PATENT SPECIFICATION

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(54) LOW REACTIVITY PENALTY BURNABLE POISON RODS

(71) We, WESTINGHOUSE ELECTRIC CORPORATION of Westinghouse Building, Gateway Center, Pittsburgh, Pennsylvania, United States of America, a company organised and existing under the laws of the Commonwealth of Pennsylvania, 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 burnable poison rods of nuclear reactors and more particularly to burnable poison rods having a relatively large moderator to poison ratio.

In many nuclear reactors designs, a coolant which also serves as the moderator is circulated through the reactor core in order to remove the heat produced by the fission process within the core. The core consists of a specified number of fuel rods which are held in bundles by spacer grids and top and bottom fittings. The fuel rods are constructed of cylindrical tubes containing a nuclear fuel such as low enrichment uranium dioxide fuel pellets. The bundles, known as fuel assemblies, are arranged in a pattern which approximates a right circular cylinder.

During reactor operation, the fissionable isotopes within the nuclear fuel pellets absorb neutrons and subsequently fission thereby generating heat. In addition to the depletion of fissionable material, the fission process results in the formation of fission products, some of which readily absorb neutrons. These effects, depletion and the fission products, are partially offset by the buildup of fissionable isotopes such as plutonium which occurs in the non-fission absorption of neutrons in fertile materials such as U-238. Therefore, in order to compensate for the decrease in the reactivity of the core that occurs with the depletion of the fissionable fuel and the buildup of fission products, excess reactivity is built into the reactor at the start of each cycle. This excess reactivity is controlled by neutron absorbing material in the form of boron dissolved in the primary coolant and burnable poison rods.

The concentration of the boron dissolved in the primary coolant is varied to provide control and to compensate for the long-term reactivity requirements of fuel depletion, fission product poisoning, burnable poison depletion, and the cold-to-operating moderator temperature change. However, as the boron concentration is increased, the moderator temperature coefficient becomes less negative. The use of a soluble poison alone would result in a positive moderator coefficient at the beginning-of-life for the first cycle and can result in a positive coefficient in subsequent cycles depending upon the fuel loading for that cycle. Therefore, burnable poison rods are used to reduce the soluble boron concentration sufficiently to insure that the moderator temperature coefficient is negative for power operating conditions.

A burnable poison absorbs neutrons without producing new or additional neutrons and without being transformed into new poisons as a result of neutron absorption. A typical burnable poison that exhibits these traits is boron-10 which is approximately 20% of the naturally occurring boron. Boron-10 on being irradiated by thermal neutrons undergoes the reaction $B^{10}+n^{1}\rightarrow Li^{7}+He^{4}$ which results in the absorption of a neutron and the depletion of boron-10 without the production of additional poison.

Burnable poisons are conventionally used in rods installed at vacant rod cluster control (RCC) locations within the fuel assembly. The burnable poison concentration in the rods and the number of burnable poison rods inserted in the core are specified so that the soluble boron concentration is reduced sufficiently to insure that the moderator temperature coefficient is negative for power operating conditions. During operation the poison content in these rods is depleted, thus adding positive reactivity to offset some of the negative reactivity from fuel depletion and fission product buildup. At the end-of-life conditions some residual poison may remain resulting in a net decrease in the core lifetime. In addition, the burnable poison rods displace moderator and the parasitic structural materials of the burnable poison rod absorb neutrons further decreasing the available reactivity lifetime of the core. In addition to reactivity control, the burnable poison rods are strategically located to provide a favorable radial power distribution.

In the U.S. Patent No. 3,510,350 to P. M. Wood, issued May 5, 1970 a burnable poison rod is described wherein a borosilicate glass tube is disposed in the annular space between two concentric metal tubes. An internal axial void is provided within the inner metal tube which provides a gas plenum to receive the gaseous reaction products such as helium gas that result when the boron absorbs neutrons. The burnable poison rods are appropriately placed within the fuel assembly in vacant RCC location. While the patent to Wood does describe a particular type of burnable poison rod it would be advantageous to minimize the amount of burnable poison remaining at the end of life in order to increase the core lifetime.

A fuel assembly shroud that employs burnable poison is described in U.S. Patent No. 3,663,366 to T. O. Sauar, issued May 16, 1972. The shroud comprises compound plates of stainless steel and zirconium wherein enriched boron-10 is dispersed in the sheets of stainless steel. However, the Sauar patent does not describe the use of burnable poison in poison rods capable of being arranged with fuel elements in the fuel assembly.

The use of boric acid or borosilicate glass in control rods of educational nuclear reactors is described in U.S. Patent No. 3,110,656 to M. M. Mills, issued November 12, 1963. Of course, the use of a neutron absorber in control rods is fundamental but suffers from the common disadvantages of control rods in general in that they are not designed to deplete with irradiation. In addition, burnable poisons have been added to the nuclear fuel material and has been employed in the composition of the fuel element cladding.

While there exists in the prior art, numerous uses for burnable poison in nuclear reactors, the problem of providing sufficient burnable poison at the beginning of the life of the reactor core to compensate for excess reactivity while minimizing this negative reactivity contribution near the end of the core life so as to prolong the core life, nevertheless, has not satisfactorily been solved and it is therefore the object of the present invention to provide a burnable poison rod which improves present conditions, that is, which permits longer life and greater burn-up of a nuclear core.

With this object in view the present invention resides in a burnable poison rod for use in a nuclear reactor comprising an elongated tubular sheath enclosing a neutron absorbing material, characterized in that at least during operation of said reactor said sheath also encloses a neutron moderating material.

The excess reactivity existing at the beginning of core life is compensated for by the depletion of the burnable poison throughout the life of the core, so that the life of the core is extended.

The invention will become more readily apparent from the following description of a preferred embodiment thereof shown, by way of example only, in the accompanying drawings, wherein:

Figure 1 is a partial cross-sectional view in elevation of a fuel assembly;

Figure 2 is a cross-sectional view taken along line II—II of Figure 1;

Figure 3 is a cross-sectional view in elevation of a burnable poison rod;

Figure 4 is a cross-sectional view of a burnable poison rod; and

Figure 5 is a cross-sectional view in elevation of an alternate burnable poison rod.

Referring to Figures 1 and 2, a fuel assembly referred to generally as 10 comprises an upper end support 12, a lower end support 14, guide tubes 16, positioning grids 18, fuel elements 20, and poison rods 22. Upper end support 12 and lower end support 14 support guide tube 16 and fuel element 20 while positioning grids 18 maintain proper alignment among guide tubes 16 and fuel element 20. Guide tubes 16 may be hollow cylindrical tubes of zirconium or other low neutron absorbing material that are capable of supporting poison rods 22 therein. Fuel assemblies 10 are arranged vertically within a reactor vessel (not shown) to form a core (not shown) so as to produce heat by nuclear fission in a manner well understood by those skilled in the art. The reactor coolant which may be water flows through the reactor vessel upwardly through and in heat transfer relationship with fuel assemblies 10. In such a manner, heat is transferred from fuel assemblies 10 to the reactor coolant. In such a configuration, poison rods 22 are capable of absorbing neutrons thus controlling the reactivity level of the core so that excess reactivity may be added to the core by increasing the enrichment of the nuclear fuel in each fuel assembly 10. Loading the core with initial excess reactivity increases the length of time that the core is capable of producing heat without being reloaded with fresh fuel assemblies 10. In this concept it is, however, important that the poison rods 22 become depleted near the end of the core's life so that the poison rods 22 will not create a reactivity penalty by absorbing neutrons.

Referring now to Figures 3 and 4, poison rod 22 has a cylindrical metallic outer sheath 24 that may be manufactured from zircaloy tubing and may have an outside diameter of approximately 0.38 inches and an inside diameter of approximately 0.33 inches. A lower end plug 26 having a center bore 28 therein is attached to the lower end of outer sheath 24 by suitable means such as welding. A cylindrical metallic inner sheath 30 is concentrically disposed within outer sheath 24 and is attached at its lower end to lower end plug 26. Inner sheath 30 may be manufactured from zircaloy tubing and may have an outside diameter of approximately .20 inch and an inside diameter of approximately 0.16 inch. An upper end plug 32 having an opening 34 is attached to outer sheath 24 and inner sheath 30 near their top ends. Inner sheath 30 and outer sheath 24 define therebetween an annulus 36 that is closed at its ends by lower end plug 26 and upper end plug 32. A coil spring 38 is disposed in annulus 36 and rests therein on lower end plug 26. Pellets 40 which are annular pellets conforming to annulus 36 are disposed in annulus 36 and rest on coil spring 38. Pellets 40 may be composed of a burnable poison such as boron carbide-aluminum oxide (B_4C—Al_2O_3), other borides such as zirconium diboride (ZrB_2), or oxides such as gadolinium oxide (Gd_2O_3). Coil spring 38 serves to maintain pellets 40 in approximately the same location relative to outer sheath 24. As pellets 40 become depleted by neutron absorption they release reaction products such as helium gas. An annular space 42 may be provided near the top of poison rod 22 between the bottom of upper end plug 32 and the top of the stack of pellets 40 so as to provide a cavity for accommodating the reaction products of pellets 40. Of course, these reaction products may also be accommodated in the lower part of annulus 36 in the space around coil spring 38.

Still referring to Figures 3 and 4, on its inner side inner sheath 30 defines an inner bore 44 that extends from lower end plug 26 up into upper end plug 32. Near its lower end, inner bore 44 is in fluid communication with center bore 28 and at its upper end inner bore 44 is in fluid communication with outlet plenum 46 which is defined within upper end plug 32. Outlet plenum 46 is also in fluid communication with openings 34. Reactor coolant which is normally water and acts as a neutron moderator not only flows around outer sheath 24 but also flows upwardly through an opening in guide tube 16 and upwardly through center bore 28, inner bore 44, outlet plenum 46, and through openings 34. In this manner, inner bore 44 becomes substantially filled with water. The water in inner bore 44 substantially increases neutron moderation in and around poison rod 22 which, over the life time of the core, substantially increases the depletion of pellets 40 and increases the core burnup. The use of such a burnable poison rod, allows the initial reactivity of the core to be increased without incurring an end of life penalty. It is estimated that the use of a poison rod 22 as herein described will increase the first core burnup by about 350 MWD/MTU which decreases the fuel cycle cost for the first core by about 1.3%. Under these conditions the resulting savings in yellow cake (U_3O_8) is about 14,000 lbs. While minor differences in the size of pellet 40 may not be important, the increase in water fraction of poison rod 22 is important. Therefore, not only should the annular thickness of pellet 40 be manufactured as small as possible but the amount of water displaced by poison rod 22 should be minimized thereby increasing neutron moderation. Therefore, the invention provides a burnable poison rod with an inner channel open to the reactor coolant that minimizes displacement of the coolant thereby increasing neutron moderation thus increasing depletion of the burnable poison and increasing nuclear fuel burnup.

While there is described what is now considered to be the preferred embodiment of the invention it is, of course, understood that various other modifications and variations will occur to those skilled in the art. The claims, therefore, are intended to include all such modifications and variations which fall within the true spirit and scope of the present invention. For example, coil spring 38 may be replaced by another biasing mechanism. Pellets 40 may be replaced by a powder of a higher poison composition. Such powder will allow annulus 36 to be made smaller thus increasing the inner space for water thereby further minimizing displacement of water.

Another alternative is shown in Figure 5 wherein lower end plug 26 and upper end plug 32 are closed and sealed to outer sheath 24. A water soluble burnable poison compound such as boron or cadmium is enclosed within outer sheath 24. In this configuration, when the burnable poison has been depleted only water remains which greatly minimizes the displacement of water. Moreover, in this concept the fluid nature of the solution provides a more even depletion of the poison in the rod.

WHAT WE CLAIM IS:—

1. A burnable poison rod for use in a nuclear reactor comprising an elongated tubular sheath enclosing a neutron absorbing material, characterized in that at least during operation of said reactor said sheath also encloses a neutron moderating material.

2. A burnable poison rod as claimed in claim 1, wherein lower and upper end plugs are sealed to sheath, characterized in that a solution of water and a boron compound is contained within said sheath thereby increasing the water fraction of said burnable poison rod thus increasing neutron moderation.

3. A burnable poison rod as claimed in claim 1, characterized in that said sheath is a hollow zircaloy tube having a coating of boron carbide thereon and its interior is in fluid communica-

tion with the reactor coolant, said reactor coolant filling said hollow zircaloy tube.

4. A burnable poison rod as claimed in claim 1 and comprising an elongated tubular outer sheath, an elongated tubular innear sheath disposed concentrically within said outer sheath and defining an annulus therebetween, upper and lower end plugs attached to said sheaths, and annular pellets of a burnable poison disposed in said annulus, characterized in that said upper and lower end plugs have axial passages providing communication with the interior of said inner sheath so as to allow reactor coolant to flow through said inner sheath thereby increasing the moderator content of said burnable poison rod.

5. A burnable poison rod as claimed in claim 4, characterized in that said burnable poison rod further comprises spring means disposed in said annulus and resting on said lower end plug for supporting said annular pellets.

6. A burnable poison rod as claimed in claims 4 or 5, characterized in that said annular pellets are composed of boron carbide-aluminum oxide.

7. A burnable poison rod as claimed in claims 4 or 5, characterized in that said annular pellets are composed of zirconium diboride.

8. A burnable poison rod as claimed in claims 4 or 5, characterized in that said annular pellets are composed of gadolinium oxide.

9. A burnable poison rod for use in a nuclear reactor substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

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1554997 COMPLETE SPECIFICATION

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

Sheet 1

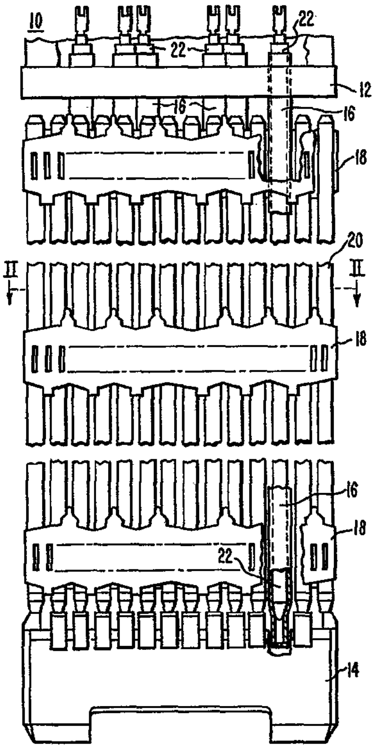

FIG. 1

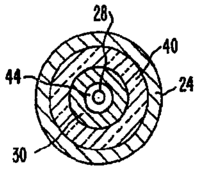

FIG. 4

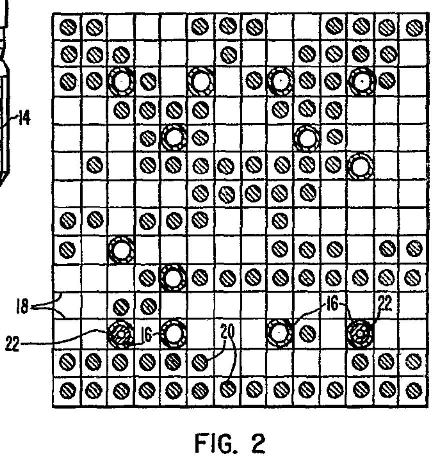

FIG. 2

1554997 COMPLETE SPECIFICATION

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

Sheet 2

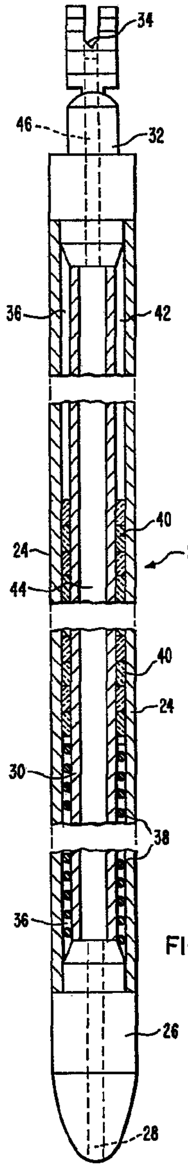

FIG. 3

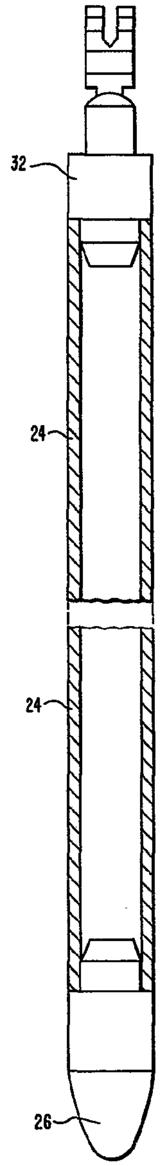

FIG. 5