NUCLEAR ENGINEERING INTERNATIONAL

**FEATURE**

**FUEL AND FUEL CYCLE**

# The core of stage two

01 September 2005

**A new air-sensitive plutonium-rich mixed carbide fuel has been developed for the Fast Breeder Test Reactor at Kalpakkam in India. By Baldev Raj**

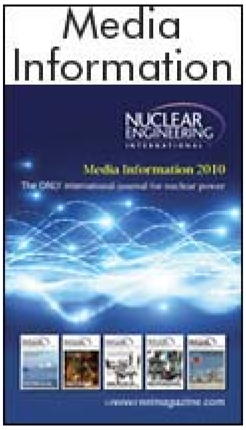
The Fast Breeder Test Reactor (FBTR) was commissioned in 1985 at the Indira Gandhi Centre for Atomic Research (IGCAR) in Kalpakkam. The project forms the first step towards developing indigenous fast reactor technology as part of the second stage of India's three-stage nuclear power programme.

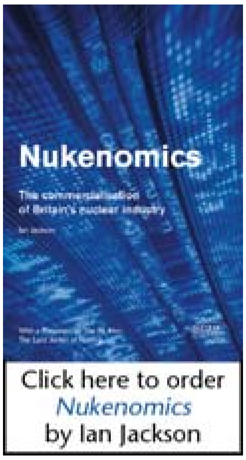
The FBTR at the Indira Gandhi Centre for Atomic Research

While carbide fuels have been studied in detail in many countries, and extensive test irradiations reported, the FBTR is the only reactor in the world to have used a carbide as its driver fuel. The decision to deploy this fuel was taken under difficult circumstances and with very little literature data to back up the decision.

Uranium-plutonium mixed oxide fuel enriched to 85% U-235 was originally intended to be used as the driver fuel but its sale to India was embargoed. The fuel designers therefore had to investigate designs based on a new fuel which could be fabricated indigenously. Based on the small amount of data available in the literature and the limited measurements that could be carried out at that time, the decision was made to use uranium-plutonium mixed carbide (with Pu/(U+Pu) = 0.7 for Mark I and 0.55 for the full core) as the fuel.

The crucial data on thermal conductivity and melting point of the fuel was measured at the Bhabha Atomic Research Centre (BARC) at Mumbai. Carbon potential measurements on the fuel at IGCAR indicated that the fuel would be





compatible with the stainless steel cladding chosen for the FBTR. This conclusion was confirmed by the results of the fuel clad compatibility experiments carried out in miniature capsules containing the fuel in contact with the cladding material. Based on this limited data along with extensive modeling of the influence of the constituents of the fuel and the impurities (oxygen and nitrogen), the fuel specifications were arrived at and the fuel design progressed.

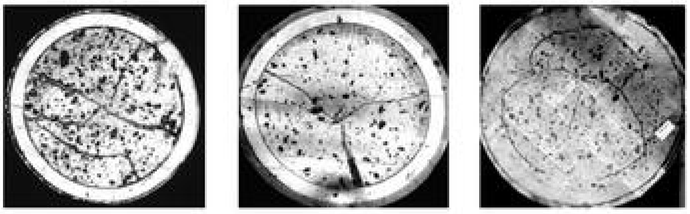
Production of the mixed carbide is carried out at BARC

Meanwhile, out-of-pile simulation studies carried out at IGCAR using the direct electrical heating technique provided assurance that the fuel-clad gap would be closed fully in a few hours at the operating heat ratings and that the fuel could be operated at 400W/cm without risk of centreline melting.

The fabrication of the highly pyrophoric carbide fuel is another challenge as it needs to be carried out in high purity inert atmosphere glove boxes. The mixed carbide is produced from the oxides of uranium and plutonium through the carbothermic reduction process carried out at BARC. The fabrication process has been optimised to produce fuel pellets and pins consistently meeting the stringent specifications.

## FUEL PERFORMANCE

The reactor now is operating with a high availability factor (>80 %) without any fuel failure so far in the entire core. The fuel has reached a burnup of over 140GWd/tHM, far higher than the originally envisaged burnup of 50GWd/t. (The burnup achieved corresponds to energy production of 3360kWh from every gram of the fuel.) Such a high burnup translates into usage of a very low amount of fuel for energy production, which in turns leads to less fuel fabrication, less waste produced and finally, better economics.



Burnup levels of 25, 50 and 100GWd/tHM

This burnup has been achieved through a slow though steady process, punctuated by post-irradiation examination at different stages to demonstrate to the safety authorities that the fuel was performing satisfactorily. The burnup was determined using the conventional method of mass spectrometry as well as the advanced method of high performance liquid chromatography.

Detailed post-irradiation examination of the FBTR fuel, consisting of visual, dimensional and metallurgical examinations has been carried out on the fuel discharged at 25, 50 and 100 GWd/t in hot cells. At each stage of the examination, the data obtained provided confidence to the designers and the safety authorities that the fuel could be taken to higher levels of burnup. Measurement of the residual ductility in the cladding and its creep behaviour has indicated that the fuel could be taken to a burnup of 150GWd/t.

Detailed modeling of the chemical state of various fission products and fuel constituents at high burnup has also confirmed that a metallic phase rich in plutonium (which could have a low melting point) may not be formed up to a burnup of 150GWd/t. The post-irradiation examination of the fuel discharged at 150GWd/t is yet to be carried out. However, it is clear that the successful FBTR fuel performance is due to a combination of a wide range of areas including fuel design, specification, manufacturing to stringent tolerances, extensive characterisation, expertise in handling and operations in inert atmospheres, modeling and post-irradiation examination.

## SPENT FUEL REPROCESSING

Internationally, one of the concerns about the fast reactor fuel cycle based on carbide fuel involves its reprocessing. The dissolution of carbide fuels in nitric acid, leading to the formation of a number of organic compounds, has been a subject of considerable interest because of the possible interference that could be caused by the organic compounds. It is also to be noted that there is no international experience on reprocessing of such plutonium-rich carbide fuel. The development and implementation of the reprocessing technology of the carbide is being carried out in the Reprocessing Development Laboratory in IGCAR through systematic R&D on various process steps, including development of codes for simulating the extraction behaviour as well as advanced equipment.

A compact hot cell facility was commissioned in 2003 for reprocessing FBTR spent fuel and also to establish the process and equipment for high burnup plutonium-rich fuels. The facility has 250mm thick lead shielding, is constructed on an area of 11x2m, and has a height of 3m. It houses an a-tight stainless steel containment box 10m long, 1.2m wide and 1.5m high with radiation-shielding windows and several items for remote operation and maintenance. There are 35 specially designed process vessels, 30 pieces of equipment and 2km of stainless steel piping involving 3000 bends and 2000 joints.

The compact hot cell facility for FBTR spent fuel reprocessing was commissioned in 2003

For reprocessing FBTR spent mixed carbide fuel, an advanced Purex process has been developed. The fuel subassemblies are dismantled and the pins are loaded in magazines. These magazines are kept in La Calhene containers and are transported to the plant in shielded casks. The fuel is chopped in a single pin chopper and dissolved in an electrolytic dissolver. After clarification in a centrifuge and three cycles of solvent extraction using indigenously developed centrifugal extractors, Pu and U are separated in pure form for use in the nuclear reactors. The solvent extraction process is based on tributyl phosphate solvent.

Reprocessing of 25, 50 and 100GWd/t burnup FBTR fuel pins has been successfully carried out in this facility with stage-wise clearances from the Atomic Energy Regulatory Board. The results of all the campaigns, the recovery and product purity, are very good.

The successful reprocessing of FBTR spent fuel after only two years of discharge from the reactor with as high a burnup as 100GWd/t demonstrates the maturity of Indian reprocessing technology. India is committed to efficiently close the fast reactor fuel cycle by safely reprocessing future discharges of spent fuel with increasing burnups.

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Published by Global Trade Media, a trading division of Progressive Media Group