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(54) METHOD OF CONTAINING SPENT NUCLEAR FUEL OR HIGH-LEVEL NUCLEAR FUEL WASTE

(71) We, ASEA AKTIEBOLAG, a Swedish Company of Västerås, Sweden, 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:—

While nuclear fuel is being used, radioactive substances are formed which for a long period of time emit radiation which is harmful to living cells. It is therefore necessary to store spent nuclear fuel or high-level waste which is separated during the reprocessing of the fuel in such a way that the radioactive substances formed cannot spread into the environment and harmfully affect the biosphere. The predominant radioactive substances which are easily taken up by organisms and are therefore particularly dangerous are strontium-90 and caesium-137. These have relatively short half-lives and are thus dangerous for a limited period of time only. In the fuel rods there are further formed radioactive gases, plutonium, radioactive uranium isotopes and transuranic elements. The major part of these substances have a very long half-life and are thus dangerous for a very long period. For the final storage the aim is to achieve a safe enclosure of spent nuclear fuel or highly radioactive (i.e. "high-level") nuclear fuel waste in such a way that the rods or the waste are protected from attack, for example from subsoil water containing corrosive and dissolving substances, which upon contact with the fuel rod or the waste may leach out any radioactive substances included therein and spread them to the surroundings.

The present invention relates to a method of containing spent nuclear fuel or high-level nuclear fuel waste hermetically in a ceramic capsule of a very resistant material, which isolates the contained fuel or waste from the surroundings for a long period of time. The capsule is therefore suitable for so-called final safe storage of the fuel or the waste. The produced capsules containing waste may be deposited in rock cavities. They may be stored freely in air in dry rock cavities and be cooled by the air, or they may be placed in cavities in the sides or on the floor of the rock and be embedded in clay which prevents or delays the scattering of radioactive material which may possibly leak out from the capsules. It is also possible to immerse the capsules in great ocean depths. The flow rate in water at great ocean depths is very small and it takes a very long time before water from great ocean depths has moved to the upper surface of the ocean where the majority of the organisms of the ocean live. It takes such a long time before any leaking radioactive material reaches the upper ocean layers that the radioactivity will completely or partly have decayed. In addition, the dilution reduces the concentration.

According to the invention, a method of containing spent nuclear fuel or high-level nuclear fuel waste in a resistant material for isolating the fuel or waste from the environment, is characterised in that an open container and a cover fitting the opening of said container are made of a ceramic material which is given high density by isostatic hot pressing, the nuclear fuel or waste is placed in the container, the cover is placed over the opening of the container, the container with the cover is contained in a gas-tight casing, and then the open container and the cover are subjected to isostatic hot pressing to join them into a homogeneous monolithic body with a completely closed storage space.

It is important that the container and the cover should have such a strength that only a limited reduction of diameter is obtained during this joining of the container and the cover into a closed ceramic capsule. It is desirable to maintain a free volume within the capsule where gaseous, active products formed in the fuel or the waste can be collected and retained. It is further desirable to avoid crushing or compressing the contained material. The storage space of the finished capsule may have a diameter of 200 mm or more and a length of 3000 mm or more. If the capsule is manufactured from a material which substantially consists of aluminium oxide, the pressing—both in the manufacture of the container and the cover and in the joining of these—is suitably performed at a temperature of from 1300° to 1400°C and at a pressure of from 0.5 to 2 kbar.

The container can be made with one single major storage space or with a plurality of small storage spaces, each one for the reception of one or more fuel rods or waste bodies. The container can be made as a cylinder, open at both ends, and with a separate bottom. The end surfaces of the cover and the cylinder may be plane and ground to be well fitting. By applying a powder layer between the opposed surfaces of the container and the cover, a certain clearance between the surfaces can be tolerated. To prevent a radial compression of the cylinder at the joint during the hot pressing, the cover and the container can be provided with frusto-conical cooperating surfaces so as to obtain a certain support effect. Normally, however, it is more advantageous to locate a radial support body inside the capsule at the joint between the container and the cover. This support body is suitably made so that its coefficient of expansion is greater than the coefficient of expansion of the surrounding container wall. In this way it can be prevented that the shrinkage of the finished storage capsule becomes greater than the shrinkage of the support body which is not heated to the same temperature. A shrinkage is aimed at during the cooling so that a clearance is obtained between the wall of the finished capsule and the support body. If the container and cover of the capsule are made of a material with a high content of aluminium oxide, Al_2O_3, the filling body may suitably be manufactured of a material with a high content of magnesium oxide, MgO. The filling body may be homogeneous but can also consist of a core of a ceramic material which is surrounded by a relatively thick metallic casing. In such a coherent filling body, the desired greater coefficient of expansion can be obtained even if the core consists of the same material as the walls of the container. The desired effect can be achieved if the thickness of the casing around the core consists of stainless steel with 18% chromium and 8% nickel. The thickness of the casing material should then suitably be 2.5% to 5% of the diameter of the filling body. For smaller containers and for containers with several storage spaces, it is possible to use plane covers. For larger containers with one single storage space, a dome-shaped cover is most practical. A cover shaped as half a spherical shell takes up an external over-pressure in a favourable manner and can therefore be made relatively thin. The container can also be made as a bottle. The sealing can then be facilitated by a plug or a cap, but the filling of fuel rods or waste is made more difficult.

When sealing the capsule it is only necessary to heat the area around the confronting container and cover surfaces, which are to be joined together, to the sintering temperature. The heating of contained fuel or enclosed waste should be restricted. During sealing, the heating can therefore be concentrated to the upper part. The other part of the capsule is then only heated to the extent it is necessary for preventing the occurrence of detrimental stresses. The joining can be performed in a pressure chamber with a furnace space of limited height in the upper part of the chamber. However, there is nothing preventing the prepressing of the capsule parts and the joining of them from being performed in the same furnace equipment. The lower part of the heater of the furnace can then as a rule, only be utilised partially. To be able to utilise heating elements also in the lower part of a furnace, the lower part of the ceramic capsule can be provided with an outer thermal insulation. It is also possible to protect the fuel or the waste in the capsule by embedding it in powdered thermally insulating material.

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

Figure 1 is a schematic sectional view showing a capsule for containment of spent nuclear fuel inserted in a pressure furnace for joining together the cover and the hollow cylindrical container by isostatic hot pressing,

Figure 2 is a section through the capsule taken along the line A—A in Figure 1,

Figure 3 is a sectional view of a capsule containing a number of nuclear waste cylinders arranged for connection of the cover and the hollow container by isostatic hot pressing,

Figure 4 is a sectional view of a part of a variant of the capsule of Figure 3, and

Figures 5 and 6 are sectional views of a capsule with a plurality of storage spaces for individual fuel rods or waste cylinders, Figure 5 showing the capsule before it is isostatically hot pressed into the form shown in Figure 6.

Referring to Figures 1 and 2, the numeral 1 designates a pressure chamber which is built up from a high-pressure cylinder 2 and end closures in the form of a cover 3 and a bottom 4, which project into the cylinder 2. During a pressing operation the end closures are held in the cylinder by force-absorbing yokes 5 and 6 in a press stand, the remainder of which is not shown. The pressure chamber contains a furnace space 7. Around the furnace space are a cylindrical heater 8 with annular channels 9 and heating elements 10 and a cylindrical thermally insulating sheath 11 which is sealed by a thermally insulating cover 12 at the top. The furnace space 7 is thus thermally insulated from the walls of the pressure chamber 1 which take up the gas pressure and are thus subjected to considerable stresses. The heater 8 and the sheath 11 rest on a ring 13 which is joined in gas-tight manner to the bottom 4, thus preventing the circulation of gas.

A capsule 14 with fuel rods 15 is placed on a thermally insulating plate 16 on the bottom 4. The capsule 14 comprises a prepressed ceramic container 17, open at one end, in which the rods 15 are placed on a filling plate 26. The wall of the container 17 has a frusto-conical surface 19 at its upper end. A prepressed ceramic cover 20 with a frusto-conical surface 21 is placed on the upper end of the container 17. A layer 22 of insulating material is arranged above the rods 15. The ceramic container 17 with its cover 20 is surrounded by a gas-tight casing 23 consisting of a sheet metal cylinder 24 with a lid 25 and a bottom 18 which are connected in gas-tight manner by welds 27 and 28. The lower portion of the capsule 14 is surrounded by a layer 29 of insulating material. Because of this layer of insulating material, the entire heater 8 can be used and the heating still be concentrated substantially around the upper portion of the capsule, where the surfaces 19 and 21 are joined through high pressure and high temperature so that the container 17 and the cover 20 will form a closed hollow case which safely isolates the fuel rods 15 from the surroundings. The lower portion of the capsule 14 need not, and should not, be heated to the same extent as the portion around the cover 20. The fuel rods should not be heated to the temperature which is required for joining the cover and the container.

Figure 3 shows a waste capsule 30 comprising a cylindrical container 31 with a dome-shaped cover 32. A number of glass cylinders 33 containing waste are placed in the container 31. The glass cylinders are embedded in a powdered or granular material 34 with a certain thermal insulating ability so that the glass cylinders 33 will be heated to a lesser extent than the container 31 without using an insulating layer 29 as in Figures 1 and 2. The upper portion of the container 31 contains a support plate 35 which is intended to prevent radial compression of the upper portion of the container 31, since the shape of the cover 32 is such that it does not provide any significant radial supporting function. In a gap between the container 31 and the cover 32 there is a ceramic powder layer 42 which, during the isostatic hot pressing, is sintered and bonded with the material of the container 31 and the cover 32 so as to form a closed hollow case. The container with the cover is enclosed in the usual manner in a gas-tight sheet metallic casing 36. This consists of a sheet metal cylinder 37 with a cover 38 and a bottom 39 which are joined by welds 40 and 41.

Figure 4 shows a variant of the waste capsule 30 with a composite support body 35 which is made of a core 35*a* of a ceramic material and a metallic casing 35*b*. In this variant the support body 35 also fills up the dome-shaped cover 32 completely. The coefficient of expansion of this composite support body is, with a suitable dimensioning, greater than that of the container even if the same material is used in the core 35*a* as in the container 31 and in the cover 32.

Figures 5 and 6 show a capsule 50 with a plurality of storage spaces. This capsule 50 is built up from a ceramic cylinder 51 with a number of through channels 52, a ceramic bottom 53, a ceramic cover 54 and a surrounding ceramic powder layer 55 which are joined through isostatic hot pressing into a homogeneous monolithic body with closed storage spaces 56 for a number of waste cylinders or fuel rods 57. The cylinder, the cover, the bottom and the powder are contained in a gas-tight metal casing 58 during the pressing.

WHAT WE CLAIM IS:—

1. A method of containing spent nuclear fuel or high-level nuclear fuel waste in a resistant material for isolating the fuel or waste from the environment, characterised in that an open container and a cover fitting the opening of said container are made of a ceramic material which is given high density by isostatic hot pressing, the nuclear fuel or waste is placed in the container, the cover is placed over the opening of the container, the container with the cover is contained in a gas-tight casing, and then the open container and the cover are subjected to isostatic hot pressing to join them into a homogeneous monolithic body with a completely closed storage space.

2. A method according to claim 1, in which the container is made with a single storage space for a plurality of fuel rods or waste bodies.

3. A method according to claim 1, in which the container is made with a plurality of storage spaces each for the reception of one or more fuel rods or waste bodies.

4. A method according to any of the preceding claims, in which the container is made as a cylinder and a separate bottom.

5. A method according to any of the

preceding claims, in which during the joining of the container and the cover, heating of the ceramic material to substantially sintering temperature is limited to the area around the joint.

6. A method according to claim 5, in which the container is partly surrounded by thermally insulating material.

7. A method according to any of the preceding claims, in which a support body is mounted in the container at the joint between the open container and the cover.

8. A method according to claim 7, in which the co-efficient of expansion of the support body is greater than that of the container and the cover.

9. A method according to any of claims 1 to 4, in which the container with the cover is mounted in a sheet metal casing and is surrounded by a powder layer which is joined to the cover and casing during the hot pressing.

10. A method of containing spent nuclear fuel or high-level nuclear fuel waste substantially as herein described with reference to Figures 1 and 2, or Figures 1 and 2 as modified by Figure 3, Figure 4 or Figures 5 and 6, of the accompanying drawings.

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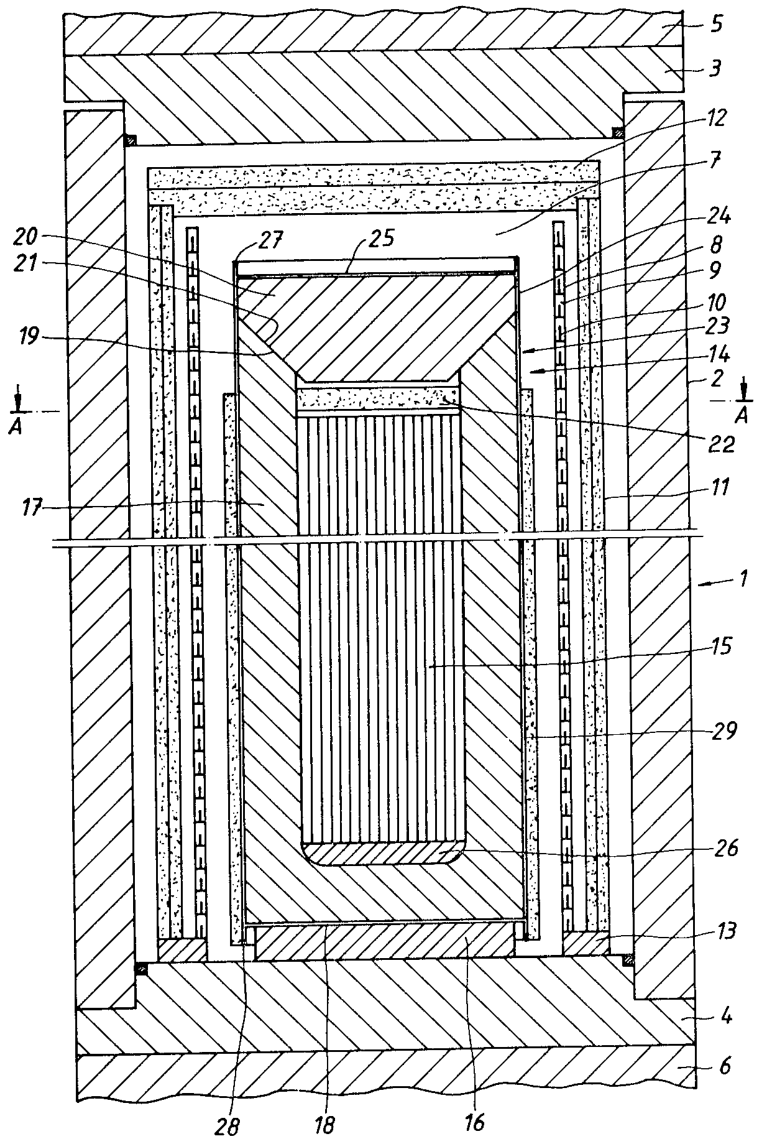
1592519 COMPLETE SPECIFICATION

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

Sheet 1

Fig. 1



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Sheet 2

Fig. 2

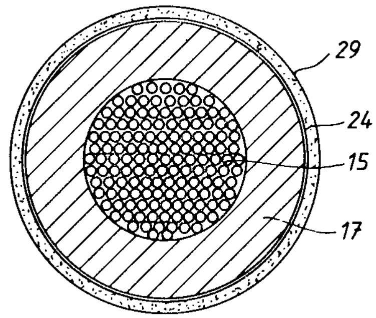
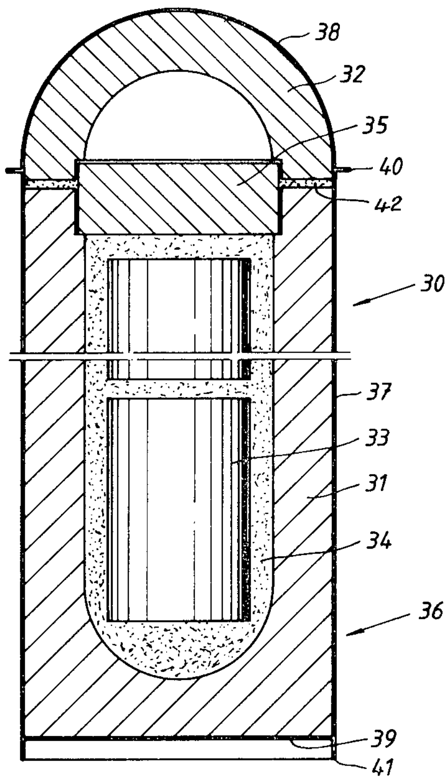


Fig. 3



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Sheet 3

Fig. 4

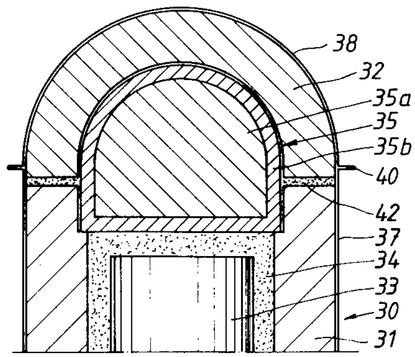

Fig. 5

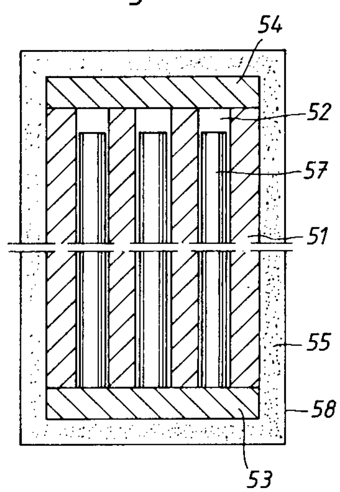

Fig. 6