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(54) IMPROVEMENTS IN OR RELATING TO THE CONTROL OF NUCLEAR REACTORS

(71) We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, London, a British Authority, 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 the control of nuclear reactors. In particular it is concerned with the control of reactors by the variation of the amount of neutron absorbing material within the core of the reactor.

The present invention provides a control device, for charging as a unit into the core of a liquid cooled nuclear reactor, comprising:

(a) an upper reservoir and a lower receiver for liquid neutron absorber with a pipe for flow of the absorber from the reservoir to the receiver;

(b) flow control means for controlling flow between reservoir and receiver;

(c) a pipe for flow of nuclear reactor liquid coolant or other liquid through said control device;

(d) means associated with pipe (c) for effecting control of the flow control means (b) according to the rate of flow of liquid in the pipe (c); and

(e) means for returning liquid neutron absorber in the receiver to the reservoir.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings in which

Figure 1 is a longitudinal sectional elevation of a first embodiment cf the invention;

Figure 2 is an isometric detail of a component of the device of Figure 1;

Figure 3 is a graph;

Figure 4 is a longitudinal sectional elevation of a second embodiment of the invention.

Figure 1 of the drawings shows a control device applicable to a sodium cooled nuclear reactor. The device is mounted in a control or shut-off channel 1 of the reactor core structure 2 which has a central fuel zone 3. The device comprises a cylindrical casing 4 divided by a transverse baffle 5 into a lower receiver 6 which is located in the fuel zone 3 of the core structure 2 and an upper reservoir 7 disposed above the receiver 6. A feed line or pipe 8 links the reservoir 7 with the receiver 6 and a return line 9 links the receiver 6 with the reservoir 7. A duct or pipe 10 for sodium reactor coolant passes longitudinally through the casing 4 extending through the receiver 6 and the reservoir 7. The duct 10 and the return line 9 from the receiver 6 to the reservoir 7 extend through a flow coupler 11 of the type described hereafter.

The device of Figure 1 is shown in a "withdrawn" condition that is with lithium 6 metal 12 held in the reservoir 7 out of the fuel zone 3 of the core structure 2.

In reservoir 7 and extending into receiver 6 there is disposed a flow control means for controlling flow between reservoir and receiver. This means includes a syphon chamber 13 round the skirt 14 of which lithium-6 metal 12 held in the reservoir 7 chamber 13 and, under suitable conditions, into the open upper end 15 of feed line 8, which has a U-bend 16 at its lower end. The free space above the lithium in the reservoir 7 and in the syphon chamber 13 is occupied by argon gas. The pressure of gas in the free space within syphon chamber 13 is governed by a control line 17 which has a leg 18 extending downwards from the receiver 6 through the flow coupler 11 and a parallel leg 19 extending downwards from the reservoir 7 through the receiver 6. The legs 18 and 19 of the control line 17 are joined at their lower ends by a Y junction 20. With the lithium metal 12 occupying the reservoir 7, the U-bend 16 of the feed line 8 is filled with lithium metal. The leg 19 of the control line 17 is completely filled with lithium metal whilst the leg 18 of the control line 17 is filled with lithium metal up to the level of the top of the flow coupler 11.

The flow coupler 11 is of the type generally disclosed in British Patent No. 745,460. A flow coupler is an electromagnetic liquid metal pump comprising at least a pair of parallel ducts for liquid metal. A magnetic field is applied transversely across the ducts such that by pumping liquid metal through one of the ducts an EMF and hence a current is generated in the liquid metal being pumped through the duct. The EMF drives a current through the liquid metal in the second duct and in accordance with the Faraday principle an electromagnetic pumping action is exterted on the liquid metal in the second duct. As shown in Figure 2 the flow coupler 11 comprises a rectangular casing 21 divided by partitions 22 into ducts 23, 24, 25 and 26. A magnetic field is set up by a permanent magnet passing transversely across the ducts 23, 24, 25 and 26. In the arrangement of Figure 1 the duct 10 for liquid sodium reactor coolant passes through the duct 23 of the flow coupler 11, the return line 9 from the receiver 6 to the reservoir 7 passes through the duct 25 and the leg 18 of the control line 17 passes through the duct 26. When sodium reactor coolant is passing upwards through the duct 10 as shown in Figure 1 it generates an EMF which in turn creates a downwards pumping action on lithium in the return line 9 and the leg 18 of the control line 17. The flow coupler 11 may have a switching line 29 passing through the duct 24. The switching line 29 is a closed loop with sodium contained in the bottom U of the loop. The effect of this switching line 29 is that as reactor coolant sodium flow through the duct 10 is gradually increased there is initially no pumping action on the lithium in the return line 9 and the leg 18 of the control line 17. At first as the rate of flow of reactor coolant sodium through the duct 10 is increased static sodium in the bottom U of the switching line 29 is drawn up into the duct 24 of the flow coupler 11. At a threshold value of reactor coolant sodium flow rate through the duct 10 maximum pumping action is rapidly achieved on the lithium in the return line 9 and the leg 18 of the control line 17. This is shown in Figure 3 where the threshold pumping effect is shown as occurring at a sodium flow rate of about 25% of the full reactor sodium coolant flow rate.

An adjustable gag 30 is fitted at the upper end of the duct 10. Adjustment of the gag 30 is by means of a rod 31 extending through penetrations in the reactor roof. Also a flow cut off plate 32 is mounted over the sodium outlet 33 from the gag 30. The plate 32 is held up by an electromagnet which can be de-energised to drop the plate 32 into place over the sodium outlet 33.

In the case, for example, of a flow coupler 11 having a threshold pumping effect at 25% of the full reactor sodium coolant flow rate the gas 30 is set so that the sodium flow rate through the duct 10 corresponds to 30% reactor sodium coolant flow rate. In this condition the flow coupler 11 generates a downwardly acting pressure in the lithium within the leg 18 of the control line 17 (since the leg 18 passes through the flow coupler 11). This pressure acts through the leg 19 of the control line 17 to maintain sufficient gas pressure above the lithium in the syphon chamber 13 to prevent the lithium level in the syphon chamber 13 rising to the open upper end 15 of the feed line 8 despite the head of lithium in the reservoir 7 and the pressure of gas above the surface of lithium in the reservoir 7. The flow coupler 11 also applies a downwardly acting pressure in the lithium in the return line 9 from the receiver 6 to the reservoir 7. The flow coupler 11 generates a sufficient head to prevent lithium discharging from the reservoir 7 into the receiver 6 through the return line 9.

In the event of reactor coolant sodium flow rate through the duct 10 falling below the threshold value of 25% of full reactor coolant flow rate the pressure induced by the flow coupler 11 in the lithium within the control line 17 will fall. As a consequence of the pressure loss in the leg 19 of control line 17 the gas pressure above the surface of the lithium in the syphon chamber 13 will fall so that the head of lithium in the reservoir 7 will be sufficient to drive the lithium in the syphon chamber upwardly to cause lithium overflow through the upper open end 15 of feed line 8 and so into the receiver 6. This flow of lithium from the reservoir 7 into the receiver 6 will continue until the reservoir 7 is drained of lithium to below the level of the skirt 14 of the syphon chamber 13 even if the reactor coolant sodium flow rate through the duct 10 is returned to its normal value of 30% of full reactor coolant flow rate during the lithium injection period. Loss of pressure will also occur in the return line 9 from the receiver 6 to the reservoir 7. Hence some lithium will flow from the reservoir 7 into the receiver 6 through the return line 9 and there will also be some lithium flow from the reservoir 7 into the receiver 6 through the control line 17. However the return line 9 and the control line 17 are made of small bore compared with the feed line 8 so that the majority of lithium flow will be through the feed line 8. On completion of lithium transfer from the reservoir 7 into the receiver 6 the free space above the lithium in the receiver 6 and the free space in the reservoir 7 are occupied by argon gas whose pressure in the free spaces is equalised by a vent line 34 extending between the receiver 6 and the reservoir 7. As the bottom U-bend 16 in the feed line 8 remains filled with lithium the control line 17 will also remain filled with lithium.

When reactor coolant sodium flow rate through the duct 10 is subsequently returned to its normal value of 30% of full reactor coolant flow rate the flow coupler 11 will pump lithium at a slow rate from the receiver 6 through the return line 9 into the reservoir 7. Also the flow coupler 11 will re-establish pressure in the lithium in the control line 17. As the reservoir 7 fills, gas will be trapped in the syphon chamber 13 and pressurised so as to result in the final level differences shown in Figures 1, that is, with the lithium once again held in the reservoir 7. In view of the differences in bore sizes between the return line 9 and the feed line 8 lithium cannot be withdrawn from the reservoir 6 at a greater rate than that at which it can flow into the receiver 6 through the feed line 8, providing a safety measure.

It will be seen that the control device of Figure 1 operates to shut down the reactor if the reactor coolant flow rate falls to a level such that the reactor coolant sodium flow rate through the duct 10 falls below the level for threshold excitation of the flow coupler 11. Also the device can be made to operate by stopping or inhibiting flow of reactor coolant sodium through the duct 10 by dropping the flow cut off plate 32. The plate 32 is dropped by de-energisation of its supporting electromagnet, the magnet being de-energised in response to a suitable transducer sensitive to a change in some other reactor parameter which could lead to a need for reactor shut down — typically high fuel temperature, high flux density or a signal indicating a failure of fuel sheathing.

Referring to Figure 4 of the drawings this shows a second form of control device also applicable to a sodium cooled nuclear reactor. Again the device is mounted in a control or shut off channel 1 of the reactor core structure 2 which has a central fuel zone 3.

The device comprises a cylindrical casing 40 divided by a tranverse baffle 41 into a lower receiver 42 which is located in the fuel zone 3 of the core structure 2 and an upper reservoir 43 disposed above the receiver 42. A discharge line 44 having a U bend 45 at its lower end leads from the bottom of the reservoir 43 to the bottom of the lower reservoir 42. A common return and control line 46 leads from the lower end of the receiver 42 to the lower end of the reservoir 43. The line 46 terminates in a cup 47 at its upper end within the reservoir 43. A duct 48 for sodium reactor coolant passes longitudinally through the casing 40, extending through the receiver 42 and the reservoir 43. The duct 48 and the line 46 from the receiver 42 to the reservoir 43 extend through a flow coupler 49 of similar type to that shown in Figure 2. A gas lock bell 50 is fitted in the reservoir 43 over the cup 47 at the upper end of the line 46 and the upper end of the discharge line 44 in the reservoir 43. A gas lock break tube 51 extends vertically from the cup 47 at the upper end of the line 46 through the gas lock bell 50 to the upper end of the reservoir 43. The upper end of the reservoir 43 is connected with the upper end of the receiver 42 by a vent line 52. Similarly to the control device of Figure 1 an adjustable gag 53 is fitted at the upper end of the duct 48 and also a magnetically supported flow cut off plate 54 is mounted over the sodium outlet 55 of the gag 53.

Normally in the "withdrawn" condition of the device of Figure 4 lithium metal is held in the upper reservoir 43 and for shut down of the reactor the lithium is allowed to flow by gravity from the upper reservoir 43 into the lower receiver 42 in the fuel zone 3 of the reactor core structure 2.

The detailed operation of the device is best described by starting with the condition in which the device is "inserted", that is, with the lithium contained in the receiver 42.

The gag 53 is set to provide a sodium flow rate through the duct 48 of 25% of full reactor coolant flow rate and the flow coupler 49 is of the type fitted with a switching line so as to become activated at a flow rate of 20% full flow rate and so as to reach maximum pumping efficiency at 25% full flow rate.

On raising the reactor coolant flow to result in 20% full flow rate in the duct 48 lithium will begin to be pumped from the lower receiver 42 into the upper reservoir 43 through the line 46. At a reactor coolant flow corresponding to 25% full flow rate through the duct 48 maximum pumping efficiency of the flow coupler 49 is achieved, the flow coupler 49 generating, for example, a 2 metre head of lithium at this flow rate.

Typically it will take about 10 minutes to transfer the lithium from the lower receiver 42 to the upper reservoir 43 under these conditions and this ensures a low rate of reactivity insertion. Whilst the upper reservoir 43 is being filled with lithium, argon cover gas is displaced via the vent line 52 to the lower receiver 42. Since the lithium is supplied to the upper reservoir 43 by overflow from the cup 47 under the gas lock bell 50 some cover gas is trapped under the bell 50. A 'U' of lithium which is always present in the U-bend 45 at the lower end of the discharge line 44 prevents gas escaping from the lower receiver by this route. The gas lock break tube 51 dips into the cup 47 at the upper end of the line 46. The transfer of lithium ceases when the level of lithium in the right hand leg of the line 46 passes below the top of the flow coupler 49. When this occurs the efficiency of the flow coupler 49 decreases so as to maintain an approximately constant delivery head if sodium flow through the duct 48 increases above 25% full reactor coolant flow rate.

In this condition the control device is in the "withdrawn" state with lithium in the upper reservoir 42 below the top of the gas lock break tube 51 and the vent line 52. Within the gas lock bell 50 the lithium surface lies below the entrance to the discharge line 44 and within the U-bend 45 at the botom of the discharge line 44 the lithium is depressed on the inlet side as shown in Figure 4. The cup 47 is full of lithium and so is the gas lock break tube 51. Now suppose that the delivery pressure of the flow coupler 49 acting on the lithium in the line 46 falls by a small amount, e.g. 1 centimetre, equal to the amount by which the gas lock break tube 51 dips into the cup 47. (The delivery pressure of the flow coupler 49 will fall for example due to fall in sodium flow rate through the duct 48 consequent on a fall in the reactor coolant flow rate.) The end of the gas lock break tube 51 will be disconnected from the lithium surface in the cup 47 and the lithium in the gas lock break tube will partly discharge into the cup 47 and then be blown out by the excess gas pressure in the gas lock bell 50 into the main body of lithium in the upper reservoir 43 and the gas pressure under the gas lock bell will drop. The lithium in the upper reservoir 43 is then hydrostatically unstable and it will rise in the gas lock bell 50, overflow into the discharge line 44 and from thence into the lower receiver 42, until the lower edge of the gas lock bell 50 is above the free lithium surface in the upper reservoir 43.

The control device of Figure 4 can also be caused to "insert" by dropping of the flow cut off plate 54 to inhibit or cut off sodium flow through the duct 48. In this case also the flow cut off plate 54 is dropped by de-energisation of its holding magnet in response to a change in a reactor parameter resulting from a fault condition arising.

In the case of the control devices shown in Figures 1 and 4 the flow couplers are powered by flow or sodium drawn from the main reactor coolant flow, thus, in the particular case, employing failure of coolant flow as the parameter change causing "insertion" of the devices to shut down the reactor. In the case of a non-metal liquid-cooled reactor the flow couplers may be powered by a separate liquid metal circuit causing flow in ducts 10/48 and the flow of reactor coolant may drive a turbine which is coupled to a liquid metal pump in the separate circuit. In this way the reactor coolant flow is directly correlated with the separate liquid metal flow, changes in the reactor coolant flow producing corresponding changes in the separate liquid metal flow.

The control devices of Figures 1 and 4 can also be caused to "insert" if overheating of the reactor coolant sodium occurs. If the magnets of the flow couplers are selected from a material which loses its magnetic property when its Curie temperature is exceeded then on that temperature being exceeded (typically when gamma heating from the reactor core structure exceeds cooling produced by a flow of sodium coolant) the magnetic property would disappear and the coupling acton of the flow couplers would be lost.

The control devices of the above embodiments have the advantage of being chargeable as a unit into an existing control rod channel of a nuclear reactor the devices also being removable from the channel for maintenance as a unit.

WHAT WE CLAIM IS:—

1. A control device, for charging as a unit into the core of a liquid cooled nuclear reactor, comprising:

(a) an upper reservoir and a lower receiver for liquid neutron absorber with a pipe for flow of the absorber from the reservoir to the receiver;
(b) flow control means for controlling flow between reservoir and receiver;
(c) a pipe for flow of nuclear reactor liquid coolant or other liquid through said control device;
(d) means associated with pipe (c) for effecting control of the flow control means (b) according to the rate of flow of liquid in the pipe (c); and
(e) means for returning liquid neutron absorber in the receiver to the reservoir.

2. A control device according to claim 1 wherein the means (d) and the means (e) each comprise a duct said ducts being co-related with the pipe (c) in an electromagnetic flow coupler having a pumping side and an EMF generating side in this way:

(i) a pipe (c) is on the said EMF generating side, and
(ii) said ducts are on the said pumping side.

3. A control device according to claim 2 in which the flow control means (b) comprises a gas lock and syphon and the means (d) comprises a control pipe extending from the duct of means (d) on the pumping side of the flow coupler whereby the pumping pressure in said duct controls the pressure in the gas lock and hence controls flow, through the syphon, of liquid neutron absorber between the upper reservoir and lower receiver.

4. A control device according to claim 1 in which means (d) and the means (e) include a duct common to both means, this duct being co-related with the pipe (c) in an electromagnetic flow coupler so that the common duct is on the EMF pumping side of the flow coupler and the pipe (c) on the EMF generating side of the flow coupler.

5. A control device according to claim 1, having means for obstructing flow of liquid in pipe (c) and an electromagnet for holding said means in the unobstructed position from where it can fall by gravity to the obstructed position on de-energising the electromagent whereby said flow control means (b) is activated to permit flow from the reservoir to the receiver.

6. A control device according to any preceding claim charged with a liquid metal neutron absorber and located in the core structure of a liquid metal cooled nuclear reactor, said pipe (c) being connected to accept flow of reactor coolant so that the device operates to shut down the reactor in the event of failure of flow of said coolant.

7. A control device as claimed in claim 6 wherein the neutron absorber is lithium-6.

8. A control device for a nuclear reactor substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

9. A control device for a nuclear reactor substantially as hereinbefore described with reference to Figure 4 of the accompanying drawings.

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Agent for the Applicants.

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1298804 COMPLETE SPECIFICATION

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

Sheet 1

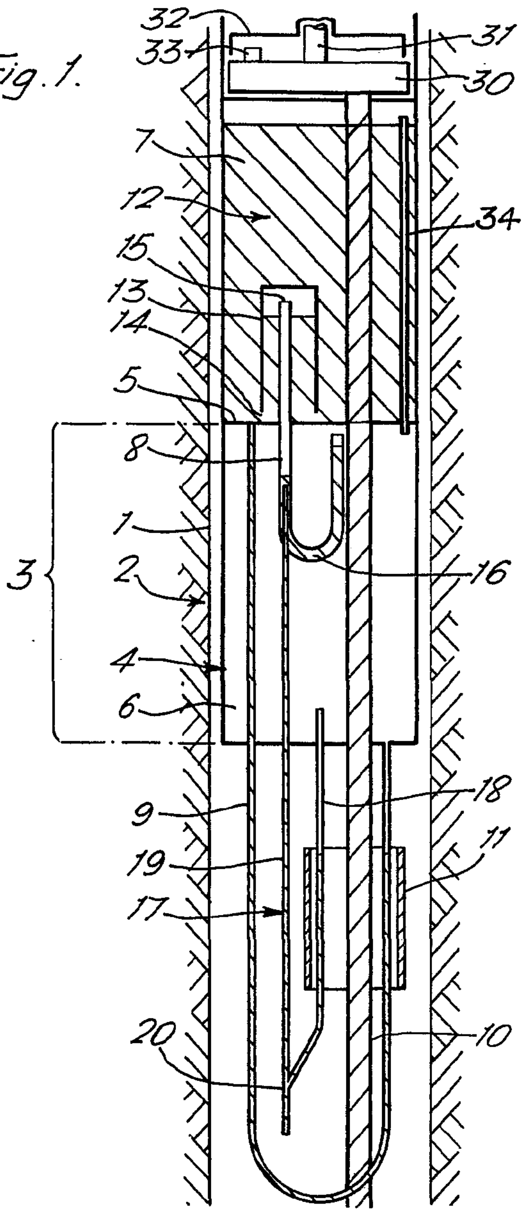
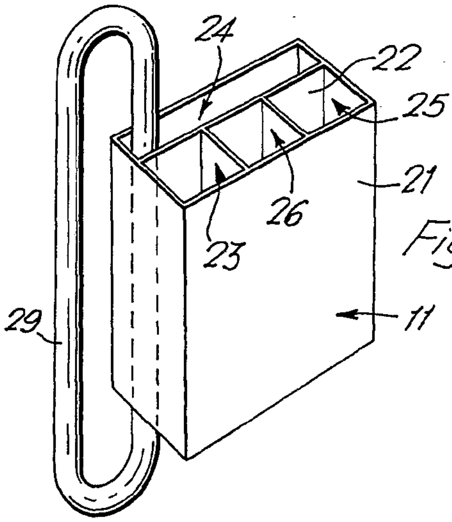


Fig. 1.


24
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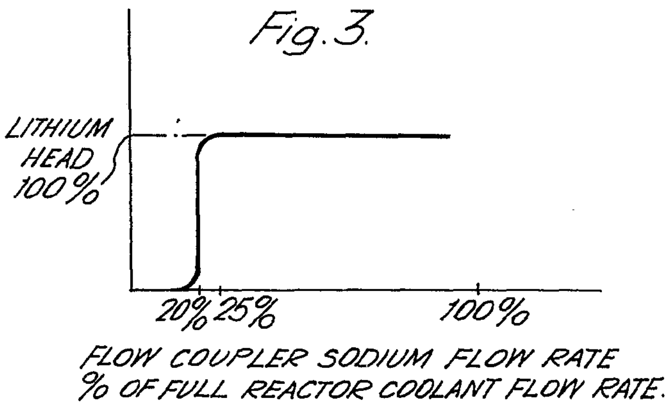
11

Fig. 2.

Fig. 3.


LITHIUM HEAD 100%
20%
25%
100%
FLOW COUPLER SODIUM FLOW RATE
% OF FULL REACTOR COOLANT FLOW RATE.

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

Sheet 3

Fig. 4.