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The Revival of NUKEM's HTR Fuel Technology in the Course of the Nuclear Renaissance

Abstract

This paper describes some general aspects relevant for the current and future consideration of High Temperature Reactor (HTR) technology within the nuclear industry.

A general view of the historical background of NUKEM in the field of High Temperature Reactor fuel development and production is given. NUKEM's current activities, and the way that the recovery of NUKEM's unique know-how in this field of technology has been achieved, are described.

Further, it addresses some prospects and project opportunities in the worldwide nuclear market being the reason and chance for the revival of the unique technique in the course of the international renaissance of the nuclear industry.

1. Introduction

Because of the continuously increasing worldwide demand for energy, especially in the emerging nations and the Third World, nuclear power is coming under more and more serious consideration as the cleanest energy source with regard to climatic influence and in connection with the international interest and efforts in reducing CO_2 emissions.

HTR technology meanwhile is being seriously considered by several countries because of its unique safety features, especially its inherent safety, which is based on the reactor concept and its respective fuel design.

In addition, the high temperature level opens the opportunity to produce hydrogen and to substitute fossil fuels for process heat generation avoiding CO_2 emission. Some of the special advantages in the application of the HTR technology, based on the HTR reactor concept and the HTR fuel design, are highlighted below:

- 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 He-gas generation (production of liquid hydrocarbons).
- Application of alternative H_2 generation techniques.

2. Historical background of NUKEM

Starting in the early 1960s, the development of HTR reactors and their associated fuel was carried out both in Europe and the USA. In Europe, work was concentrated in the UK and Germany. The German High Temperature Reactor program was initiated in the early 1960s as part of the German civil nuclear development program. A consortium consisting of the Jülich Research Centre (KFA), Brown Boveri and Cie BBC and NUKEM was founded to cover the development and commercialisation of the HTR cycle in Germany. NUKEM's responsibilities within this program were the design of fuel and fuel specification, the development of the fuel manufacturing processes and the production of HTR fuel. During the 1970s and 1980s NUKEM, through its 100% subsidiary HOBEG (Hoch Temperatur Brennelement GmbH), manufactured and supplied more than 250,000 spherical fuel elements for the AVR experimental reactor at Jülich and more than 1,000,000 fuel elements for the Thorium High Temperature Reactor (THTR) at Hamm-Uentrop in Germany.

Based on a highly systematic approach and the development of special quality control procedures for the production processes, the fuel quality was continuously investigated and quality standards were established. Consequently, the highest level of HTR fuel quality with regard to fission product release was achieved at that time, which still represents the valid quality standard of today.

As it became evident that there may be further interest in Pebble Bed Reactors, NUKEM contracted the former key personnel (HTR Expert Team), who were formerly responsible for the development of and the commercial operation of the HOBEG fuel production plant.

The unique know-how of the HTR fuel technology was consequently recovered at NUKEM. The HTR Expert Team has a significant share in the recovery of the technology within NUKEM and will also in future be available to NUKEM for technical consultancy and support.

3. The fuel production processes

The HTR fuel in its various forms (spheres or blocks) is based on 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 (SiC) layer. While the inner PyC layer is porous and capable of absorbing 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. In particular, the high quality German LEU TRISO spherical fuel, based on the NUKEM design, has demonstrated the best fission product release rate, particularly at high temperatures. The ~10% enriched uranium triple-coated isotropic particles are contained in a moulded graphite sphere. A fuel sphere consists of approximately 9g of uranium (some 15,000 particles) and has a diameter of 60 mm; the total mass of a fuel sphere is 210g (*Figure 1*).

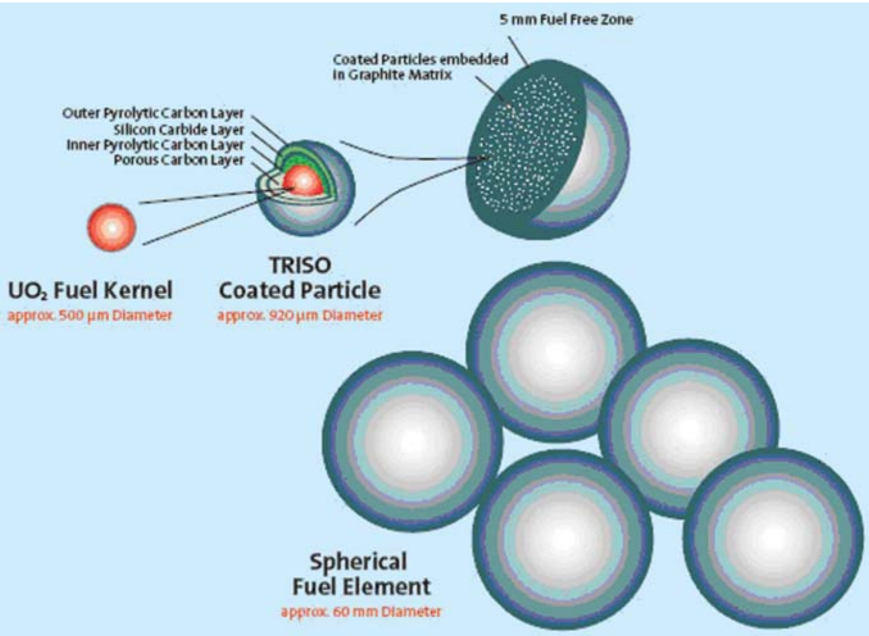

Figure 1. Schematic of spherical fuel element

In fact, the fuel sphere production process comprises four major fuel production process areas as well as two recycling areas for the recovery of uranium and other valuable materials (*Figure 2*).

4. Current activities

Although some consultancy services in the field of HTR fuel technology were performed by key experts of NUKEM at the request of the International Atomic Energy Agency (IAEA) at the end of the 1990s, it was in the year 2000 that the revival of the HTR know-how within NUKEM began in earnest.

Starting with a detailed feasibility study in 2000/2001 for the HTR fuel plant project of South Africa, NUKEM has continuously extended its involvement in the PBMR's fuel plant project. After the performance of the contract for the provision of professional services for the basic design of the HTR fuel production processes in 2005, a significant order for the provision of the detail design was awarded. Since August 2005, NUKEM has been carrying out the detail engineering, mainly to support the preparation of the safety report and the licensing procedure and is supporting the procurement of equipment.

The whole facility has been broken down into roughly 200 work inquiry packages. Typical packages represent furnaces, reaction vessels, storage tanks, containment enclosures, mechanical equipment and the like. All inquiry packages were defined by a standardized set of documentation, with descriptions, flow sheets, layouts, data sheets and functional specifications as core documents. They ask for offers covering supply of documentation, hardware, FAT,

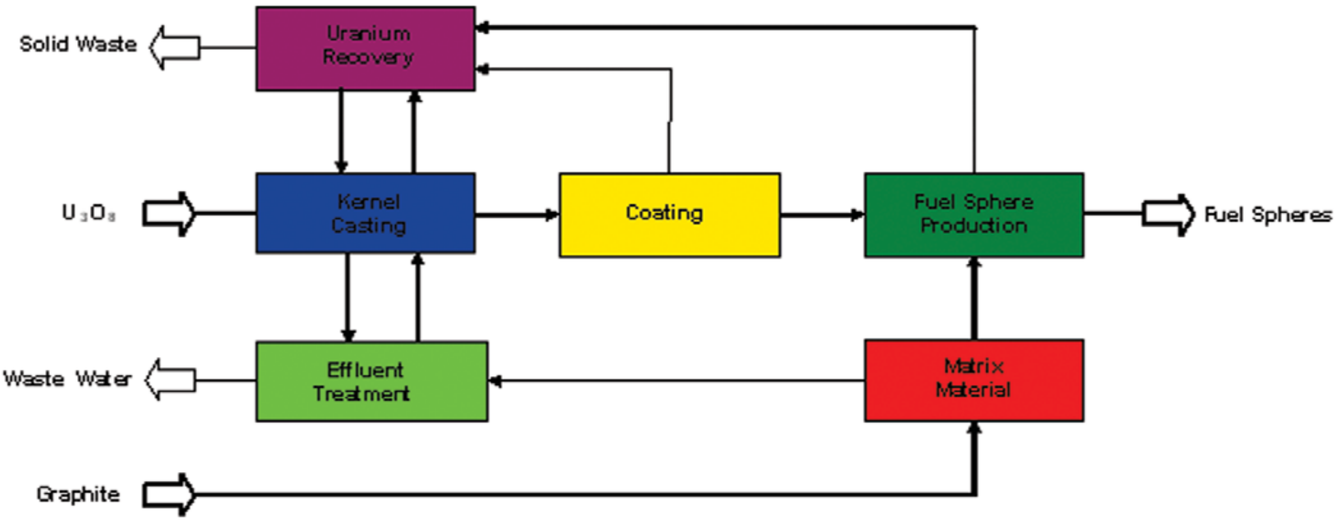

Figure 2. Overview of the HTR fuel production process

shipment, installation at site and support during commissioning.

Currently the procurement activities, after all enquiry requisitions necessary for tendering have been sent out to potential suppliers, concentrate on the adjudication of incoming tenders, on clarification of open questions and the preparation of recommendations for order placement. Once orders have been placed, the check of the MDD (manufacturer design documentation) will follow.

In the course of the design activities described above, NUKEM has established an engineering team of approximately 40 highly qualified and experienced engineers supported by a South African engineering subcontractor. This engineering team is permanently in consultation with the HTR expert team, to ensure that the know-how is transferred and that the equivalence requirements are met during the design.

Since that time NUKEM has also been providing engineering and consultancy services in that field of industrial development for other customers and interested parties.

5. Future project prospects and opportunities

In the course of the worldwide increasing demand for energy, the use of HTR technology as one possibility for the generation of nuclear power is being taken more and more into consideration by several countries, and especially by fast developing countries such as South Africa, China and India. At the moment the PBMR project in South Africa is the most advance pebble bed reactor project in the world. Its successful realization will be of paramount importance for HTR technology's prospects in the future.

The South African PBMR Pty Ltd is targeting the start of operation of its first Pebble Bed Modular Reactor in 2013. After the successful commissioning of the reactor demonstration plant at Koeberg, close to Cape Town, and the HTR fuel production plant at Pelindaba, close to Johannesburg, a number of modular arranged reactors are planned for construction in South Africa. These will contribute significantly to the future electricity supply in South Africa. The export of the technology thereafter is envisaged.

In China, due to the dramatic increase in demand for energy, nuclear power is expanding significantly. In addition to a large number of NPPs already under construction and planned, the program for the realization of a HTR-Module within the next 5 years has already been started. Certainly, the HTR-Module in China will be just an option, contributing to China's energy mix. But based on the experience of operating the HTR-10 test reactor, it is a most promising technology. Therefore, it is one of the key and top priority projects within the government's science and technology program.

At present South Korea is engaged in its Nuclear Key Technology Hydrogen Development and Demonstration Project (NHDD-Project). As Korea is more than 95% dependent on imported energy, the Korean government is pursuing an entry into nuclear hydrogen production. The major target of Korea is to produce 40% of the national energy demand in 2025 by themselves in order to reduce both energy imports and, simultaneously, CO2 emissions. Thus, HTR technology is being considered as a promising technique for the generation of hydrogen and liquid hydrocarbons. The NHDD Project is seen as a key technology development project within the 12 year national R&D program of Korea and is fully supported by the Ministry of Science and Technology (MOST) of Korea. It was launched at KAERI in 2006.

Being comparable to China, as one of the countries with both a large population and a fast developing economy, the future demand for energy in India will be as enormous as in China. The difference to be pointed out here is the technological and economical isolation of India with regard to its nuclear industry, due to India not having accepted the IAEA safeguards and the international non-proliferation conditions of the Nuclear Suppliers Group (NSG). Now, as India is turning towards acceptance of the international guidelines, various nuclear power reactor projects are already waiting for kick off. HTR technology is one of the techniques of great interest, because it has special advantages of not necessarily requiring an overall power grid and not requiring the amount of cooling water typically required by LWRs. Furthermore, India has immense thorium resources that could be preferably used for HTR fuel.

Also, in the U.S. the Department of Energy (DoE) is seeking industry participation for engineering services to design a Next Generation Nuclear Plant (NGNP). Already in September 2006, US$8 million was awarded for a pre-conceptual design for the NGNP. A recent announcement, based on these pre-conceptual design activities, is a proposal to build a high temperature reactor capable of producing hydrogen, electricity and/or process heat.

Of course, in several other countries worldwide, High Temperature Reactor technology is being seriously taken into consideration as an essential and attractive element of their future power supply strategy, as well as for other associated technological applications.