Creation of Indian Experimental Benchmarks for Thorium Fuel Cycle

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IAEA CRP on "Evaluated Data for the Thorium-Uranium fuel cycle".
Title of the Contract: Benchmark validation studies for Thorium-Uranium fuel cycle.
(RC No: IND12485)

Chief Scientific Investigator: S. Ganesan

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Organization of this talk

CREATION OF EXPERIMENTAL INDIAN BENCHMARKS

This progress report deals mainly with the two specific tasks within the scope of this IAEA-CRP:

- **PIE Benchmark: Thorium Irradiation experiments and PIE burnup measurements in PHWRs. In progress. A few more months of intense activity to get finalized.**

- **CRITICALITY BENCHMARK: Formulation, creation and peer-review of KAMINI experimental criticality benchmark. Already peer-reviewed and accepted for inclusion the ICSBEP in 2005.**

- **General information (As Appendix)**

India is actively participating in the IAEA-CRP on "Evaluated Nuclear data for Thorium-Uranium Fuel Cycle," to share our information and to benefit from the developments related to the use of thorium around the world.

India has more than 30% of world's thorium reserves

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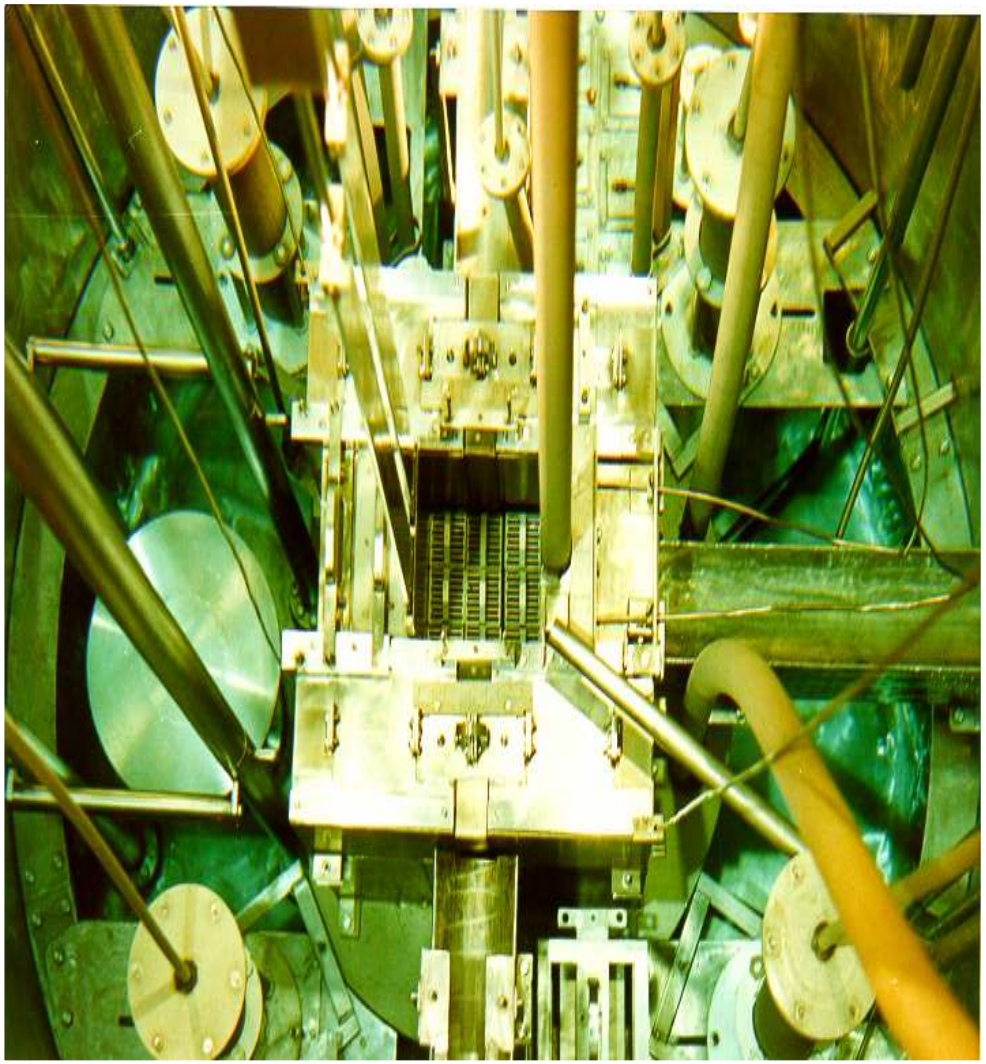
General issues in PIE benchmarking and KAMINI benchmarking

- Both experimental benchmarks are very complicated. Significant progress has been successfully achieved.
- India is new to the concept of ICSBEP benchmarking.
- The work load was grossly underestimated. Internal peer reviews and resolution of QA issues.
- Permission to publish was obtained. India shares information and is welcome to benefit from the developments related to the use of thorium around the world.
- AHWR (Case study in INPRO) and CHTR has overlapping interests with GEN-IV systems and with ADSS involving thorium



- *Power – 30 kW;*
- *Fuel – U-233 (20 Wt %) and Al alloy*
- *Total Fuel Inventory - ≈600 g of U-233*
- *Reflector – BeO;*
- *Moderator and Coolant – Demineralised light water*
- *Core Cooling – By natural convection*
- *Control Elements – Cd plates*

BENCHMARKING KAMINI

- The Kalpakkam Mini (KAMINI) is a U-233 fueled, low power (30kW) research reactor designed and built by the BARC and IGCAR joint venture.
- One criticality configuration made on 29 Oct. 1996 has been evaluated and accepted as a benchmark.
- Benchmarking an operating system is healthier as people are unlikely to have retired and feedback from fabricators are available.

- **Unique distinction being the only reactor operating with U-233 as fuel in the whole world now.**

ICSBEP

Sample Calculation Result (United States). The mean value by sample calculations by MCNP

K-eff: 0.99134± 0.00025

The uncertainty in benchmark of KAMINI in the characterization of the predicted

k_{eff} is ± 0.00744

K-eff: 1.03 (C. P. Reddy and E. Radha, " KAMINI benchmarking by Monte Carlo methods-experience and sensitivity studies", DAE-BRNS National Workshop on Nuclear Data for Reactor Technology and Fuel Cycle, March 7-10, 2005, Bhabha Atomic Research Centre (2005)).

K-eff: 1.017 (D. K. Mohapatra, C. Sunil Sunny, P. Mohanakrishnan and K. V. Subbaiah, "Monte Carlo modeling of KAMINI", Annals of Nuclear Energy, 31, 2185-2194, (2004)).

See website of the ICSBEP: http://icsbep.inl.gov/2005/ for details

- **The present improvement in k_{eff} is due to some of the following important improvements.**
  - **Fuel density**
  - **BeO density**
  - **Inclusion of aperture control plate**
  - **Fuel isotopic composition**
  - **Subassembly wise density of fuel**
  - **Impurities in fuel, aluminum, BeO and zircaloy.**
  - **Inclusion of core cage.**
- **The improvements due to the first three factors have the maximum influence on the results.**

Indian Progress in BENCHMARKING

•J. B. BRIGGS (INL, USA), Co-ordinator of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) visited BARC in March 2005.

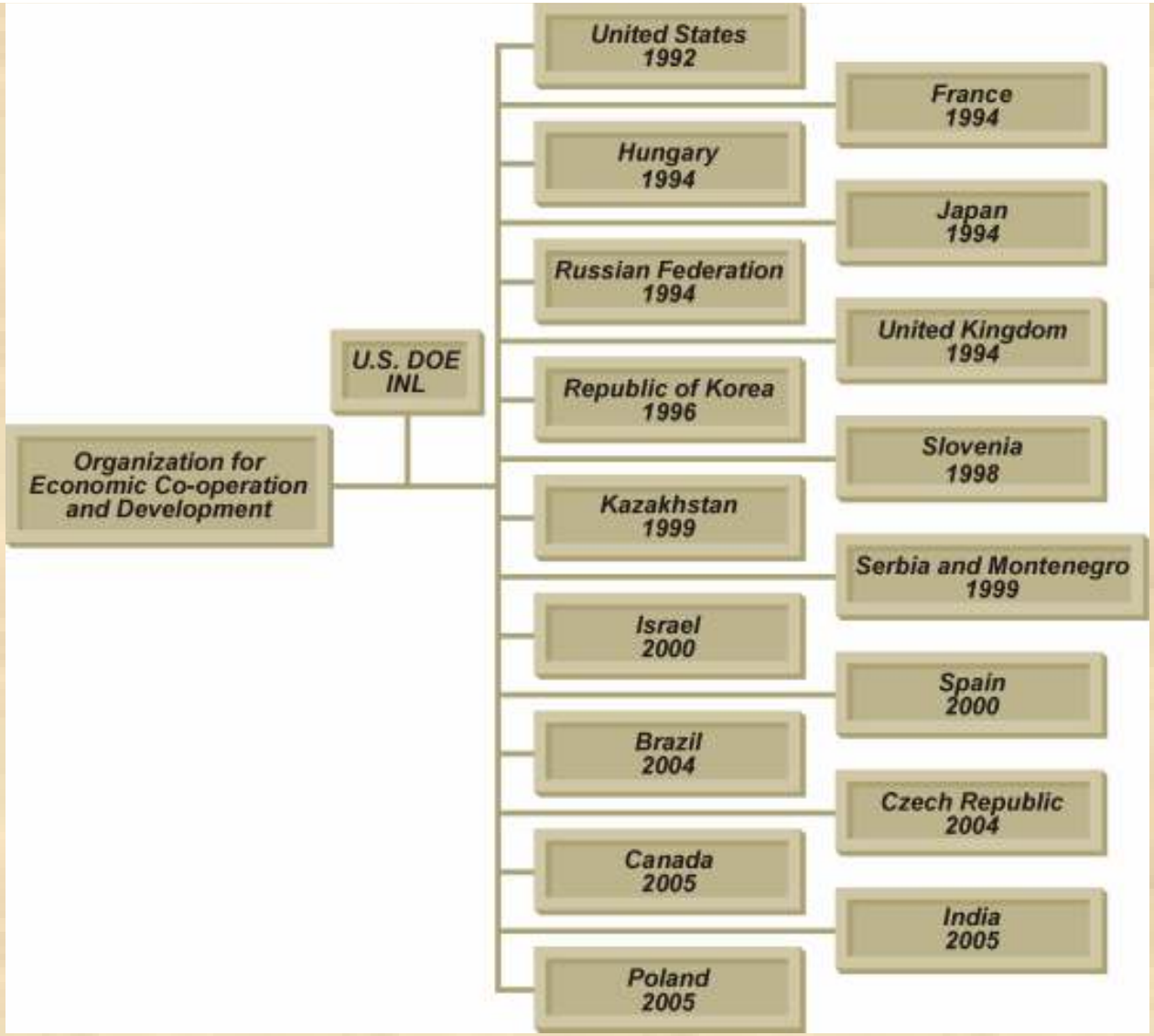
•As the evaluation report evolved with finer details, permission to publish was obtained from the Indian authorities. Since the last RCM of this CRP, several internal peer reviews and meetings conducted to ensure the highest level of QA

•India presented the first version in the ICSBEP Working Group Meeting, May 16 –20, 2005, New York City, New York. This version went through a series of peer reviews.

•India presented the KAMINI Benchmark in the 8th Korean Nuclear data Workshop, August 25-26, 2005, Pohang Accelerator Laboratory (PAL), Pohang, Korea.

•Sep. 2005: The ICSBEP accepted KAMINI for publication. India thus formally joins the USDOE-NEA efforts in the preparation of the International Handbook of Evaluated Criticality Safety Benchmark Experiments.

•See website of the ICSBEP: http://icsbep.inl.gov/2005/ for details. A copy of the current evaluation of KAMINI is available. At this time, final and minor editing is in progress. The internet version should be ready before March 1, 2005.



The full report on KAMINI benchmark is available

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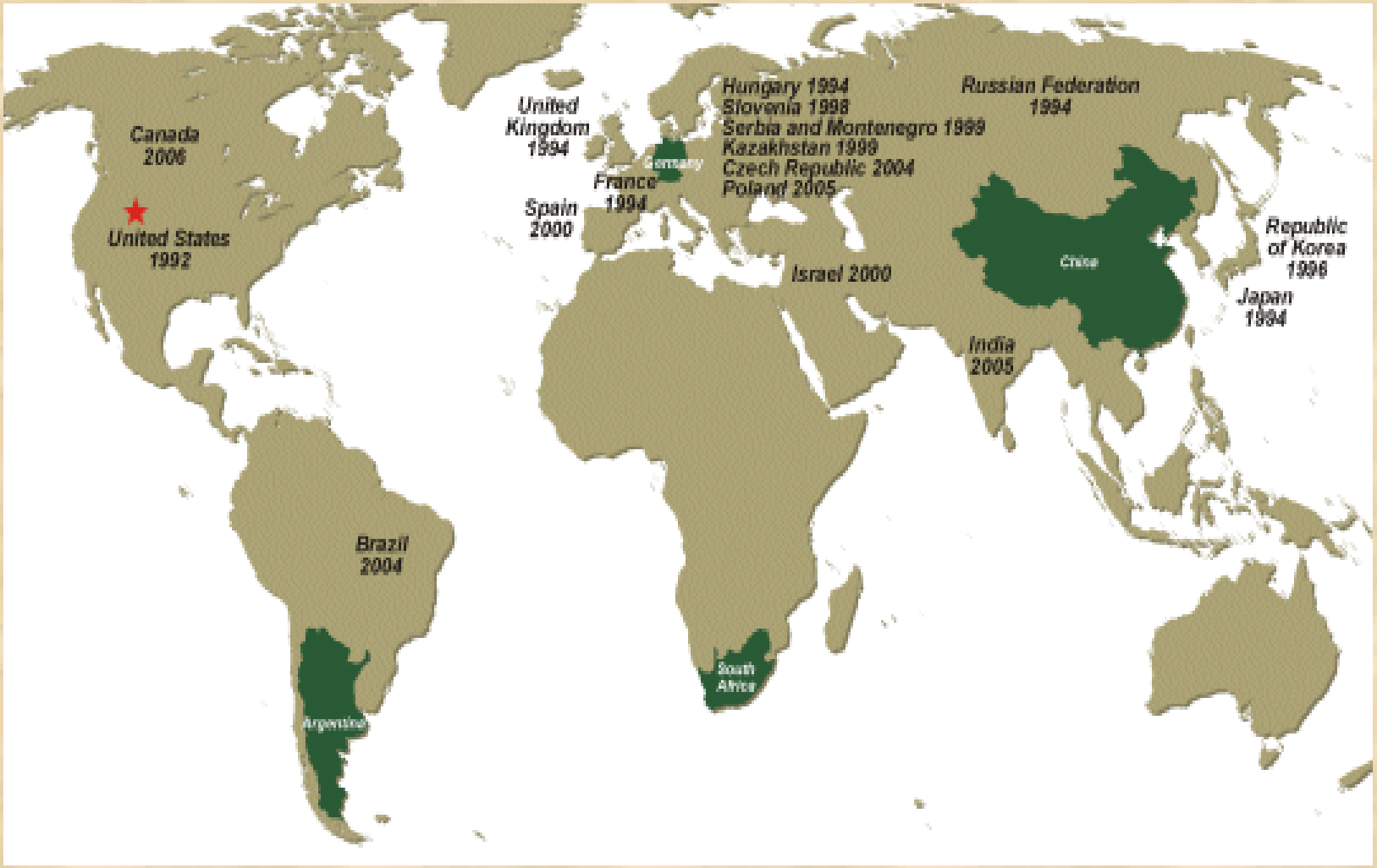

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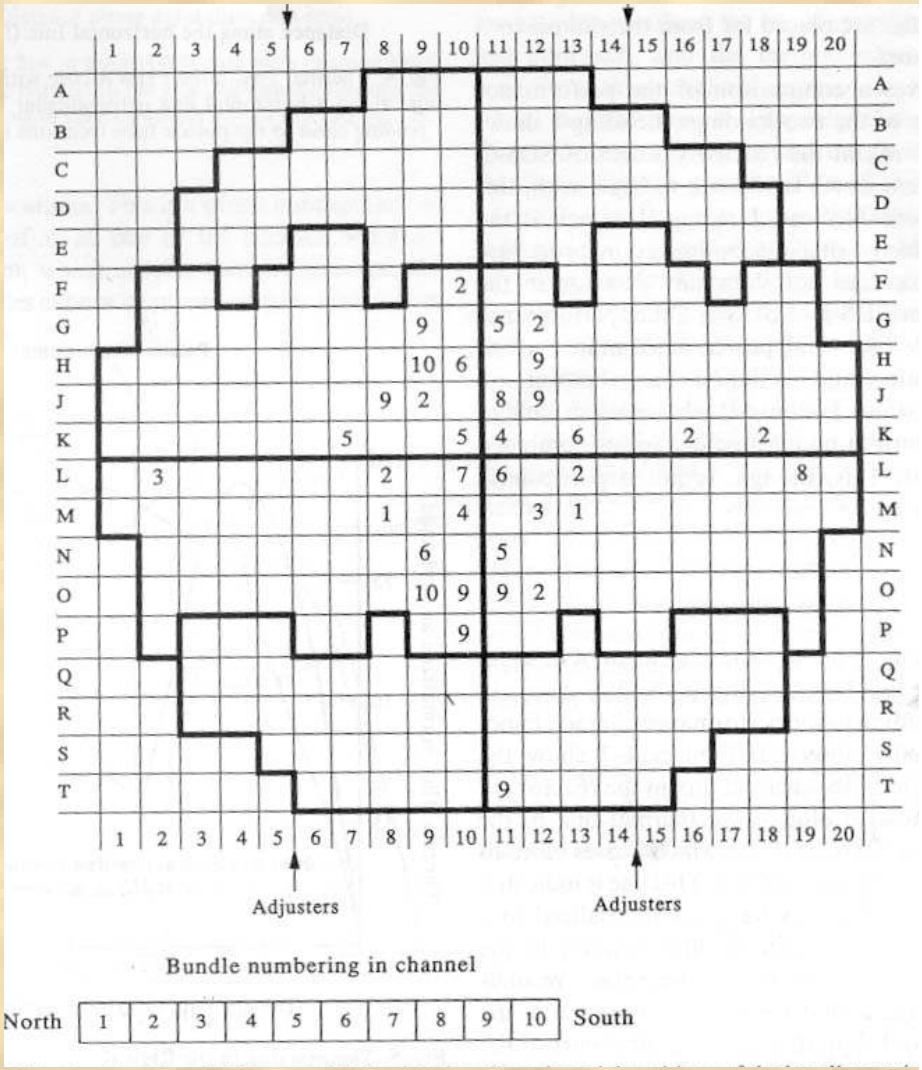
Thorium loading in the initial core of KAPS-2 unit

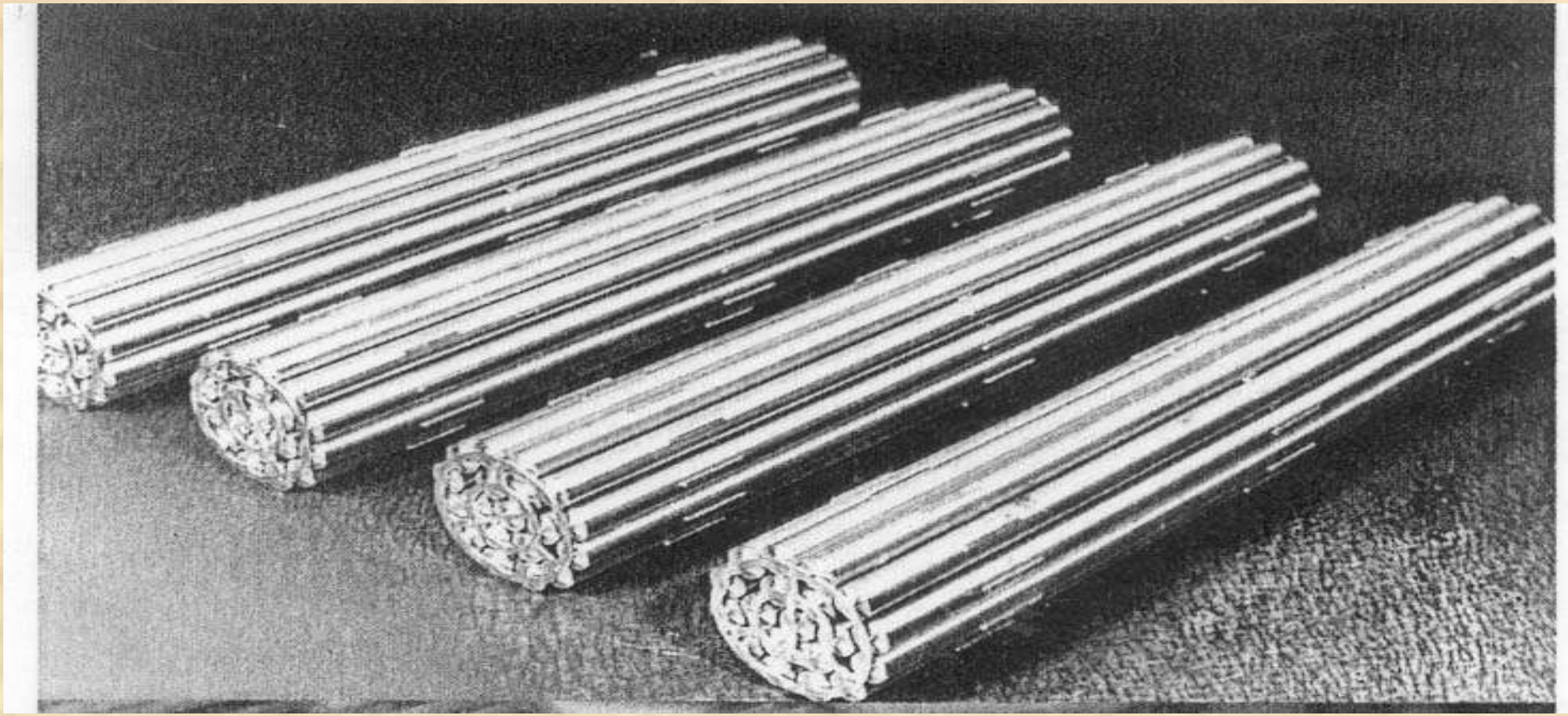
INDIA IS THE ONLY COUNTRY HAVING AN ON-GOING PROGRAMME OF THORIUM IRRADIATIONS IN ALL PHWRs FOR INITIAL POWER FLATTENING

Thorium loading in the initial core of KAPS-2 unit

The axial positions of the 35 bundles of thorium oxide bundles are indicated by Arabic numerals. The remaining (3025 in the active core +612 outside active core) bundles are of natural uranium.



PIE Benchmark: Thorium Irradiation experiments and PIE burnup measurements in PHWRs.



Thorium Fuel bundle is used for power flattening in 220MWe PHWR in India

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EXPERIMENTAL RESULTS

Isotopic Contents in (J-11-9) Fuel Rod – 3rd Ring; KAPP-2 (PHWR)

E values in gms per tonne of thorium

^{232}U	7.2
^{233}U	12357
^{234}U	1414.8
^{235}U	147.7
^{236}U	15.2
Sum (^{232}U, ^{233}U, ^{234}U, ^{235}U and ^{236}U)	13941.9

SUMMARY

- J-11 (9) ThO_2 bundle
- 508 FPDs irradiation time ;
- 4.5 years cooling time

– PIED made available about 5 gms from above bundle
– Dissolution studies (PDD, NRG)
– Gamma spectrometric analysis (RCD)
– Burnup determination - TIMS (FCD)

Burnup	$^{232}U/^{233}U$
Calculated 10,500 MWd/t	~ 80- 100 ppm (old) (RPDD)
	540 ppm (new (RPDD)
	Measured
	569 ppm (FRD)
12,500 MWd/t (FCD)	549 ppm (FCD)
10,800 MWd/t (RCD)	

RCD Measured the following burnup monitors (Activity per tonne of thorium)

^{106}Ru, ^{125}Sb,

^{134}Cs, ^{137}Cs,

^{144}Ce, ^{154}Eu,

^{155}Eu, ^{106}Ru,

^{208}Tl, ^{228}Th

Dissolver solution fission product analysis By Gamma Spectrometry

S.No.	Nuclide	Activity per g of the dissolver solution at the end of irradiation	Activity per Ton of thorium at the end of irradiation	No. of Fissions / Ton of Thorium
1.	^{106}Ru	$(1.93 \pm 0.07) \times 10^{6}$	9.84×10^{14}	2.73×10^{25}
2.	^{125}Sb	$(3.91 \pm 0.02) \times 10^{5}$	1.99×10^{14}	2.69×10^{25}
3.	^{134}Cs	$(1.69 \pm 0.01) \times 10^{6}$	8.62×10^{14}	--
4.	^{137}Cs	$(2.90 \pm 0.02) \times 10^{6}$	1.48×10^{15}	3.02×10^{25}
5.	^{144}Ce	$(4.90 \pm 0.04) \times 10^{7}$	2.50×10^{16}	3.33×10^{25}

No. of fissions per metric Ton of thorium = $(2.94 \pm 0.30) \times 10^{25}$

= 10800.0 MWD

CREATION OF INDIAN EXPERIMENTAL BENCHMARK ON THORIUM IRRADIATION AND PIE MEASUREMENTS IN PHWR

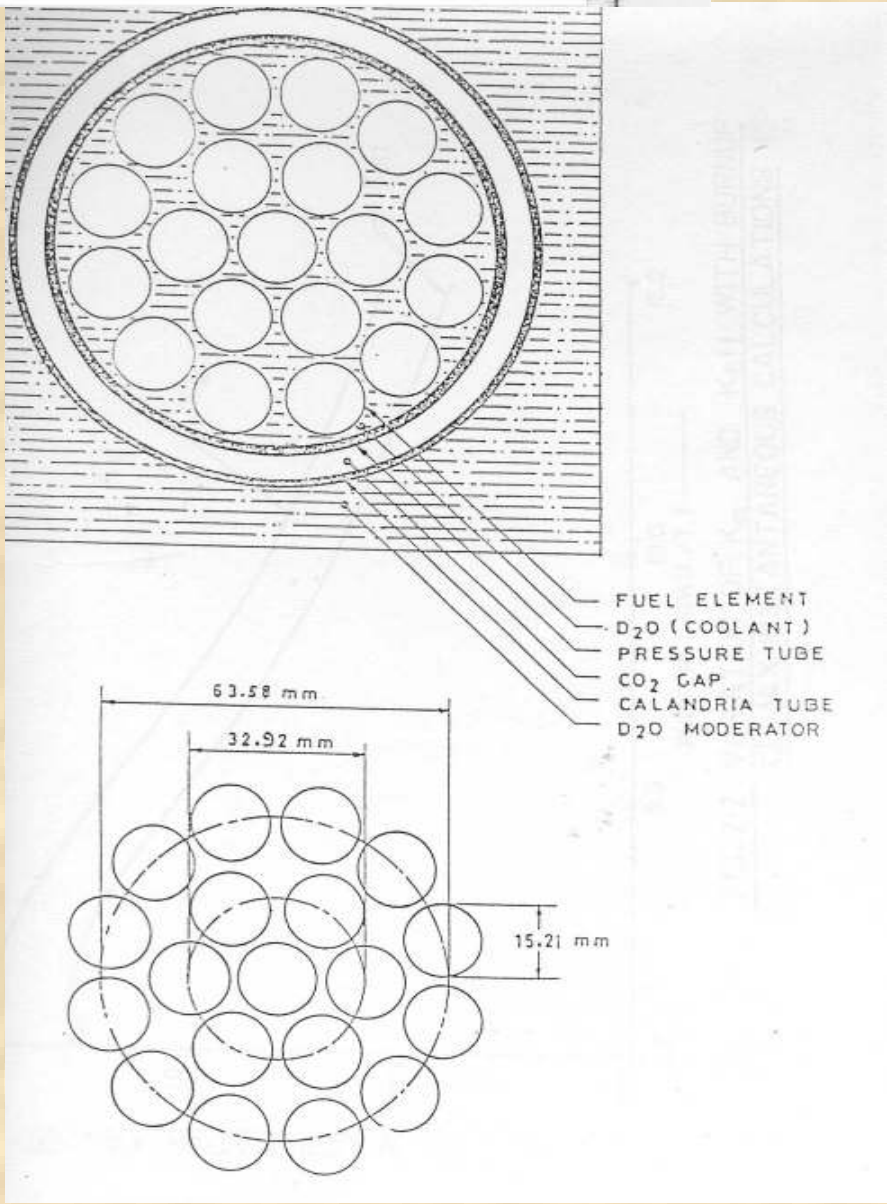
- **The details presented in the earlier meetings include published details including some new raw experimental integral data. The new experimental integral data submitted already to the IAEA under the scope of this CRP thus far include the following: Actual measured value of $^{232}U/^{232}U$ in ppm;**

- **Measured values (in gms) of isotopes of uranium ^{232}U, ^{233}U, ^{234}U, ^{235}U ^{236}U and ^{238}U formed in thoria 19-rod cluster**

- **Several burnup (fission product) monitors such as experimental values of activity per ton of thorium at the end of irradiation for ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs and ^{144}Ce.**
- **Actual power history for the irradiation of thorium bundle was submitted to the IAEA along with a starter specification for the 19-rod lattice for the thorium and natural uranium bundles in the Indian PHWR. These details are being upgraded to benchmarking quality.**

UNIT CELL FOR 19 ELEMENT CLUSTER

- **CSI is actively in collaboration with NPCIL (S. A. Bhardwaj, A. Kumar, Sherly Ray, Fernando, Suresh Misra , M.V. Parikh and Colleagues):**
- **Upgradation of all the specifications and details**



UPGRADATION OF ALL THE DETAILS

By inclusion of the following:

- **Specification of impurities,**
- **Uncertainties in the composition including in impurities nd**
- **specification of tolerances in dimensions;**
- **a calculational model of the lattice, Monte Carlo (MCNP) and super-cell (using codes such as WIMS or the equivalent Indian codes for the lattice) and the core; and a sample listing of the code inputs.**
- **Preparation of Autocad drawings**
- **Documentation**

UPGRADATION OF ALL THE DETAILS

(Slide Continued)

- **Currently all these details are being improved to international benchmarking quality level (ICSBEP) based upon the lessons drawn and the successful Indian experience, mentioned below, in the benchmarking of the KAMINI reactor.**
- **Visit of a Brazilian scientist for 2 weeks sponsored by the IAEA to BARC in Feb 2006 to work on this benchmark is confirmed.**

Acknowledgments

The author thanks Shri. R. K. Sinha, Dr. R. Srivenkatesan, BARC for many useful discussions and for their keen interest in this work. A large number of colleagues from various Divisions in BARC and other units of DAE have actively supported and participated in this IAEA-CRP and generously contributed to the technical discussions.

Acknowledgments (Continued)

In the case of KAMINI benchmarking, the author would like to thank, in addition, several external reviewers from the USA (Virginia F. Dean, J. Blair Briggs, Richard. D. McKnight, D. Heinrichs and others). Their criticism, seeking clarifications and providing valuable feedback greatly helped improve the quality of KAMINI benchmarking. The fruitful interactions with KAERI (C. S. Gil, Do Heon KIM) are gratefully acknowledged with thanks. The CSI specially thanks Andrej Trkov of the IAEA-NDS for useful discussions.

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APPENDIX

General information

General information

- India recognizes the need for reliable nuclear data for all evaluations for several hundreds of isotopes/elements in all stages of the nuclear fuel cycle.
- The BARC nuclear data Mirror website site http://www-nds.indcentre.org.in is now fully operational.
- BARC has signed LOI with CERN on n_TOF collaboration for 2006-2011.
- INDIA has joined ITER (6 billion USD PROJECT) as an equal partner (12 participants). Nearly 500 million USD is India's contribution in kind. The involvement in ITER (D-T reaction) is triggering awareness on Fusion Evaluated Nuclear Data Library-2, the official nuclear data library from the IAEA for the design of ITER and more interest in nuclear data (14MeV neutron) for fusion applications in India.

General information

FUTURE PLANS:

Sensitivity studies using IAEA-CRP data for Th-U Fuel cycle

Other experimental criticality Benchmarks:

PURNIMA III: KAMINI is built from the experience of PURNIMA III reactor.

Some of the main differences between KAMINI and PURNIMA III are:

1. Fine control rod

2. Smaller reactor vessel

3. Absence of beam tubes

4. Difference in reflector dimension However it is found some crucial data like control rod height at criticality, details of control rods are not available. A thorough search of documents is being made to obtain the missing data. In case this data is not found, more sensitivity studies are to be performed. This may increase the uncertainty in the evaluation.

General information

PURNIMA II:

233U Uranyl nitrate solution reactor and critical data is available for various concentrations. Uncertainties for this benchmark are expected to be less.

PURNIMA I:

Plutonium fuelled fast reactor. This benchmark will be of great use in the evaluation of plutonium data for fast systems. Since the experiments were done nearly 30 years back, retrieving the data will be difficult.

MANY more Indian experimental benchmarks?

General information

A Multi-purpose Critical Facility (CF)

General information

Critical Facility for AHWR and 500 MWe PHWR

- Validation of theoretical simulation models and Nuclear Data
- The physics and engineering design completed – PSAR being reviewed by Design Safety Review Committee

•Calandria : 330 cm dia, 500 cm height
Variable pitch 20-30 cm

Nominal Reactor Fission Power: 100 Watts
Thermal Neutron Flux (Average): 10^8 n/cm^2/sec
72 cm bottom graphite zone
6 shut off rods
Partial Moderator Dump

Three Types of Cores:

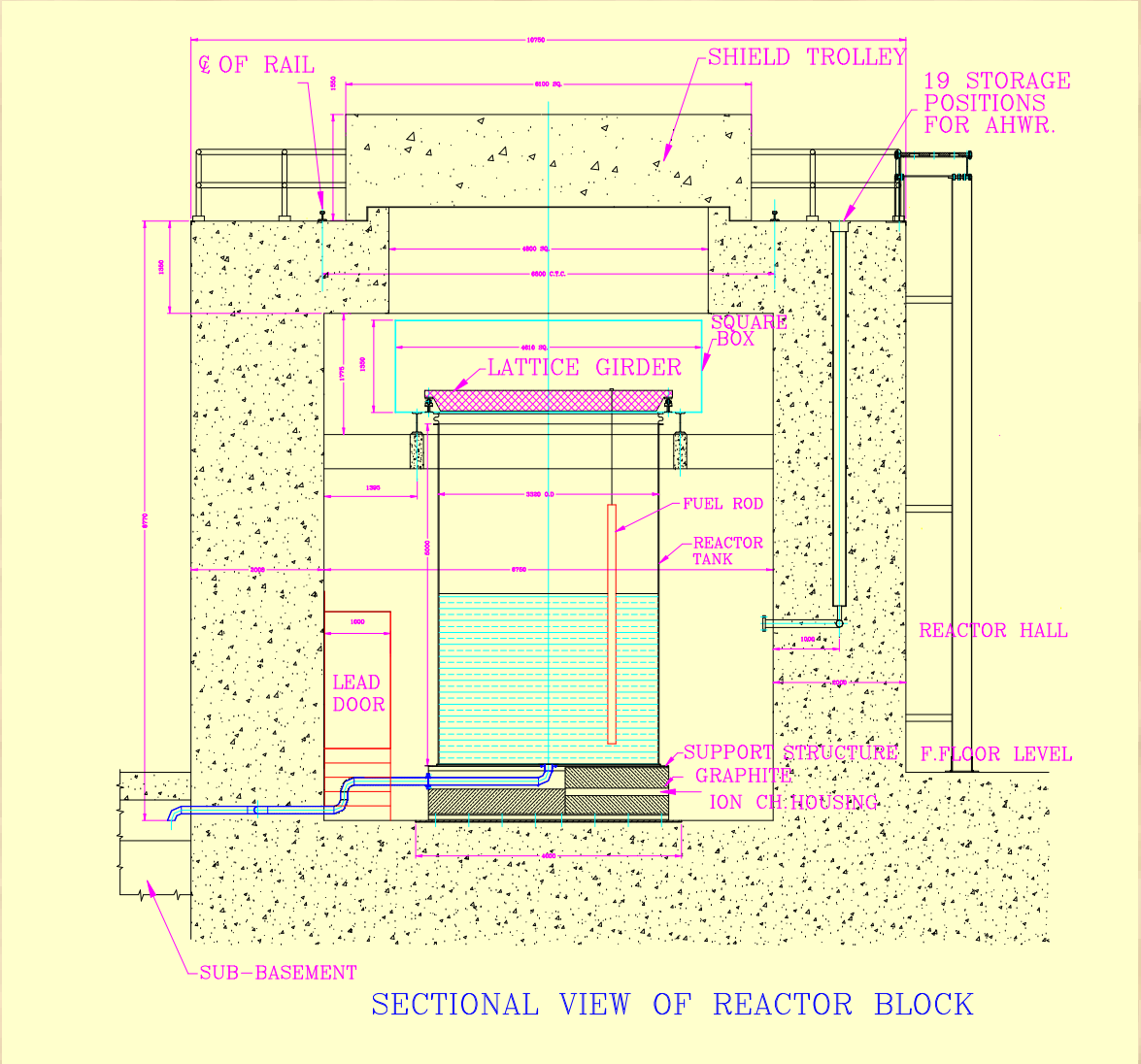
•Reference Lattice Core : 19 rod cluster NU metal (RLC) (Dhruva pin size)
61 lattice locations (6 for SRs)
27 cm pitch

•AHWR : Central 9 positions for AHWR cluster; rest RLC

•PHWR 500 : 69 lattice locations (6 for SRs)
Six 37 rod standard fuel bundles per channel

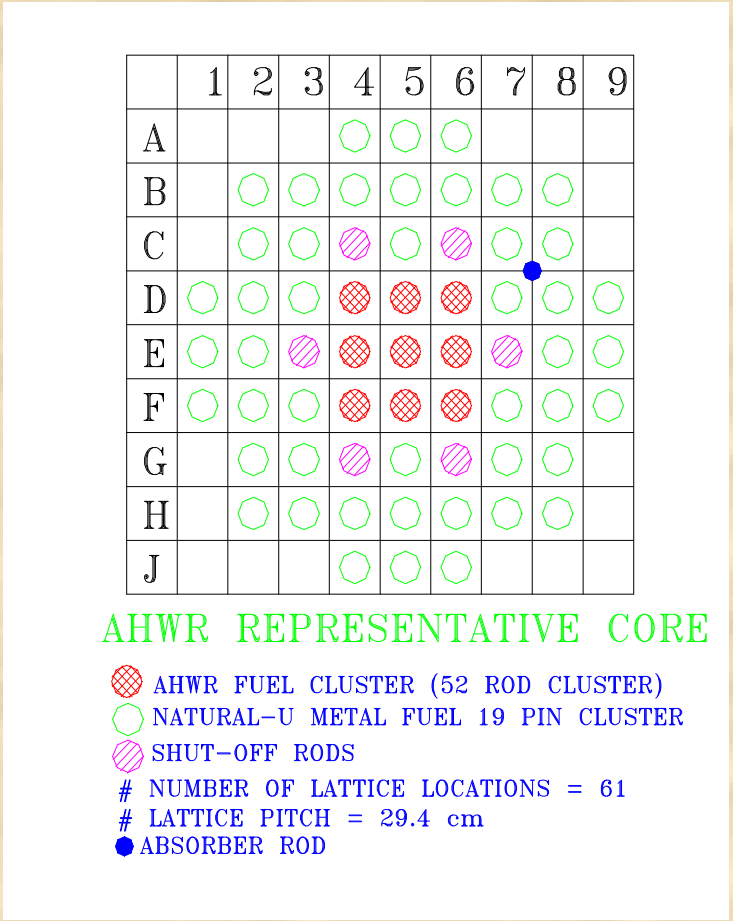
General information

Critical facility for AHWR



General information

CRITICAL FACILITY FOR AHWR AND 500 MW(e) PHWR (Under construction)



General information

Nuclear data sensitivity calculations

The critical height of the CF with AHWR representative core increases by 5cm and 7 cm respectively when "endfb6.lib" WIMS-D library is replaced by the "iaea.lib" and "jendl3.lib" libraries.

For natural uranium core this is about 2cm.

The replacement of multigroup data of ^{232}Th alone in "jendl3.lib" by "endfb6.lib" changes the k-infinity by 10.24mk, "jendl3.lib" yielding a higher calculated value of k-infinity.

The self-shielded capture resonance integrals for ^{232}Th are higher in "jendl3.lib" by several tens of percent as compared to 0.1% target accuracy.

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