PATENT SPECIFICATION (11) 1 554 898

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(21) Application No. 52317/76 (22) Filed 15 Dec. 1976 (19)

(31) Convention Application No. 641646 (32) Filed 17 Dec. 1975 in

(33) United States of America (US)

(44) Complete Specification Published 31 Oct. 1979

(51) INT. CL.[2] G21C 15/08

(52) Index at Acceptance
G6C 394 39Y 47Y 65Y 667 BX

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(54) NUCLEAR REACTOR

(71) We, GENERAL ATOMIC COMPANY, a partnership organised under the laws of the State of California, of 10955 John Jay Hopkins Drive, San Diego, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a nuclear reactor in which cooling fluid is passed through the reactor core to remove heat therefrom. The heated fluid coolant may then be employed for the purpose of producing steam for power generation, driving turbine machinery for power generation, applying heat in an industrial process, etc.

Localized regions of extremely high temperature within the reactor core may raise the temperature of coolant passing through that localized region to temperatures substantially above that of the average temperature of the coolant issuing from the core. These localized hot streams of coolant, commonly referred to as "hot streaks", may have an adverse effect on the core bottom plenum linings, cross duct lining, and heat exchanger coils in the reactor system. The need to allow for the possibility of hot streaks is one of the important limiting factors in reactor design and affects start-up and load following operation, orifice and thermocouple probe design, duct and reboiler materials, etc.

It is an object of the invention to provide a nuclear reactor which reduces the presence of hot streaks. In accordance with the invention, the nuclear reactor comprises a core having a plurality of columnar fuel regions, each fuel region having coolant passages for conducting fluid coolant through the fuel region, a plurality of valves, one for each fuel region for regulating the flow of coolant through the coolant passages of that fuel region, and collecting means for the fluid coolant located at the downstream end of the coolant passages and including a plurality of inlets for each one of a plurality of discharge orifices, the arrangement being such that the inlets for any given discharge orifice receive coolant from each of a plurality of adjacent fuel regions.

The invention provides a nuclear reactor which combines the coolant flows from neighboring fuel regions in a manner which results in an averaging of the coolant temperature at the outlet of the core.

The invention will be explained further by way of example with reference to the accompanying drawings wherein:—

Figure 1 is a perspective cut-away view, partially in section, illustrating a portion of a nuclear reactor constructed in accordance with the invention;

Figure 2 is a top sectional view of a portion of the core of the reactor of Figure 1, taken at the level of the line 2-2 of Figure 1;

Figure 3 is a top view of a core support block used in the core of the reactor of Figure 1;

Figure 4 is a bottom view of the core support block of Figure 3;

Figure 5 is a partial sectional view of the core support block of Figures 3 and 4; and

Figure 6 is a plan view of a core support structure in a further embodiment of the invention.

In the drawings, the nuclear reactor comprises a core having a plurality of columnar fuel regions 11.

The general shape of the core is that of a right circular cylinder having a diameter which is slightly greater than its height. The core is made up of a plurality of columns of separate fuel blocks 21 of hexagonal cross section arranged on a uniform triangular pitch. Each fuel region 11 comprises seven columns of fuel blocks 21. The fuel blocks are preferably made of extruded graphite in which a plurality of rods (not shown) of fissionable material are imbedded. Each of the fuel blocks is provided with a plurality of passages which align to form vertical cooling passages 13 therein. The passages 13 extend completely through the fuel blocks and are located in the same position in each of the fuel blocks. Thus, the vertical cooling passages 13, which are utilized to pass coolant gas through the reactor core extend completely through the length of each of the columns of fuel blocks.

The fuel blocks 21 also contain vertical holes 23, which extent through only part of the length of each block 21, to permit handling equipment, not shown, to be lowered into the block for raising and lowering same during fuelling and refuelling. Some of the columns of fuel blocks 21 are displaced axially relative to other columns to eliminate the possibility of transverse displacement of the fuel blocks across the core at their interfaces. Alignment of the passages 13 may be maintained by a plurality of graphite dowel pins (not shown) extending from the top face of each fuel block and fitting into mating holes in the bottom of the block immediately above.

The core also includes a reflector consisting of an outer wall of graphite blocks 25 identical in shape to the fuel blocks 21. Additional reflector blocks 27 are disposed in the same columnar arrangement as the fuel blocks, forming continuations of the fuel block columns in two layers above and two layers below. The reflector blocks 27 include passages forming continuations of the passages 13 in the fuel blocks. The height of some of the reflector blocks is different from the others in order to compensate for the vertical offset of some of the fuel block columns.

The radially outer portion of the reflector consists of a plurality of graphite reflector blocks 29, also arranged in columns. The reflector blocks 29 are substantially larger than the reflector blocks 25 and are shaped with two opposite outwardly diverging sides, an arcuate outer side and an irregularly shaped inner side opposite the arcuate side. the inner side of each reflector block 29 forms a mating engagement with adjacent columns of the reflector blocks 25, and the arcuate side forms part of an exterior cylindrical surface. The reflector configuration, of course, may be departed from, but the foregoing described configuration has been found satisfactory.

The reflector further consists of a top layer of reflector blocks 31 over the columns of fuel blocks 21. Each of the reflector blocks 31 has passages therein forming a continuation of the passages 13 and is provided with a metal cap 33. The metal caps 33 extend above the top of the reflector blocks 31 and form a hollow space above the upper ends of the coolant passages 13. A circular opening 35 is defined by the metal caps above each fuel region. A valve 15 is placed in each of the openings 35 to control the flow rate of coolant gas through the opening to each region 11 from the space above the core. The vertical sides of the caps 33 are arranged so that the caps surrounding an opening 35 form a separate plenum communicating with such opening. The outer columns of reflector elements 29 are not provided with caps but extent as solid blocks all the way to the top. Each of the caps 33 is provided with a central opening therein, and tubes 36, aligned with the holes 23, pass through such openings. The tubes 36 facilitate reception of a pickup tool, not shown, for removing the capped reflector blocks 31 during refuelling.

The columns of fuel blocks and reflector blocks rest upon a layer of large graphite core support blocks 41. Each support block 41 supports the seven columns of fuel blocks of a respective fuel region 11. The columns of fuel and reflector blocks are positioned on the support blocks 41 by a plurality of graphite dowels (not shown) which provide lateral restraint and column alignment at the bottom of the core.

As may be seen from Figure 1, the lowermost layer of reflector blocks 27 is designed such that the coolant passages 13 in each block converge into a collection chamber 43 formed in each block. Each of the support blocks 41 has a plurality of inlets 19, each communicating with a respective one of the chambers 43. As may be seen in Figures 3, 4 and 5, there are six inlets 19 in each support block 41. Each of the inlets 19 diverges from the others to a discharge orifice 18 at the outside of the block. Each discharge orifice 18 is formed by parts of three adjacent blocks 41 and discharges the coolant gas below the layer of support blocks. Thus, the layer of core support blocks defines the collecting means 17.

The layer of core support blocks 41 is radially surrounded and continued by a plurality of larger core support blocks 50. The core support blocks 50 are shaped to mate with the blocks 41 and to form a cylindrical outer surface. The blocks 50 support the side columns of reflector blocks 25 and 29. A cylindrical metal shroud 51 surrounds the core.

The graphite core support blocks 41 and 50 are supported from a core support floor, not shown, by a plurality of vertical graphite posts, also not shown. The graphite posts have spherical ends to permit them to rock slightly to accommodate differential expansion between the parts of the structure.

Coolant gas collected in the space above the top of the reactor core and its surrounding reflector passes through the valves 15 and openings 35 into the plenums formed by the caps 33. The gas then enters the passages 13 flowing therethrough and into the chambers 43. As the gas flows through the passages 13, it is heated by the reactor core due to the heat generated by the fission chain reaction in the core. The hot gas is collected in the chambers 43 and then passes through the support blocks 41, through the passages 19 and 18 therein, and is discharged into the space below the lower support blocks 41. From there, the coolant gas passes through suitable ducts, not shown, to steam generators or turbines, also not shown.

Suitable passages, not illustrated, are provided in the reflector block at the base of the central column in each seven column fuel region for the purpose of distributing the coolant passing through the passages 13 of the central column to the collection chambers 43 in the reflector blocks at the base of the six peripheral columns. This is necessary because the reflector block at the base of the central column is not located directly opposite an inlet 19.

The support blocks 41 are shaped as shown in Figures 3 and 4 so that each support block is positioned under a respective fuel region. In Figure 2, a view of a typical support block is shown by the cross-hatched area superimposed on the plan view of part of the core structure cross section. The locations of the discharge orifices 18 are also indicated superimposed on the plan view.

In the illustrated embodiment, the inlets 19 in the adjacent support blocks which communicate with a common discharge orifice 18 form a group of three inlets. The collection chambers 43 in each column communicate with a respective one of the inlets. Accordingly, the three inlets of a group combine in a single discharge orifice the outflow from columns from three different fuel regions.

As a result of this arrangement, the coolant from part of each region is mixed with coolant coming from two other regions in a single discharge orifice. Thus, coolant from each region issues through a total of six different discharge orifices, each discharge orifice carrying the coolant from three columns, each from a different region.

Referring to Figure 5, the internal structure of a core support block may be more clearly seen. The discharge orifices 18 are each formed by parts of three adjacent blocks.

In order to measure the temperature of coolant coming from each of the three columns just prior to their combining in the support block discharge orifice, a single straight thermocouple bundle 55 (Figure 4) is used. There is always a straight line which can pass through all three columns of a group of three mutually joining columns. As may be seen in Figure 4, one thermocouple 57 is provided for each of the joining columns. By this manner, six thermocouples per region are provided which provides no redundancy per column but a considerable redundancy per region. Thus, even if two thermocouples are inactive, information about the region's behaviour is still supplied by four others.

As shown in Figure 2, three thermocouple bundles 55 may be used for each region, each of which has thermocouples 57 for two of the discharge orifices 18 below that region. The three bundles run in different directions and cross another bundle serving the same region only at one point. Common mode failure possibilities are thus greatly reduced. Only an accident at a specific point can disable two of the three bundles at the same time and an incident would have to spread through six columns to disable all three bundles of a region.

The information provided from the six thermocouples serving each region may be applied to a control computer (not shown) and averaged to adjust the coolant flow valve 15 for that region. The readings from each column may be used individually to evaluate column imbalance, column power distribution, and column average graphite and fuel temperatures. The information may also be averaged in groups of three to provide information about actual coolant temperature distribution and thus determine if any hot streaks remain.

During reactor operation, the coolant flow through various regions may be varied depending upon the life of the fuel in a particular region. Since each outlet from the core support structure carries the flow from three regions, each of which may be at a different stage of life and therefore with different coolant flows, the total flow is less for the same cross section, and the pressure drop in the core support block is lowered.

In Figure 6, an alternative embodiment is illustrated. Here the core support blocks 41a and 41b are irregularly shaped so as to extend under portions of four adjacent fuel regions as shown in detail for support block 41b (heavily outlined in Figure 6) and the four fuel regions A, B, C and D shown by dotted lines and shadings. The support block 41b extends under the central column and two adjacent peripheral columns of region A, under two adjacent peripheral columns of region B and under one peripheral column of each of regions C and D. Thus, each core support block supports a total of seven fuel block columns, one of which is a central column from one fuel region and six of which are peripheral columns from that region and three other adjacent fuel regions. The discharge orifices 18 are thus each located entirely within a core support block and not formed by the juncture of three such blocks as in the embodiment of Figures 2-5.

It may be seen, therefore, that the core of the invention is less susceptible to deleterious affects caused by hot streaks. A homogenizing of the coolant results and temperature monitoring is facilitated.

WHAT WE CLAIM IS:—

1. A nuclear reactor comprising a core having a plurality of columnar fuel regions, each fuel region having coolant passages for conducting fluid coolant through the fuel region, a plurality of valves, one for each fuel region for regulating the flow of coolant through the coolant passages of that fuel region, and collecting means for the fluid coolant located at the downstream end of the coolant passages and including a plurality of inlets for each one of a plurality of discharge orifices, the arrangement being such that the inlets for any given discharge orifice receive coolant from each of a plurality of adjacent fuel regions.

2. A nuclear reactor according to Claim 1, wherein each of the fuel regions comprises a plurality of columns of disengageable fuel elements having aligned passaged therein together forming the coolant passages.

3. A nuclear reactor according to Claim 2, wherein each inlet communicates with coolant passages in a different one of the fuel columns.

4. A nuclear reactor according to Claim 1 including temperature measuring devices located in the collecting means for measuring the temperature of the coolant discharged from the fuel regions prior to passing to the respective discharge orifice.

5. A nuclear reactor according to Claim 4, wherein the temperature measuring devices are positioned in each inlet.

6. A nuclear reactor according to Claim 2, comprising collecting chambers formed in reflector blocks located at the downstream end of the fuel columns for collecting the coolant from the coolant passages in the fuel columns, the collecting chambers communicating with the inlets of the collecting means.

7. A nuclear reactor according to Claim 1, wherein said inlets and discharge orifices are formed in or by support blocks for the core.

8. A nuclear reactor according to Claim 7, wherein the fuel columns are of hexagonal cross section, wherein each of the fuel regions comprises six columns arranged about a seventh central column, wherein each support block is formed to extend under one of the fuel regions, and wherein each discharge orifice is defined by portions of three adjacent support blocks.

9. A nuclear reactor according to Claim 7, wherein the fuel columns are hexagonal in cross section, wherein each of the fuel regions comprises six columns arranged about a seventh central columns, and wherein the support blocks are formed to extend under three adjacent columns including the central one of a first region, two columns of a second region adjacent to the first region, and one column from each of two further regions each adjacent to the first and second regions.

10. A nuclear reactor as claimed in Claim 1 and substantially as described with reference to the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1979.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1554898 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

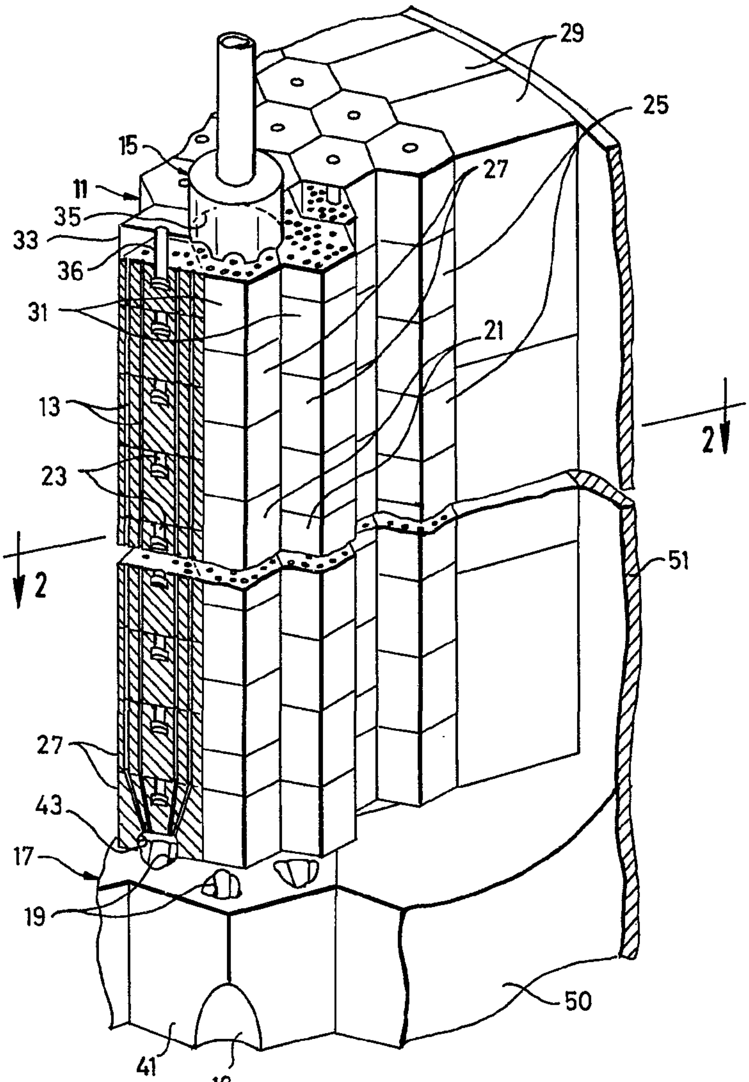


FIG.1

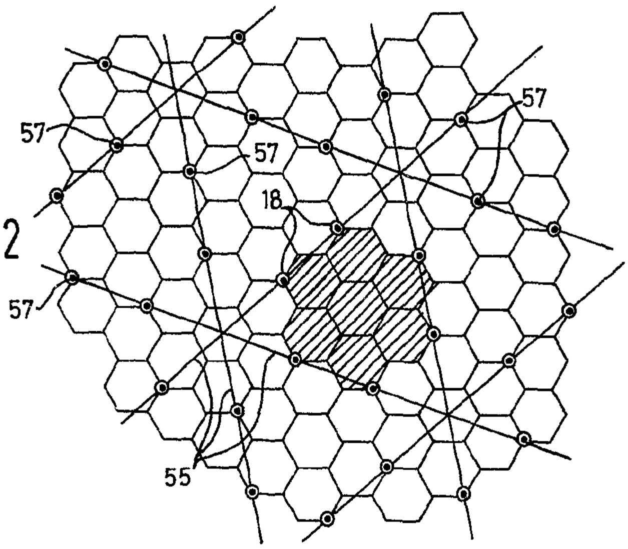


FIG.2

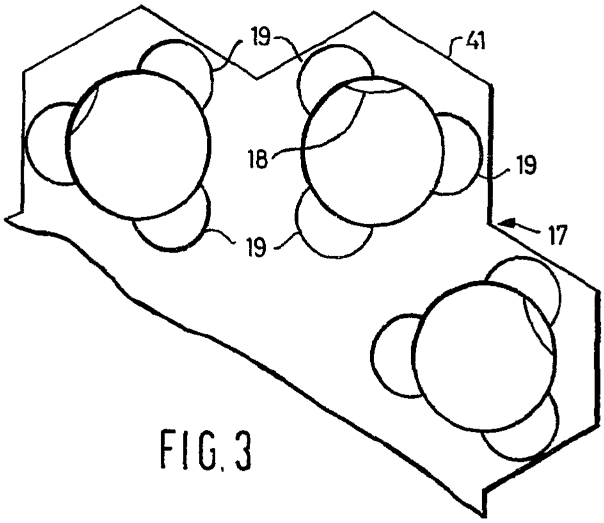


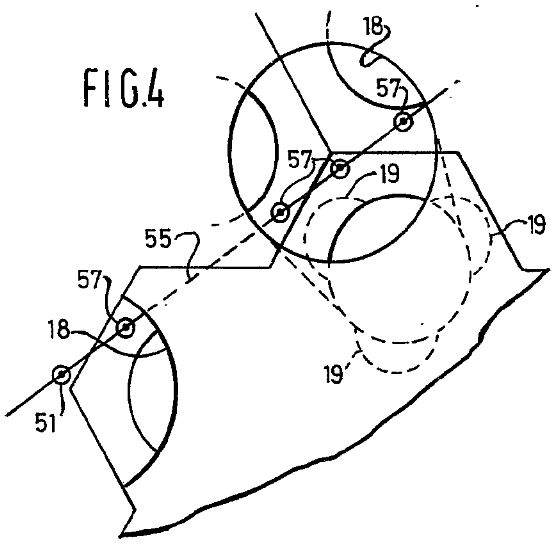
FIG.3

1554898 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

FIG.4



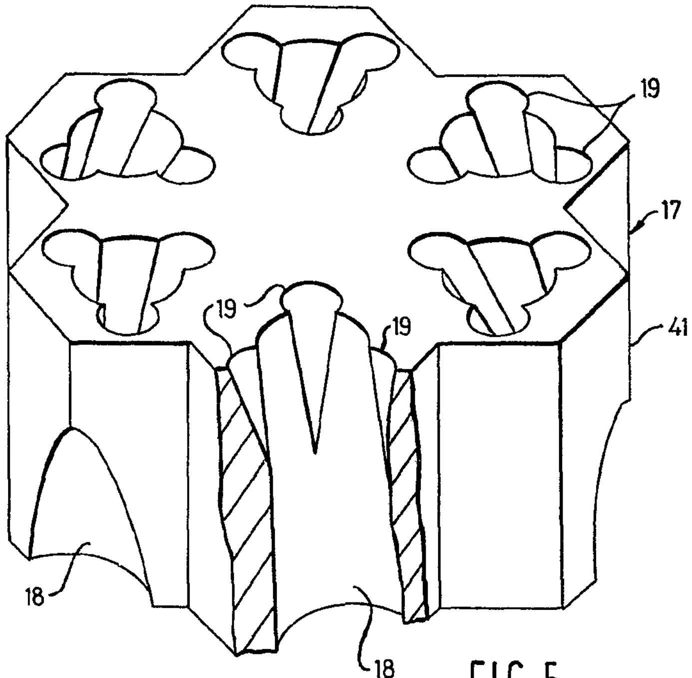


FIG. 5

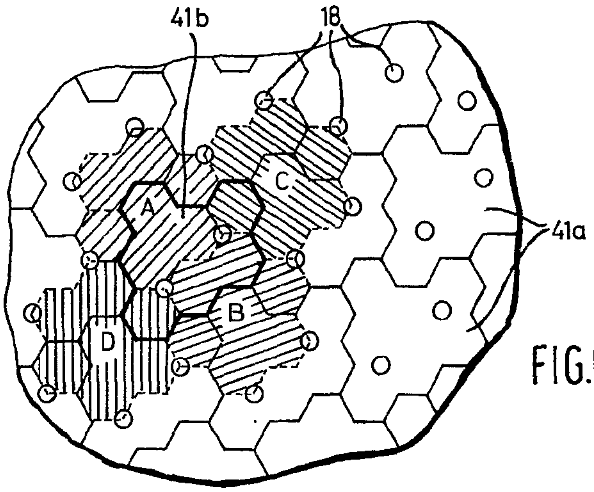


FIG.6