Feb. 16, 1965 J. G. LEWIS 3,170,018

HIGH TEMPERATURE FURNACE

Filed May 3, 1960 4 Sheets-Sheet 1

FIG. 1

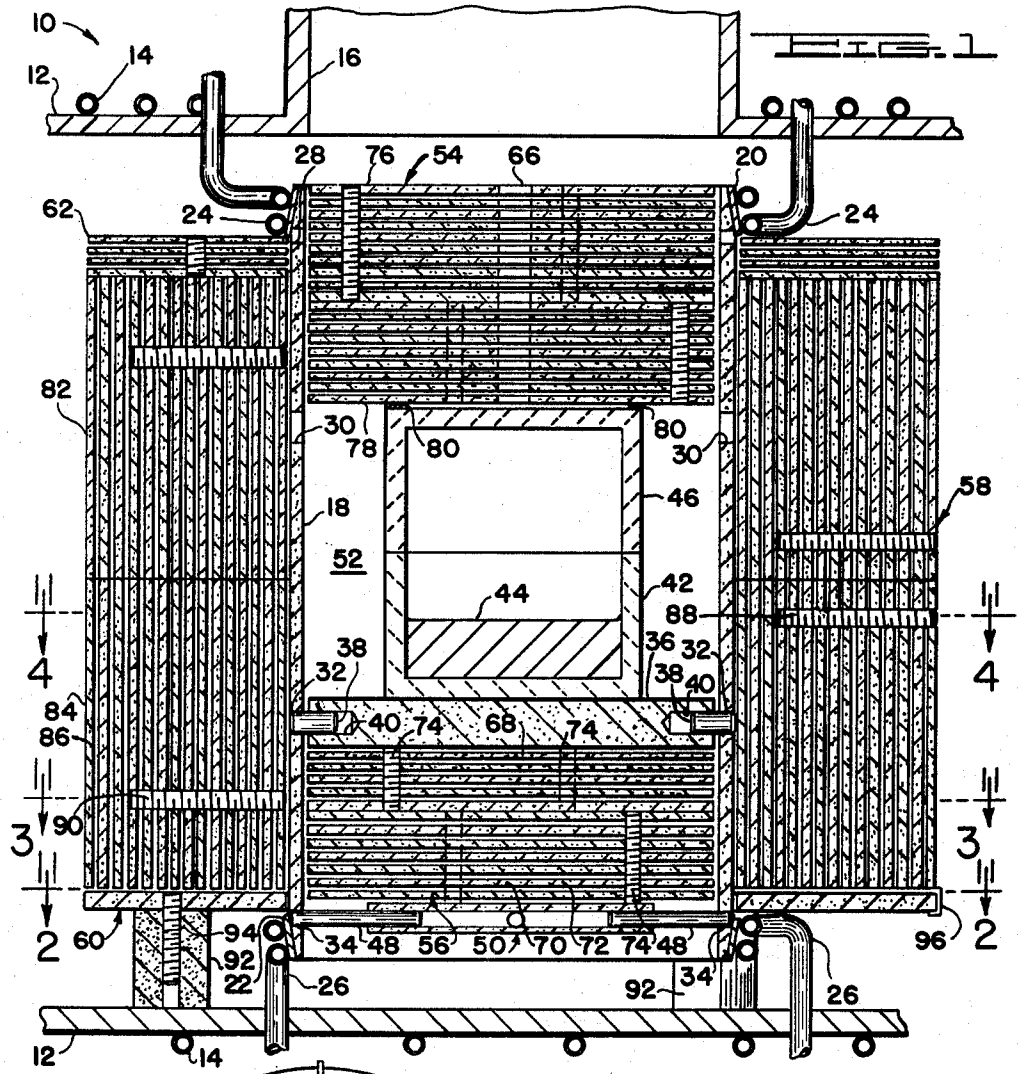
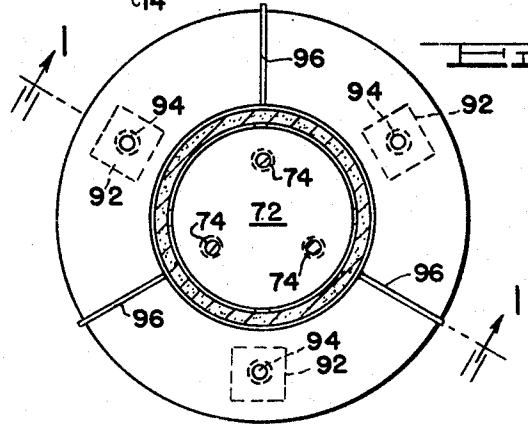


FIG. 2



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FIG. 3

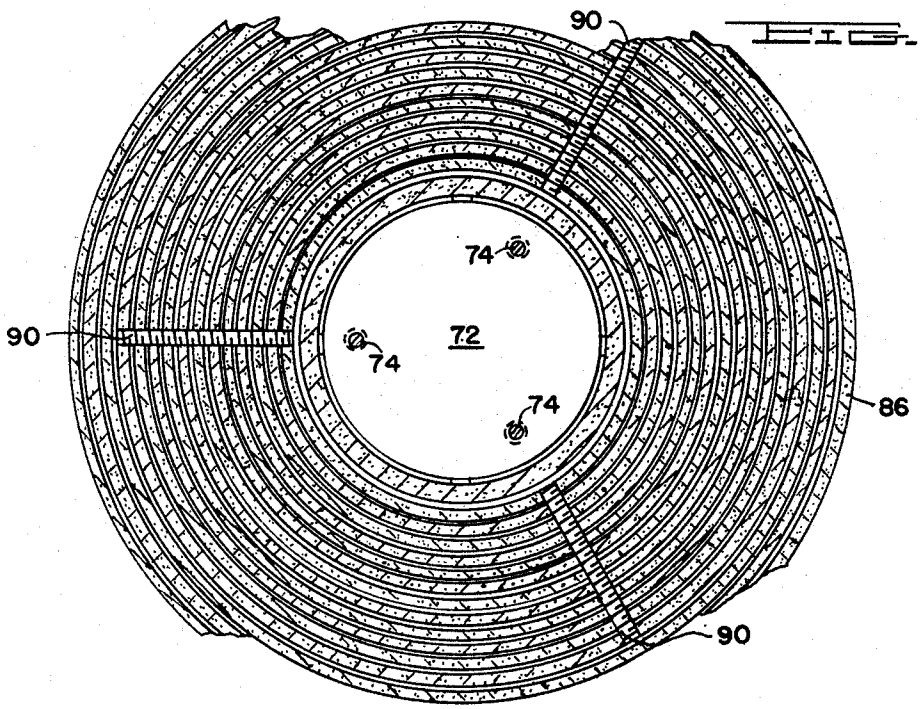
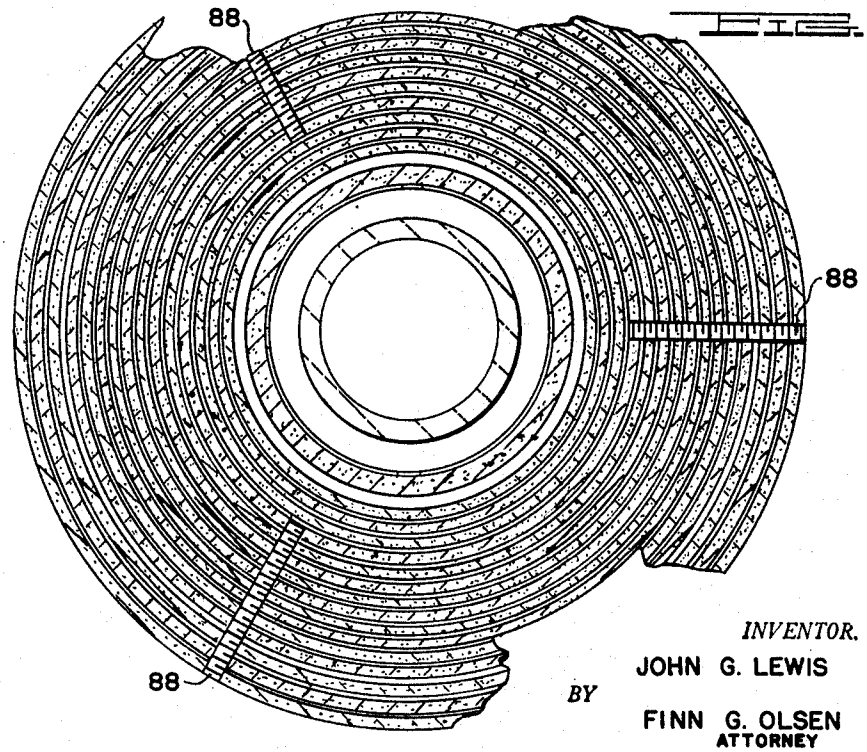


FIG. 4



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HIGH TEMPERATURE FURNACE

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FIG. 5

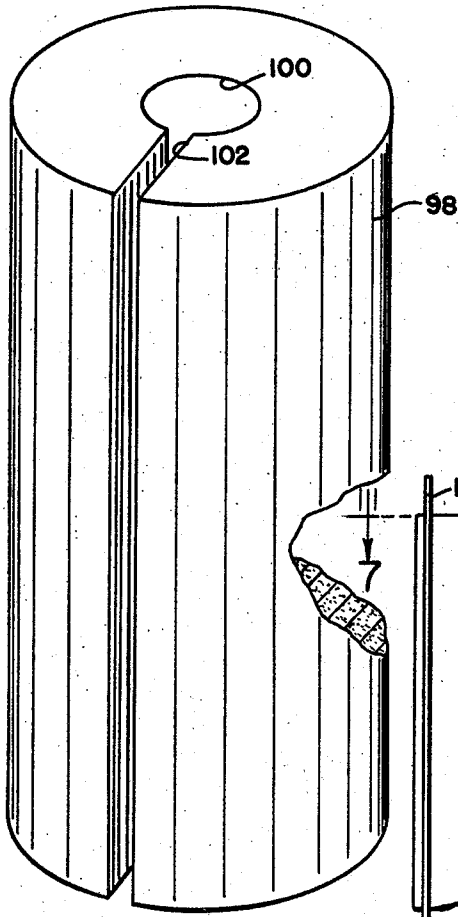


FIG. 6

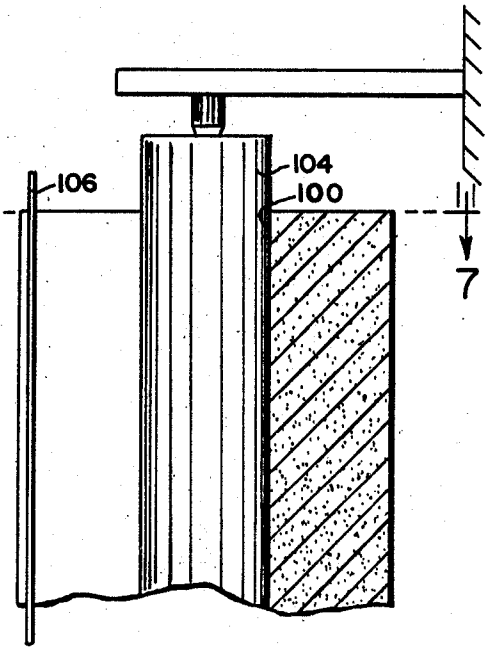
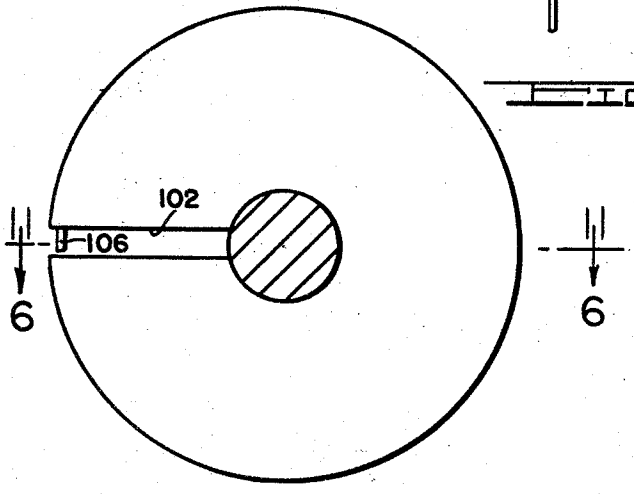


FIG. 7



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FIG. 8

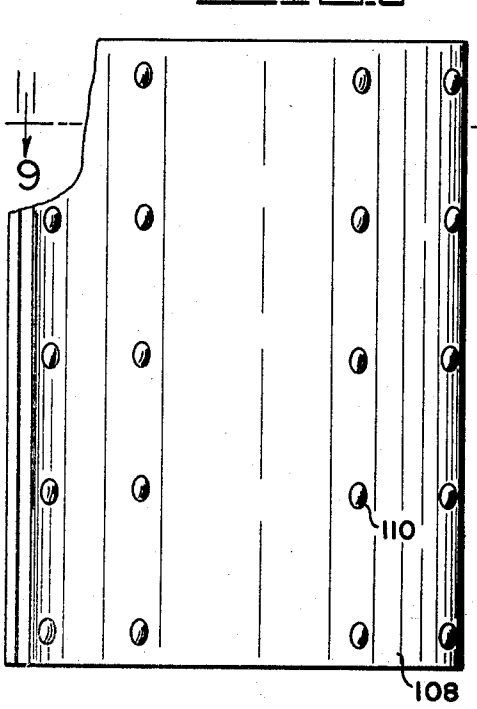


FIG. 9

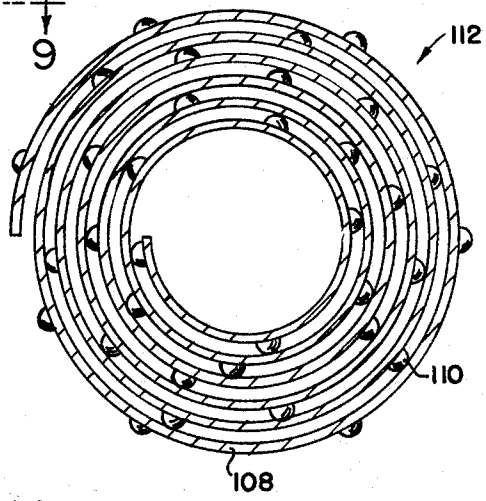
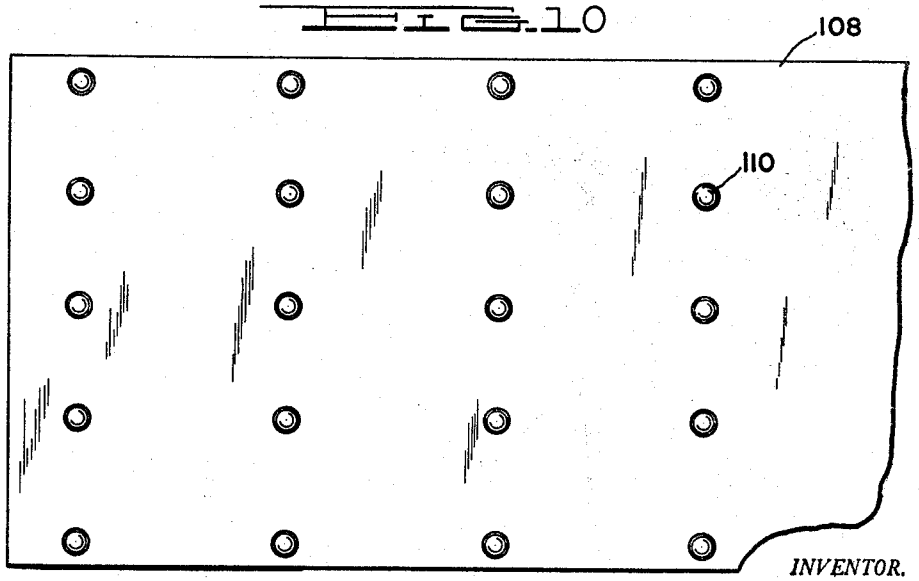


FIG. 10



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United States Patent Office 3,170,018 Patented Feb. 16, 1965

3,170,018

HIGH TEMPERATURE FURNACE

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Filed May 3, 1960, Ser. No. 26,472
10 Claims. (Cl. 13—31)

The present invention relates to improvements in high temperature furnaces and more particularly to shielding apparatus forming a part of a high temperature furnace and to methods of making such apparatus. The apparatus is particularly adapted for use in a furnace of the type disclosed in the copending application of John G. Lewis and Harold A. Ohlgren, Serial No. 834,686, filed August 19, 1959.

The present invention especially deals with heat radiation shielding means for use in a furnace of the foregoing type for more effectively producing materials such as are disclosed in the aforesaid application and for producing other materials in inert atmospheres at temperatures of up to 6000° F. and above. A special feature of the furnace embodying the present invention is its capabilities of producing zones of uniform heat at temperatures limited only by the resistance to temperature of the materials of construction and capable of operating in a vacuum or operating when filled with an inert gas.

Many kinds of furnaces of more or less conventional design are already well known. Many derive their source of heat from combustion, and are not comparable with the furnace embodying the present invention which employs electrical power as a source of heat. Other electrical furnaces differ significantly from the present furnace in one or more respects, some deriving their heat from the resistance to the passage of an electrical current through a resistance wire which is wound on a temperature-resisting muffle strong enough to be self-supporting, and transferring heat by convection, conduction and radiation to the work to be heated. Others, such as an induction furnace impart their heat to the work to be processed by inducing an electrical current in the work itself or through a conducting material surrounding the work. Other electric furnaces employ an arc as the source of heat, or use the basic idea of creating heat by the resistance to the passage of electric current, and such arc furnaces are capable of reaching relatively high temperatures.

Furnaces have also been constructed employing the concentration of solar radiation by mirrors, lenses, or other optical devices. These furnaces reach high temperatures but ordinarily can heat only a highly restricted area or volume of work to such high temperatures. Other furnaces are available which reach exceedingly high temperatures, such as those employing high temperature sparks or radio frequency induction heating of ionized gas streams or high pressure arcs. Thus, there is an almost unending number of furnace designs, most of which are limited specifically to certain applications and needs. However, none of these other prior art furnace designs are capable of providing uniform high temperatures in relatively large heating zones and wherein the heating zones are relatively free from contaminants.

The furnace embodying the present invention is a high temperature radiant resistance furnace in which relatively high currents are passed through a heating element of a highly refractory material, such as graphite, and in which heat is conveyed to the work contained in an opening or heating zone in the resistor principally by radiation. The subject furnace is believed to be unique in that it provides the possibility of temperatures approaching those available in some arcs, which are normally quite limited in heated volume, with a heated

volume which is sufficiently large to accommodate crucibles or samples, for example, of at least twelve inches in each dimension. Furthermore, this furnace is generally not limited in larger dimensions of work to be heated except by economics, and will simultaneously provide the high temperatures in relatively large volumes in an environment which is essentially free from contamination of the atmosphere, combustion gases and the volatile materials normally found in arcs.

It has been shown through research and industrial utilization of highly reactive materials that a design or type of furnace is needed which requires vacuum or inert environments in order to purify materials or to retain previous purities while conducting operations such as melting, casting, vaporizing, and heat treating such as annealing or carburizing in research or industrial operations that require high uniform temperatures and close control of environment. Typical materials which require or may require such a furnace during various operations are the metals titanium, zirconium, hafnium, thorium, niobium, tantalum, tungsten, molybdenum; the oxides, carbides, borides, and other compounds of these metals. Operations which can be conducted in this furnace, and which are particularly difficult in other types of furnaces, are the vaporizing of the metals or their compounds and the melting of extremely refractory materials, such as tantalum and tungsten in portions of substantial size. Some of such operations are described in the aforesaid application, Serial No. 834,686.

In order to carry on operations of the foregoing character it is necessary that the high temperature electric resistance furnace be able to provide a heating zone wherein temperatures may economically exceed 5000° F. at pressures of one micron mercury absolute or less, and at the same time to avoid imparting contaminants to work or materials being heated. Prior devices in the resistance furnace art have been unable to satisfactorily accomplish these ends because, among other reasons, the furnaces heretofore used, if able to reach the desired temperatures, have had to rely to some extent on insulation to protect the furnace housing from the high temperatures within the furnace, and such insulation has either contaminated the work or materials by giving off gases or has deteriorated or melted under the high temperature conditions. Thus, the prior furnaces have been unable to reach the high temperatures required under the specified contamination free atmosphere.

One of the important aspects of the present invention is the construction and arrangement of the radiation shielding employed for surrounding the heating element whereby refractory insulation can be eliminated and heat losses are controlled thereby conserving heat and reducing the required electrical power input. It has been discovered that the approach taken in prior art devices of attempting to use insulation in the furnace and of using radiation shielding spaced relatively widely apart from one another and from the heating zone is unsound, and that the most effective furnace for the purposes desired is realized when constructed to eliminate as near as possible all heat radiation from the heating zone, and the principle upon which the design of the disclosed furnace apparatus is based is that control of heat losses by thermal radiation is the principal requirement in a successful high temperature furnace. This end is accomplished in the present invention by the unique construction and arrangement of radiation shielding employed.

Accordingly, it is an object of the present invention to provide in a high temperature electric resistance furnace, improved radiation shielding whereby the heating element and the work contained therein can reach as high a temperature as the materials, the heater element and the work can withstand and at a relatively low power input.

It is another object of the present invention to provide a furnace structure of the foregoing character capable of uniformly heating work samples to high temperatures in the ranges of 6000° F. and above, and further to carry on such operations in high vacuums such as those represented by absolute pressures less than one micron of mercury.

It is still another object of the present invention to provide a furnace structure of the foregoing character which is adapted to heat work samples to approximately the same high temperatures in inert gases.

It is still another object of the present invention to provide a furnace structure of the foregoing character which will not impart contaminants to work being heated within the heating zone.

It is still another object of the present invention to provide radiation shielding of the foregoing character which is constructed and arranged so that highly effective thermal radiation shielding is provided even when using high emissivity material, thereby permitting use of materials, such as graphite, which are characterized by the relatively high strength and rigidity they exhibit at temperatures in the range of 5000° F. to 6800° F.

Still another object of the present invention is to provide radiation shielding which is characterized by its relatively small, compact construction in proportion to the high degree of effective shielding provided and which is constructed and arranged so that it will not be readily warped or otherwise readily damaged by the high temperatures of the furnace.

It is still another object of the present invention to provide improved radiation shielding which is characterized by its relatively low cost.

It is still another object of the present invention to provide novel methods of producing improved radiation shielding.

Other objects of this invention will appear in the following description and appended claims, reference being had to the accompanying drawings forming a part of this specification wherein like reference characters designate corresponding parts in the several views.

In the drawings:

FIGURE 1 is a fragmentary vertical section taken on the lines 1—1 of FIGURE 2 illustrating an electric resistance furnace with radiation shielding therein embodying one form of the present invention;

FIGURE 2 is a section in reduced scale taken on the lines 2—2 of FIGURE 1;

FIGURE 3 is a section, with portions broken away, taken on the lines 3—3 of FIGURE 1;

FIGURE 4 is another section, with portions broken away, taken on lines 4—4 of FIGURE 1;

FIGURE 5 is a perspective view of a graphite cylinder which has been cut in preparation for cutting shielding therefrom;

FIGURE 6 is a fragmentary section taken on line 6—6 of FIGURE 7 showing the method of cutting shielding from the graphite cylinder of FIGURE 5;

FIGURE 7 is a section taken on the line 7—7 of FIGURE 6;

FIGURE 8 is an elevation of another type of shielding that can be used in the furnace illustrated in FIGURE 1;

FIGURE 9 is a section taken on the lines 9—9 of FIGURE 8; and

FIGURE 10 is a developed view of the shielding shown in FIGURE 8.

Before explaining the present invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and arrangement of parts illustrated in the accompanying drawings, since the invention is capable of other embodiments and of being practiced or carried out in various ways. Also, it is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

A substantial portion of the complete furnace system in which the present invention is embodied is of relatively conventional construction, such as the vacuum envelope, cooling system, vacuum pumping system, the inert gas and air vent system, vacuum and pressure gauges, the window for viewing the interior of the furnace, the temperature measuring instruments employed. The envelope or casing for the furnace comprises essentially a metal tank of suitable size, preferably of stainless steel. This tank has openings which are sealed by O-ring flanges. It is of a construction, such as heli-arc welding, which provides pore-free joints in a base metal selected to contain a minimum of gases or porosity. Cooling is provided by brazing coils, of copper or other suitable metal, placed at intervals or continuously over the exterior of the vacuum envelope and the flanges attached thereto where required because of the temperatures which the parts would otherwise reach. The vacuum system normally comprises a diffusion pump and a mechanical pump in series with suitable valving and vapor baffles to allow the system to be evacuated. The pressure gauges employed for the furnace are of normal commercial construction. A Bourdon tube gauge gives vacuums down to about one inch of mercury absolute and pressures to about fifty pounds. A thermocouple vacuum gauge is used to read absolute pressures from 1000 to one micron mercury absolute. A Philips cold cathode vacuum gauge can be used from about 25 microns down to $\frac{1}{1000}$ micron or less. A trapped McLeod mercury vacuum gauge is useful from 0.01 to 5000 microns and is normally used as a check on the performance of the continuous electrical gauges.

It is desirable to have means of visually observing the behavior of events inside the furnace during operation at high temperatures. For this purpose, a Pyrex or quartz transparent flat disc is sealed into the nozzle on some desirable point of the furnace, such as on top coaxial with the furnace tube. By placing the glass on the O ring which is constrained by a groove cut into the nozzle upon which the glass is resting, it is possible to restrain this glass by placing first a rubber cushion and then a backing flange over the glass, bolting this assembly in order to hold pressure if the furnace is operating under pressure. However, if all operations are conducted under vacuum or partial vacuum, it is not necessary to bolt the glass to the nozzle.

Temperatures within the furnace are normally estimated by use of an optical pyrometer such as the Leeds and Northrop Optical Pyrometer. This instrument is employed in a conventional manner by sighting through the transparent window which is provided within the furnace. The conventional features described above are not fully illustrated in the drawings nor will they be described in greater detail. For further illustrations and descriptions, reference is made to the aforesaid copending application, Serial No. 834,686.

Resistance heating elements for the furnace have been constructed in a variety of shapes, all having in common features so that power is admitted to the heating element by means of water-cooled brass or copper electrical contacts which may also serve as mechanical supports and maintain a firm pressure to assure good electrical contact. A variety of such heating elements can be seen in the aforesaid copending application, Serial No. 834,686. The heating elements, being normally constructed of graphite or carbide, are designed first to have a sufficient mechanical strength to support objects within themselves and to support required contact pressure of the end fittings. These requirements dictate substantial cross-sections and mechanical strengths. Such large cross-sections in proportion to the lengths of the tube result in relatively low electrical resistances within the tubes, often only a few thousandths of an ohm or less. Therefore, in order to supply electrical power to a resistance element of such low resistance, it is necessary to supply the power from a source whose impedance is matched to that of the tube. For example, a 25 kw. transformer is employed with the present invention con-

verting power from 240 volts or thereabouts to 10 volts, with a resulting current of 2500 amperes through a tube at full power. Such a tube would be about 1½ inch diameter by 2 inch outside diameter by 12 inches long. As a further example, a 50 kw. transformer may be employed converting power from 240 volts to 10 volts, with a resulting current of 5000 amperes feeding a tube 4½ inches inside diameter by 5¼ inches outside diameter by 20 inches long. A further example calls for supply 50 kw. at 10 volts to a 0.1 inch thick, 2 inch outside diameter tantalum carbide tube 12 inches in length.

A power control system which has been found quite convenient and relatively economical is that comprising a saturable reactor which controls the flow of 240 volt power into the system and controls the voltage which occurs at the outlet contacts of this reactor. The current passes through the reactor in series with a step-down transformer which converts the resulting regulated primary voltage, which might vary from 20 to 30 volts up to 190 volts, depending upon the degree of saturation applied to the reactor. The transformer then puts out a secondary voltage which might vary from 1 volt to 10 volts. Such a reactor requires a minimum of controls and instruments, normally comprising only a small autotransformer and any primary and secondary current voltage and power meters which may be necessary or desirable. Current is passed into the furnace through copper lugs which are brazed on to the stainless steel heads and body of the furnace as required by the specific electrical circuit chosen. Thus, the heads of the furnace serve to seal the vacuum or pressure chamber, while supporting the electrical resistance tube or heating element, and also serve to conduct the power through to the heating element. It is desirable to choose material of construction for the furnace shell such that none of these functions will be interfered with. Thus, stainless steel becomes a most desirable material because it is resistant to quite high temperatures, 1000 and 1200° F. if need be, although normally operating several hundred degrees Fahrenheit if the water-cooling system is functioning properly. The stainless steel also has a rather high electrical resistance as metals go and is non-magnetic. Consequently, the heavy currents which pass co-axially within the cylindrical shell induce a minimum of eddy currents in the furnace parts. Therefore, most of the power goes into the heating element proper. If carbon steel or other magnetic material is used for the furnace shell, large eddy current losses and heat in the shell are encountered. Such eddy currents rob the furnace heating element of needed power and introduce expensive cooling problems on the shell.

Referring now to the drawings the present invention will be described in greater detail. The high temperature electric resistance furnace **10** is shown fragmentarily and has a stainless steel housing **12** having water cooling coils **14** there around and an opening **16** for access to the furnace and for providing a sight glass (not shown). Positioned co-axially of the opening **16** is an electric resistance heating element **18** in the form of a cylindrical tube or sleeve and constructed of graphite. The heating element **18** is preferably tapered at its opposite ends, as shown, and these ends fit into contact with metallic conducting collars **20, 22**, formed of brass, which in turn nest in and are soldered to the spirally wound spring coils **24, 26** which are tubular metal elements, the opposite ends of which extend through the top and bottom walls, respectively, of the housing **12**. The coils **24, 26** are of sufficient resilience to permit the heating element **18** to be releasably held between collars **20, 22** with good electrical contact being maintained between these parts, and the coils **24, 26** serve as electrical conductors which are also water cooled. Thus, the coils **24, 26** not only serve as supports or spring mountings and electrical conductors for the heating element **18**, but also act as liquid coolant conductors in heat exchange relationship with the collars **20, 22**. The electrical conductors receive current from the power system described generally above and in greater detail in the aforesaid application, Serial No. 834,686.

The heating element **18** has a series of circumferentially arranged holes **28, 30, 32** and **34** therein which may be used for supporting radiation shielding or work samples within the heating element **18** or for vent purposes, as will be described presently. In the embodiment illustrated in FIGURE 1, a circular graphite plate **36** is supported in the heating element **18** by four circumferentially spaced graphite pins **38** (only two of which are shown), said pins extending into the openings **32** and into corresponding openings **40** in the plate **36**. When supported in this manner the plate **36** defines the lower end of the useable heating zone within the heating element **18**. The plate **36** also acts as a supporting surface for the crucible **42** which contains a preselected material **44** adapted to be vaporized and deposited upon the interior surface of the upper, inverted crucible **46**. It is to be understood, however, that the crucibles **42** and **46** form no part of the present invention and are shown merely to illustrate one operation to which the furnace can be put, and it is to be understood that various other operations can also be carried on in this furnace.

The openings **30** are used in the disclosed embodiment to vent the heating zone so that excessive vapors from the preselected material **44** can be removed through the vacuum system, but these openings **30** may be used to support shielding in the upper end of heating element **18**, if desired. The openings **28** may also be used for supporting shielding and also serve to receive a pry-off tool to aid in removing the collar **20** when disassembling the furnace.

The openings **34** are shown receiving the graphite pins **48** which are a part of the graphite spider **50**. The latter serves to support radiation shielding, to be described, and it is to be understood that other suitable refractory supports may also be used. The openings **34** also serve to receive a pry-off tool to aid in removing the collar **22** when disassembling the furnace.

The radiation shielding surrounding the heating zone **52** and the heating element **18** will now be described. This shielding includes the first set of axially aligned, closely spaced, thin graphite disks **54** in the upper end of heating element **18**; a second set of axially aligned, closely spaced, thin graphite disks **56** in the lower end of heating element **18**; the set of concentric, thin, closely spaced, graphite sleeves **58** encircling the heating element **18**; and such secondary shielding disks **60** and **62** which are annular in shape and encircle the ends of the heating element **18**.

The sets of graphite disks **54** and **56** are similarly constructed except that the illustrated set **54** has an axial opening **66** therein for taking temperature readings of the crucible **46** or other material or samples which may be in the heating zone **52**. Since these sets are similar in other respects, only set **56** will be described. In the disclosed embodiment, set **56** is in two separable sections **68** and **70** which are in axial alignment and which are formed separately merely to facilitate making and handling the same. Each section **68** and **70** has a plurality of thin, flat graphite disks **72** which preferably are about 1/16 inch or less in thickness; and these disks are placed apart 1/16 inch or less. The disks **72** are held in their spaced relation by means of three graphite studs **74**.

Each section **68** and **70** is constructed by initially cutting the disks **72** to the desired thickness from a solid cylinder of graphite. The disks **72** are then stacked together with spacers holding them in their desired spaced relation and holes for the studs **74** are drilled and tapped therein.

The graphite studs **74** are then screwed into the tapped holes and the spacers are removed. In making these

sections 68 and 70 it is desired to cut the disks 72 as thin as possible and to space them as close together as is possible within practical limits. It is found that the dimensions set forth above provide shielding sections which are sufficiently sturdy to permit normal handling during assembly of the shielding in the furnace. It is also desirable to minimize the heat loss through conductance that may occur through the studs 74. Thus, it is desirable to use the minimum of such studs; and it is found that a set of three studs at about one-half the radius from the center of the disks and on 120° separations, using ¼ inch studs for disks about twelve inches in diameter, is normally adequate to provide structural strength with minimum heat loss by direct conductance.

The sections 68 and 70 are supported on the graphite spider 50 and are dimensioned so that the outer peripheries of the disks 72 are closely adjacent the inner wall of the heating element 18, but out of contact therewith so as to provide optimum radiation shielding without permitting conductance of heat from the heating zone 52 via the heating element 18 and radiation shielding 56 to portions of the furnace external of the heating element 18 and without electrical short-circuiting of heating element 18.

The radiation shielding 54 is similarly formed in two sections 76 and 78 which are supported directly on the crucible 46 by means of graphite spacing elements 80. However, any other suitable support means may be used for this purpose when other operations are being carried out within the heating zone 52. Thus, a spider corresponding to the spider 50 may be supported in the holes 30 and the sections 76 and 78 may be carried by such spider.

Referring next to FIGURES 1, 3 and 4, the radiation shielding 58 will be described. This shielding is also made in two sections for convenience of handling and manufacture, but it can be made either in a single or in plural sections, as desired. For purposes of identification, the upper section will be identified by the reference number 82 and the lower section will be identified by the reference number 84. Since these sections are identical in construction, only section 84 will be described in detail.

The section 84 is made of a plurality of concentric graphite sleeves 86, each having a wall thickness of about 1/16 inch, with the sleeves being progressively larger in diameter so that the space between adjacent sleeves will be 1/16 inch or less. These sleeves are held together by two sets of studs 88 and 90. The studs 88 are arranged 120 degrees apart and extend radially inwardly through tapped holes in the shields 86. The studs 90 are also arranged 120 degrees apart, 60 degrees out of phase with the studs 88, and extend radially outwardly through other tapped holes in the shields 86. The section 84 is also dimensioned so that the radially innermost sleeve 86 will be closely adjacent to, but spaced from, the outer surface of the heating element 18.

The section 84 is supported in place by the annular graphite ring or disk 60 which serves the additional function of acting as a radiation shield reducing radiation of heat from between the shields 86 to the bottom wall of the furnace housing 12. The graphite ring 60 has three graphite legs 92 which rest on the bottom wall of the housing 12 and are attached to the ring 60 by the graphite screws 94. It is desirable to avoid contact between the shielding section 84 and the shielding ring 60, and in small furnaces it is possible to achieve this end by placing three tantalum wires 96 on the ring 60 prior to placing the section 84 thereon. In this manner the section 84 will be spaced from the ring 60 by the wires 96, but this arangement is generally satisfactory only in small furnace units, and in larger furnace units in which the heating element 18 may be a foot or more in diameter, the use of the tantalum wires as spacers may be dispensed with.

The upper section 82 is supported directly by the lower section 84, merely by resting on the latter. The radiation shields 62 similarly are supported directly on the upper section 82 by resting thereon and function to reduce heat radiation from between shields 86 to the top wall of furnace housing 12. The radiation shields 62 are annular with their inner diameters slightly larger than the heating element 18 so as to avoid contact therewith. In other respects the shields 62 are constructed the same as the shields 54 and 56.

One of the features of the present invention is the manner of constructing the shielding sections 82 and 84 For an explanation of this feature, attention is directed to FIGURES 5, 6 and 7.

When a cylindrical tube, such as the heating element 18, is to be shielded on the outside by a sequence of closely spaced thin concentric graphite shields 86, such an assembly can be made by turning a cylinder of graphite 98 of required outside dimensions and then boring a hole 100 through the middle of no greater diameter than that required for inside dimensions to fit around the tube, and then making a radial cut 102 about ¼ inch wide through one wall of the cylinder completely from top to bottom and removing the slice. A metal shaft 104 can then be placed through the central bored hole 100 and used to position the hollow cylinder of graphite 98 with respect to a cutting medium such as a suitable blade 106 on a band saw, for example, a ¼ inch skip tooth blade. The assembly just described can then be used to feed the hollow cylinder of graphite 98 against the saw blade 106 in such a way that the blade 106 cuts off an approximately 1/16 inch sheet of graphite during each revolution of the hollow graphite cylinder 98. The cylinder 98 is normally placed into the saw by turning the cylinder by hand. After each thin shell is so cut from the base hollow cylinder of graphite, the hold-down center which locates the metal shaft around which the graphite cylinder 98 rotates is removed and the thin shell 86 is removed from around the hollow graphite cylinder 98. The cylinder 98 is then replaced in such a position with respect to the saw blade 106 that an additional thin cylinder 86 can be cut off in a like manner.

Repetition of this procedure results in cutting a concentric series of hollow cylindrical graphite shells 86, each about 1/16 inch thick and separated by an annular space approximately 3/64 inch. Each hollow cylindrical shell has a slot about ¼ inch wide missing longitudinally along an altitude.

After the requisite numbers of sleeves or shells 86 have been cut, such as fifteen, for example, they are assembled with the slots in staggered relation and spacers hold the sleeves 86 in their proper concentric positions. The tapped holes for receiving the studs 88 and 90 are then formed in the sleeves 86 and thereafter such studs are screwed into place. The spacers are then removed and the assembly of sleeves is then ready to be inserted into the furnace.

The graphite used in all of the above described shielding is preferably of a fine grained, relatively dense graphite, such as Great Lakes Carbon H3LM or equal, heated sufficiently during manufacture to be nearly free of volatile matter. A denser grade of graphite, such as Graphite Specialties Graph-i-tite G, offers certain advantages, especially in the extremely high temperature uses, since it vaporizes less rapidly than the other graphite just mentioned.

The above described shields can also be made of suitable refractory metals by cutting sheets and holding them together with studs or wire as required.

The common problem encountered in either the concentric cylindrical or the disk types of shields, when using metals, is that the metals often warp and either cause electrical shorts, thus melting the shields in part, or cause the shields to touch each other, thus reducing greatly the shielding effectiveness of such an array. It is for these reasons, as well as for reasons of cost, that

the use of graphite shields is favored where temperature conditions up to 6000° F. permit. Above 6000° F. the graphite may vaporize producing an undesirable contaminant in the environment of the heated material or work sample. It may therefore be necessary to use materials, such as metal carbides, where temperatures in the neighborhood of 6000 to 6800° F. are required, both because the rapid vaporization of graphite at these temperatures would cause rapid destruction of the graphite shields and tubes, as well as for the reason that such vaporization will cause contamination of the region within the furnace.

One such arrangement of a refractory metal is shown in FIGURES 8, 9 and 10. As there shown the developed sheet **108**, which is about .005 inch thick has dimples **110** formed therein. The sheet is then wound into a spiral as shown in section in FIGURE 9 so as to form the generally cylindrical shielding **112** which is adapted to fit around, in spaced relation, a heating element such as the heating element **18**. In this embodiment the dimples **110** serve to maintain substantially all of each convolution away from adjacent convolutions.

Suitable materials from which the shielding **112** may be made are high-melting metallic carbides, such as tantalum carbide, zirconium carbide-tantalum carbide, hafnium carbide-tantalum carbide, and the like, or metals such as tantalum, molybdenum or other high melting metals. Shields of the foregoing design may be fabricated from desirable metallic carbides by first making the shields of the metal and then converting the metal to the carbide as by a gaseous phase carburization conducted at high temperature.

As previously stated, the principle upon which the present furnace design is based is that control of heat losses by thermal radiation is the principal requirement in a successful high temperature furnace. Heat losses by conduction through graphite are not normally so serious or limiting as those by radiation. This is true in part because the loss of heat by conduction would increase proportionately with temperature in a material which had a constant thermal conductivity. Therefore, one would pay only a proportionate penalty of heat loss with given increases in temperature. However, the heat loss due to radiation increases with the fourth power of the temperature of the hot object. In employing graphite, a still further gain is realized since the conductivity of graphite, normally about 70 to 80 B.t.u./hr./sq.ft./° F./ft. at room temperature, decreases to about 8 to 10 B.t.u./hr./sq.ft./° F./ft. at 4000 to 5000° F. Thus, one encounters only a very modest heat loss by conduction when employing graphite and this heat loss is relatively smaller than that which is encountered when using other refractory materials.

Another particular advantage in making the shields from graphite is that graphite is relatively cheap and available compared with the refractory metals which may be competitive with it. Graphite has a rather high emissivity, of the order of 0.7 to 0.9 or higher, and, therefore, graphite by itself does not reflect very much heat. Rather, it allows radiation from its colder side to radiate heat away almost as fast as heat is received on its hotter side. However, the emissivity of the graphite can be held below about 0.8, especially by light coatings of vaporized metals, such as titanium or silicon. Then, a succession of about fifteen such graphite shields can be used to achieve quite effective thermal radiation shielding, depending upon the emissivity, the temperature required, and the power available. No one shield reflects enough heat to be a sufficient shield by itself, but the succession of shields has a multiplicative effect upon the shielding effectiveness. Thus, while a single graphite shield having an emissivity of between 0.7 to 0.85 may radiate a substantial amount of heat absorbed by it, the present invention enables use of a material, such as graphite in the emissivity range of 0.7 to 0.85 approximately, and by the use of thin, closely spaced, multiple sheets of such material to devise an array of such sheets which has an effective emissivity in the range of 0.03 to 0.05, which is substantially the ultimate that can be realized when working in the high temperature ranges for which the present invention is intended. It is found that an effective emissivity in the range of 0.03 to 0.05 can be realized when the aforesaid array has a thickness of approximately fifteen of such closely spaced sheets; and since the lower limit for emissivity is zero, not much more can be gained in attempting to lower the emissivity by the addition of still more sheets of the material.

Graphite usually has a sufficiently low emissivity to be used without deliberate coating. However, coating with a metal having a refractory carbide does lower emissivity enough to help shielding effectiveness greatly. A light coating of such metal carbide might form on untreated graphite from residual ash components in the graphite, such as titanium and silicon.

Thus, very efficient furnaces can be provided utilizing the graphite shielding comprising the present invention for temperatures up to 6000° F., and when temperatures of higher ranges, such as 6000° F. to 6800° F. are desired, the metal carbides described above can be used. Operations can be carried on under these conditions where heating zones of relatively large volume are provided with uniform temperatures of the desired ranges and are obtained in inert atmospheres which for the purposes of this application are to be understood as being either a state of vacuum or consisting generally of one of the noble gases.

The embodiments disclosed above have utilized shields of a circular shape, but it is to be understood that other suitable arrays may also be made wherein closely spaced refractory units are arranged so as to have a multiplicative effect upon the shielding effectiveness and wherein the shielded area of the shielded object is maintained at a maximum, and such suitable arrays are intended to come within the scope of the claims.

Having thus described my invention, I claim:

1. In an electric resistance furnace having a heater tube defining therein a heating zone, an annular heat radiation shielding member encircling said tube comprising a rigid structure having a plurality of thin, concentric, graphite sleeves secured in close, spaced relationship by a plurality of graphite studs threadedly connected to said sleeves.

2. In an electric resistance furnace having a heater tube defining therein a heating zone intermediate its ends, a cylindrical heat radiation shielding member inserted into one end of said tube in spaced relation thereto comprising a rigid structure having a plurality of thin, co-axial, graphite disks secured in close, spaced, parallel relationship by a plurality of graphite studs threadedly connected to said disks.

3. In an electric resistance furnace adapted to maintain an inert atmosphere therein, a heater tube and heat radiation shield assembly comprising a vertical cylindrical graphite heater tube adapted to be supported between the upper and lower walls of said furnace and having a heating zone therein between its ends, and a plurality of sets of heat radiation shield members substantially enclosing the open ends and the outer circumference of said heater tube in substantially non-heat conduction relationship with respect to said heater tube, each of said sets having a plurality of thin graphite sheets in close, parallel, spaced relationship, and means for conducting electric current through said heater tube.

4. In an electric resistance furnace adapted to maintain an inert atmosphere therein, a heater tube and heat radiation shield assembly comprising a vertical cylindrical graphite heater tube adapted to be supported between the upper and lower walls of said furnace and having a heating zone therein between its ends, and a plurality of sets

of heat radiation shield members substantially enclosing the open ends and the outer circumference of said heater tube in substantially non-heat conduction relationship with respect to said heater tube, each of said sets having a plurality of thin graphite sheets in close, parallel, spaced relationship, the graphite sheets in each set being held in their spaced relationship by graphite studs extending through and threadedly connected to said sheets, and means for conducting electric current through said heater tube.

5. In an electric resistance furnace adapted to maintain an inert atmosphere therein, a heater tube and heat radiation shield assembly comprising a vertical cylindrical graphite heater tube adapted to be supported between the upper and lower walls of said furnace and having a heating zone therein between its ends, and a plurality of sets of heat radiation shield members substantially enclosing the open ends and the outer circumference of said heater tube in substantially non-heat conduction relationship with respect to said heater tube, each of said sets having a plurality of thin graphite sheets in close, parallel, spaced relation ship, at least one of said sets including a plurality of concentric sleeves enclosing said heater tube and being supported on an annular graphite ring with legs adapted to rest on the lower wall of said furnace, and means for conducting electric current through said heater tube.

6. The combination claimed in claim 5, wherein said plurality of concentric sleeves are maintained in spaced relationship to said annular graphite ring by a plurality of thin radially extending elements on the upper surface of said ring on which said sleeves rest.

7. The combination claimed in claim 6, wherein said radially extending elements are segments of wire formed of tantalum.

8. In an electric resistance furnace adapted to maintain an inert atmosphere therein, a heater tube and heat radiation shield assembly comprising a vertical cylindrical graphite heater tube adapted to be supported between the upper and lower walls of said furnace and having a heating zone intermediate its ends, a plurality of thin circular graphite disks co-axially arranged in closely spaced relationship within opposite ends of said tube to provide shielding for restricting heat radiation from said heating zone through the ends of said tube, said disks having an external diameter slightly less than the internal diameter of said tube and being co-axially positioned with respect thereto so that said disks are out of heat conduction relationship with respect to said tube, and a plurality of substantially cylindrical co-axial graphite sleeves in closely spaced parallel relation enclosing the outer wall of said tube, said sleeves being substantially out of heat conduction relationship with one another and with respect to said tube for restricting heat radiation from the outer wall of said tube, and means at the upper and lower ends of said tube for conducting electric current through said tube.

9. In an electric resistance furnace adapted to maintain an inert atmosphere therein, a graphite heater tube and shield assembly comprising a vertical cylindrical graphite heater tube supported in spaced relation from the upper and lower walls of the furnace, a graphite spider-like structure mounted in the lower end of said tube, a transversely positioned circular graphite plate positioned in said tube intermediate the ends thereof to define thereabove in conjunction with the inner wall of said tube a heating zone, a first set of closely spaced axially aligned thin graphite disks supported on said spider and extending upward to a position closely adjacent to and spaced from said plate and having the outer peripheries of the disks adjacent to and spaced from the inner wall of said tube, a second set of closely spaced axially aligned thin graphite disks supported in the upper portion of said heater tube with the outer peripheries of the disks adjacent to and closely spaced from the inner wall of the heater tube, an annular graphite ring encircling said heater tube adjacent the lower end thereof and supported on graphite legs on the bottom wall of said furnace, a set of thin concentric cylindrical graphite sleeves encircling said heater tube and positioned closely adjacent the outer wall of said heater tube substantially its entire length, and electrical conductors connected to the upper and lower ends of said heater tube for passing electric current through said tube.

10. The combination claimed in claim 9 wherein said graphite heater tube and shield assembly includes a set of closely spaced thin annular graphite disks seated on the upper ends of said sleeves.

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