ThEC13 Summary and a Look into the Future

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ThEC13: A Significant Success

The purpose of ThEC13 was to review and update the status of thorium energy technologies, from R&D to industrial developments. ThEC13 beautifully fulfilled that goal, as the attendance statistics confirm. About 200 people from 32 countries were actually present at CERN in the Globe of Science and Innovation, including some prestigious scientific and political personalities. In addition, more than 5000 connections were made worldwide to the live webcast.

The conference received broad political and scientific support, which is a clear sign of the renewed interest in thorium technologies, which even reaches into the nuclear industry. AREVA and SOLVAY used the conference to make an important announcement about their long-term strategy concerning thorium:

"AREVA and SOLVAY are joining their know-how to add value to thorium's entire life cycle" [1].

Clearly, in the short time available to me, I cannot do justice to the many excellent presentations given during these three and half days, and my summary will inevitably be somewhat biased.

Government support was also illustrated by the announcement at the conference of a significant industrial grant for thorium chemistry awarded by the Czech ministry of Trade and Industry to the research group headed by Jan Uhlíř of UJV-ŘEŽ in Prague in support of a cooperative venture with the DOE in the US.

Thorium

In his introductory talk, Carlo Rubbia brilliantly summarized the case for considering thorium as a new source of energy. He pointed out that, as it must be used in the breeding mode, "thorium is a practically sustainable source of energy, on the human timescale" [2].

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As ^{232}Th is six neutron captures away from ^{238}U, the production of transuranium elements (TRU), which constitute the long-term component of nuclear waste, is minimized, and this physical property can be used to destroy existing nuclear waste and military plutonium, while producing energy. For the same reason, a thorium fuel cycle has unique potential in terms of nuclear weapon proliferation resistance.

Even though ^{233}U is generally considered better in terms of breeding than ^{235}U and ^{239}Pu (Fig. 1), for reasons of reactor physics, it cannot be simply substituted in place of uranium in a standard critical reactor. In the fast neutron flux required to minimize waste production and to optimize TRU destruction, breeding with ^{233}U is less favorable than with ^{239}Pu (Fig. 1). Therefore, something additional has to be done in order to use thorium efficiently.

Options for the Practical Utilization of Thorium

At ThEC13, three options for the practical utilization of thorium were reviewed:

- Using thorium blankets around reactor cores to breed ^{233}U;
- Continuously circulating the fuel through the core, such as to always have fresh fuel, which can be achieved either in pebble bed reactors (once-through pellet fuel cycle) or in molten salt reactors (MSR), with recirculation of the liquid fuel and requiring reprocessing on-line;
- Using a particle accelerator to provide the extra neutrons needed to sustain fission reactions in a subcritical core, in so-called accelerator-driven systems (ADS). This is the solution proposed, in particular, by C. Rubbia and promoted by iThEC, the main organizer of this conference.

Pebble bed reactors were not discussed at the conference, but it was mentioned that, after the pioneering

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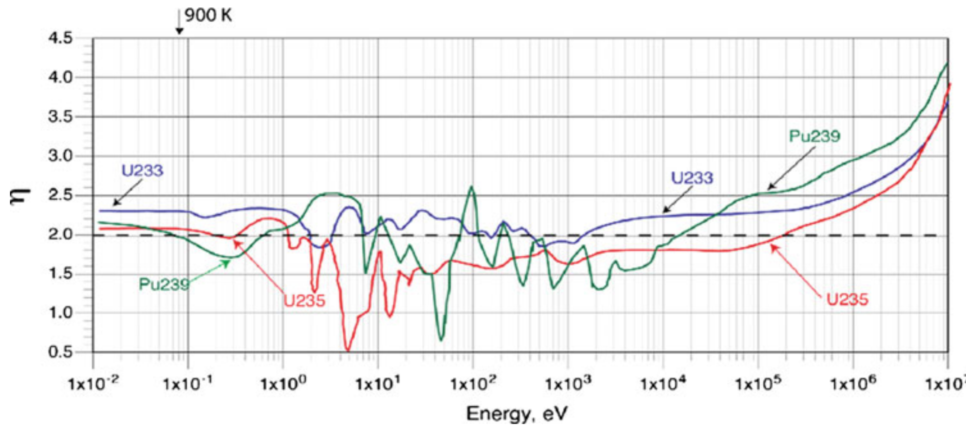

Fig. 1 Number of neutrons produced per neutron absorbed (η) in ^{233}U, ^{235}U, and ^{239}Pu, as a function of neutron kinetic energy, taken from [2]. For breeding to be possible, η has to be larger than 2

THTR-300 project at AVR, Jülich, Germany, was dropped, there were on-going developments in South Africa, United States, and Turkey.

Molten salt reactors (Fig. 2) are based on a technology that seems to focus a lot of interest, if one can judge by the number of talks related to the subject at this conference (ten talks). The subject was well introduced by Merle-Lucotte [4], who presented the physics of thorium molten salt fast reactors. It appeared that MSRs are clearly a line of research where coordination between the various worldwide R&D efforts should be improved, as there is still a lot of work needed to demonstrate the practicality of this scheme on an industrial scale. There is a particularly well-focused and advanced MSR program at the Shanghai Institute of Applied Physics in China, reported by Xu [5]. In the discussion, it was noted that R&D should be extended to other salts that allow a fast neutron energy spectrum, favouring transmutation, and that licensing issues should not be underestimated, but should be addressed from the beginning, as MSRs imply new safety considerations (different confinement barriers,

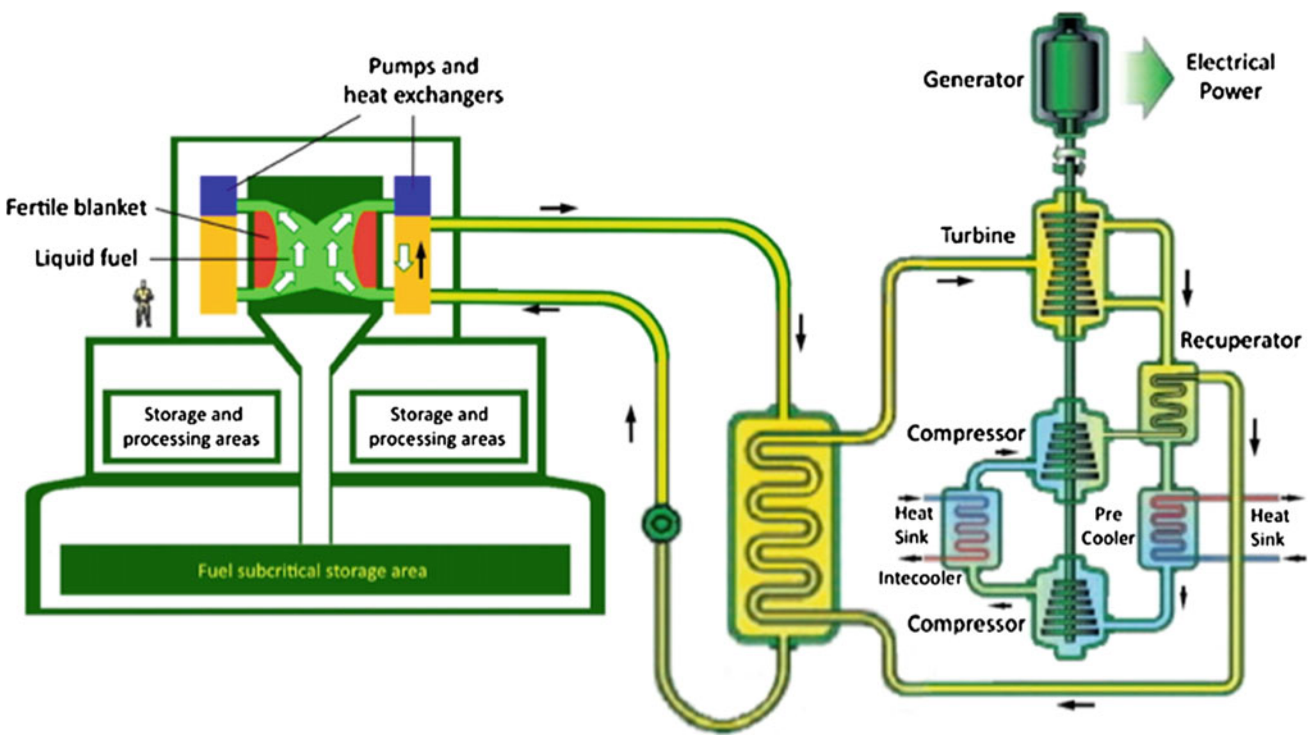

Fig. 2 The molten salt reactor scheme, from Madden's presentation [3], showing the three basic circuits of such systems: fuel circuit, intermediate circuit, and thermal energy conversion circuit

chemical extraction on-line, neutron irradiation outside the core, temporary stops of the chemical extraction flow, corrosion, etc.).

Accelerator-driven systems were the subject of the largest number of talks (fourteen talks). The readiness status of the main technological elements was reviewed:

- Progress in accelerator technology [cyclotrons and linear accelerators (linacs)] is significant, as explained by Mueller [6]. Mandrillon [7] presented an innovative approach to high-power cyclotron beams. Barlow advocates the use of non-scaling fixed-field alternating gradient accelerators (FFAG) [8]. The good news is that, today, both linac and cyclotron proton beams have achieved a sustained power in excess of 1 MW;
- Progress on neutron spallation targets was reported, including the success of MEGAPIE [9], the first MW-class neutron source, which operated successfully for three months at SINQ [10] in Switzerland and the Spallation Neutron Source (SNS) [11] in the United States, now fully operational at a power of 1.3 MW;
- Various core designs were also described.

The most advanced project is MYRRHA [12] (Fig. 3), details of which were presented by its project leader Hamid Ait Abderrahim. Several other ADS concepts, at various stages of developments, were described, including a thorium-fueled reactor for power generation by Rubbia and Aker Solutions [2], and for which a detailed engineering design already exists. A Troitsk demonstrator project [13] in Russia, based on an existing accelerator complex, was presented by Stanyslav F. Sidorkin. Presentations of ADS R&D in China (CADS) [14] and Japan [15] for burning minor actinides, and in India [16], with a view to simplify the present thorium utilization scheme, were also made. In

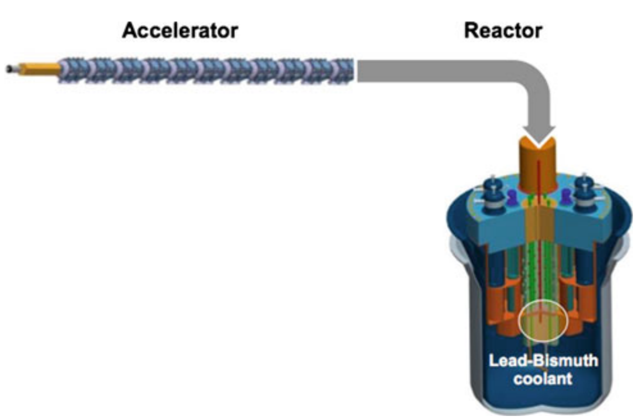

Fig. 3 The ADS scheme, illustrated by the MYRRHA prototype, taken from Aït Abderrahim's presentation [12], showing the accelerator inserting protons vertically onto a target, located at the center of a subcritical nuclear core, that produces neutrons by spallation

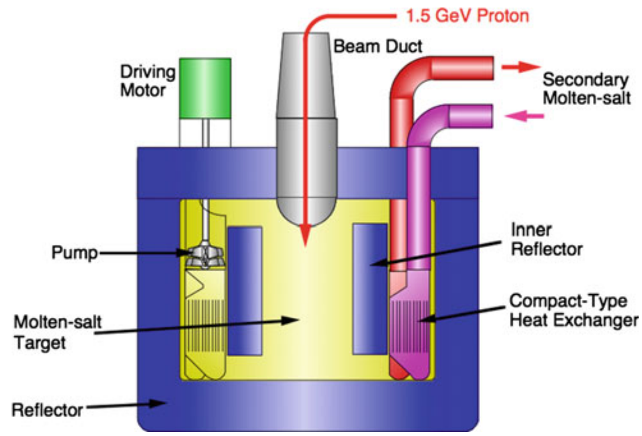

Fig. 4 Example of a molten salt ADS transmuter, as presented by Sasa [18]

Kharkov, Ukraine, the Kharkov Institute of Physics and Technology (KIPT) neutron source [17] is being completed and will be licensed for low enriched uranium (LEU).

Alternative ADS concepts were also presented at ThEC13, in particular the molten salt ADS by Rubbia [2], Sasa (Japan) [18] (Fig. 4), and Chai (Korea) [19].

ADS were also the subject of several other presentations addressing specific aspects, such as reactivity measurements by beam pulses, corrosion and material compatibility, etc.

As in the case of MSR R&D, the need for a coordinated worldwide effort is evident, to avoid duplication of tests, and to progress as quickly as possible from physics concepts to technological choices. The main issue for ADS today is the absence of a demonstrator. This is more of a political issue (funding) than a scientific one. This is clearly where the thorium community should concentrate its effort.

National and International Thorium Programs

India has by far the most advanced practical scheme for using thorium, based on three existing technologies, presented by Vijayan [20]:

- Use of a thorium blanket around heavy water reactors (HWR), CANDU, or light water reactors (LWR) to produce plutonium from the limited Indian uranium supply;
- Use of sodium-cooled uranium–plutonium fast reactors with a thorium blanket to breed ^{233}U. The first 500 MW_e prototype of a fast breeder nuclear reactor is being commissioned at the Madras Atomic Power Station, in Kalpakkam, India;
- Reprocessing the thorium blanket and manufacturing ^{233}U–Th fuel for advanced fast or thermal water reactors.

This strategy, which covers both the front-end and back-end of the fuel cycle, clearly works in principle. However, there remain concerns over the complexity of a scheme requiring the maintenance of three different reactor technologies. In addition, sustainability is questionable, and the present scheme does not solve the issue of nuclear waste.

National programs of Belgium, China, Czech Republic, France, India, Japan, Norway, Sweden, Turkey, and the UK, with different levels of involvement in thorium R&D, were presented. In Europe, the MYRRHA project dominates the scene, even though it is not yet fully funded, and does not include thorium fuel in its program. Nevertheless, it develops the basic elements needed for future thorium ADS.

Thorium Fuel Cycle

Two sessions were devoted to the thorium fuel cycle. The subject had already been briefly discussed by Rubbia, who presented new concepts in his introductory talk [2]. Presentations included various related subjects, such as commercial development of thorium fuel, licensing, back-end of the fuel cycle, pyro-electrical and aqueous reprocessing, etc.

Simulation of Thorium Systems

Ganesan [21] gave a very detailed status of the nuclear data related to thorium, and Gunsing et al. [22] described the impressive performance of the neutron time-of-flight (n_TOF) facility [23] at CERN, which provides the precise data (Fig. 5) needed to simulate new systems. Today, the physics of ADS is well understood and thorium systems can be simulated with high reliability.

Conclusion

At ThEC13, an impressive amount of R&D work was presented on various aspects of thorium technologies. R&D on thorium, regardless of its present specific purpose, should be encouraged. On the other hand, many activities are taking place in parallel worldwide, but not in a coherent way. International cooperation is a necessity in view of the importance of the energy issue, which is a challenge facing the whole world and requiring a global response.

Is it possible to converge on concrete projects, generating partnerships within international collaborations? In the round table discussion, Anil Kakodkar suggested that thorium could very well be a theme for international cooperation [24]. The CERN collaboration model should work for any new significant project. Developments common to MSR and ADS should be encouraged whenever possible (for instance, regarding the fuel cycle).

ThEC13 will be documented in a book of proceedings, which should contribute to this goal and making it a reference for the field of thorium technologies.

The goal of iThEC is to promote international cooperation in the development of thorium technologies, to provide abundant, safe, and clean energy for humankind. This is perhaps illustrated by one photo taken at the ThEC13 banquet (Fig. 6) of representatives from the two main countries, China and India, that are likely to define the energy future of our planet.

On behalf of iThEC and of the ThEC13 Organizing Committee, I would like to thank you all for having

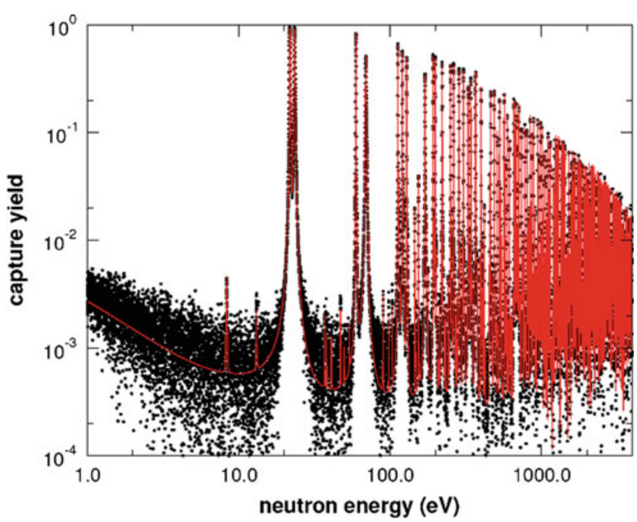

Fig. 5 Measurement of the neutron capture reaction rate on ^{232}Th at n_TOF [23], illustrating the high resolution with which resonances can be resolved. Taken from Gunsing et al. [22]

Fig. 6 Honjie Xu, China, Jean-Pierre Revol, iThEC, and Anil Kakodkar, India, at the ThEC13 banquet. *Photo* Credit Jean-Pierre Revol

contributed in such a professional way to this conference, by making presentations, by preparing posters, by participating in discussions, or simply by your presence here, in the CERN Globe of Science and Innovation.

Acknowledgments I would also like to thank CERN for providing an ideal environment for scientific discussions, and my colleagues from iThEC, who worked enthusiastically to make ThEC13 a great success.

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