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MODERATOR-FUEL ELEMENT

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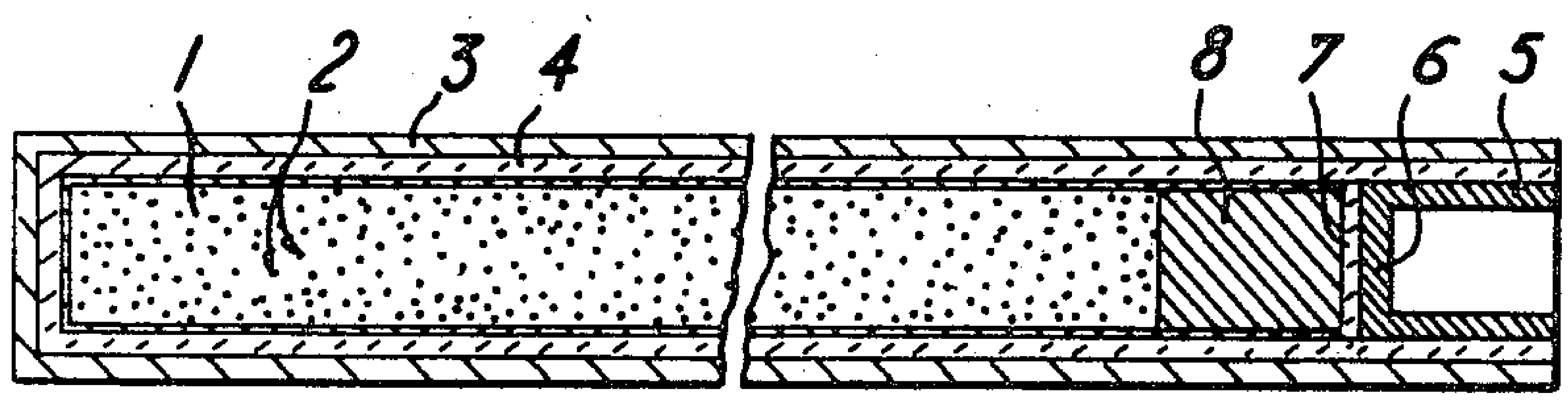

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MODERATOR-FUEL ELEMENT

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This invention relates to a moderator-fuel element which is primarily intended to be employed in nuclear reactors for spacecraft, and also to a method of manufacture of said element or a like element.

The essential features which are required of reactors of this type are lightness of weight and small bulk. It is consequently an advantage to make use of moderator-fuel elements containing spherical particles of enriched fuel which are dispersed in a solid moderator formed of a metal hydride having a high hydrogen concentration. Zirconium hydride is mainly employed for this purpose.

Elements of this type are clad with a protective jacket or can for retention of fission gases and hydrogen and are arranged in parallel clusters between which cooling fluid is circulated. The cooling fluid is cooled by means of a secondary fluid circuit comprising a radiator which is cooled by radiation in space. In order to reduce the overall size of the reactor, it is naturally essential to ensure that the said radiator has as small a surface area as possible and therefore a temperature which is as high as possible. In point of fact, this temperature is limited by the nature of the hydrides which are usually employed as moderators and which decompose at relatively low temperatures, with the result that can-temperatures of the order of 700° C. cannot be exceeded.

The present invention is concerned with a moderator-fuel element which is primarily intended for use in reactors for space vehicle propulsion and which affords the same advantages as the elements of the prior art referred-to above but which can additionally be utilized under good conditions at temperatures of a much higher order.

The moderator-fuel element in accordance with the invention which contains spherical particles of refractory fuel dispersed in a solid moderator, is characterized in that said moderator consists of yttrium hydride, the spherical particles of refractory fuel being coated with a layer of material which does not react with yttrium hydride, such as molybdenum. Yttrium hydride is stable at temperatures which can exceed 900° C. to 1,000° C. and, even at these temperatures, still has a hydrogen concentration of more than 5.10^{22} atoms per $cm.^3$. This concentration permits of excellent neutron economy in respect of a very small volume of moderator.

The intended function of the coating which is applied over the spherical fuel particles is to prevent the yttrium from attacking the fuel by preventing any contact between these latter. It has been observed, for example, that uranium oxide is reduced by yttrium at 1,000° C.; uranium carbide is also attacked. On the other hand, it has been found that molybdenum and other compounds such as SiC, $MoSi_2$ and BeO remain compatible with yttrium at temperatures of the order of 1,000° C.

According to a preferred embodiment of the invention which is more especially directed to reactors which are cooled by circulation of a liquid alkali metal, the moderator-fuel element is clad with a jacket or can of molybdenum or of a refractory alloy (Hastelloy or Inconel, for example) which is lined internally with an impervious layer for inhibiting diffusion of hydrogen. This layer can be formed in particular of a nitride, carbide, silicide, boride or even oxide formed, for example, by suitable treatment of the can. These examples are not given by way of limitation; thus, excellent imperviousness of the can can be ensured by means of an enamel having a base of aluminum and zirconium silicates in particular.

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Depending on the composition of the anti-diffusion layer which is provided, it may prove necessary or advantageous to form an intermediate metallic layer between the moderator and the can, for example in order to prevent any reaction between a silicate-base enamel and the yttrium hydride.

The present invention is also concerned with a method of fabrication of the moderator-fuel element as hereinabove defined or of any element of like nature.

This method is characterized in that it consists in grinding the yttrium, in mixing the ground product with particles of refractory fuel which have previously been coated with a material which does not react with yttrium, in sintering said mixture, in placing the sintered product in a metal can after machining if necessary, then in hydriding the mass of yttrium.

The sintering of the ground yttrium which contains the fuel is preferably carried out at a temperature of the order of 1,000° C. after hydrostatic pressing under a pressure in the vicinity of 1 $t./cm.^2$. Hydriding can be carried out in particular by placing the element in a hydrogen atmosphere at a pressure of the order of 100 mm. of mercury at 1 atmosphere and at a temperature ranging from 800 to 900° C. Once the hydriding process is completed, the hydrogen pressure is preferably adjusted to approximately 200 mm. of mercury.

Reference being had to the single accompanying figure, there will now be described below a particular method of fabrication of the moderator-fuel element in accordance with the invention, said method being chosen by way of non-limitative example.

The element described is intended to be employed in a reaction which is cooled by circulation of NaK. Said element consists of a cylindrical rod **1** having a diameter of 15 mm. and made up of spherical fuel particles **2** dispersed in an yttrium hydride matrix which constitutes the moderator.

The fuel which is employed in the particular case herein described is uranium oxide UO_2. However, it would also be possible to make use of any other refractory fuel such as a carbide, a silicide or a nitride. By reason of the fact that the uranium oxide would be reduced by the yttrium hydride, the spherical fuel particles, which are approximately 150μ in diameter, are provided with a thin coat of molybdenum having a thickness within the range of 3 to 10μ.

The rod **1** is contained in a molybdenum can **3** which is lined with an enamel layer **4** having a thickness of 0.3 mm. The thickness of the molybdenum can itself is also in the vicinity of 0.3 mm. The purpose of the enamel coating is to prevent any diffusion of hydrogen through the can.

In the particular case which is described, there has been employed an enamel having a base of aluminum silicate (55%) and zirconium silicate (45%). In order to avoid any problem of incompatibility with yttrium, a thin molybdenum film 0.05 mm. in thickness is applied between the rod and the enamelled can.

The can **3** is of greater length than the rod **1**. A hollow cylindrical end-cap **5** which is also formed of molybdenum is fitted in the end of the can. The base **6** of said end-cap is provided on the side facing the rod **1** with an enamel coating **7** which completes the enamel lining of the can itself. A magnesia pellet **8** is interposed between the end of the rod **1** and the end-cap **5**. The intended function of said pellet is to prevent any contact between the enamel and the yttrium hydride, while at the same time ensuring thermal insulation so as to prevent any over-heating of the moderator when the enamel coating is applied to the base 6 of the end-cap. In fact, the enamel coating of the end-cap is preferably formed by high-frequency heating after fitting in position so as to ensure continuity of the impervious enamel lining of the can.

There will now be described one particular mode of execution of the method of manufacture in accordance with the invention as applicable to the construction of the element hereinabove described. The following description is given by way of indication and is not intended to imply any limitation of the method according to the invention.

The initial operation consists in mixing the yttrium powder with the fuel particles which have been previously coated with molybdenum.

The sintering of the powdered mixture is then carried out. This sintering process is advantageously carried out at a temperature within the range of 1,000 to 1,200° C. and preferably in the vicinity of 1,000° C., after hydrostatic pressing under a pressure ranging from approximately 1 t./cm.^{2} to 5 t./cm.^{2}. The density of the product thus obtained is in the vicinity of 95% of theoretical.

The rod thus obtained may if necessary be machined to the desired size. It is inserted in the enamelled molybdenum can which is lined with a continuous molybdenum film, then hydrided in situ. This operation is performed at 850° C. at a pressure of 200 mm. of mercury.

The advantage of this method lies in the fact that it avoids manipulation of the hydride which is both brittle and difficult to machine. The method also makes it possible to establish good thermal contact between the enamelled can and the moderator, in view of the fact that the hydriding process results in an increase in volume of the order of 5.6% under the operating conditions hereinabove described, wherein the end product obtained is a hydride corresponding to the formula YH_1, 85.

The proton concentration obtained under the same conditions is of the order of 5.10^{22} nuclei of hydrogen per cm.^{3}.

The magnesia pellet is then inserted in the can until it is brought into contact with the rod, followed by the molybdenum end-cap. The enamelling of the end-cap is carried out by high frequency heating so as to ensure the continuity of the impervious lining.

What we claim is:

1. Moderator-fuel element containing refractory-fuel particles dispersed in a solid moderator consisting of yttrium hydride, said refractory-fuel particles being coated with a layer of molybdenum.

2. Moderator-fuel element in accordance with claim **1** including a molybdenum can surrounding said moderator and an anti-diffusion layer formed between the solid moderator and said can so as to prevent the diffusion of hydrogen.

3. Moderator-fuel element in accordance with claim **2**, wherein said anti-diffusion layer consists of an enamel having a base of aluminum silicate and zirconium silicate and is separated from the yttrium hydride by an intermediate protective layer.

4. Moderator-fuel element in accordance with claim **3**, wherein said intermediate layer is formed of molybdenum.

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