

LIGHT WATER REACTOR FUEL ELEMENT SUITABLE FOR THORIUM EMPLOYMENT IN A DISCRETE SEED AND BLANKET CONFIGURATION WITH THE AIM TO ATTAIN CONVERSION RATIOS ABOVE THE RANGE OF ONE

M. F. Hrovat, K.-H. Grosse and R. Seemann

ALD Vacuum Technologies GmbH
Wilhelm-Rohn-Strasse 35
63450 Hanau, Germany

JAHRESTAGUNG KERNTECHNIK HAMBURG

MAY 2008

The thorium resources in the world are relatively large. According to the International Atomic Energy Agency (IAEA) publication "Red Book" they amount to 4.5 million metric tons and are about 4 times greater than the resources of uranium.

The fuel element described in this paper could be used in light water reactors. The seed (feed) rods contain uranium 235 as fissionable material and the blanket (breed) rods contain thorium and uranium. The thorium in the blanket rods is converted to fissionable U-233 by irradiation with thermal neutrons. The U-233 produced is a valuable fissionable material and is characterised by high η -values. By optimised configuration and loading of the seed- and blanket rods the thorium is converted to U-233 and the U-238 is converted to fissionable plutonium isotopes. Consequently more fissionable material can be generated than is used. The fuel cycle is also flexible. Thus U-235, fissionable plutonium isotopes or weapons-grade plutonium can be used.

Based on knowledge obtained in the development of fuel elements for material test reactors (MTR), high temperature reactors (HTR) and light water reactors (LWR), a new design of fuel element suitable for thorium employment in PWR is described. The cross section of the proposed fuel element is 993 cm² and its length is 4,8 m, so that it is geometrically similar to the fuel element for a 1228 MWe PWR.

Fig. 1A illustrates the cross section of proposed FE with a hexagonal configuration of centrally located 91 seed rods surrounded by 126 blanket rods.

Fig. 1B illustrates the FE with a square layout of centrally located 100 seed rods surrounded by 156 blanket rods.¹

To simplify the presentation burnable poison rods and water tubes for control rods are not considered.

One of the most important features of the proposed FE is the introduction of the moulded seed rods presented in the next fig. 2. The moulded seed rods contain the fissionable material in form of discrete particles embedded in a zirconium matrix. The particles are homogeneously distributed in the inner part of the rod. The inner fuel containing part is well bonded to the outer fuel cladding and forms a single unit with it. To improve the heat transfer to the cooling water, the outer surface of the seed rod has a profiled shape. Following the design features of the moulded seed

rod are in accordance with the properties of MTR plate type FEs. The MTR-reactors are characterised by very high core power densities (e.g. the core power density of the RHF in Grenoble comes to $1000\text{W}/\text{cm}^3$)^{2,3}.

The discrete particles within the seed rods are TRISO coated particles. The feed coated particles are uranium or plutonium dioxide microspheres coated with pyrolytic carbon and silicon carbide. One of them is represented in Fig. 3A.

Fig. 3B shows BISO (U,Th) O_2 coated particles after irradiation at high burn up of 168.000 MWd/t. The coated particles are a typical feature of HTR-FE technology^{4,5,6}

In table. 4 the most relevant data for the proposed FE are compiled and compared with the 1229 MWe PWR-FE. In particular it has to be emphasised the very high specific cooling surface of 1527,6 cm^2/liter of the seed rods, relative high desirable moderator/fuel volume ratio of 3,45 in the seed region and considerably lower ratio in the blanket region of 1,97.

Hence the core power density of the proposed FE can be considerably increased above the value of $100\text{ W}/\text{cm}^3$. The benefit of high moderator fuel ratio in the seed is, that it results in a substantial reduction in the generation of high level radioactive wastes, particularly transuranic actinides. On the other hand the considerably lower moderator fuel ratio in the blankets reduces the formation of protactinium which will interfere U-233 conversion and facilitate the conversion of U-238 to fissionable plutonium isotopes.¹ Consequently the conversion rate for U-233 and for Pu-239 (built up from U-238) is facilitated. For further increase of the conversion rate it is favourable to replace the rods step by step. On average the seed rods remain in the core for 2 or 3 years.⁷ The desired residence time for blanket rods is significantly longer at 7 to 8 years.

As a result described already (above) and due to the employment of the proposed moulded seed rods the breeding in PWR seems to be visible.

After the end of life the seed rods are removed from the core, cut into pieces 0,8 m length and embedded into blocks made out of graphite. The graphite blocks are then placed in underground stores without the need for reprocessing. It is of course a prerequisite that the silicon carbide coating on the fuel particles remain intact.⁸

The technology for embedding the parts of the seed rods into graphite blocks is in the hands of ALD.⁹ It was gained in frame of development of moulded block fuel elements development for the high temperature gas cooled reactors.

The (U,Th) O_2 pellets for the blanket rods are produced according to the hot impact densification method.^{10,11} The breeding pellets have a mixed crystal structure and are soluble in nitric acid.¹²

Fig. 5 shows a moulded graphite block with embedded coated particles containing 18 kg heavy metal.

To test moulded seed rods with required high thermal capability and required high burn up it is proposed to replace the fuel rods of the standard PWR-FE partly or totally by moulded feed rods. With the square arrangement shown in Fig. 1B the proposed fuel element can be placed into existing PWRs without greater modification of the geometry of the fuel element or of the reactor core.

CONCLUSION

- Introduction of the moulded seed rods with increased profiled shaped cooling surface and application of TRISO coated fuel particles
- Following the core power density can be considerably raised
- Relative high moderator fuel ratio of 3,45 in the seed regions, compared with the considerably lower moderator fuel ratio of 1,97 in the blanket regions
- **Consequently the breeding in PWR seems to be visible**
- The removed seed rods are cut into pieces 0,8 m in the length, embedded into moulded graphite blocks and the blocks final disposed without the need for reprocessing
- The (U, Th)O₂ pellets are produced according to the hot impact densification method, have a mixed crystal structure and are soluble in nitric acid
- Finally with the proposed fuel element concept it seems to be possible to realize reliable close fuel cycles.

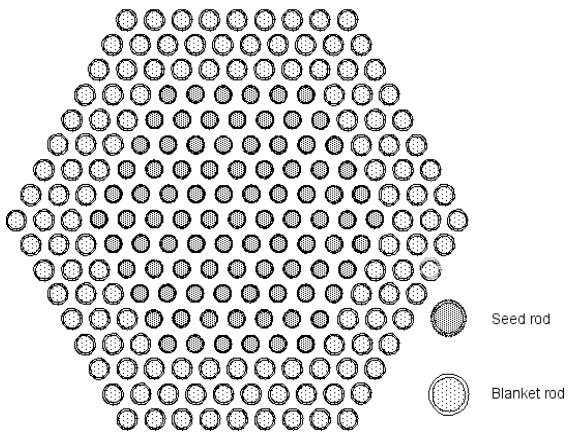


Fig. 1A Arrangement with hexagonal configuration of centrally located 91 seed rods, surrounded by annular located 126 blanket rods

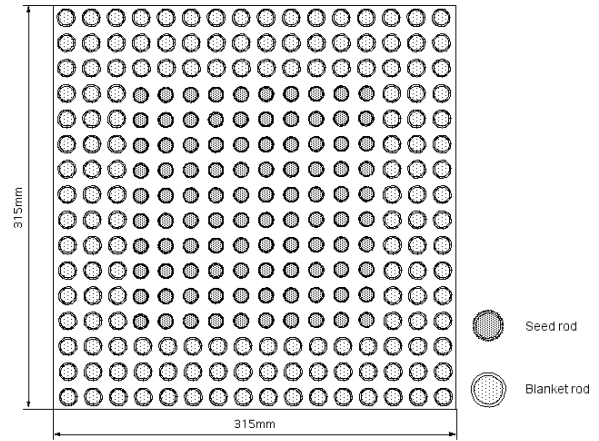


Fig. 1B Arrangement with square configuration of centrally located 100 seed rods, surrounded by square located 156 blanket rods

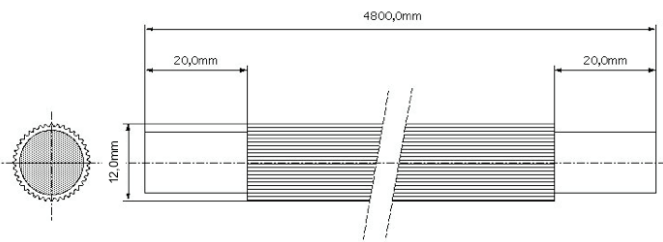


Fig. 2A Molded Seed Rod Dimensions

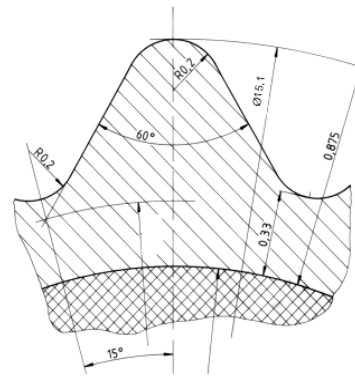


Fig. 2B Molded Seed Rod Surface Profile

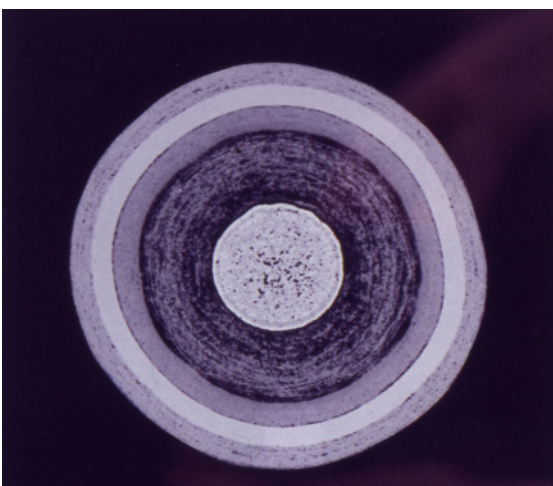


Fig. 3A UO_2 Seed Coated Particle after Irradiation, U-235 appr. 95%, Kernel Diameter appr. 200 μm

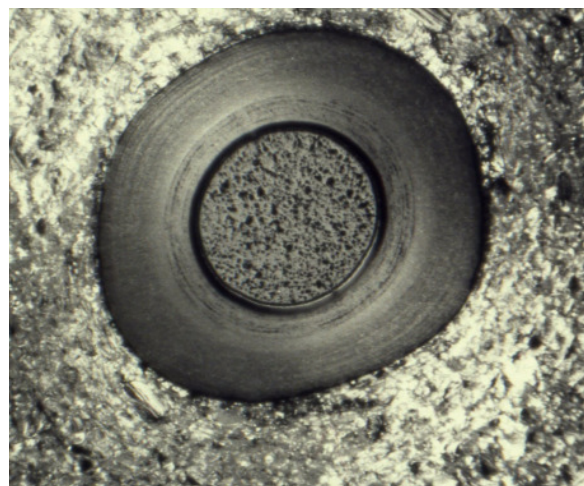


Fig. 3B $(U,Th)O_2$ Coated Particle after Irradiation, $T = 1600^\circ C$, Fluence $7,7 \times 10^{21} n/cm^2$, $E \geq 0,1 MeV$, Burn up fima 16,8% = 168.000 MWd/t

| FE Type | | PWR FE Reference | Proposed FE with Hexagonal Configuration |
|--|--------------------|------------------|--|
| Lenght | cm | 480 | 480 |
| Cross sectional Aera | cm ² | 992 | 993 |
| Number of Rods | | | |
| - Total | | 256 | 217 |
| - Seed | | - | 91 |
| - Blanket | | - | 126 |
| Rod Diameter | | | |
| - Fuel | mm | 11,2 | - |
| - Seed | mm | - | 11,2 |
| - Blanket | mm | - | 14 |
| Cross Sectional Area for cooling water | | | |
| - Fuel | % | 75 | - |
| - Seed | % | - | 78 |
| - Blanket | % | - | 66 |
| Specific cooling surface | | | |
| - Fuel | cm ² /l | 907,6 | - |
| - Seed | cm ² /l | - | 1527,6 |
| - Blanket | cm ² /l | - | 963,5 |
| Moderator Ratio | | | |
| - Fuel | | 2,94 | - |
| - Seed | | - | 3,45 |
| - Blanket | | - | 1,97 |

Table 4 Design Data Comparison of Propoeed FEs with reference to 1228 MWe PWR-FE



Fig. 5 Molded Block FE with embedded Coated Particles,
Heavy Metal = 18kg

References

- 1) A. Radkowsky, U.S. Patent No. 5.864.593, Jan. 26, 1999
- 2) M. Hrovat et. al. "Advanced MTR Fuel"
Nuclear Europe Journal of ENS, No. 6, June, 1985
- 3) M. Hrovat: „Verbundgepresstes stabförmiges Hochleistungsbrennelement für MTR - Reaktoren“
ALD interner Bericht, April, 2007
- 4) R.A.U. Huddle, to UKEA British Patent No. 878927, March, 31, 1959
- 5) C.A. Rennie: "The Place of the High Temperature Reactors"
New Scientist, May, 25, 1967
- 6) W.V. Goedel: "Coated Particle Fuels in HTR: A Summary of Current Applications"
Nuclear Applications Vol. 3, October 1967
- 7) L.R. Shepherd: "HTR and the Dragon Reactor Experiment"
Journal of B.N.E.S. , July, 5, 1966
- 8) M. Hrovat, Deutsches Patent Nr. 10144352, July 2007
- 9) M. Hrovat: „Gepresstes Blockbrennelement (Monolith) für HT-Reaktoren“
ALD interner Bericht, April 2003
- 10) M. Hrovat et al.: "Hot Impact Densification, a New Method for Producing High Density Ceramic Pellets with Close Shape Tolerances"
Nuclear Technology Vol. 58, July 1987
- 11) M. Hrovat: "Hot Impact Densification, Powerful Method for Producing Fuel Pellets with Close Shape Tolerances"
ALD interner Bericht, March 2007
- 12) M. Hrovat et al.: „Das Heißschlagverdichten – Ein neues Verfahren zur Herstellung keramischer Brennstofftabletten mit engen Formtoleranzen“
Journal of Nuclear Materials, Vol. 124, 1984
- 13) D. P. Stinton et al., "Coating of Crystalline Nuclear Waste Forms to Improve Inertness"
ORNL-Report, August 1982