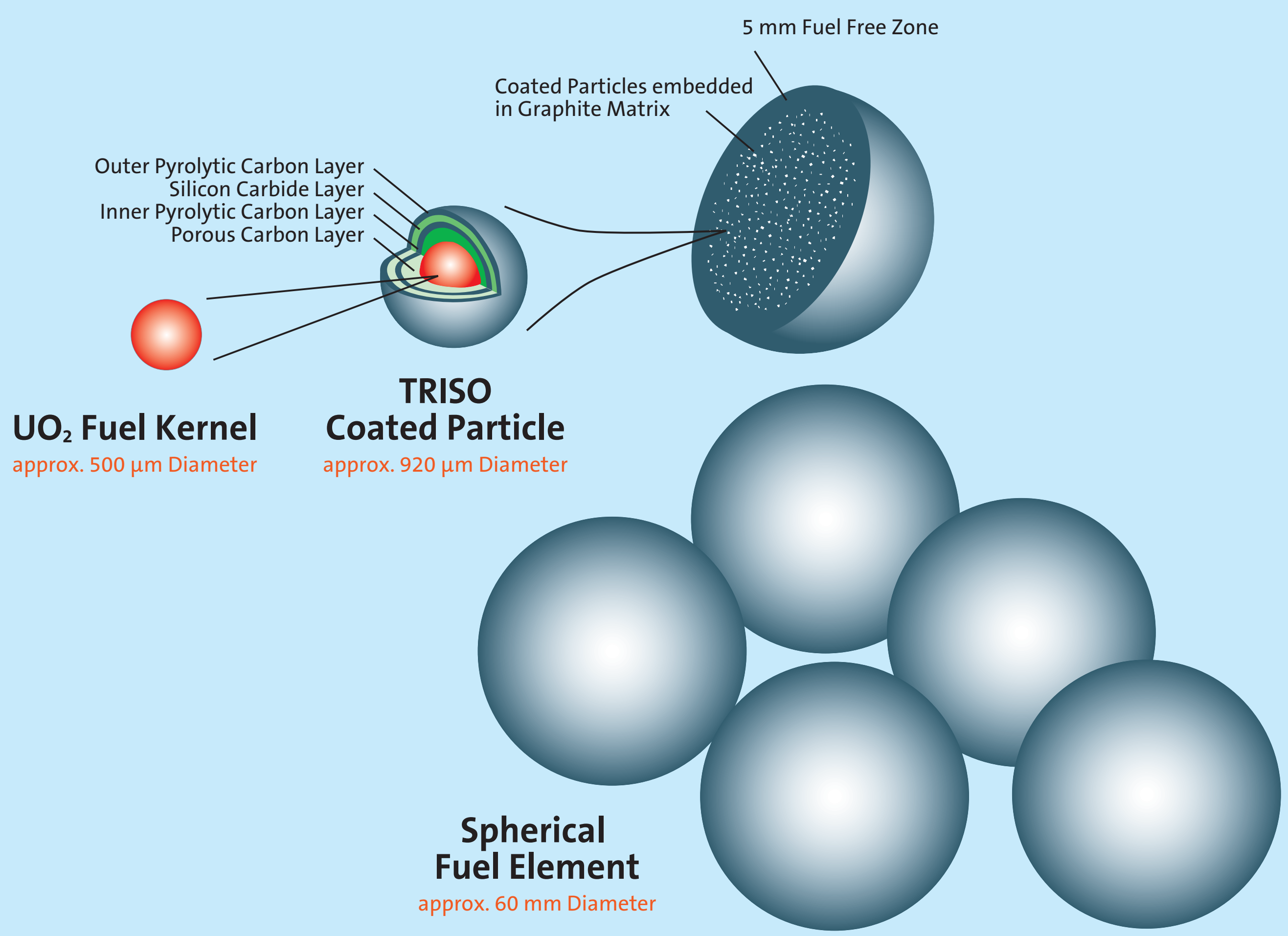
HTR-FUEL TECHNOLOGY

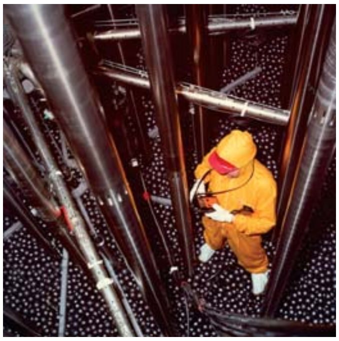


Current Motivation and Historical Background

Due to the dramatically increasing world wide demand on energy, especially in the emerging nations and the third world, nuclear power is again being taken more and more under serious consideration as the cleanest energy source with regard to climatic influence and in connection with the international interest and efforts in reducing the CO_2 emission. Here the HTR Technology is especially considered due to its unique safety features, based on the modular design and the relatively small reactor core. The high temperature level opens the opportunity to produce Hydrogen and to substitute fossil fuels for process heat generation under avoidance of CO_2 emission. Some of the special advantages in the application of the HTR Technology being based on the HTR Fuel design are highlighted hereafter:

- Power supply for industrial cluster areas
- Power supply for fast developing areas of increasing power consumption without sufficient access to the overall power grid
- Inherent Safety Philosophy
- Possibility of various process heat applications due to high temperature H_2-gas generation (production of liquid hydrocarbons)
- Application of alternative H_2 generation techniques
- Reduction of CO_2 emission

HTR Fuel Sphere Sample



First Core Loading of the THTR

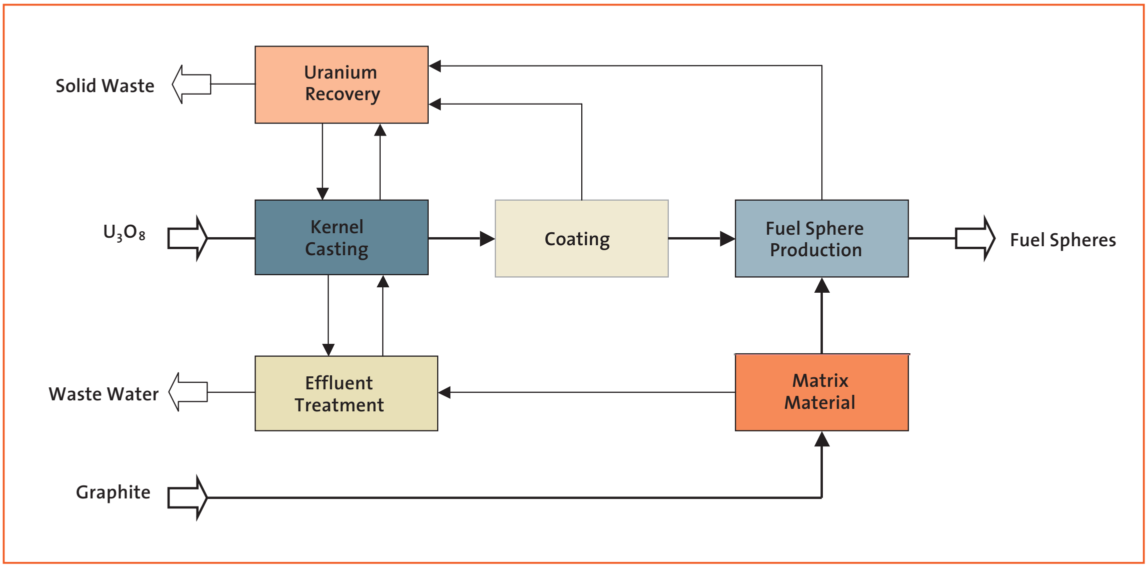
The development of the HTR Fuel in Germany has been systematically performed by NUKEM in the 1970’s and the 80’s and during this time NUKEM did successfully manufacture more than one million fuel elements for the “Atom-versuchskraftwerk” (AVR) at Jülich and for the “Thorium-Hochtemperaturreaktor” (THTR) at Hamm-Uentrop in Germany.

The Fuel Element Technology

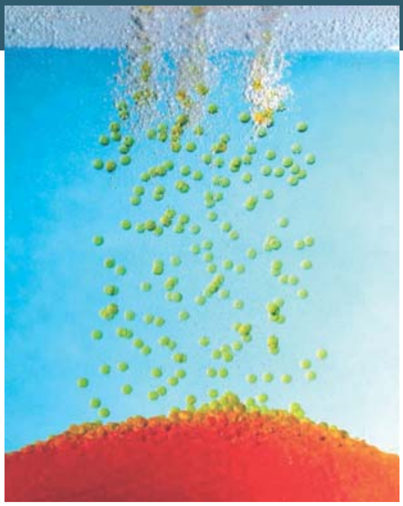
The HTR fuel in its various forms (spheres or blocks) consist first of all of small fuel kernels of about 500 µm in diameter. Each of these uranium oxide or carbide kernels is coated with several layers of pyrocarbon (PyC) as well as an additional silicon carbide layer. While the inner pyrocarbon layer is porous and capable to absorb gaseous fission products, the dense outer PyC layer forms the barrier against fission product release. The SiC layer improves the mechanical strengths of this barrier and thus the retention capacity for certain fission products. Especially the high quality German LEU TRISO spherical fuel based on the NUKEM design has ever demonstrated the best fission product release rate, particular at high temperatures. The approximately 10% enriched uranium TRISO coated particles are contained in a moulded graphite sphere. A fuel sphere consists of approximately 9 g of uranium (some 15 000 particles) and has a diameter of 60 mm; the total mass of a fuel sphere is 210 g.

In fact the fuel sphere production process is comprising four major fuel production process areas as well as two recycling areas for the recovery of Uranium and other valuable materials. In the following these process areas are listed and shortly described:

- Kernel production process
- Coating process
- Matrix Material production process
- Fuel sphere production process
- Effluent treatment process
- Uranium recovery process



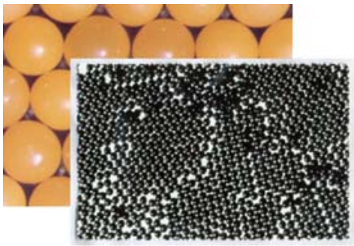
Overview of the HTR Fuel Production Processes



Kernel Casting

Kernel Production

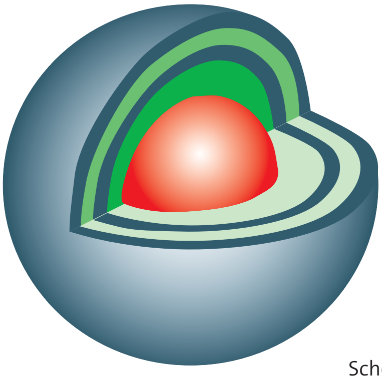
In the Kernel production facility, fresh U_3O_8 is dissolved in nitric acid and mixed with special chemicals (Polyvinyl alcohol, Tetrahydrofurfuryl alcohol) to a viscous Uranyl Nitrate solution. This solution is cast to form micro spheres, which are gelled, washed with Isopropyl alcohol and water, dried and calcined to form UO_3. The UO_3 is reduced to UO_2 under Hydrogen and sintered to Kernels, which nearly reach the theoretical density. The finished Kernels undergo special mechanical processes; sieving, sorting on vibrating tables, sampling and portioning, to deliver the right quality to the next process step. The figure below shows the Kernels in different stages, the shrinkage by a factor of approximately 75 from casting to sintering requires adequate processes to avoid damage.



Kernels in Different Production Stages

Coating

Within the Coating facility the Kernels receive four coatings using a chemical vapour deposition (CVD) furnace to produce the Coated Particles. The first layer deposited on the kernels is porous Carbon. This is followed by a thin coating of pyrolytic Carbon (a very dense form of heat-treated Carbon), a layer of Silicon Carbide and another layer of pyrolytic Carbon. The first layer allows fission products to collect as well as to accommodate any geometrical deformation of the Uranium Dioxide Kernel. The Silicon Carbide layer serves as the main barrier for retention of fission products even at temperatures far above the operational limit. The two pyrolytic Carbon layers support the fission product retention, they allow the preparation of the Silicon Carbon layer, and they serve as a mechanical protection. The Coated Particles undergo the same quality control steps like the Kernels and additional specific ones as the very important leach test. The fuel specification allows only one defective particle in a Fuel Sphere.



Schematic of a Coated Particle

Matrix Material Production

The matrix graphite powder is generated in the matrix production facility by mixing natural and electro-Graphite powder with resin solution in a kneader. The mixture is dried and re-milled to a fine powder. This relatively complex process is necessary to achieve the required homogeneous distribution of all components in the final powder.

Fuel Sphere Production

In the fuel sphere production facility the Coated Particles are overcoated with a layer of matrix graphite powder (MGP). Again quality assurance steps are applied as with the Kernel and Coated Particle. The overcoated particles are dosed into matrix graphite powder and pressed to the core of a fuel sphere. Then an additional 5 mm layer of matrix graphite material is added to form a "non-fuel" zone. The resulting Fuel Sphere achieves its final diameter by a machining process and is then carbonised and annealed at 2000 °C. The finished Fuel Spheres are subject to numerous Quality Control steps, amongst which the 100% X-ray controls the centricity of the fuel core and the freeness of Uranium of the shell. Also very important is the check of free Uranium in the Fuel Sphere, which would be a result of SiC shell breakage during fabrication.

Sample of Pressed Fuel Sphere Cores

Effluent Treatment

The effluents from the production processes are treated in the Effluent Treatment Facility. The main purpose is to recycle process liquids like Isopropyl alcohol, Tetrahydrofurfuryl alcohol and Ammonium Hydroxide solution, for the reuse in the Kernel facility. The resulting aqueous liquids are decontaminated prior to release. The waste organic liquids and solids are thermally oxidised, and Uranium residues are fed to internal recycling.

Uranium Recovery

The scrap material from the production process such as odd Kernels, odd Coated Particles and off-spec Fuel Spheres as well as other Uranium-bearing materials are recycled in the Uranium Recovery Facility to form recycled U_3O_8, which is reused in the Kernel production process. The graphite of the Fuel spheres and the Coated Particles are burned in the graphite oxidation furnace. The Silicon Carbide layer of the resulting coated particles is cracked with a roller crusher and the uranium is dissolved in nitric acid. The resulting Uranyl Nitrate solution is transferred into Ammoniumdiuranate or UO_4 and then calcined to U_3O_8.

NUKEM Services in HTR Fuel Technology

Based on the past performance experience of NUKEM and based on the recent activities in connection with the engineering contract for the PBMR Fuel Plant project in South Africa, NUKEM today is highly qualified and capable to offer a wide spectrum of services. NUKEM's capabilities range from the integrated design engineer and service provider for the design and delivery of key process components up to turn key supplier of the fuel production processes. Thus for any HTR fuel plant project including the recycling processes as part of the HTR fuel production, NUKEM is the competent partner to potential customers world wide, offering the following services:

- Consulting services for
  - Feasibility studies
  - Conceptual design
  - Business plans and reports
  - Product qualification
  - Licensing and approval procedures
- Design and engineering services for
  - Basic and Detail engineering
  - Safety issues (preparation of safety report, etc.)
  - Installation and commissioning
  - Operation support
- Supply and procurement services for
  - Key components
  - Complete production and recycling processes
  - Turn key supply of a fuel production facility

In order to professionally offer theses services currently NUKEM has available a highly qualified engineering team of 30 to 40 engineers who combine the past performance and development experience in the HTR Fuel Technology with state of the art process design experience under consideration of nowadays regulations and standards. This engineering team is significantly supported by the HTR Expert Group, known as the "Old Wise Men", who had developed, designed and operated the former NUKEM HTR Fuel Production Plant.

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