 37, if the stop were above the position of Fig. 2.

As shown in Fig. 1, the heater 13 is an electric high-frequency induction coil that surrounds and is spaced from the cylindrical heater 34. The cylindrical heater becomes very hot from eddy currents generated therein by current of 10,000 cycles/sec. or more flowing in the coil heater 13 and melts the charge in the crucible 12 by radiant heat. The cylindrical heater 34 acts as a stabilizer in permitting the energy loss from the coil heater 13 to be varied. Preferably, the coil is formed of a solid bar or strip of tungsten or molybdenum. The coil is supported in notches in three posts 42 spaced 120° from one another, only two posts being shown. The posts 42 are formed of a ceramic such as magnesium silicate and aluminum silicate and are held upright in cups 45 attached to a table 46. Cups 45 and table 46 are formed of stainless steel having coatings of zirconia or alumina which prevent metal spilled from the crucible 12 from sticking.

Leads 47 and 48, preferably of nickel, are supported vertically in contact with the ends of the coil of the heater 13 in the table 46 by means of insulators 49 and rings 50, the insulators 49 being damped to opposite sides of the table 46 at an opening therein, and the rings 50 being bonded to the lead 48 and engaging the insulators 49 above and below. The lead 47 goes through the lead 48 and is, of course, insulated therefrom.

The table 46 has a circumferential flange 51 which prevents metal spilled on the table from flowing off the table. The table is centered in the vessel 10 by the member 38 which fits in a central opening in the table 46 and in a lifting ring 52 which is bonded to the table 46. As shown in Fig. 1, the table 46 is carried on three posts 53, spaced 120° from one another, only one post being shown. The posts 53 are secured to the base 16 and extend through the table 46 and through bushings 54 which are secured to the bottom of the table 46 and transmit the lead thereof to the posts 53.

The posts 53 angularly locate the table 46 so that the heater leads 47 and 48 are positioned to plug vertically into copper conductors 56 and 57, respectively, which are insulated from one another. Conductors 56 and 57 extend through an inlet 57*a* to the container ring 15, which inlet is connected through a pipe 57*b* and a valve 57*c* to a vacuum source 57*d* and to a source 57*e* of gas under pressure.

The table 46 supports three legs 58, only one being shown. The legs are spaced 120° from one another and extend into openings in the table 46. The legs 58 get lateral support from reduced extensions 58*a* of the posts 53 and an incomplete ring or horseshoe 58*b*. The legs 58 extend through and are secured to the ring 58*b*, which is incomplete in order to make room for the heater leads 47 and 48. At intermediate portions of their lengths the legs 58 carry and are fixed to an annular tray 59, which supports a channeled ring 60, in turn supporting a resistance heater 61. This heater is cylindrical and surrounds the tubular molds in spaced relation thereto. At their upper ends the legs 58 carry and are fixed to an annular shelf 62.

As shown in Figs. 1 and 3, a lifting ring 63 is secured to the annular shelf 62. Within the lifting ring 63 is a sleeve 64 having a supporting flange 65. The sleeve 64 is supported on the shelf 62 by a ring 66 and three pins 67, only two pins being shown. The sleeve 66 embraces the lifting ring 63. The pins 67 are fixed to the sleeve 64 at 120° intervals and extend outwards therefrom through vertical axial slots 68 in the lifting ring 63 and inclined peripheral slots in 69 in the ring 66. Angular movement of the ring 66, which is produced by manipulation of a piece 70 fixed to the ring 66 causes lifting and lowering of the sleeve 64 and of the tubular molds 11 carried thereby.

The supporting flange 65 on the sleeve 64 carries an upper pallet 71 through which the tubular molds 11 extend and which support the molds or, more particularly, enlarged closed flattened ends 72 formed on the molds. The molds 11 are supported laterally by a lower pallet 73 through which the molds extend. The lower pallet 73 is supported from the upper pallet 71 in spaced relation therebelow by means of a tubular member 74, which is welded to the pallets 71 and 73. The upper pallet 71 has a threaded connection with a rod 75, in turn connected with a lifting member 76, by means of which the entire assembly of molds 11, pallets 71 and 73, and member 74 may be lifted out of the sleeve 64.

The posts 53, legs 58, ring 58*b*, tray 59, shelf 62, sleeve 64, and ring 66 are formed of stainless steel. The pallets 71 and 73 and the tubular member 74 are formed of stainless steel, AISA #30, composed of 25 w./o. Cr, 20 w./o. Ni, (w./o. signifies weight percentage) and the balance substantially Fe.

Each tubular mold 11 is formed of a high-silica glass possessing exceptional stability, high softening point, and very high resistance to heat shock, because of a very low thermal expansion. Such a glass may be composed of 96 w./o. silica, 4 w./o. boron oxide, and traces of oxides of aluminum, sodium, iron, and arsenic. The closed end 72 on each mold 11 may be formed by pinching. Each mold 11 may, for example, have a length of 17", an outer diameter of .25", and an inner diameter of .1475". Each mold 11 has an interior coating formed from a colloidal suspension of graphite in water to which 5% to 33% of U_3O_8 or ThO_2 has been added. A small quantity of ethyl alcohol is used in both of these coating mixtures to obtain the proper consistency prior to application. The purpose of the interior coating of each mold 11 is to assure that the casting have a good surface and extend through the entire length of the mold. The molds 11 may number twenty-five and be arranged in two circular rows around the tubular member 74.

The charge to be melted in the crucible 12 is formed from highly enriched irradiated fuel elements taken from a fast reactor. These fuel elements or pins, after being removed from their jackets, are pyrometallurgically processed with magnesium oxide or aluminum oxide for the removal of the volatile and more easily oxidized or slagged constituents. 5% by weight of new metal in the form of pure uranium is added. The charge to be melted finally has the following composition:

	Percent by weight
Zirconium	0.10
Niobium	0.01
Molybdenum	3.42
Technicium	0.99
Ruthenium	2.63
Rhodium	0.47
Palladium	0.30
Uranium	balance

(Approximately 90% enriched in U_{235})

The new rods to be cast in the molds 11 have a diameter of 0.144±0.001". After being cut to length, the rods will be 14.22" long; the length of the rods as cast will, of course, be somewhat greater than 14.22", for example, 16".

Melting and casting procedure

The charge to be melted is placed in the crucible **12**. The plurality of molds **11** is positioned as shown in Figs. 1 and 3. Then the bell **14** is applied and sealed so that the vessel **10** is sealed.

Now the vessel **10** is evacuated. When the pressure in the vessel is reduced to about 50 microns Hg, the induction heater **13** is turned on to begin induction melting of the charge in the crucible. Heating is continued until the charge melts and reaches a temperature of 1250°–1400° C., for example, 1340° C., in a period of 1½ to 3 hours. In the meantime, the molds **11** will have been heated by the heater **61** to a temperature of 350°–500° C., for example, 450° C. As is to be noted from Figs. 1 and 3, the heater **61** overlaps the sleeve **64** a considerable amount so that the closed ends **72** of the molds **11** will be heated as hot as the other portions of the molds.

Now the vacuum source **57***d* is isolated from the vessel **10**, and the crucible **12** is lifted by the piston **36***a* until the melted metal in the crucible submerges the lower open ends of the tubular molds **11** an appreciable amount, for example, ½ to ¾", to the position shown in phantom in Fig. 1. Next the source **70** is connected with the vessel **10** to supply helium or argon to the vessel at a pressure of about 45 p.s.i.a. The resulting pressure difference, applied suddenly across the walls of the submerged tubular molds **11**, is enough to overcome the inertia of the molten metal in the crucible **12** and to cause it to rise in and completely fill the molds **11**, where the metal solidifies. The casting cycle is completed about 10 seconds after pressurization with the lowering of the crucible **12** and the remainder of the molten metal therein.

The vessel **10** and its contents are allowed to cool for 45 to 60 min. after completion of the casting cycle before the assembly of molds **11**, pallets **71** and **73**, and tubular member are removed. The cast pins, contracting diametrally on cooling, may sometimes be removed from the molds **11** without damage thereto. Often the molds **11** are broken away from the cast pins by being pulverized in crushing wheels. The cast pins may be sheared or otherwise reduced to desired length. No other machining operation is required; the side surfaces of the pins are finished to size in the casting operation.

The cast pins can be used in stainless-steel jackets with sodium metal serving as thermal bonds between the jackets and the pins. Reference is made to page 19 of Zinn application, Serial No. 437,017, filed June 15, 1954, now U.S. Patent No. 2,841,545, for a disclosure of utility for a nuclear-fuel rod of about the same dimensions as the rod of the present application.

It is also possible to use the present casting method and apparatus in which the tubular molds employed remain as the jackets of the fuel elements. In this event, the tubular molds will be formed of tantalum, vanadium, or zirconium. When the tubular molds remain as fuel-element jackets, the pins are thermally bonded directly to the jackets.

Figs. 4–7 show the application of the casting method and apparatus of the present invention to the forming of a composite metallic article **77**, comprising a cylindrical shell **78** of hexagonal shape, an upper end plate **79**, a lower end plate **80**, a plurality of parallel spaced tubes **81** extending within the shell **78** and secured to openings in the end plates **79** and **80**, and a cast mass **82** filling the shell **78** and completely surrounding each of the tubes **81**.

The shell **78** and upper end plate **79** may be formed integral with one another from a drawn piece, or they may be separately formed and soldered or welded to one another. The shell **78** and lower end plate **80** are separately formed and welded or soldered to one another. The end plates **79** and **80** are of hexagonal shape to conform to the hexagonal shape of the shell **78**.

As shown in Fig. 6, the shell **78** has three extensions **83**, and the lower end plate **80** has three extensions **84**. The extensions **83** and **84** are brought together and welded or soldered to form sprues **85**, which, as shown in Figs. 4 and 5, extend from three alternate sides of the shell **78**. Each sprue **85** comprises a short portion **86** extending radially outwards from the lower end of the shell **78** and a long portion **87** extending from the short portion **86** longitudinally downwardly from the shell **78** and having a beveled open end **88**.

The cast mass **82** is placed in the shell **78** by the method and apparatus of the present invention. The composite article **77**, without the cast mass **82**, but with the sprues **85**, is placed in the sealed vessel **10** of Fig. 1, along with the crucible **12**, which is considerably below the position of Fig. 4, so that the ends **88** of the sprues are above the top of the crucibles so as to be free of the charge therein. The vessel **10** is evacuated; then the charge in the crucible **12** is melted, and the empty article **77** is preheated; then the crucible **12** is raised to the position of Fig. 4 so that the sprues **85** dip into the molten charge in the crucible; and then gas under pressure is applied to the vessel **10** and acts against the molten charge to force it upwardly through the sprues **85** into the shell **78**. The beveled ends **88** on the sprues **85** facilitate the flow of molten metal into the sprues; the gas in the vessel **10** drives the metal downwards in the crucible **12** and upwards in the sprues **85**, and the beveled ends **88** provide a better transition from downward flow to upward flow than would straight ends on the sprues.

After the cast mass **82** completely fills the shell **78** and cools for a sufficient length of time, the composite article **77** is removed from the vessel. Now, as shown in Fig. 7, each sprue **85** and the solidified metal therein are cut off so that only a flap **89** remains, which is bent down and welded or soldered to the lower end plate **80** so as to complete the enclosing of the cast mass **82**. This mass is now completely enclosed in the shell **78**, end plates **79** and **80**, and tubes **81**.

The cast mass **82** may have the same composition as the rods cast in the tubular molds **11**. In such a case the shell **78**, end plates **79** and **80**, and tubes **81** are formed of niobium or tantalum. The composite article **77** then is a nuclear-fuel element suitable for use in a nuclear reactor; liquid metal will be passed through the tubes **81** to absorb heat from the cast mass **82**.

However, the composite article **77** may be put to other uses if it is formed of other materials. For example, the cast mass **82** may be formed of copper, and the shell **78**, end plates **79** and **80**, and tubes **81** may be formed of steel. In this case, the composite article **77** is a heat exchanger in the conventional sense; one fluid to be heated will be passed through certain tubes **81** and another fluid will be passed through the remaining tubes **81** to heat the said one fluid.

It is also understood that the invention is not to be limited by the details given herein but that it may be modified within the scope of the appended claims.

What is claimed is:

1. A method of making an object, comprising providing a cylindrical shell of hexagonal shape having end plates with openings and longitudinal tubes welded to the end plates at the openings, the shell having three sprues formed at the juncture of one end plate with thee sides of the cylindrical shell spaced from one another, applying a vacuum to a mass of metal and to the sprues of the shell, melting the metal, inserting the sprues into the molten metal, and applying gas under pressure against the metal to make the same go as far as the end plate away from the sprues and surround each of the tubes.

2. The method specified in claim 1 and further comprising the steps of cutting off each of the sprues and the solidified metal therein except for a small flap of

each sprue, bending the flaps against the shell, and welding them to the shell to enclose completely the cast metal in the shell.

3. The method specified in claim 1, the ends of the sprues being beveled to facilitate flow of the molten metal thereinto.

4. A one-piece tubular mold open at one end and closed at the other, the mold being formed of glass composed of 96 w./o. silica, 4 w./o. boron oxide, and traces of oxides of aluminum, sodium, iron, and arsenic, the mold having an interior coating formed from a colloidal suspension of graphite in water to which 5 w./o. to 33 w./o. of an oxide selected from the group consisting of U_3O_8 and ThO_2 is added.

References Cited in the file of this patent

UNITED STATES PATENTS

1,703,739	Klepsch	Feb. 26, 1929
2,009,489	Fritzsche	July 30, 1935
2,160,645	Cooper	May 30, 1939
2,289,484	Coley	July 14, 1942
2,564,308	Nagel	Aug. 14, 1951
2,632,216	McQuaid	Mar. 24, 1953
2,756,138	Meister	July 24, 1956
2,792,606	Sylvester	May 21, 1957
2,806,271	Operhall	Sept. 17, 1957
2,812,265	Folsom	Nov. 5, 1957