iThEC

INTERNATIONAL THORIUM ENERGY COMMITTEE

ADS Activities of the international Thorium Energy Committee

Maurice BOURQUIN
Geneva, Switzerland

TCADS-4, October 14, 2019

Ambition of iThEC

To promote R&D on the use of thorium in order to transmute long-lived nuclear waste, with a view on energy production, by focusing on Accelerator-Driven Systems.

iThEC supports fully the efforts on ADS made by MYRRHA, ADANES/CIADS, and those in Japan, USA, Russia…

Thorium Energy for the World

- **First task for iThEC: Organize the Thorium Energy Conference 2013 *(ThEC13)***
- **The main world actors were all represented *(32 countries)***
- ThEC13 Proceedings available on line: www.springer.com/gb/book/9783319265407

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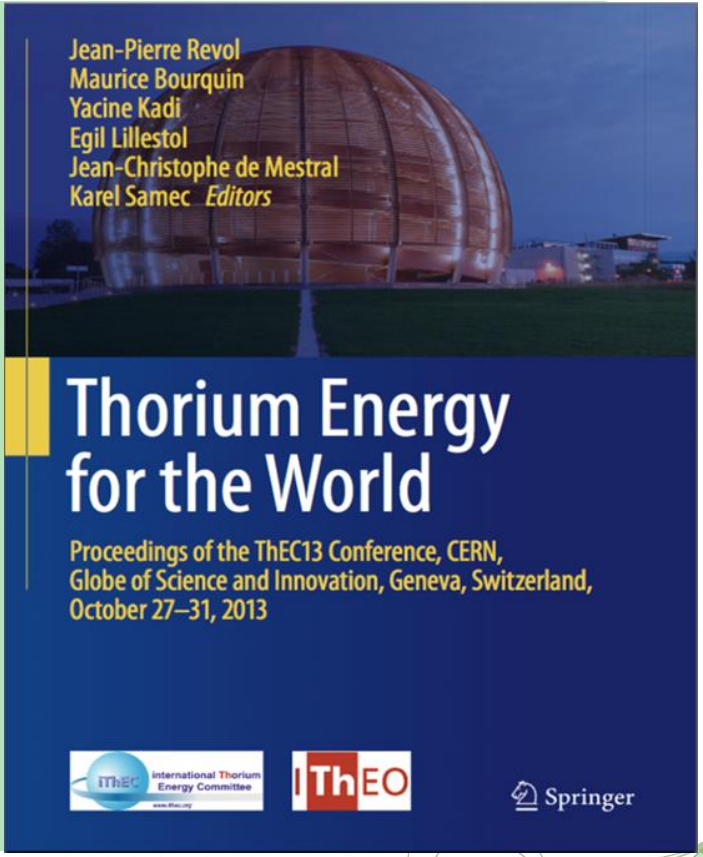


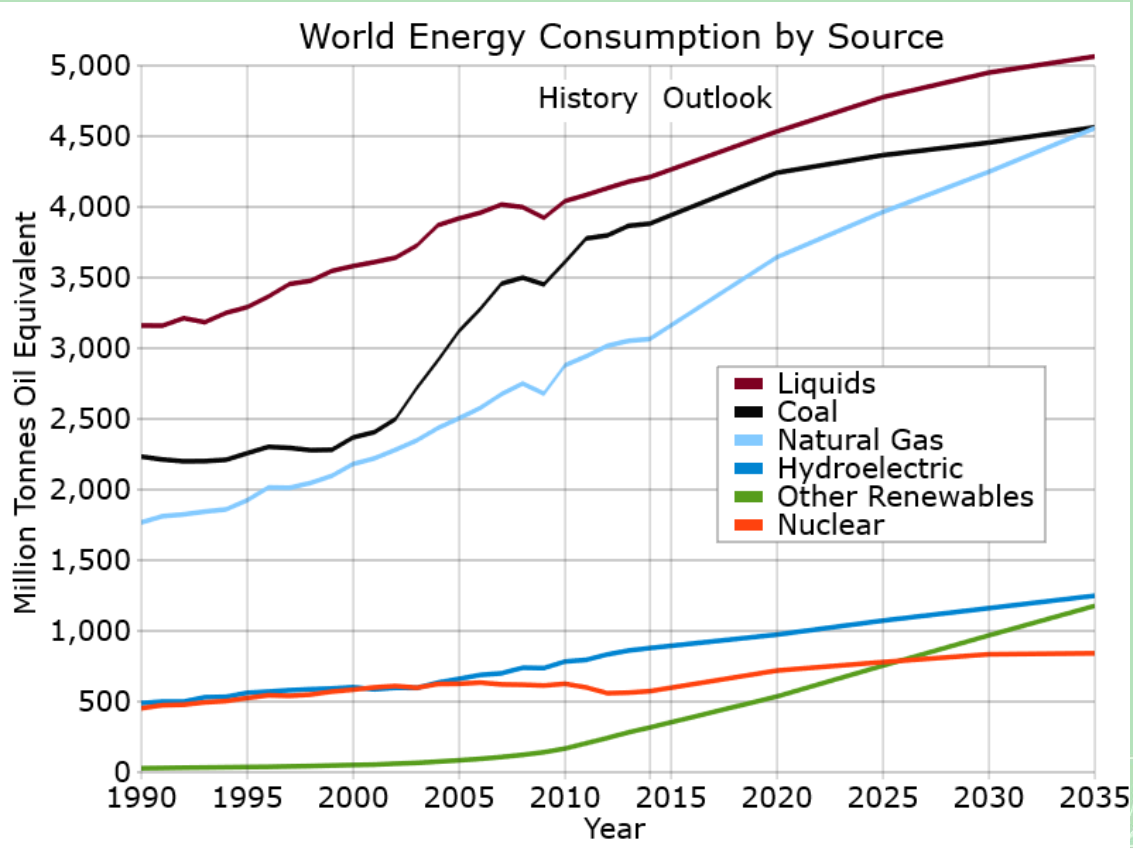
Ambition of iThEC

- The **global effort and level of support** are insufficient in view of the global challenges of rising electricity demands,
  - associated with digitalisation of society, increase of world population and economic development .

- and of the issues of climate change/ atmospheric pollution.

- T**he most affordable electricity we can provide** comes from fossil fuels, coal, oil and gas.

Global Electricity Demand



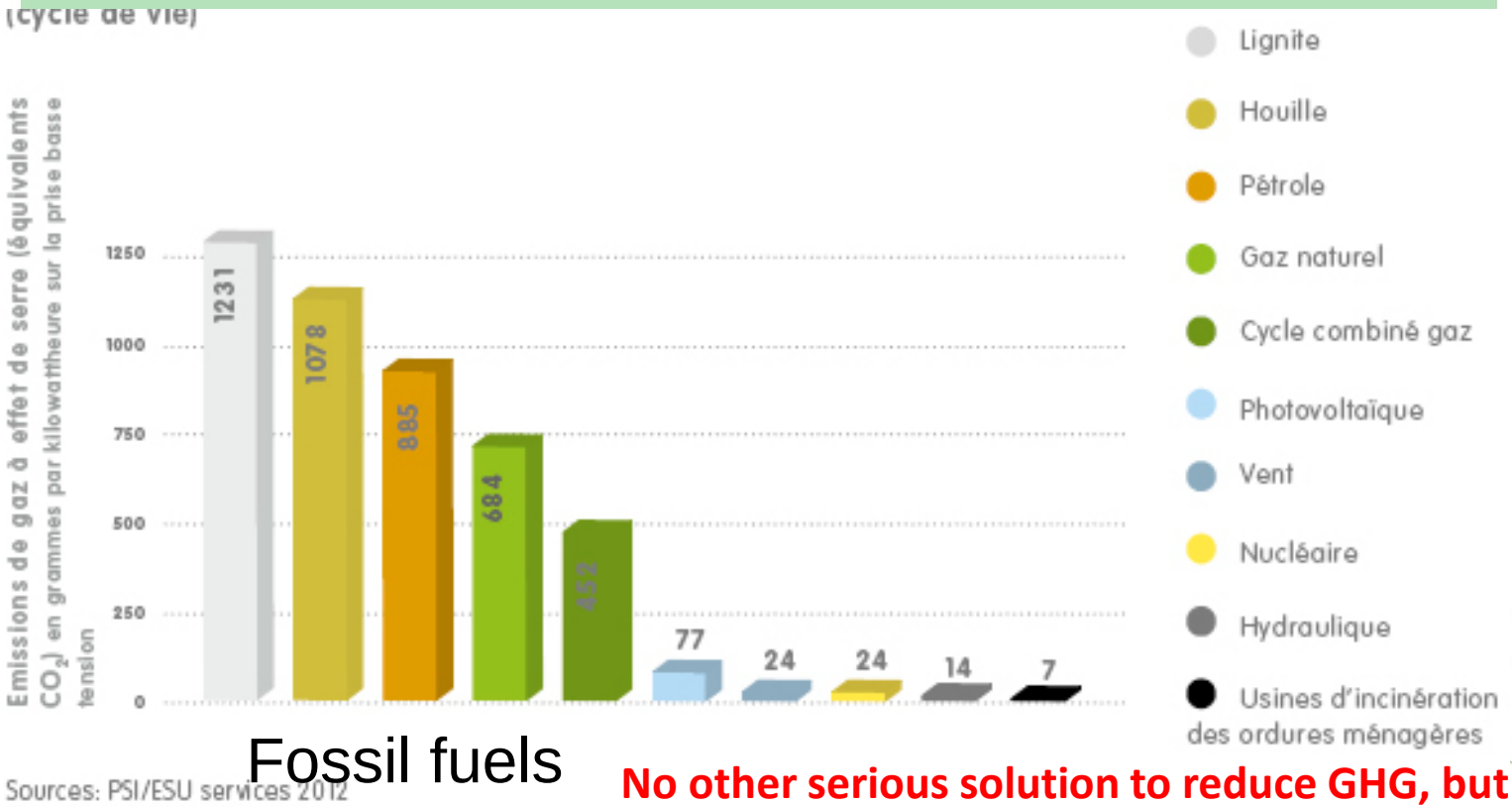
Fossil fuels

VRE

Intermittent, geographicaly dependent

BP Statistical Review of world energy - all data, 11 juin 2019.

Greenhouse gas emissions (g/KWh)



Fossil fuels

Sources: PSI/ESU services 2012

No other serious solution to reduce GHG, but to develop hydroelectric and nuclear energies !!!

Nuclear energy

- Only nuclear generated electricity is CO2 neutral, and also continuous, and geographically efficient.

- **However many people believe that nuclear-power, based on present technology, has no sustainable future.**

  - **70% of the people interrogated in France by BTV believe that NPP contribute to the climate change.**

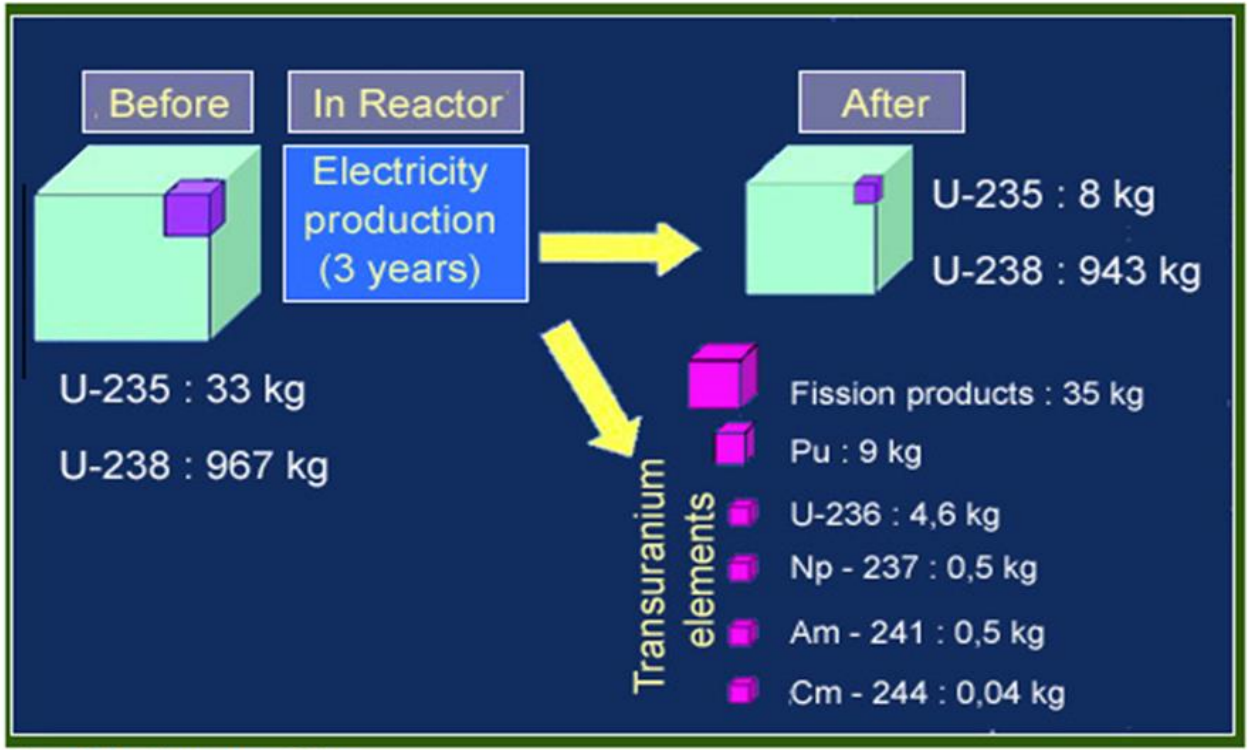
International Conference on Climate Change and the Role of Nuclear Power 2019, Vienna

Nuclear energy issues: economics

Mühleberg NPP in Switzerland will cease operation on December 20, 2019…

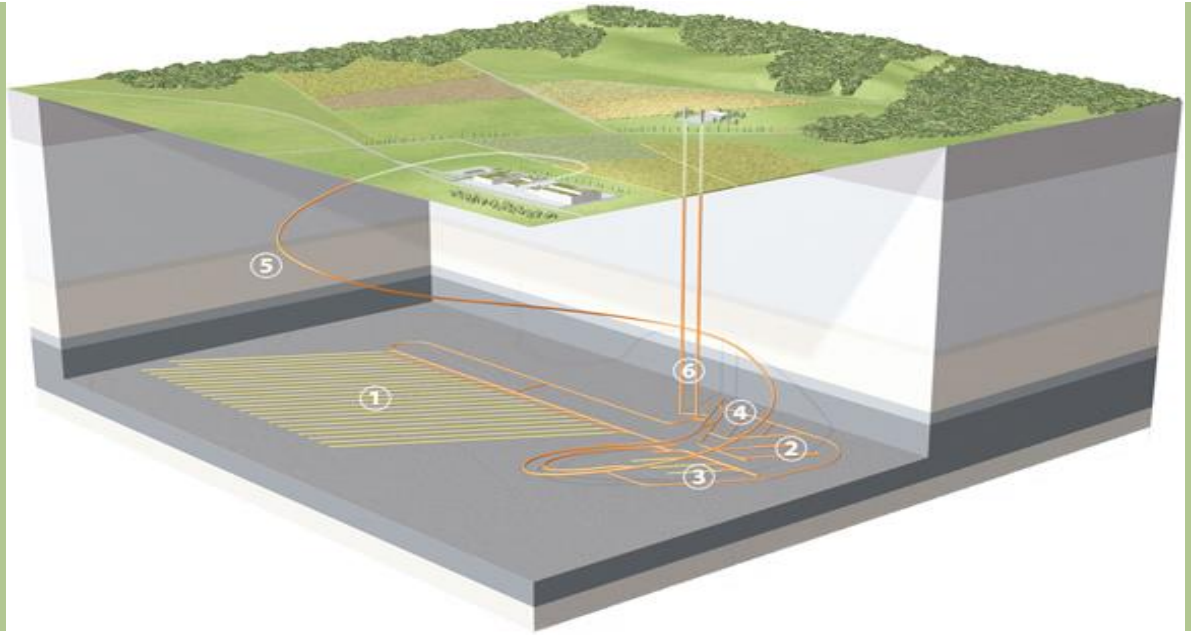
and will not be replaced

Other issue: management of high level nuclear waste is problematic



Spent fuel composition
Distribution (in kg per tonne of fuel) and mass produced by the principal radioactive elements present in fuel unloaded from an irradiated pressurised water reactor core.
©IPHC/IN2P3 (Source: Isabelle Billard)

Deep Geological Repository for High-Level Waste, the "only solution" ?



Heat + radioactivity

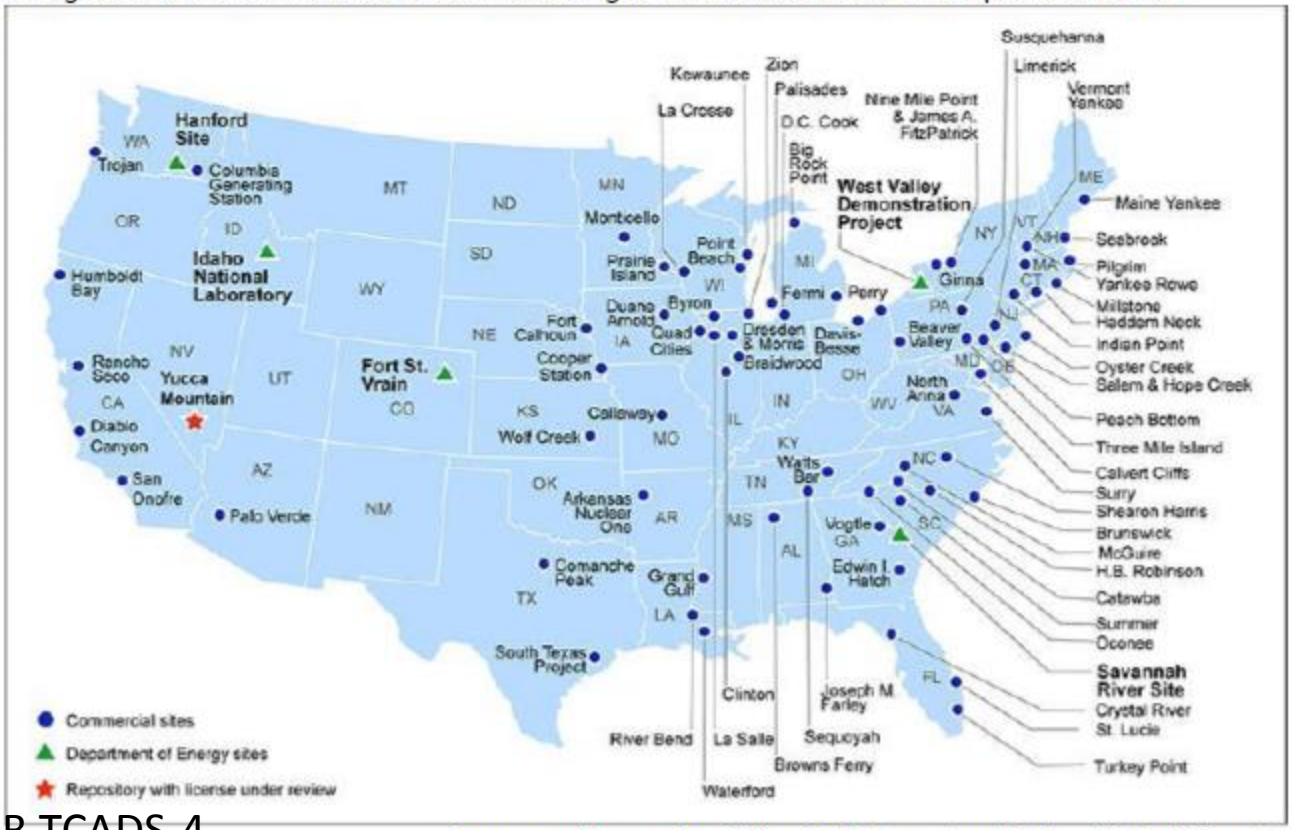
Half-lives:
Strontium-90 and cesium-137 about 30 years
Plutonium-239 24,000 years, Np, Am, Cm

Image: Infel AG, Claudio Köppel

Three possible sites being explored in Switzerland, but «the solution» may not be acceptable.

80 Temporary Storage Sites across 35 States

Storage Sites for Defense-Related and Commercial High-Level Radioactive Waste and Spent Nuclear Fuel



Source: Department of Energy | GAO-17-174

Government Accounting Office 2017 - Report on Nuclear Waste. Link-p.12

- Department of Energy 2009 estimate of temporary "on-site" storage of nuclear waste

$300,000/Ton - 100 year perio

GAO 2009 - Link-p.71

There are no "on-site" storag cost estimate for the lifetime of the waste, 300,000 years.

- Est. Cost of direct storage: $670,000 /Ton (CBO 2007 - Link-p.7)

- Est. Cost of reprocessing: $700,000 - $1,520K /Ton (ibid)

In 2018 $ from 2007 by Inflation Calculator

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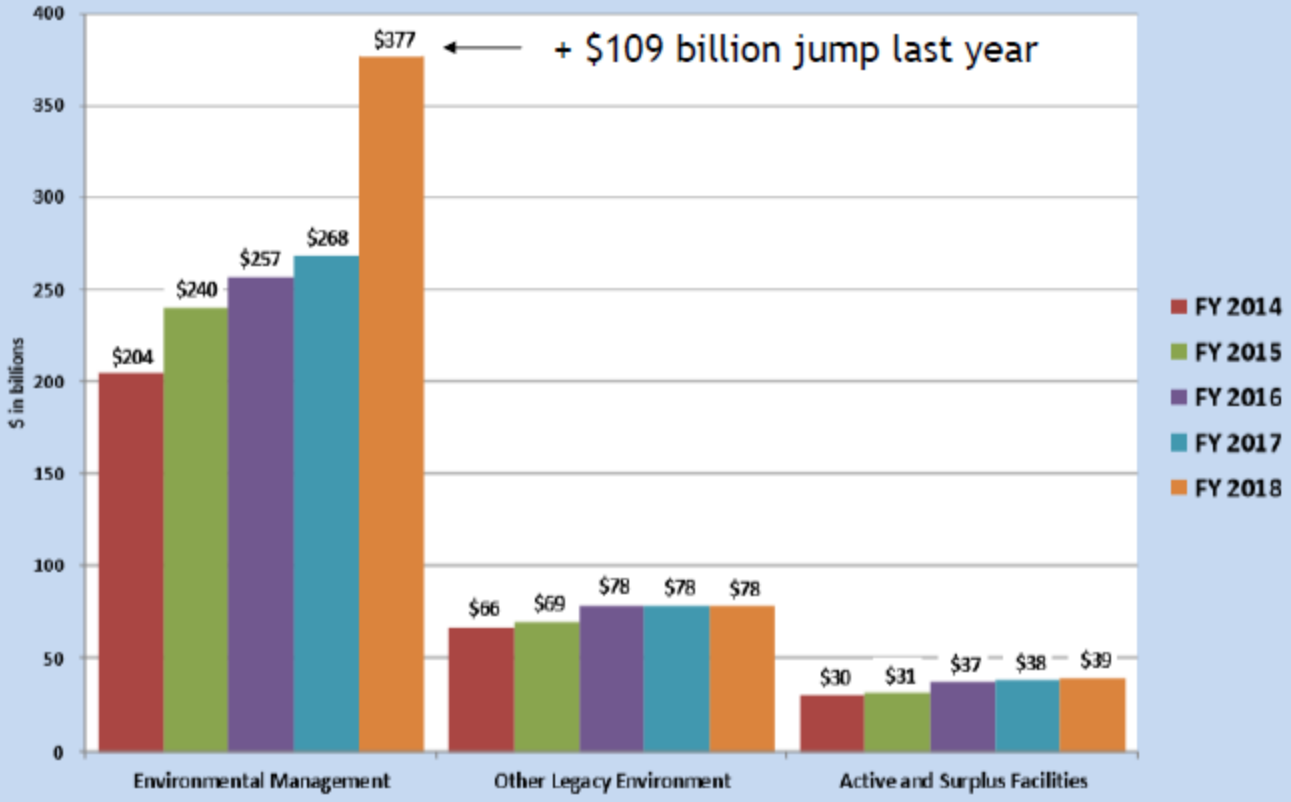
Out of Control Costs

Source: US Dept of Energy, 2018 Fiscal Year Report. Link-p.22

"Most of the department of Energy (DOE) environmental liabilities are managed by the Environmental Management (EM) program."

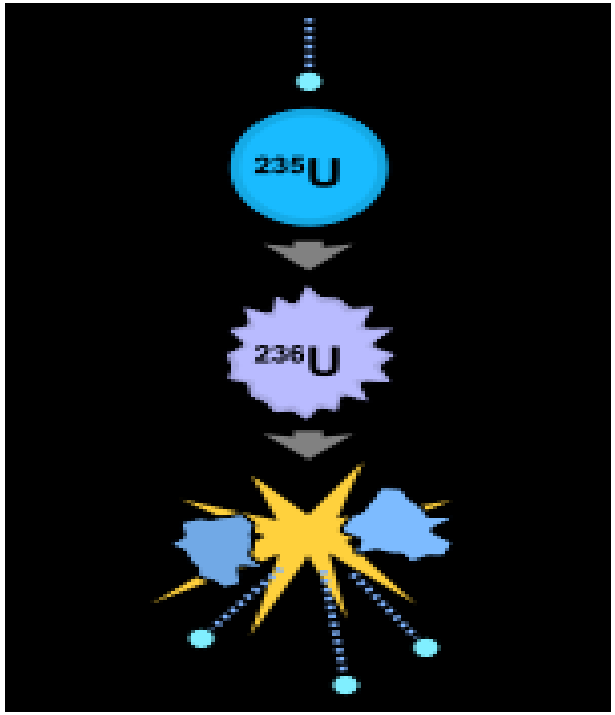
"It includes managing thousands of contaminated facilities…, overseeing the safe management of large quantities of radioactive waste and nuclear



Finding an alternative to uranium NPP

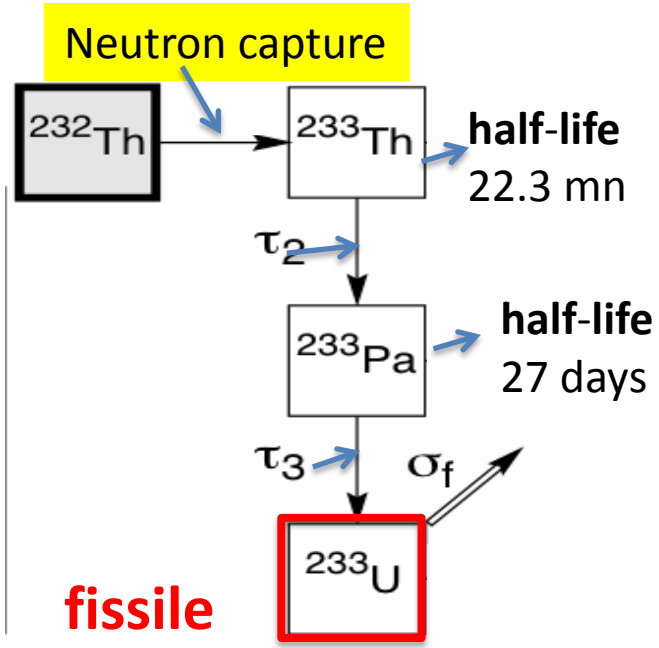
Fission of uranium

fissile

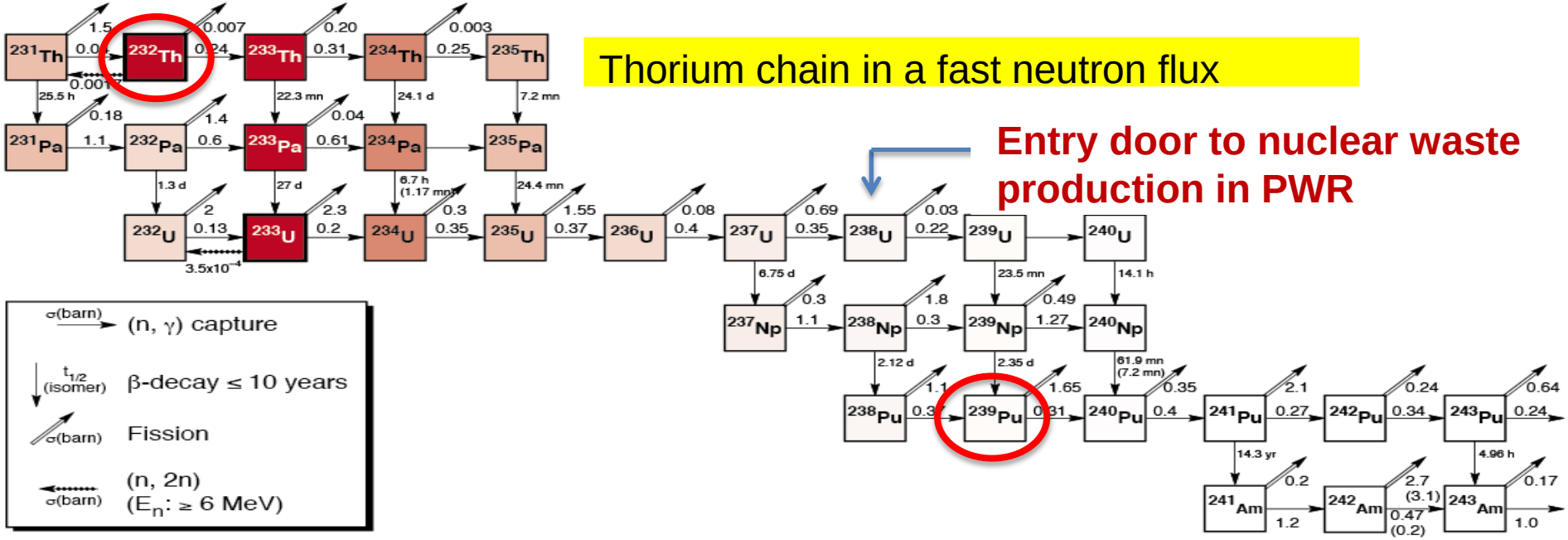


Thorium breeding

fertile



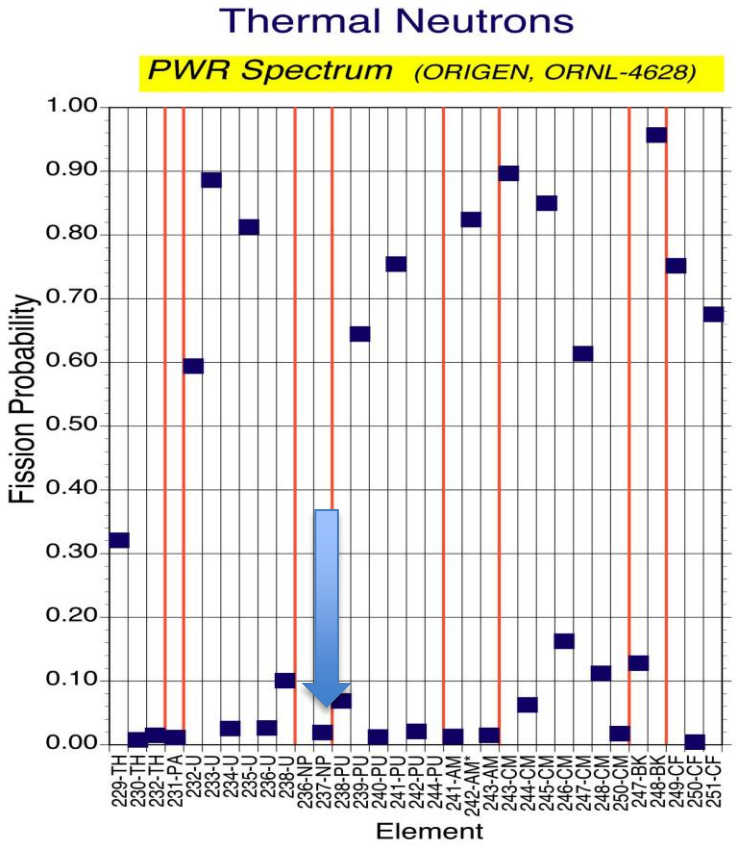
Thorium minimizes high level waste production

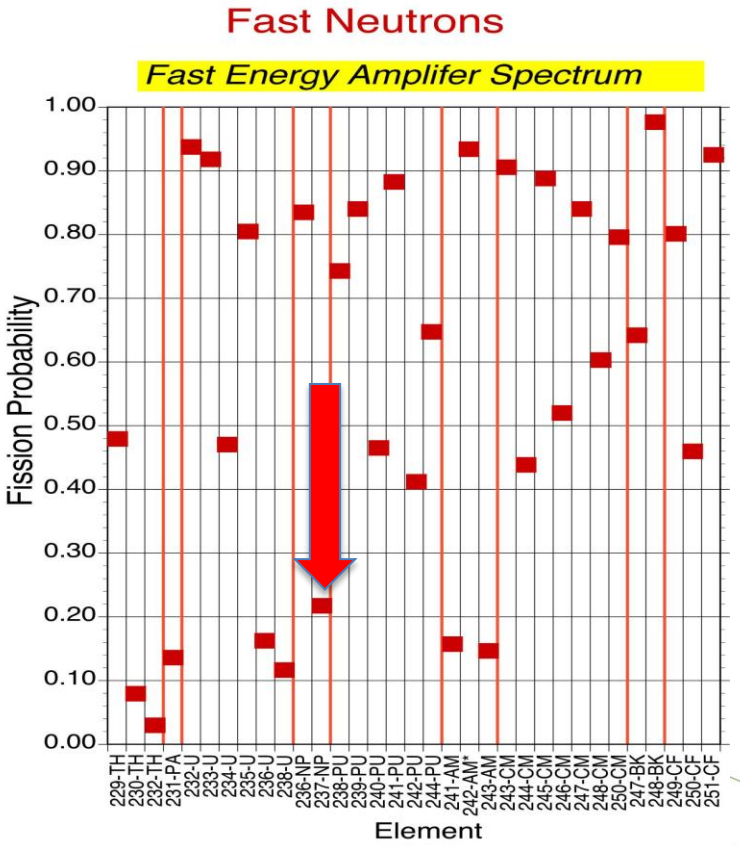


Thorium chain in a fast neutron flux

Entry door to nuclear waste production in PWR

Fast neutron spectrum enhances TRU fission probability



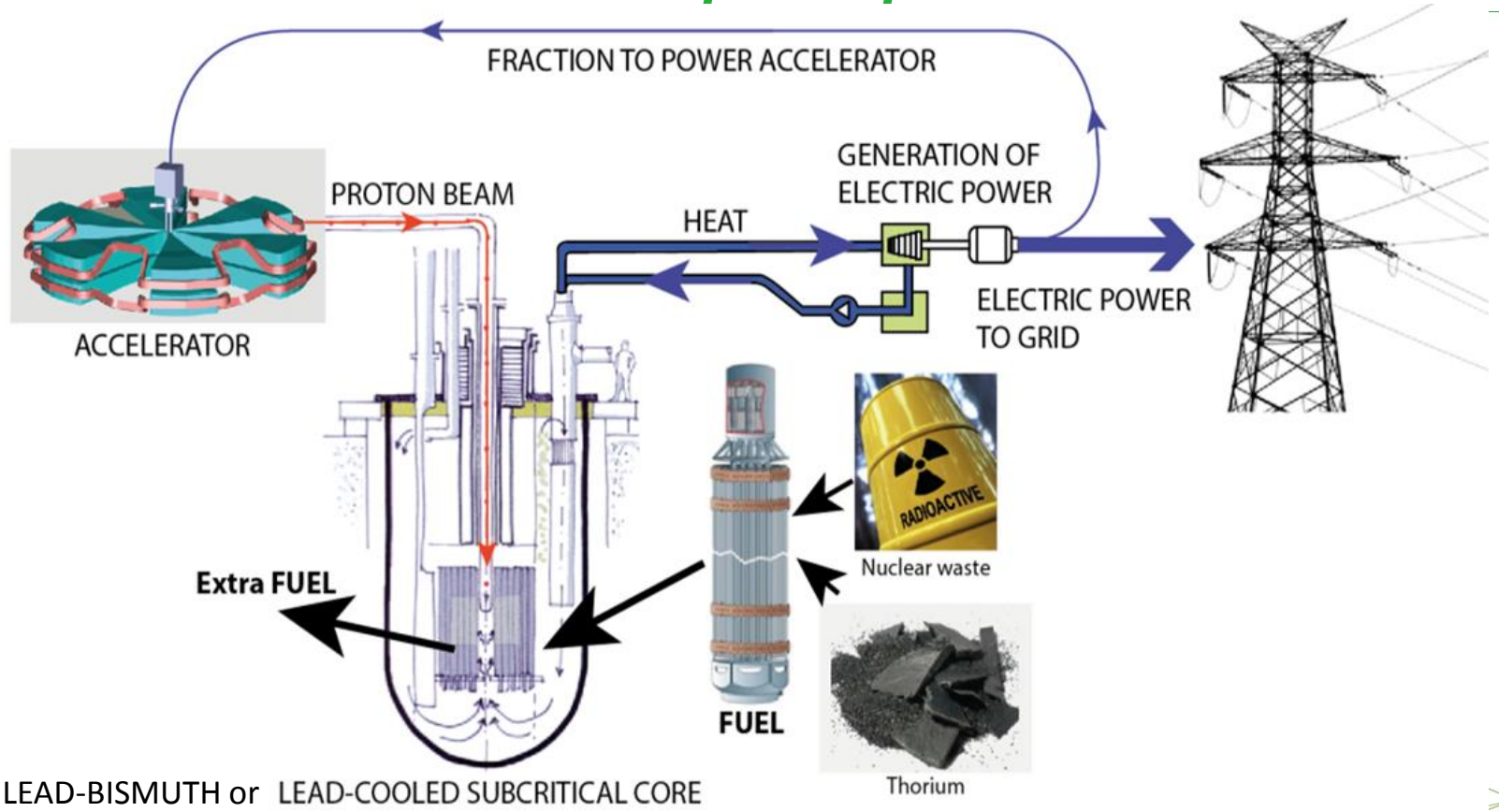


Comparaison of sources of fast neutrons, a recent Russian study

- In **fast neutron reactors,** for effective MA burnout, their concentration must be high:
  - High MA concentration leads to reactor reactivity issues
  - Fabrication of such high concentration fuel is very complex
  - Economic and exporting issues are almost impossible to handle
- **Hybrid thermonuclear installations** are fully unproven.
- Progress in accelerator technology, as well as in spallation target technology, makes the **ADS concept** realistic: an innovative approach to safety and waste management. R&D program EUROTRANS, state-of-the-art MYRRHA, CIADS…

The ambition of iThEC: participation to this scheme

AIMA Development



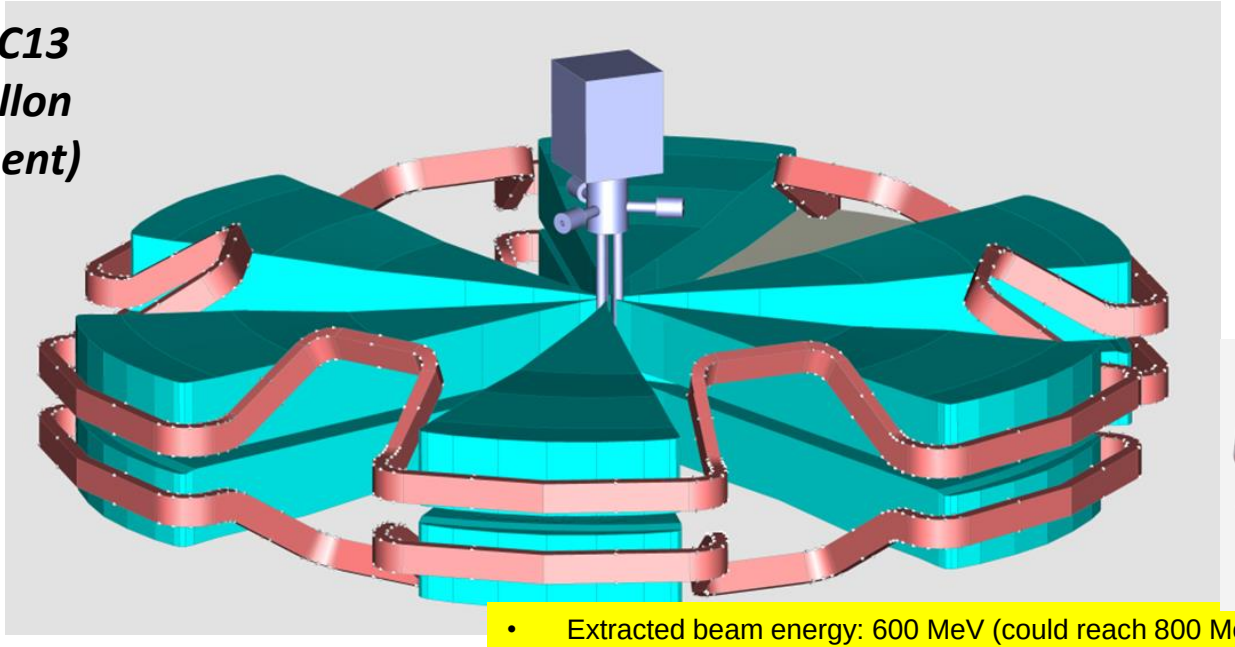
The accelerator: a key in the strategy

- A **cyclotron option is** the reasonable one
  - to power waste burners on many sites
  - avoid HLW transportation over large distances.
- The circular accelerator should have
  - High beam-power to grid-power efficiency (20-30 %)
  - Multiple injection systems for increased reliability and reduced beam trips
  - Small footprint and weight for investment cost reduction
  - Easier maintenance thanks to fewer parts, swappable cavities.
- We support efforts and collaborate with INFN Catania, AIMA Development, Paul Scherrer Institute…

Single Stage High Power Cyclotron for ADS

Innovative design: compactness, efficiency ,reliability, lower cost

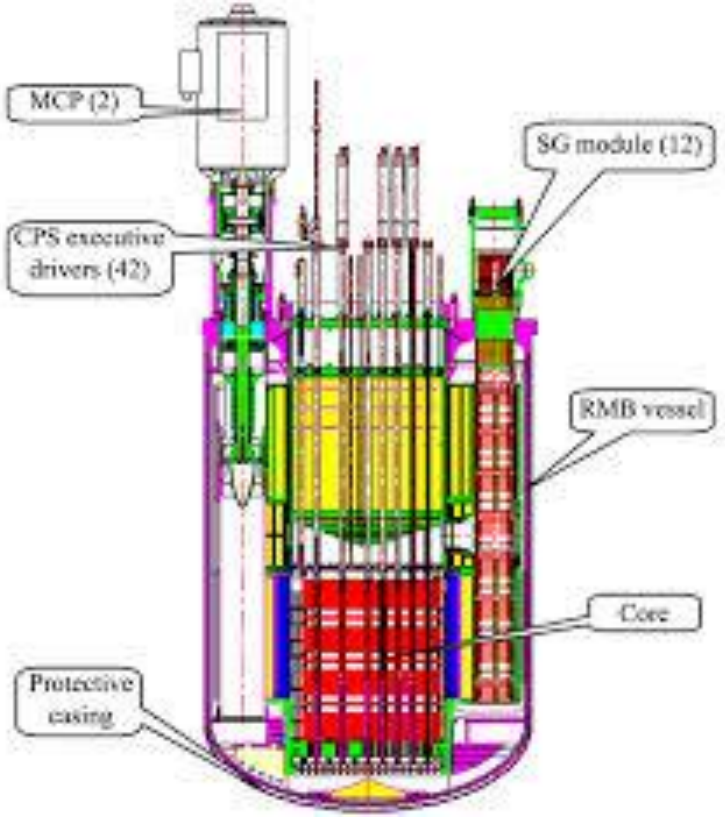
Presented at ThEC13
By Pierre Mandrillon
(AIMA Development)



- Extracted beam energy: 600 MeV (could reach 800 MeV), current: 6 mA
- Based on the reverse valley field concept
- Superconducting coil current density: 43.5 A/mm^2
- **Extraction radius: 4.5 m**
- 3 injection lines

HLM (Heavy Liquid Metal) cooled sub-critical reactors

- We support the efforts for the development of HLM as coolant. Excellent thermodynamic properties with low-pressure, chemically stable liquids.
  - The SVBR-100 reactor(Pb-Bi cooling) was in development in Russia, now in China
  - The BREST-OD-300 reactor (Pb-cooling) in Russia. More experiments and tests are required from regulatory authorities.
- Are reference designs, apart from the necessary modifications required by the positioning of a lead-bismuth target.



Reactor monobloc vessel of SVBR-100

Implementation of the iThEC scheme: three initiatives

1. iThEC initiated a proposal to Euratom

- With CERN*, CIEMAT (Sp), CVR (CZ), NINE (It), ENEA (It), University of Genova, Paul Scherrer Institute (CH), Hydromine (Lux), INFN, KTH (Sw), and the University of Stuttgart (G).
  * coordination
- The partners are studying **licensing issues for ADS** to smooth the way for their future development
- The project will concentrate on small modular reactors **(SMR's)** based on the scheme of iThEC

ADS SMR

SMRs are newer generation reactors designed to generate electric power up to 300 MWe, whose components and systems can be shop fabricated and then transported as modules to the sites for installation as demand arises (IAEA)

ADS SMR

- A large-scale commercial deployment of SMR is directly conditioned by the **economics of the technology**:
  - the ambition is to design a **cost competitive system** for transmuting HLW and other applications (electricity production at less than 5 cents/kWh).

- The analysis will include comparisons with standard SMR's and review:
  - Construction cost and cost of associated thorium fuel cycle;
  - Waste transmutation performance and other applications;
  - Evaluation of the social and political benefits;
  - Potential contribution to the energy mix scenarios envisaged for the future, highly country dependant.

2. iThEC promotes thorium ADS at level of governments

- Europe : meetings with government representatives
- Switzerland : report to ministry of Education, Research and Innovation
- Russian Federation : discussion with the government
- World Economic Forum: presentations

3. An early ADS experiment

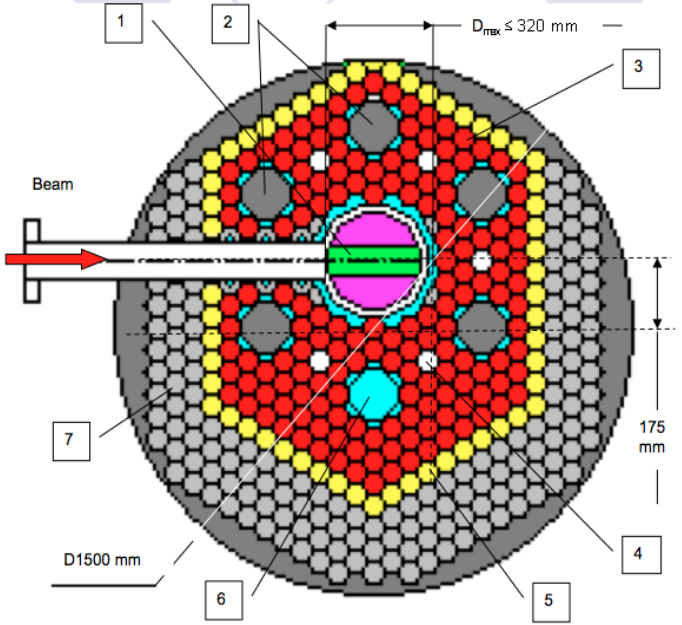
- The construction of industrial demonstrators have started with MYRRHA, CIADS et al.
- Given their very long time scale, there is a window of opportunity to make a major impact on the design, licensing and operation of ADS,
  - by experimenting earlier **the coupling properties between an accelerator and a fast neutron subcritical core**
  - **by defining procedures** that ongoing projects will only discover rather late in their program.
  - by demonstrating on a macroscopic scale **the efficient transmutation of Pu, MA & LLFP** with an ADS.
  - by testing various **thorium-based fuels** in a fast neutron spectrum

iThEC recognized that having an early ADS experiment could be a decisive and realistic possibility

At ThEC13 **Stanislav SIDORKIN** presented a proposal of an ADS experiment at Troitsk, Russia, using the Moscow Meson Factory, at the Institute for Nuclear Research.

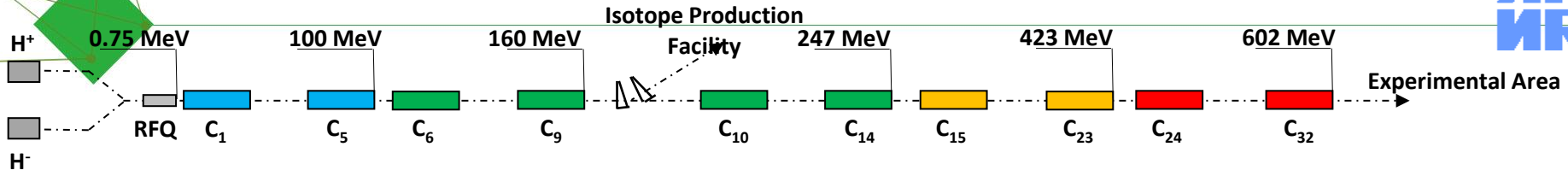
The modules with enriched fuel and MA would be manufactured, tested and studied after irradiation in the Institute of Physics and Power Engineering in Obninsk.

Conceptual scheme of research ADS



1 –target module;
2 – hermetical PbBi capsules with high enriched fuel and minor actinides;
3 – the cassettes of the water-cooled part of blanket with MOX fuel (~ 25% enr.);
4 – the module of controlled systems;
5 – decoupler (if it is required);
6 – traps of thermal neutrons (moderator) can construct in any place ;
7 – reflector.

The linear accelerator at INR Moscow



Low energy part of accelerator

5 Drift Tube Tanks

Frequency – 198.2 MHz

Output energy- 100 MeV

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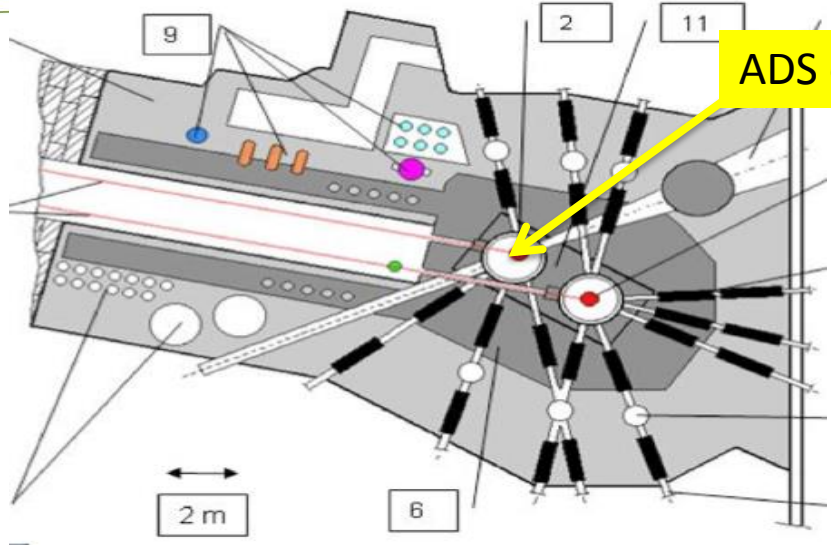
High energy part of accelerator

27 four-section Disk and Washer cavities

Frequency 991 MHz

Output energy- 600 MeV

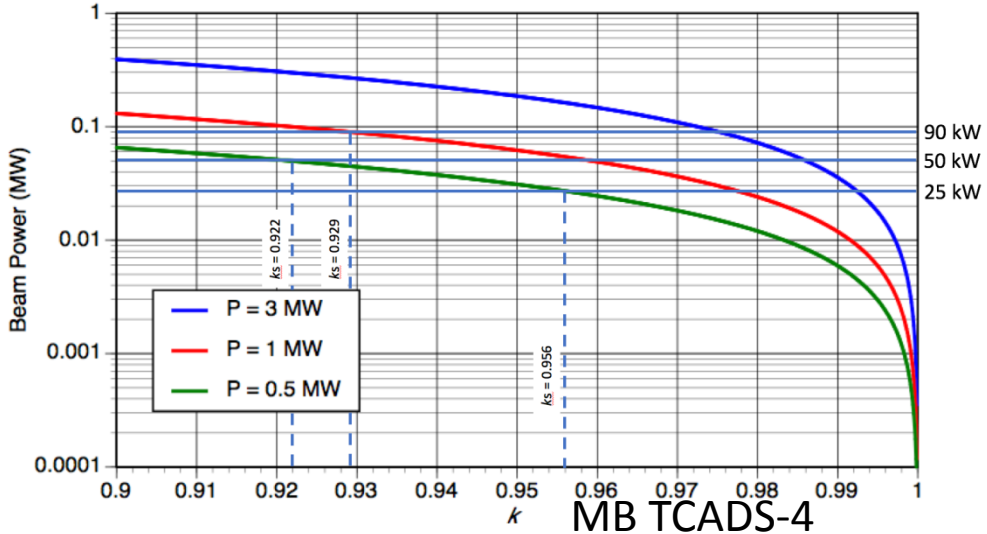
The existing infrastructure at INR Moscow



– Proton linear accelerator (≤600 MeV, ≤ 300kW)
– Spallation neutron source
– Pit on a beam line to receive a **subcritical core**
– Infrastructure to manipulate highly radioactive material
--cooling system and water treatment plant allow dissipating 30 MW

The main accelerator parameters

1. Increasing the energy to 300 MeV
2. Increasing the beam intensity
   - Beam pulse current: 15 mA (limit)
   - Beam pulse duration: 200 μs (limit)
   - Beam pulse repetition rate: increasing from 50 Hz to 100 Hz
3. Development, fabrication and replacement of the first DAW cavity (100÷113 MeV)
4. Installation of new beam line to the second compartment of neutron source.



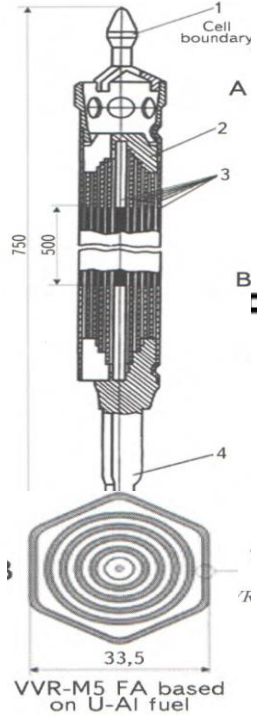
MB TCADS-4

With these achievable accelerator parameters the 1 MW line is realistic for k less than 0.98

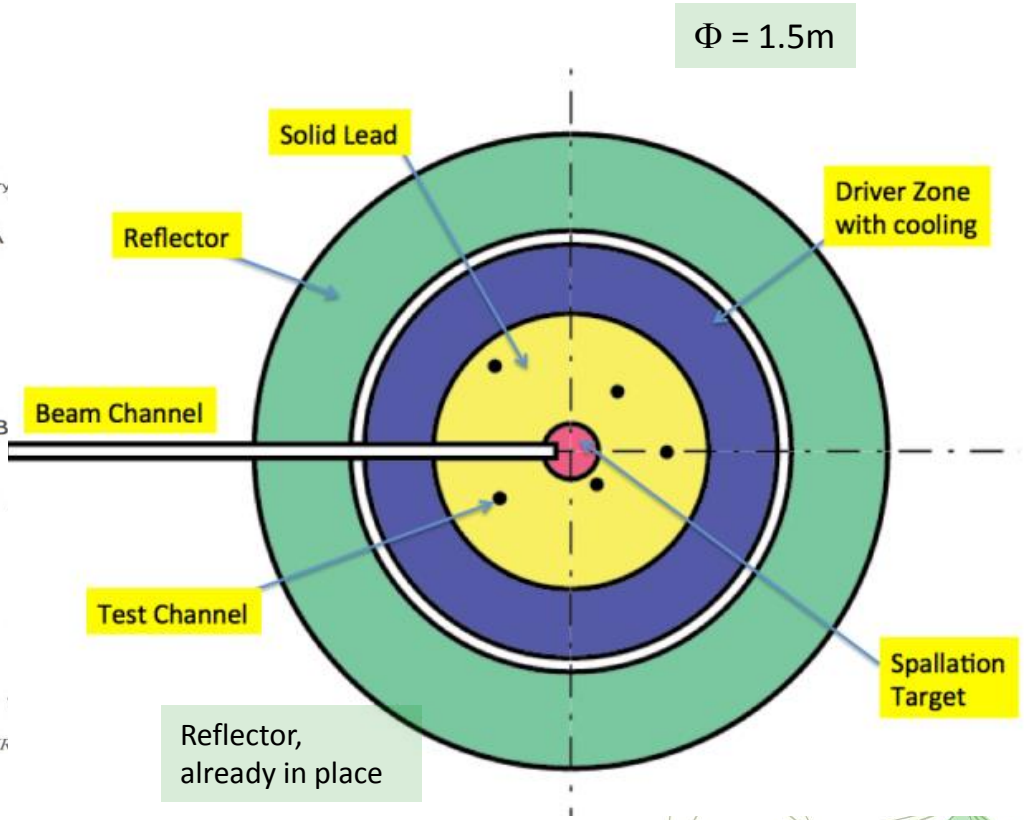
A simplified subcritical core concept

To be designed and submitted for approval to Russian safety authorities by ROSATOM specialized Agencies

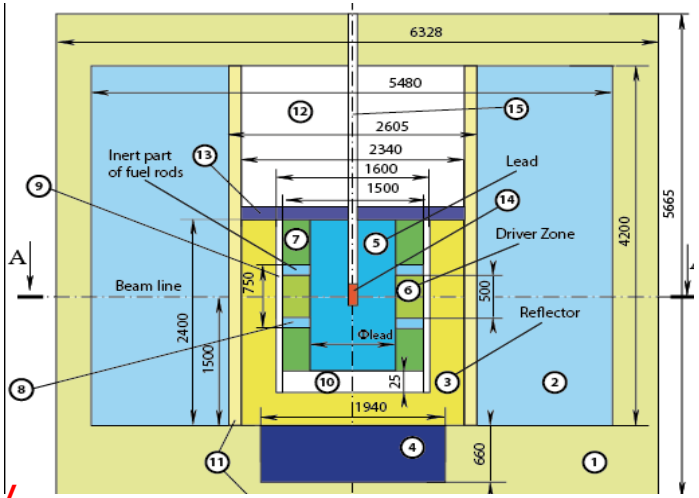
- **The tungsten target exists**
- Standard fuel assemblies from the Russian VVR-M research reactor: VVR-M2 (19.8% 235U) or VVR-C (36% 235U) instead VVR-M5 (90% 235U)

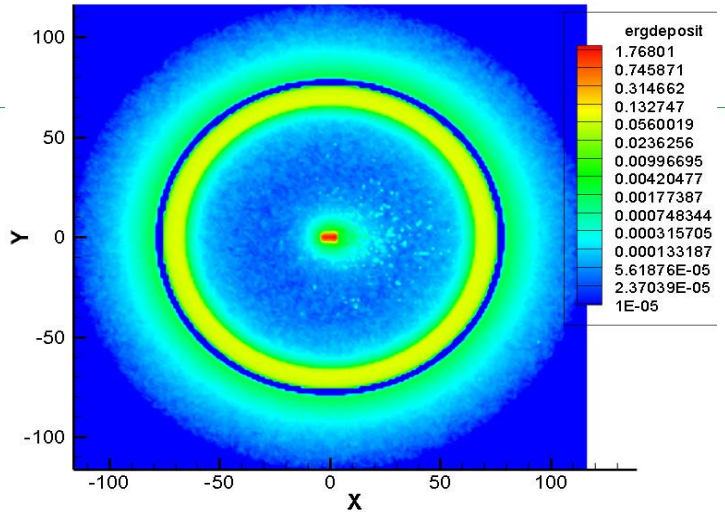


VVR-M5 FA based on U-Al fuel



Estimation of the basic parameters with ring blanket and lead diffusor





k_{eff} = 0.98

E_{proton} = 300 MeV

I_P~ 100 μA (30 KW)

Total power – 1.17 MW

Core - 1080 KW

W target - 25 KW

Reflector - 41 KW (38 KW – γ-rays)

Lead - 24 KW (22.7 KW – γ-rays

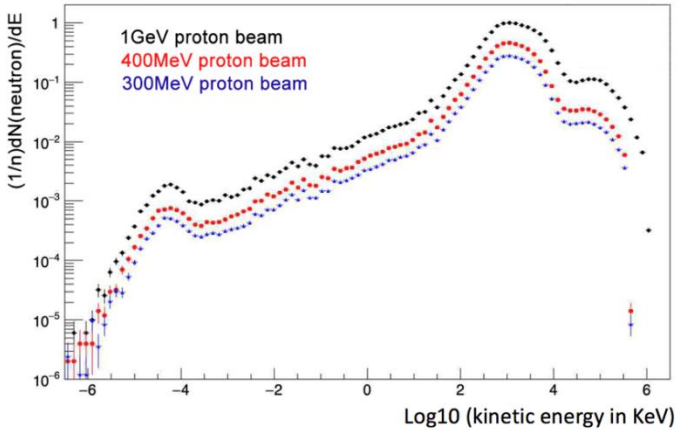


Figure 11: Energy spectrum of neutrons emerging from the target, as calculated by David Sangcheol Lee.

Work in progress

- **The optimization of the INR set up is ongoing**.
  - The goal is to optimize the probability for neutrons to reach the core, in order to produce 1 MW of power in the core at a neutron multiplication factor k value smaller than 0.98.
  - For a 100 µA proton beam current: a fast neutron flux in the Pb volume of about 10^{14} n/cm2/s for 1 MW core power output, very close to what you obtain in a full power reactor !!

- **Discussions with Russian authorities are progressing**
  - For more details, see **S.F. Sidorkin**, L.V. Kravchuk, A.V. Feschenko, E.A.Koptelov, and A.D. Rogov, Institute for Nuclear Research , Russian Academy of Sciences

Conclusions

We hope that the initiatives by iThEC can bring benefits to all ADS projects

iThEC is seeking fruitful collaborations with ADS-related projects around the world

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