ON SOME ISSUES OF THORIUM FUEL CYCLE STUDY*

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Abstract. In conceptual aspect, various reactor systems have been under study. They include PWRs fueld with Pu-Th and ^{233}U-Th, molten salt reactors, fast reactors with mixed Pu-^{233}U -Th ^{238}U fuel cycle. Burning of plutonium in thorium matrix makes it possible to convert plutonium into ^{233}U. In the long term, ecological hazard of ^{233}U thorium fuel cycle may appear to be lower, compared to uranium-plutonium one. ^{233}U plus ^{238}U blend may be good fuel for thermal reactors. Considerable efforts have been concentrated on studies of initial steps for mastering thorium cycle. In this connection, investigated were issues such as ^{233}U accumulation in thorium in various neutron spectra, methods for obtaining ^{233}U with ^{232}U levels acceptable for its simpler handling. A series of such experiments was carried out with different reactors. These experiments have confirmed the probability o initial accumulation of ^{233}U in fast reactors in the form allowing a simpler subsequent handling. This is important for experimental works on mastering the technologies of ^{233}Th fuel cycle. The program includes also the development and tests of technologies for radiochemical separation of ^{233}U from thorium, technological studies with samples of thorium and^{233}U. Experiments with critical assemblies and nuclear constant measurements are also a part of the programme for thorium and ^{233}U studies.

1. INCENTIVES FOR THE APPLICATION OF THORIUM FUEL CYCLE

The accumulation of new facts and information on the development of thorium-based fuel option is not very fast as the attitude towards this problem in many countries is not of top priority for financial support.

The material provided in [1] and [2] reflects the state-of-the art in thorium fuel cycle in Russia. Some additional considerations and results are presented in this paper.

Speaking about incentives for an application of thorium cycles, it would be appropriate to point out that thorium insertion into nuclear power plants enables the LWRs life to be prolonged; and experience accumulated, and industrial technology mastered, to be used more effectively.

It accounts for the fact that the use of thorium cycle in its different options results in favorable changes in passive safety. The application of new fuel compositions reducing the fuel temperature will also contribute to this.

An understanding of these prospects in Russia resulted in the Arsamas-16 Research Weapon Centre being set to solving the thorium problem [10].

In discussing the incentives for the application of thorium cycle, the following consideration could be pointed out:

In an advanced nuclear-power fuel complex with different reactor types, facilities on the production and reprocessing of spent fuel mixed and combined cycles are possible. For example ^{233}U build-up may be ensured in fast reactors; while for thermal ones plutonium and

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HEU may be converted into ^{233}U. Combined use of ^{233}U and plutonium in one reactor may be considered beneficial.

At the same time, the high radioactivity of ^{232}U may be an obstacle for unauthorized use of nuclear material.

Many mixed fuel cycles are yet to be studied in details.

2. STUDY OF CONCEPTS

Some new results from different concept studies have recently been added to those given in "Working Materials" [1].

Thorium fuel cycle with the composition of metallic thorium and highly enriched weapon-grade uranium oxide is initiated for utilization in light water reactors [3]. Highly enriched uranium need not be diluted to low concentrations in this case. The WWER-1000 has been taken as an example to evaluate this idea.

Owing to the physics properties of accumulated ^{233}U, and to the low temperature of the fuel composition; characteristics of this reactor on fuel use, reactivity effects, and safety change to the better. A lot of details of the analysis are given in the reference.

Joint Russian-American proposal on a WWERT reactor of "seed and blanket" type with thorium blanket in each fuel assembly [4] was reported at the 8-th ICENES Conference.

The thorium part is to be used as a dioxide and not subject to reprocessing after unloading from a reactor. Central parts of each fuel assembly are proposed to be made replaceable irrespective of thorium. Uranium-zirconium metallic alloy is used there. This alloy has been studied extensively and applied in reactors.

The idea is to create a reactor without plutonium accumulation and, with better resistance against the risk of nuclear material proliferation. Reactor technologies assimilated are stored at the same time.

The Kurchatov Institute, the Institute of Inorganic Materials, the plant in the town of Electrostal (Electrosteel) from the Russian side; and the Radkowsky Thorium Power Corporation, and BNL from the USA side, are taking part in the work.

Conceptual developments on thorium fuel cycle in other reactor types (MSR, HTR) are being continued.

3. INTEGRAL PHZSICAL EXPERIMENTS

Estimated nuclear data files for the thorium cycle are not as validated as for the uranium cycle. To test and correct them one must carry out integral experiments on critical assemblies and reactors.

IPPE is gradually realizing such a programme. Experiments on several critical assemblies with various neutron spectra have been carried out recently. The main trend is to test the neutron cross-section capture with thorium as well as obtain data on other reactions.

Experiments with insertion of various material sets were carried out at the KOBR assembly. The first experiment was undertaken for obtaining the critical ^{235}U and thorium ratios in an infinite medium [5].

Later, media with various spectra, from thermal to tight water lattice spectra; were studied in this same assembly.

A set of preliminary experimental data on these assemblies is available, but their evaluation has not been completed due to difficulties with processing. Cooperation with specialists from other countries could largely contribute to obtaining final results.

Prolonged irradiation of thorium samples with the following ^{232}U content measurements in ^{233}U were carried out at BN-350 reactor [5]. Irradiated samples analysis confirmed the ^{232}U content in the outer radial blanket of 2 to 11 ppm, with uranium content in thorium being ~1,3 g/kg.

Average cross-sections of several isotopes essential for thorium cycle were measured in BN-350 reactor core. ^{231}Pa cross-section capture was measured as well. These measurements showed the current isotope cross-sections need are to be made more precise [6].

The validity of nuclear data for thorium cycle may be expected to improve appreciably after completing the processing and analysis of available integral experiments.

4. TECHNOLOGICAL DEVELOPMENTS

Technological research and developments on fuel fabrication for thorium cycle showed the Russian specialists the need to make new long-term decisions.

Technology for fabrication of mixed uranium-thorium-oxide pellets was tested by different groups of specialists as the first step. Experimental fabrication of compact mixed uranium and thorium oxide pellets was carried out at IPPE. The experiment on technology of fabrication and properties of pellets was a success.

Kurchatov Institute together with the plant and Institute of Inorganic Materials conducted more thorough work. To fabricate uranium-thorium mixed oxide pellets, the whole technological cycle and tooling were developed. An experimental set of pellets was fabricated, quality investigations were carried out. The result was successful. This work was done for the blanket parts of WWERT fuel assembly [4].

IPPE technologists propose various dispersional fuel compositions for thorium WWER of traditional constructions, but with a new level of safety. This fuel with a matrix high heat conductivity has a low temperature with a small level of accumulated heat. As a result reactors with this fuel will achieve a higher level of safety [7].

The development of dispersional uranium composition with a metallic matrix for WWER reactor types is being carried out in Russian institutes. Large work on substantiation of UO_2 (60% vol.) - Zr (40% vol.) alloy and UO_2 - Al(silumin) alloy [8] pellet compositions has been done for some years in IPPE. The authors of these developments think UO_2 could without essential difficulties be replaced for ThO_2 - UO_2 mixture. Cermet compositions were tested in a set of experiments as well as in pile tests of experimental pins with man-made failed claddings.

Another kind of dispersional fuel with an extended pyrographite matrix [9] has been proposed as well.

A composition with 50% vol. oxide particles (thorium, uranium, plutonium) and 50% pyrographite is proposed. A graphite matrix high heat conductivity will ensure a low fuel temperature and affect safety performance favourably. Unfortunately, complex tests of this concept have not been carried out so far.

Any thorium oxide compositions will pose some problems in reprocessing spent fuel with water extraction techniques. Dry electrochemical reprocessing may seem to be in prospect. Some experimental tests with thorium oxide compositions seem to be quite promising.

However, in some concepts of thorium insertion into power reactors, reference [4], thorium oxides have not been offered for reprocessing - they must be disposed of.

Russian technologists have not considered metallic thorium compositions so far. At the same time a cermet based on thorium metallic matrix for thorium cycle in any reactors could be a good decision, in fuel reprocessing, in particular. So far in Russia physicists, not technologists, are dealing with this composition.

5. SOME GENERAL REMARKS.

Taking into consideration that accumulation and preservation of new information takes a lot of time it would be useful to extend and specify of what has already been done and given in published documents.

It might be expedient to hold international meetings of specialists from various countries on some issues of thorium cycle, for example, nuclear data and their verification, technology of fuel production based on thorium without ^{233}U and with ^{233}U, possible technologies of fuel reprocessing and so on.

Based on these extended reviews on particular questions it might be necessary to organize a more extensive international discussion.

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