

BENCHMARK RESULTS OF VARIOUS PARTICLE FUELS FOR SMALL REACTORS WITHOUT ON-SITE REFUELING

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The first Research Coordination Meeting of the International Atomic Energy Agency's Coordinated Research Project (CRP) on "Small Reactors without On-site Refueling" was held from 21 to 25 November 2005, at the Agency's Headquarters in Vienna. Small Reactors without On-site Refueling (SRWORS) are defined as reactors which have a capability to operate without refueling and reshuffling of fuel for a reasonably long period consistent with the plant economics and energy security, with no fresh and spent fuel being stored at the site outside the reactor during its service life. They also should ensure difficult unauthorized access to fuel during the whole period of its presence at the site and during transportation, and design provisions to facilitate the implementation of safeguards. This definition does not include replacement of well-contained fuel cassette(s) in a manner that prohibits clandestine diversion of nuclear fuel material.

The participants and observers were 19 in total from the involved 18 research institutions and organizations of Brazil, Croatia, India, Indonesia, Italy, Japan, Lithuania, Morocco, the Russian Federation, the United States of America and Vietnam. The purpose of the meeting was to present the results achieved, discuss progress and plan the future work related to the CRP, specifically:

- Identification and prioritization of the enabling technologies, concepts and design of SRWORS;
- Identification of requirements and broader specifications for nuclear power plants with SRWORS for selected representative regions;
- Review of the approaches to ensure lifetime core operation without refueling and definition of the scope of benchmark analysis for long-life core of SRWORS;
- Review of technical and regulatory approaches to reduce or eliminate off-site emergency planning; and
- Review of passive safety design options for SRWORS and identification of accident scenarios, passive reactivity regulating systems, and passive decay heat removal systems for comparative analysis.

At the meeting, the participants were assigned into three groups to discuss respective topics in detail. They were (1) Revising the need for relocation and evacuation measures

unique to nuclear power plants with innovative Small and Medium Reactors, (2) Design and technology development for LWRs with coated particle based fuel and (3) Design and technology development for lead, bismuth and molten salt cooled reactors.

The present paper discusses the benchmark results of various types of small reactors with particle based fuel which are under development by the participants in the group 2. Although these reactors use particle based fuel, the design concepts are quite different from each other. The reactor concepts presented at the meeting are as follows.

(1) Fixed Bed Nuclear Reactor (FBNR) by F. Sefidvash (Brazil)

The 15 mm diameter spherical fuel elements are made of compacted coated particles in a graphite matrix. The coated particles are similar to TRISO fuel with outer diameters about 2 mm. They consist of 1.58 mm diameter uranium dioxide spheres coated with 3 layers. The fuel element is clad by 1 mm thick SiC. The spherical fuel elements are suspended in the core by the flow of water coolant. Any malfunction in the reactor system will cut off the power to the coolant pump causing a stop in the flow, which will let the fuel elements to drop out of the core by the force of gravity and the enter fuel chamber where they remain passively cooled under a sub-critical condition.

(2) PFPWR50 by Y. Shimazu (Japan)

PFPWR50 uses the coated particle fuel with cladding of zircaloy or SiC. Coated particle fuel, which is used in a high temperature gas reactor (HTGR), has good confining ability of fission products inside coating. The concept of PFPWR50 can improve the conventional PWR safety and public acceptance to building nuclear reactor at the district. As another advantage, the fuel is fixed by graphite matrix, so that graphite is helpful to reduce the fuel temperature rise in case of loss of coolant accident by its large heat capacity.

(3) BWR-PB by E. Grishanin (Russian Federation)

The micro fuel is directly cooled by boiling water coolant. The design of a micro fuel element is as follows. The diameter of uranium dioxide kernel is equal to 1.3 mm for the first core. This can provide fuel elements of reliability for maximum fuel burnup as high as 10% heavy nucleus. At that condition the average burnup is equal to 6% heavy nucleus during the first core life-time. Diameter of uranium dioxide kernel for the following life-times with gradual refueling regime is planned to select at 1.4 mm. At that maximum burn-up is equal to 7% and the average burn-up is equal to 6%. Three-stage and many-collector fuel assembly has been accepted on the base of development of once-through reactor with steam overheating.

(4) AFPR-100 by G. Tsiklauri (United States of America)

The PNNL AFPR concept provides a uniquely different means to attain very high proliferation resistance while emphasizing current LWR technology with supercritical steam cycles providing 45% thermal efficiency. The AFPR concept is based upon the use of small (3-5 mm) coated fuel elements (micro-fuel elements, or MFEs) that are in direct contact with water. The fuel designs begin with large kernel Triso fuel particles with an additional

anti-corrosion barrier to keep water out of the fuel kernel. Future fuel elements may have oxide, carbide or kernels in a buffer to entrain gases, multiple containment structures and one more anti-corrosion layer, using, as appropriate, nano ceramics, nano metals and engineered nano structures.

Therefore, it was agreed that a benchmark problem should be setup in order to evaluate the difference or bias in the calculated nuclear design parameters among the participants due to the variety of design codes and the nuclear data library used in respective institutes. As the first step, it was also agreed that the benchmark problems be defined for unit cell models of the reactor concepts. The results for the benchmark problems were collected and compared. They are mainly calculated by APOLLO¹⁾ code, HAMMER²⁾ code, SRAC³⁾ code and SCALE⁴⁾ code. They cover neutron spectrum, neutron multiplication factors with burnup and other related parameters for all reactor concepts. Some additional calculations for selected points were calculated by Monte Carlo code. In the presentation, the result and the comparison are discussed. The homogenized modeling has been used in the calculation, while the double heterogeneity effect has been evaluated. The calculations have shown that studied designs are valid as long as core life is concerned.

References

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