

SUMMARY OF PAPERS

Nine papers were presented at the meeting, dealing with the following:

- evaluation of world thorium resources and incentives for further exploration;
- basic research of physical, chemical and nuclear properties of thorium;
- reactor core and blanket concepts regarding utilization of Th-based fuel;
- advanced thorium fuel fabrication technology;
- reprocessing of Th-based fuel.

1. Evaluation of world thorium resources and incentives for further exploration

Thorium in association with uranium and Rare Earth Elements (REE) occurs, as shown in the paper presented by Mr. Jayaram, India, in diverse rock types: as veins of thorite, thorianite, uranothorite and as monazite in granites, syenites, pygmatites and other acid intrusions. It also occurs as an associated element with REE bearing bastnaesite in carbonites. Monazite also occurs in quartz-pebble conglomerates, sandstones and in fluvial and beach placers.

The current knowledge of thorium resources in the world is small because of the relatively low-key exploration efforts arising out of insignificant demand. Resources recoverable at less than \$80/kg Th in the Reasonably Assured Resources (RAR) and Estimated Additional Resources-Group (EAR-I) categories are estimated at around 1.4 million tonnes and one million tonnes respectively. And this is due only to the effort made by several countries to identify either uranium or REE. India has about 31% of them. Argentina, Australia, Brazil, Burma, Canada, China, Republic of Korea, Indonesia, Malaysia and South Africa

have also considerable resources of thorium. The possibility of discovering new resources, in addition to increasing the known resources contained in the deposits already known, is good.

In spite of today's apparent unfavourability for the thorium utilization situation in the uranium market (low prices for uranium and oversupply) it seems that the perspective of thorium utilization as a nuclear fuel is realistic in the near future. This could be justified by the forecast for uranium utilization in both once-through or closed fuel cycles. Also countries which have limited resources of uranium may have to use thorium to ensure continuous growth rate of electricity generation. Taking this into account the IAEA will contribute further to the exchange of information and co-ordination of national efforts aimed at maintaining and improving knowledge on thorium resources and its utilization as a nuclear fuel.

2. Basic research of physical, chemical and nuclear properties of thorium

In general fundamental investigations are concerned with preparing the base for studying the physical properties of nuclear reactors, working with either a mixed fuel cycle or Th-based fuel.

The dependences of U-233, U-232, Pa-233 and fission products buildup upon integral thermal neutron fluxes in high flux ETR-reactor (China) have been studied, including detailed correlation between the above-mentioned values and fast to thermal flux ratios in wide range. These results may be helpful in assessing breeding potential of Th-based fuel in different type of reactors. French work (Attachment IV) on revising and reevaluations of Th-232, U-233 data revealed the following:

The value of Th-232 absorption in thermal range is apparently well-known, though absorption cross sections seem to decrease more rapidly than $1/v$ law. Accurate experimental values should be desirable to improve temperature coefficients forecast. The most desirable further work is in high energy range. The knowledge of U-233 cross sections now is not as good as that of Th-232. Further work is still needed, particularly in the thermal range of energy. This work should include a new accurate measurement of ν , β_f , fission spectrum, as well as, benchmark "clean" critical experiments, which can be easily interpreted.

3. Reactor Core and Blanket Concepts Regarding to Th-based Fuel Reactors

Strategy investigation, reactor core and blanket design are still important for successful development of Th-based fuel reactors.

The current state of the reactor and fuel cycle facility development suggest the following logics (USSR) in combination with the uranium-plutonium and uranium-thorium cycles for nuclear power. Transition to the U-Pu closed cycle, development of spent fuel regeneration, plutonium accumulation paves the way for rapid introduction of fast breeder reactors which are to be the basis of future nuclear fuel breeding. The acuteness of fuel problem can be then eased by transition of the thermal reactors to utilization of the U-233 accumulated in the fast breeder reactor blankets. That idea is supported by the Indian plans for the behaviour Th-232 investigations in blankets of fast test reactors.

There is, among others, the French idea to use Pu-Th cycle in unmodified PWRs. The main goal of this work is to find a real way for opening the Th-cycle in up-date reactors. The solution proposed consists of initial loading the whole reactor PWR-type with Th-Pu assemblies. Besides, it is an attractive means of storage plutonium in case of rather slow development of LMFBRs. U-233 can be perfectly used in Spectrum Shift Control Reactors. Regarding optimization of neutronics, calculations were being made, including pin power peak, moderator temperature coefficient etc.

Other optimistic results were described in cooperative Brazilian-German paper on Th-utilization in unmodified PWR type reactors. It can be established, that standard PWR may use $(Th, U)O_2$ fuel and even $(Th, Pu)O_2$ fuel without any changes within the reactor system. A favourable strategy to avoid the need of early reprocessing and to strive for savings in uranium might be the use of $(Th, Pu)O_2$ fuel in the once-through cycle with extended burnups.

4. Advanced thorium fuel fabrication technology

For refabrication of U-233 bearing HTR fuel kernels the EGT (External Gelation of Thorium) sol-gel process has been developed (paper,

presented by Mr. Zimmer, FRG). On the basis of this technology developed for HTR fuel production, a procedure for production of fuel pellets for water cooled reactors has also been developed (paper, presented by Mr. Peehs, FRG).

Three major modifications were made in the referred EGT process in order to produce gel microsphere which could be calcined to microspheres suitable for pelletization and sintering. First, heavy metal nitrate feed solutions of lower molarity were found to be more suitable. Secondly, calcium nitrate was added to the feed solution in order to have around 0.4 w/o CaO "sintering aid" in the subsequent calcined microspheres. Thirdly, carbon black were added to the sol prior to gelation. The pores formed in the sol-gel microspheres after burning off the carbon black particles reduce the crushing strength of the microspheres and facilitate pelletization.

The Sol-Gel Microsphere Pelletization (SGMP) process not only avoids dust generation and is easy to remotize but also produces high density pellets of desired microstructure at compaction pressures and sintering temperatures, which may be even lower than for the conventional powder route.

HTR fuel kernels are easily produced by the EGT process which needs no chemicals apart from NH_3 necessary for precipitation of heavy metals in all fuel production processes.

In the paper regarding Indian experience in fabrication of ThO_2 pellets emphasize was made on optimization pre-compacting and final compacting parameters which will lead to the reliable and economic fabrication technique of this fertile material.

The goal of this work is fabrication and supply of blanket assemblies containing thorium oxide pellets to the requisite quality, for full core of Indian Fast Breeder Reactor at Kalpakkam.

Starting with ThO_2 powder obtained by oxalate precipitation and calcination, green pellets are produced through powder metallurgical route. In order to achieve sintered densities more than 94% addition of Mg in small quantities, during oxalate precipitation stage.

An economic and viable recycling method for sintered pellets as well as powder needs to be developed.

5. Reprocessing of Th-based fuel

KFA Jülich GmbH experience in the utilization of dual cycle THOREX process for extraction of Th and U was reported (by Mr. Zimmer), as well as, the results of cold tests.

The THOREX solvent extraction process is simple to carry out since separation of Th and U is accomplished by the different extraction behaviour of the elements in their stable valency state, rather than in the PUREX process where the Pu has to be reduced to and stabilized in the trivalent state for separation.

Reprocessing of the 20 Elk-River reactor (USA) Th-U spent fuel elements was done in the ITREC plant, Italy (paper by Mr. Candelieri). The ERR used fuel had a burnup in the range of 3,650 -10,000 MWd/t. A THOREX "acid-deficient" flowsheet was used for code-contamination of U-Th in a single cycle 30% TBP solvent extraction. Unfortunately, the project terminated in 1974 and the facility is presently used for testing some of the components used in a reprocessing plant. No pellet refabrication has been done in this facility.