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Proceedings of the International Symposium on Future of Accelerator-Driven System

(Ed.) Takanori SUGAWARA

Division of Nuclear Data and Reactor Engineering
Nuclear Science and Engineering Directorate

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Japan Atomic Energy Agency
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Division of Nuclear Data and Reactor Engineering,
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The international Symposium on "Future of Accelerator-Driven System" was held on 29th February, 2012 at Gakushi-Kaikan, Tokyo, Japan hosted by Nuclear Science and Engineering Directorate, JAEA (Japan Atomic Energy Agency) and J-PARC (Japan Proton Accelerator Research Complex) Center. The objectives of the symposium were to make participants acquainted with the current status and future plans for research and development of ADS in the world and to discuss an international collaboration for ADS and P&T (Partitioning and Transmutation) technology.

About 100 scientists participated in the symposium from Belgium, China, France, India, Italy, Japan, Korea and Mongol. In the morning session, current R&D activities of ADS in Japan were reported. In the afternoon session, current R&D activities were reported from China, Korea, India, Belgium and EU. A panel discussion took place with regards to the international collaboration for ADS at the final session. Two keynote speakers presented their outlooks on the topics and seven panelists and audience discussed those topics.

Keywords: Accelerator-Driven System, Transmutation, High-Level Radioactive Waste, Minor Actinide, J-PARC, International Collaboration, Symposium, Subcritical, Spallation Target

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国際シンポジウム「加速器駆動核変換システム（ADS）の将来」講演資料集

日本原子力研究開発機構　原子力基礎工学研究部門　核工学・炉工学ユニット
（編）菅原 隆徳

（2012 年 9 月 25 日　受理）

平成 24 年 2 月 29 日に、日本原子力研究開発機構 原子力基礎工学研究部門と J-PARC センターは、東京の学士会館で国際シンポジウム「加速器駆動核変換システム（ADS）の将来」を開催した。これは、世界における ADS 研究開発の現状と将来計画を紹介し、ADS および分離変換技術に関する国際協力について議論することを目的としたものである。本報告書は、シンポジウムで発表された資料を掲載するものである。

シンポジウムには、ベルギー、中国、フランス、インド、イタリア、日本、韓国、モンゴルから約 100 名の研究者らが参加した。午前中のセッションでは、日本における ADS 研究開発の現状が報告された。午後のセッションでは、中国、韓国、インド、ベルギー、EU における ADS 研究開発の現状が報告された。午後のセッションの後、7 人のパネリストによりパネルディスカッションが行われ、主に ADS 研究開発の国際協力について議論が行われた。

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1. Preface

After the earthquake and following tsunami of one year ago, people of the Tokyo Electricity Power Company and other institutes have well-managed the damaged reactors and contaminated water in the turbine buildings. Now, the reactors are in the cold-shutdown condition, while there are some fluctuations due to trouble of temperature sensors. The contaminated water is purified by absorbents and circulated to the reactor. So, total amount of contaminated water is controlled.

However, we have still many things to do such as to discharge damaged fuels, to dismantle reactors, to store absorbent for the contaminated water, and, to dispose of radioactive wastes. Moreover, for out of Fukushima-daiichi site, there is large area to be decontaminated. JAEA continues to cooperate on these activities by simulating reactor behavior after accident, investigating properties of absorbents, simulating diffusion of radioactive particles in air, and so on.

The impact of the quake on Japanese strategy of nuclear power was also large. Almost all of the nuclear power plants are under maintenance without any confirmed schedule of restarting. The long-term strategy of nuclear power plants is being re-assessed and R&D for the fast breeding demonstration reactor is to be suspended. The situation of the nuclear energy is very difficult now in Japan, but, I believe nuclear energy is still promising and indispensable for Japan, because we do not have any other reliable energy resources in the near future. The fossil fuels are limited and discharge global warming gas. Green energies are not yet enough in quantity and quality.

It is very important to hurdle the Fukushima-Daiichi accident, and ensure the safety of current reactors based on this experience to make progress of nuclear energy. Moreover, one of the subjects of nuclear energy which should be solved is high level and long-lived radioactive waste disposal that is common in the nuclear power countries. It is known that some countries, for example, Finland and Sweden, have a plan of direct disposal of spent fuels. Japan has had a policy to reprocess spent fuels from nuclear power plants and to re-use plutonium so as to save limited uranium resources.

If Japan decides to keep this “reprocessing policy”, the first commercial reprocessing plant constructed in Rokkasho-mura will be operated. It will discharge 800 pieces of vitrified waste forms of high level waste every year. Japan’s current national policy for the high level waste is to dispose of them into deep geological repository.

The partitioning and transmutation technology of high level and long-lived waste is considered to have a potential to reduce the burden of the waste disposal. Former JAERI launched research and development of this technology in 1980s. In Japan, the OMEGA project also started in 1988 to promote R&D of the partitioning and transmutation technology as an optional measure for the backend technology. In these activities, JAEA has played an important role in the research and development of Accelerator Driven Transmutation System, ADS, as a powerful tool to incinerate minor actinide, while partitioning technology has been developed and many basic researches such as research activities for MA-nitride fuel are in progress in JAEA.

JAEA and KEK, High Energy Accelerator Research Organization, have launched "J-PARC" which is an abbreviation of Japan Proton Accelerator Research Complex. The project team has completed to construct 1st phase of this project in 2007. After that, they has started to supply neutron beam in the MLF, materials and life science experimental facility, successfully accelerated protons to 3 GeV, and observed production of neutrino from the Hadron experimental hall. When the earthquake occurred, the J-PARC was operated, but there was no significant damage on staffs and main buildings. After the quake, we inspected the facility, repaired some equipment and road, re-aligned accelerators, and finally, started test operation at the end of 2011.

Under the framework of J-PARC, there is a plan to build the TEF, Transmutation Experimental Facility. Unfortunately, construction of this facility has not been financially approved yet. However, the J-PARC project is now starting new phase after review of the IAC and Japanese government. In the new phase, to construct a part of the TEF and to design and get approval of the critical assembly with Pu and MA fuels are considered. It is expected that this facility will be constructed as the center of excellence for ADS project under the international cooperation by consolidating the powers and the dreams of young scientists and engineers gathering here.

In terms of the development of the ADS, it is not so easy for one country to complete it independently. The ADS is a hybrid system of the nuclear reactor and the accelerator, so it is absolutely necessary to unite international research resources by the cooperation among many fields such as accelerator physics, nuclear physics, nuclear engineering, and material science. International cooperation and the multidisciplinary synergy are particularly required and useful in the development of ADS.

It is well known that European countries carry out many projects successfully and effectively. Especially, in EUROTRANS project under FP6 and following CDT project under FP7, there is great effort to design the demonstration reactor for transmutation. For Asia, the energy consumption must show a significant growth in the 21st century and the nuclear power is surely required to cover certain part of the energy production. Therefore, the management of high level waste should become a major issue even in Asian countries. The Asia ADS Network was initiated in 2003 and has had 9 workshops so far in China, Korea and Japan.

In this symposium, several presentations about R&D in each country and panel discussion about the future of the ADS were programmed. This symposium is organized by Nuclear Science and Engineering Directorate, JAEA and J-PARC Center aiming at the enhancement of the national/international collaborations.

(This preface was based on the opening remarks by Dr. Hideaki YOKOMIZO, Executive Director, JAEA)

2. Summary

2.1 Outline of the Symposium

The international Symposium on “Future of Accelerator-Driven System” was held on 29th February, 2012 at Gakushi-Kaikan, Tokyo, Japan hosted by Nuclear Science and Engineering Directorate, JAEA (Japan Atomic Energy Agency) and J-PARC (Japan Proton Accelerator Research Complex) Center. The objectives of the symposium were to make participants acquainted with the current status and future plans for research and development of ADS in the world and to discuss an international collaboration for ADS and P&T (Partitioning and Transmutation) technology.

About 100 scientists participated in the symposium from Belgium, China, France, India, Italy, Japan, Korea and Mongol. After the opening remarks by Dr. H. Yokomizo (Executive Director, JAEA), Dr. A. Arima (President of Musashi Gakuen) who is the Former Minister of Education of Japan, made the speech “Expectation for Transmutation Technology” as the special session. In the morning session after the special session, current R&D activities of ADS in Japan were reported. In the afternoon session, current R&D activities were reported from China, Korea, India, Belgium and EU. A panel discussion took place with regards to the international collaboration for ADS at the final session. Two keynote speakers presented their outlooks on the topics and seven panelists and audience discussed those topics.

Secretariats of symposium:
Kazufumi TSUJIMOTO, Hayanori TAKEI, Shigeru SAITO, Hironari OBAYASHI, Kaori MAKI, Yuji KURATA, Kenji NISHIHARA, Takanori SUGAWARA, Hiroki IWAMOTO, Chiho TAKAHASHI

2.2 Brief Summary of Presentations

Dr. A. Arima, who is the president of Musashi Gakuen and Former Minister of Education in Japan, spoke about the expectation for the transmutation technology. Renewable energy and nuclear power will be the last option as energy sources, so the international cooperation is urgent and indispensable to investigate the final disposal method, to decide the final disposal site, and to develop the technologies for decommissioning nuclear reactors.

Dr. H. Yamana from Kyoto University in Japan presented the back-end issues of the Japanese nuclear utilization being discussed. Japan is re-making the energy policy with a drastic restructuring of nuclear energy policy after the Fukushima accident. Though it is not explicit now, Partitioning and Transmutation (P&T) and ADS developments have a meaning, in a sense of "flexibility of the scenario" and of "technological answer to the publics who have doubts on the safety of nuclear systems".

Dr. K. Tsujimoto from JAEA in Japan reported the present status of R&D on Accelerator Driven System in JAEA. In Japan, the Check and Review (C&R) on P&T by the Japan Atomic Energy Commission was held, and JAEA will continue the R&D activities on P&T technology and ADS.

Dr. T. Misawa from Kyoto University in Japan presented the reactor physics experiments on ADS using KUCA and the future plan for ADS Neutron Source at Kyoto University Research Reactor Institute (KURRI). As the future plan, the upgrade of FFAG (Fixed Field Alternating Gradient) accelerator system and ADS experiments with hard neutron spectrum are considered.

Dr. L. Yang from CAS (Chinese Academy of Sciences) in China explained the progress of Chinese ADS system. In the roadmap of CADS (Chinese ADS) facility, an experimental facility (0.8GeV proton beam, 100MWt core) and a demo facility (1.5GeV proton beam, 800MWt core) would be constructed by 2022 and 2032, respectively.

Dr. S. W. Hong from Sungkyunkwan University in Korea reported the R&D status of ADS in Korea. The laboratory of Sungkyunkwan University is performing the R&D for the partitioning of Sr-90, transmutation of LLFPs, life cycle assessment of ADS and so on.

Dr. P. K. Nema from BARC (Bhabha Atomic Research Centre) in India presented the plans and present status for ADS in India. In India, the ADS would sustain thorium utilization in U-233 recycle mode for thermal, and with high fuel burn up in one-through mode in fast reactors.

Dr. P. Baeten from SCK-CEN (Belgian Nuclear Research Center) in Belgium reported the advanced nuclear systems with P&T in Europe and role of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications). The R&D related to the MYRRHA project proceeds smoothly and its construction will be judged in 2015.

Dr. B. Frois from CEA in France talked about a brief overview of nuclear power in France and in Europe. Fukushima is a terrible accident and all nations have realized the need for a new approach to safety and sustainability. So, nuclear fuel cycle is one of the most important issue and the ADS has a major window of opportunity.

2.3 Summary of Panel Discussion

Dr. Y. Ikeda from JAEA chaired the panel discussion. The aim of the panel discussion was divided into two categories: the international collaboration and the collaboration with other areas and fields.

As for the international collaboration of ADS, Dr. H. Xia from SNPRI (State Nuclear Power Research Institute) in China gave a keynote talk. He pointed out that the technology challenges for ADS spread over very wide range of scientific and engineering fields, however, the ADS society is small. It is very important to share the information, the experience and the R&D effort in a well-organized way.

Dr. P. K. Nema from BARC in India mentioned that the framework for the international collaboration, like the ITER project, was desirable.

Dr. P. Baeten from SCK･CEN in Belgium mentioned that the technical issues as the collaboration expanded to the linear accelerator and the Pb-Bi technology.

As for the collaboration with other areas and fields, Dr. S. Yamashita from the University of Tokyo in Japan gave a keynote talk. He has a strong desire to design together the ADS R&D facilities such as J-PARC transmutation facility and to share ideas from the viewpoint of particle and nuclear physics, medical usage and so on. Step by step and visible progress are necessary, especially for young scientists. AAA (advanced accelerator association) is ready to cooperate the promotion of the ADS transmutation projects in Japan and in the world.

Dr. H. Oigawa from JAEA in Japan mentioned that the collaboration with other fields is very useful to attract young researchers and engineers. To attract these people, it is also necessary to construct the consistent roadmap for the ADS development under taking unique approaches with many countries based on their original idea.

Prof. S. W. Hong from Sungkyunkwan University in Korea, mentioned that almost everybody agrees with an international collaboration but it is difficult to think about how to collaborate. Because each country has its own apparatuses and different situation. He suggested that we should make some platform or working-group and discuss about what kind of international collaboration can be done.

Dr. Y. Ikeda mentioned that it is the common sense to have good collaboration and we are more seriously going to talk about how to proceed.

Prof. T. Misawa from Kyoto University in Japan mentioned that each country should continue its own researches of ADS before starting international collaboration. Without the researches, an international collaboration can't be successfully achieved.

Dr. H. Oigawa asked Prof. Hong that the working-group which he said, was voluntary base or working-group under IAEA. Prof. Hong answered that it would be a voluntary base one in the initial stage. And then, we would make some kind of framework and make realistic plan from there.

Dr. B. Frois from CEA in France commented that regardless of the scale, it's better to make a framework at beginning. He also asked to Prof. Hong what framework do you suppose? Prof. Hong answered that in the initial stage, we need a place where we can discuss about what to do freely and openly. Before making a real organization like the ITER project, it's better to have an open environment in volunteer level meeting.

Prof. S. Nagamiya from J-PARC in Japan mentioned that there are a long-term issue, for instance, the construction of the ADS plant, and today's issue like the J-PARC project. We should classify many issues into the long-term one or the today's one, very quickly. We can start the discussion about the long-term issue.

Dr. P. K. Nema pointed out that the scale could be very different, so a type of collaboration depends on that. We have to analyze what types of frameworks or consortiums have worked out in the past. We also have to analyze an efficiency of the consortiums. There are many different options and many factors which we have to take into account.

Prof. S. Nagamiya mentioned that the idea which Dr. P. K. Nema said is very important. We should discuss it as the long-term issue but at the same time, we should not stop to consider the today's issue

Closing

Prof. S. Nagamiya stated closing talk about the situation of J-PARC and scheme of the transmutation facilities.

2.4 Achievement of the Symposium

This symposium was programmed to introduce the current status and future plans of ADS in the world. The R&D programs of China and India were ambitious and the progress of MYRRHA project in Belgium was impressive. The achievement of the symposium was that the common understanding among each country was enhanced through the discussion and information exchange.

In the panel discussion, there were many positive opinions and comments to make a new framework of the ADS R&D although a specific agreement was not reached, unfortunately. Through the panel discussion, all participants shared the problems of the ADS development and the necessity of an international collaboration framework. It is important to continue the information exchange and the discussion with each country and make an effort to create a new framework of the ADS R&D.

3. Presentation Materials

3.1 Expectation for Transmutation Technology

A. Arima (Former Minister of Education in Japan)

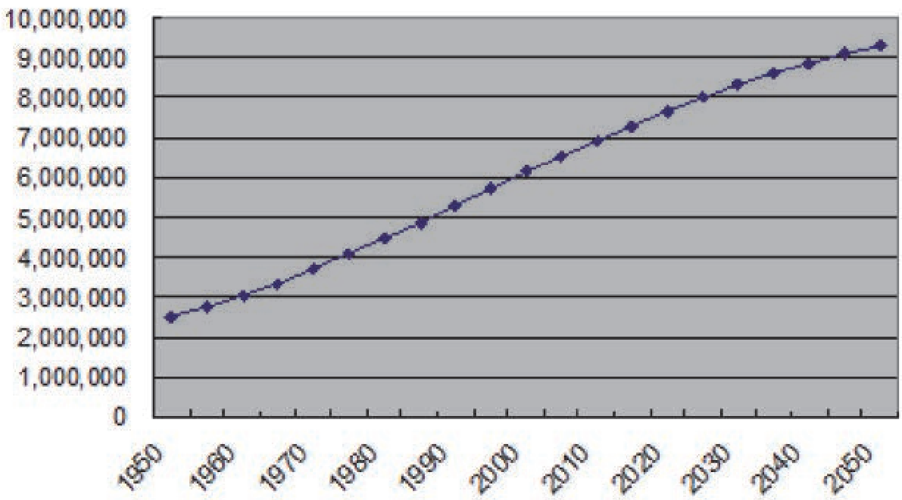
Expectation for Transmutation Technology

Akito Arima
President
Japan Radioisotope Association

1 The biggest issue facing humanity

The sharp rise in the world's population

Fig. 1 Estimation of World Population (medium variant)



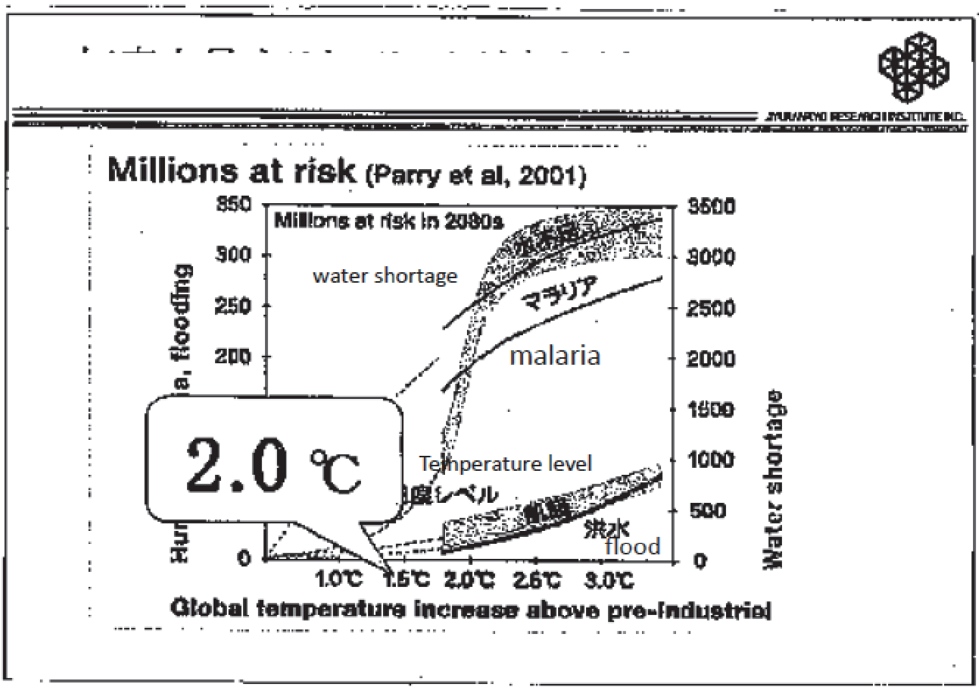
Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2010 Revision, http://esa.un.org/unpd/wpp/index.htm

2 The second big problem

Global warming

The earth's temperature increased by 0.8℃ during the 20th century. In these years, this increased further up to 1.1℃.

What's Marginal Temperature increase when Risk grows?



It was a great mistake to show the hockey-stick picture in the third report of the IPCC in 2001.

This mistake triggered the climate-gate in 2009.

So many papers which criticized the theory that the global warming is caused by CO_2 emitted by human activities.

Even though from the results of skeptic data, *the gap* in late years is so apparent with careful and simply watching from a long-term viewpoint

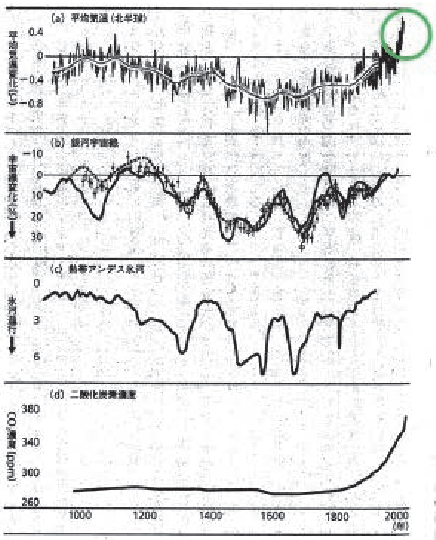


図1−11　過去1200年間の北半球平均気温(a)、銀河宇宙線強度(b)と熱帯アンデス氷河の消長(c)の経時変化。これらの変動は細部に到るまでよく対応している。平均気温は図1−1(b)と同じもの、宇宙線強度は炭素同位体^{14}Cとベリリウム同位体^{10}Beから得られた結果をまとめたもの（カークビー 2007)。比較のため、二酸化炭素濃度の変化(d)を示しておく

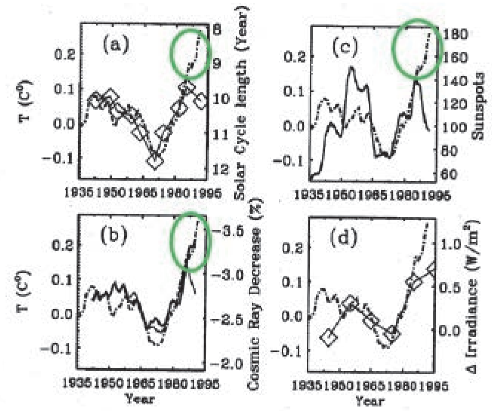


FIG. 3. 11 year average of northern hemispheric marine and land temperatures (dash-dotted line) compared with (a) unfiltered solar cycle length; (b) 11 year average of cosmic ray flux (from ion chambers 1937–1994, normalized to 1965), thick solid line; the thin solid line is cosmic ray flux from Climax, Colorado neutron monitor (arbitrarily scale); (c) 11 year average of relative sunspot number; (d) decade variation in reconstructed solar irradiance (zero level corresponds to 1367 W/m^2, adapted from Lean *et al.* [6]). Note the 11 year average has removed the solar cycle in (b) and (c).

深井有、2011，中公新書　(Svensmark, 1998. Phys. Rev.Lett.)

IPCCの(地球科学的基礎に関する)主要な結論

(1) 気候システムの温暖化には疑う余地がない。このことは、大気や海洋の世界平均温度の上昇、雪氷の広範囲にわたる融解、世界平均海面水位の上昇が観測されていることから今や明白である。

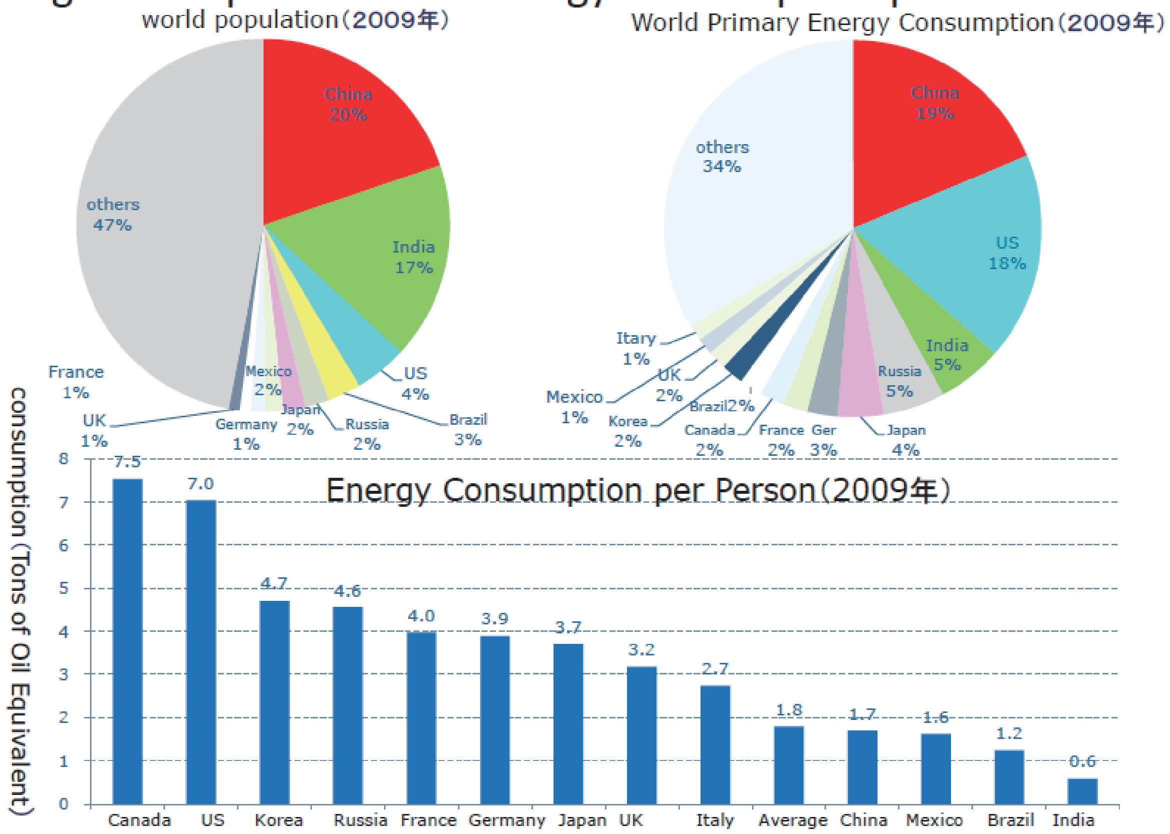
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

(2) 20世紀半ば以降に観測された世界平均気温のほとんど(大部分)は、人為起源の温室効果ガス濃度の観測された増加によってもたらされた可能性が非常に高い。

Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

8

Regional Population and Energy Consumption per Person



出典:IEA Energy Balances of OECD /NON-OECD Countries 2011

The third big problem

The depletion of fossil fuels

The fall of the civilization based n fossil fuels

Table: How Long Will the World's Energy Resources Last?

	Oil	Natural Gas	Coal	Uranium
Proven Recoverable Reserves (R)	1,237.9 billion bbls (end 2007)	177 trillion m^3 (end 2007)	847.5 billion tons (end 2007)	5.47 million tons (Jan. 2007)
Annual Production (P)	29.8 billion bbls (2007)	2.94 trillion m^3 (2007)	6.4 billion tons (2007)	2006 consumption 40,000 tons, 2006 demand 66,500 tons
Reserve/Production Ratio (R/P)	41.6 years (2007)	60.3 years (2007)	133 years (2007)	81.6 years* (2007)
Source	BP Statistical Review of World Energy 2008	BP Statistical Review of World Energy 2008	BP Statistical Review of World Energy 2008	URANIUM 2007 (OECD/NEA/IAEA)

* There are inventories of uranium so annual production is less than demand. For this reason, the Reserve/Production Ratio is calculated by dividing Proven Recoverable Reserves by Annual Demand.

Most of the large scale damage was due to the tsunami on March 11, 2011.

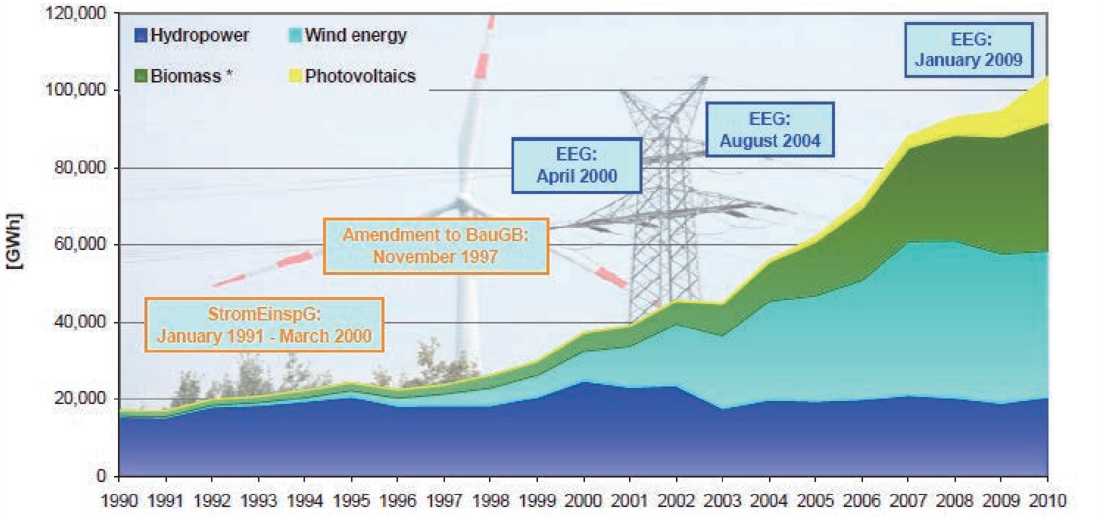
The accident at the Fukushima Daiichi Nuclear Power Station was caused by the tsunami, which overwhelmed anti-flooding measures.

Renewable energy

Germany began a program of purchasing all power produced from renewable sources.

As a result, over ten years, new energy made up 17% of all electric power generation in 2010, equal to some 80 billion kWh per annum, which if combined with hydroelectric power, puts power generation from renewable sources at about 100 billion kWh.

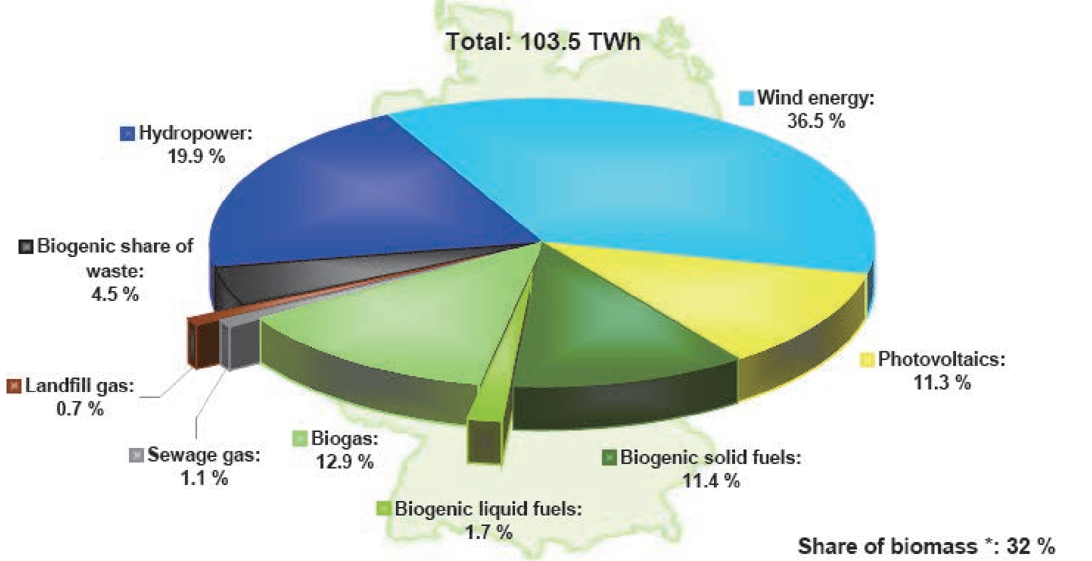
Contribution of renewable energy sources to electricity supply in Germany



* Solid and liquid biomass, biogas, sewage and landfill gas, biogenic share of waste; electricity from geothermal energy not presented due to negligible quantities produced; 1 GWh = 1 Mill. kWh; StromEinspG: Act on the Sale of Electricity to the Grid; BauGB: Construction Code; EEG: Renewable Energy Sources Act; Source: BMU-KI III 1 according to Working Group on Renewable Energy-Statistics (AGEE-Stat); image: BMU / Christoph Edelhoff; as at: July 2011; all figures provisional

BMU – KI III 1 Development of renewable energy sources in Germany in 2010 14

Structure of electricity supply from renewable energy sources in Germany 2010



* Solid and liquid biomass, biogas, sewage and landfill gas, biogenic share of waste; electricity from geothermal energy not presented due to negligible quantities produced; deviations in the totals are due to rounding; 1 TWh = 1 Bill. kWh; Source: BMU-KI III 1 according to Working Group on Renewable Energy-Statistics (AGEE-Stat); as at: July 2011; all figures provisional

BMU – KI III 1 Development of renewable energy sources in Germany in 2010 15

Japan’s total annual electric power generation in 2009 was about 1 trillion Kwh of which nuclear power production was 280 billion kWh.

80 billion Kwh per annum in Germany produced by new energy is about 8% of Japan’s total annual electric power generation, and about 30% of Japan’s total annual power generation from nuclear power.

The Japanese government's renewable energy power purchasing program, which has been introduced in 2011, is expected to achieve only 50 billion Kwh per annum in 2021.

Only 5% of total annual electric power generation in Japan. Too small !

With these slow ratio of development of renewable energy, Japan and even Germany cannot have time to battle against global warming.

We have to use nuclear energy with high safety considering the risk against particularly earthquakes, tsunami and terrors together with renewable energy.

The use of nuclear energy have two essential issues; how to manage

1 A final disposal of spent nuclear fuels and

2 decommission of used nuclear reactors

Only Finland and Sweden determined the final disposal sites of spent nuclear fuels

It is extraordinary abnormal that we don't yet have the decommissioning (backend) technology.

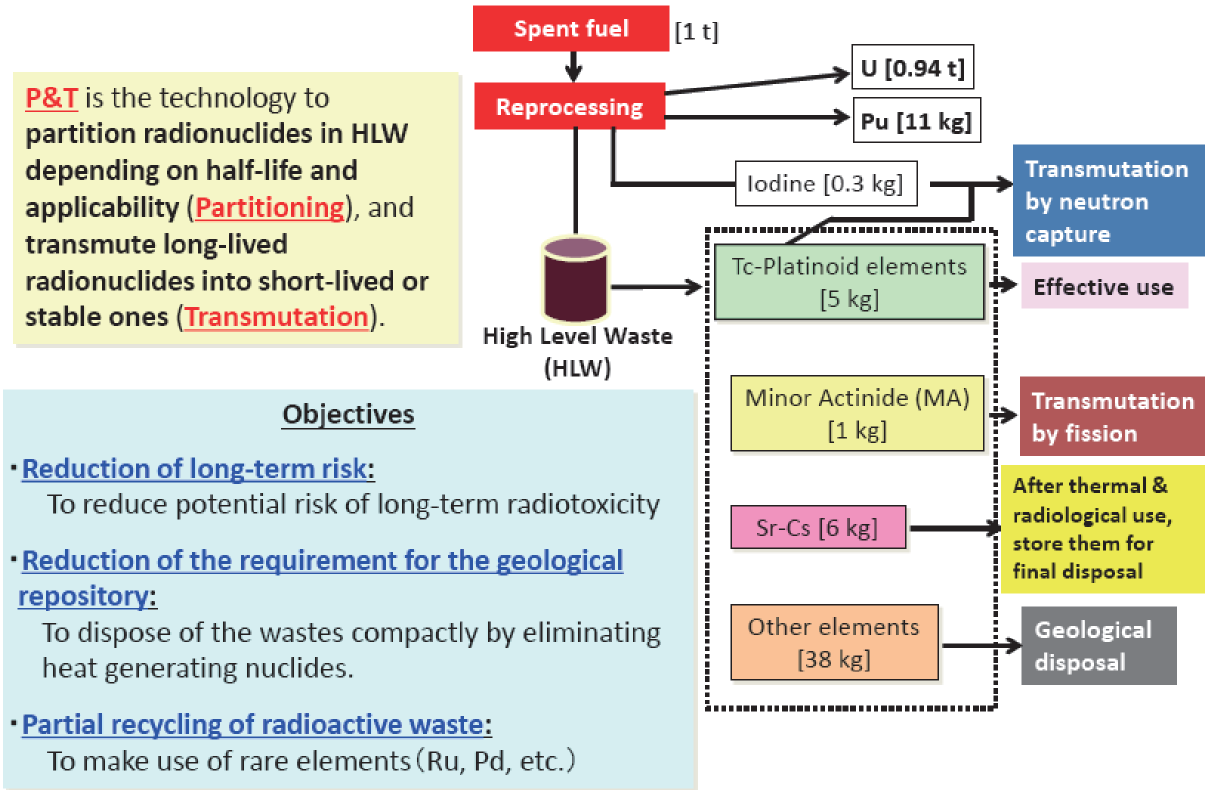
Social responsibilities of nuclear scientists and engineers.

Without solving those problems, no future for the use of nuclear energy.

Making decisions about final disposal methods and sites, and researching nuclear decommissioning technologies are serious issues for both those who agree with further use of nuclear energy and even those who are against that.

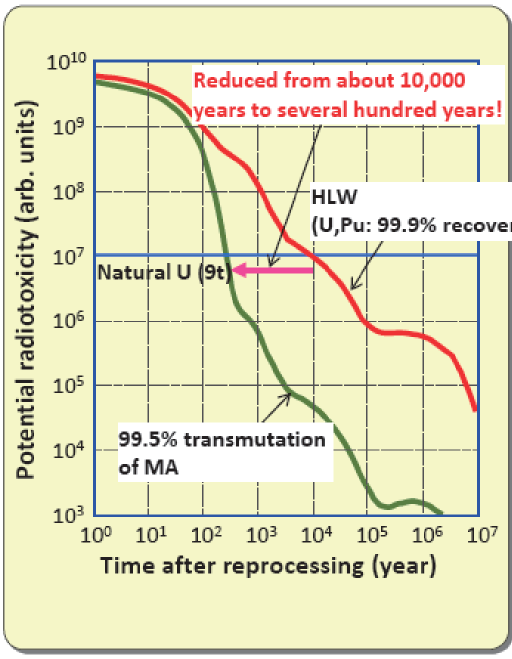
Partitioning and transmutation technology

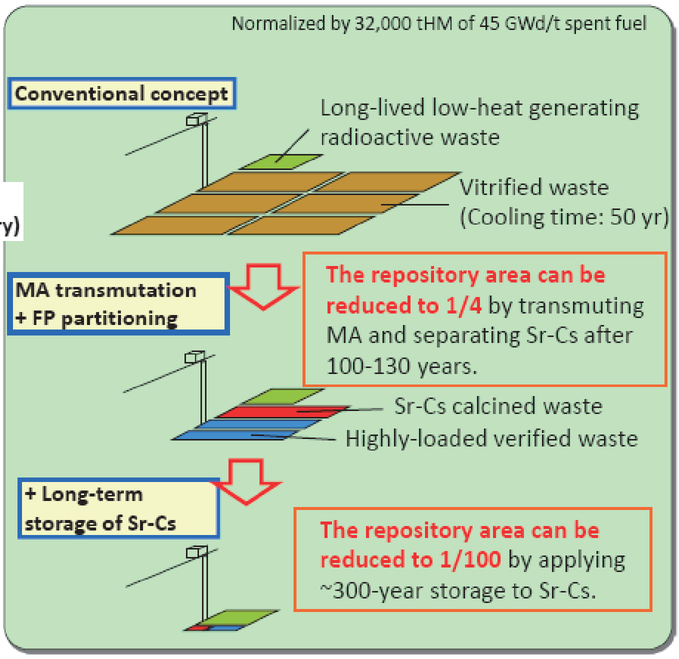
Partitioning & Transmutation



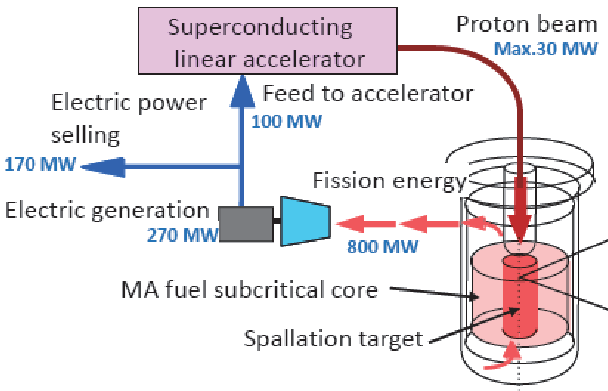
Effect of P&T

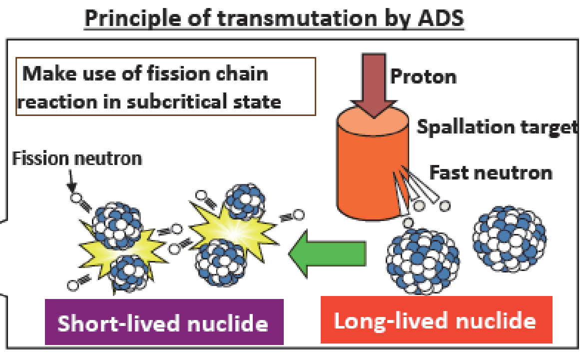
- **Reduction of long-term potential radiotoxicity**
- **Possible reduction of repository area**





Transmutation using Accelerator-Driven System(ADS)





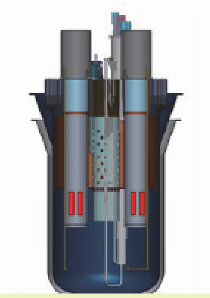
Mechanism of ADS:

- Protons are accelerated by a **superconducting accelerator** with high intensity.
- Protons are directed to a **lead-bismuth (Pb-Bi) target** through a beam duct and a beam window.
- The Pb-Bi combines a **reactor coolant** with a **spallation target**.
- Major composition of the reactor fuel is **MA**.
- Spallation reactions generate a large number of neutrons.
- MAs are transmuted by neutron-induced fission reaction.
- Neutrons generated by the fission are also used for the transmutation.
  → neutrons are increased by 20 times by a **fission chain reaction**.
- The electricity generated by ADS is partly fed to its own accelerator.

Feature of ADS:

- If the accelerator runs down, fission chain reactions come to a stop. → **High safety**
- Existing reactors (critical reactors) with a large amount of MAs cause safety difficulties, but that is not the case in ADS.
- Pb-Bi is chemically-inactive.

Global Trends on P&T



A multipurpose ADS, MYRRHA, developed at Belgium Nuclear Research Centre(SCK-CEN)

- **USA**
  - The Obama administration decided to abandon the Yucca Mountain repository.
  - Interim storage of spent fuel will be promoted based on the discussion by the **Blue Ribbon Commission**.
- **France**
  - Both of ADS and FBR are being studied under France's "2006 **Waste Management Act**."
  - However, the ADS study is conducted under the European framework.
- **Belgium**
  - The design study for an ADS prototype and associated R&D, **MYRRHAR** (about 100 MW), are in progress toward **construction from 2015**.
  - The purposes are experiments for transmutation, development of a lead-alloy-cooled fast reactor, irradiation of fuels and materials, and radioactive isotope production.
- **Europe**
  - While there are differences in nuclear energy policies among European countries, there is an agreement on needs for reduction of the burden of radioactive wastes.
  - Various projects such as EUROPART and EUROTRANS have been conducted under **Framework Programme** (FP6, FP7, etc.) in EU.
- **China**: The experimental equipment with a combination of a DT neutron source and a subcritical assembly, VENUS, was constructed. A proton accelerator project is also under consideration.
- **India**: ADS has been researched with an aim to utilize **thorium resource** as well as to transmute wastes.
- **OECD/NEA, IAEA** hosts meetings for information exchange on P&T and benchmark activities.

The Ω project of JAERI

and

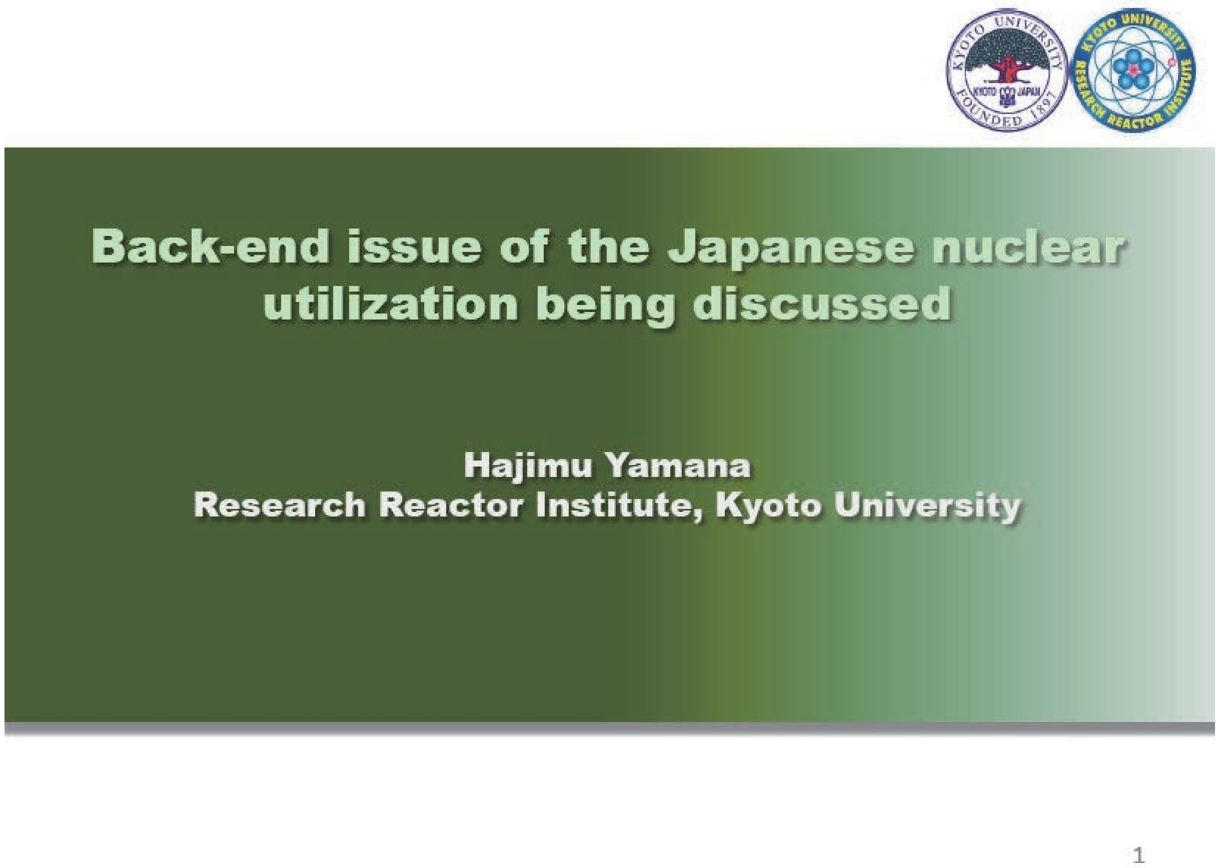
Japan Hadron Project for research of elementary particles, nuclear and condensed matter physics of KEK have been combined to establish the J-PARC under a powerful leadership of Shoji Nagamiya.

Only renewable energy and nuclear power will be the last option as energy sources.

International cooperation is urgent and indispensable to investigate final disposal method, to decide final disposal sites, and to develop the technologies for decommissioning nuclear reactors.

3.2 Back-End Issue of the Japanese Nuclear Utilization being Discussed

H. Yamana (Kyoto University)



Contents

Purpose of this talk

1. As the basis of today's discussion on future systems, P&T and ADS, review the latest status of the shift-in policy of Japanese nuclear power generation.
2. Understand the latest status of Japanese back-end, reprocessing, geologic disposal, FBR development, etc.
3. Foresee the future of Japanese fuel cycle under nuclear-reduction policy.
4. Review the up-to-date cost evaluation of nuclear fuel cycle in Japan.

2

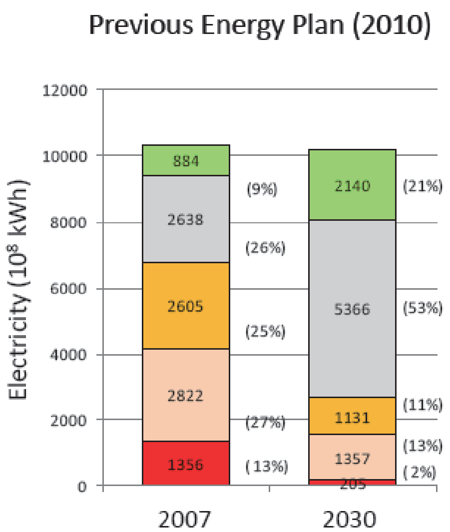
Formulation of new energy plan

✓New energy policy of Japan is being discussed under the frame of the cabinet office and MITI. It will be concluded soon.

✓Discussion on the strategy for the fuel cycle is being discussed.

Basic Directions

1. Reduce dependence on Nuclear power
2. Draw a new explicit and strategic plan to avoid shortage and price increase of energy supply
3. Thorough review and verification of nuclear energy policy to renew it



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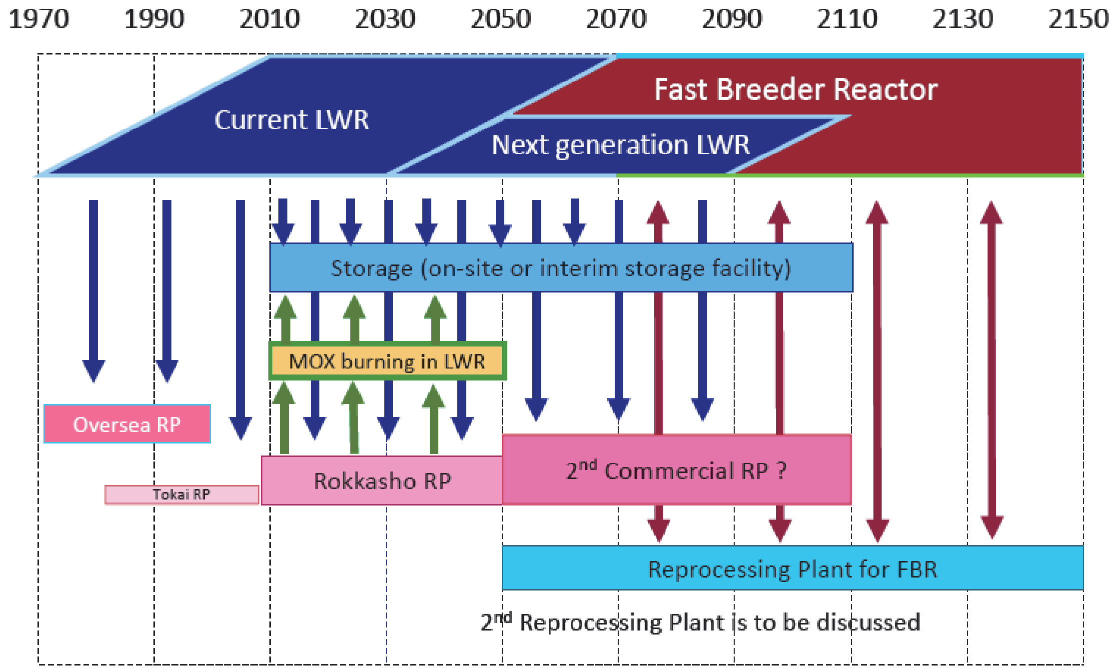
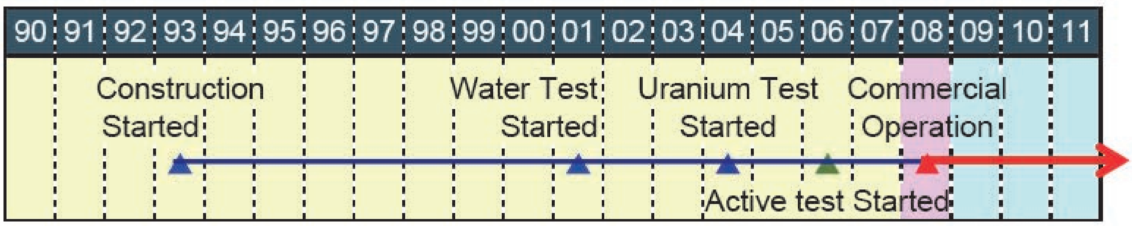
Previously envisioned Japanese fuel cycle scenario



Achievements of Rokkasho Reprocessing Plant

Construction ; started on April 28, 1993 and 99% completed.
Active test using spent fuel;
  Started on March 31, 2006 and 94% completed.
  425 tU of LWR spent fuel reprocessed.
  220 tU BWR and 205 tU PWR spent fuels.
Recovered products ;
  Uranium as oxide ; 364 tU
  Mixed Pu and U in MOX ; 6.7 tHM
Vitrified HLW in 119 canisters.
Liquid fed ceramic melter (LFCM) for waste vitrification process remains to be tested more.

Rokkasho Reprocessing Plant

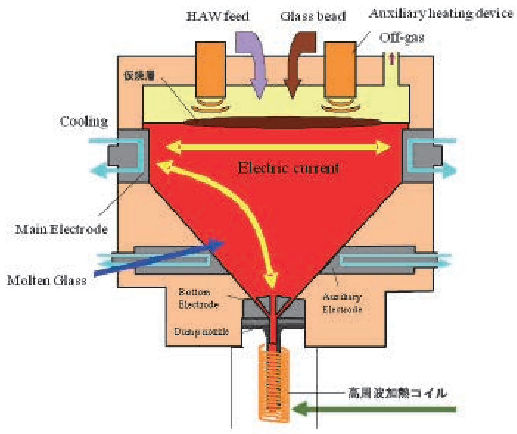


Delay of Rokkasho Reprocessing Plant

Experienced troubles of the Glass Melter, LFCM

They encountered various difficulties including that in determining the operating procedure of a large-scale liquid-fed ceramic melter (LFCM) for vitrifying the HLW liquid.

The company announced that it will finish the test operation in the autumn of 2012, based on the result of research using a large-scale mock-up facility at JAEA Tokai Laboratory and modeling and simulation technique.



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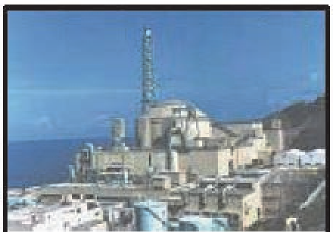
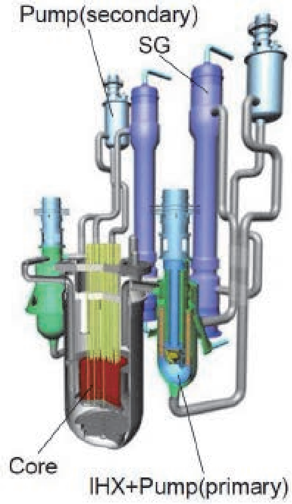
FBR development

Technologies for a commercialized FBR system have been developed since 2005, targeting the establishment of prototype reactor in 2025.



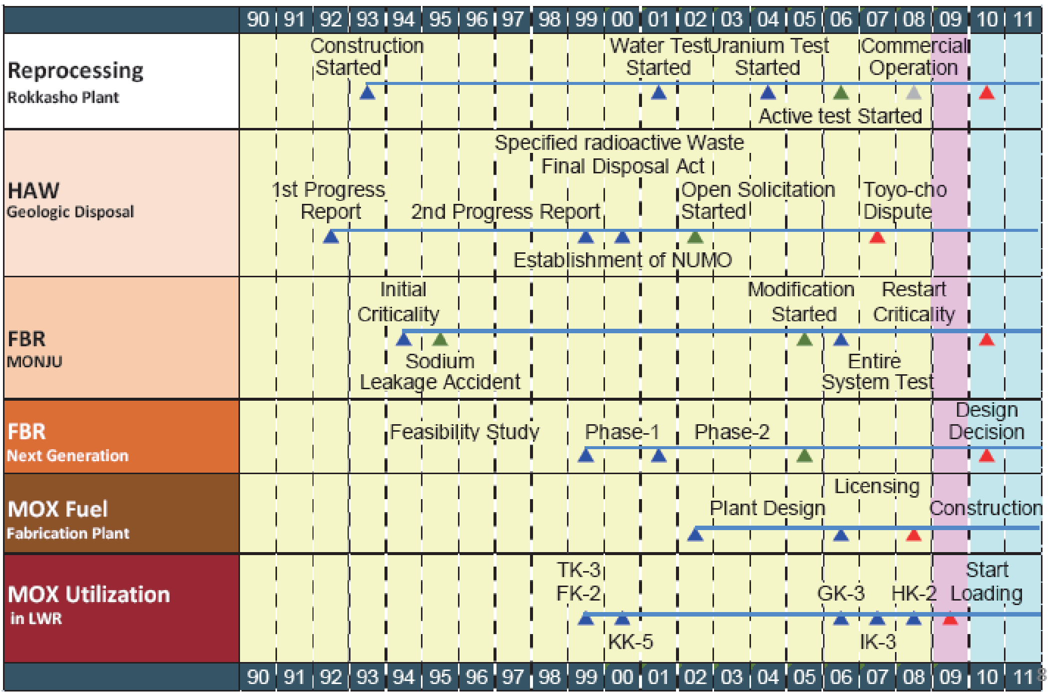
Prototype FBR, MONJU
280 MWe/Three-loop
Started testing with zero- power in 2010

Commercialized FBR Plan under development
1500 MWe/Two-loop
Various advanced designs
Decision of innovative technology: scheduled for 2010
Approved confirmation: scheduled for 2015



90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
				Feasibility Study					Pahase-1			Pahase-2							Design Decision		

Japanese nuclear fuel cycle Chronology



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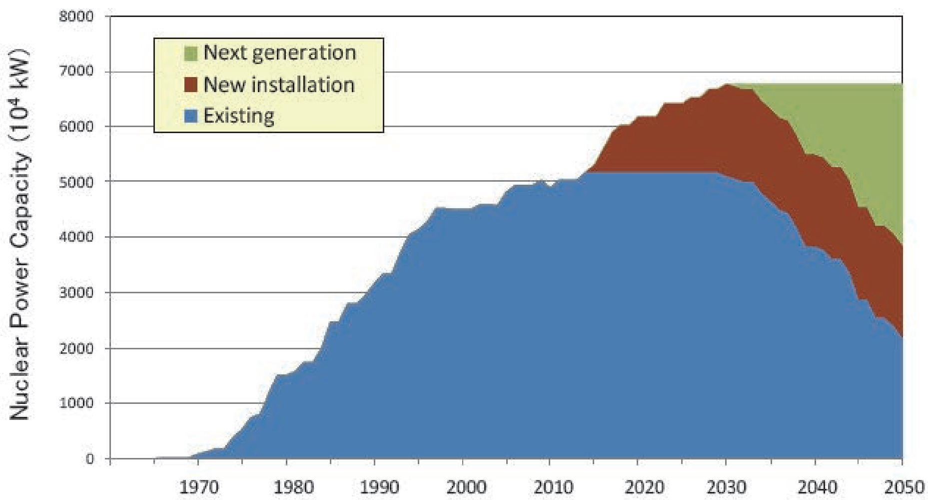
Nuclear power capacity plan (previously envisioned in 2010)



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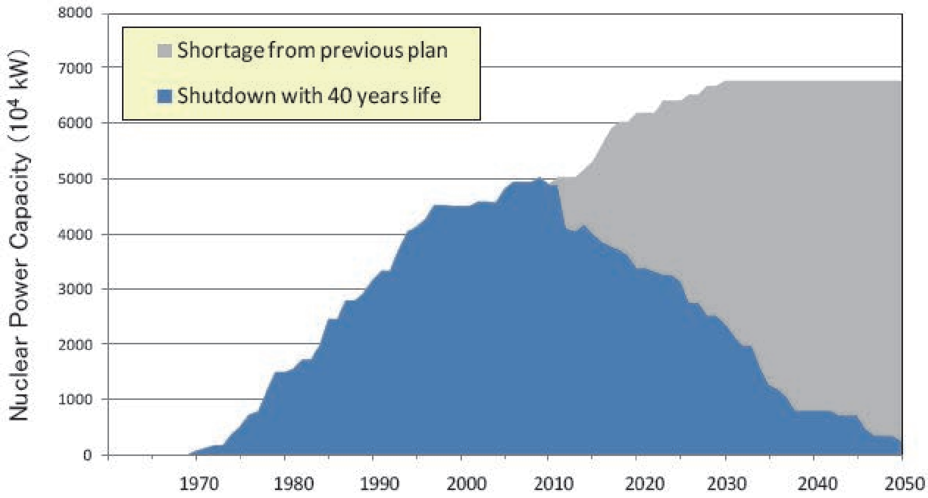
Nuclear power capacity prospect (phase-out with 40 y lifetime)



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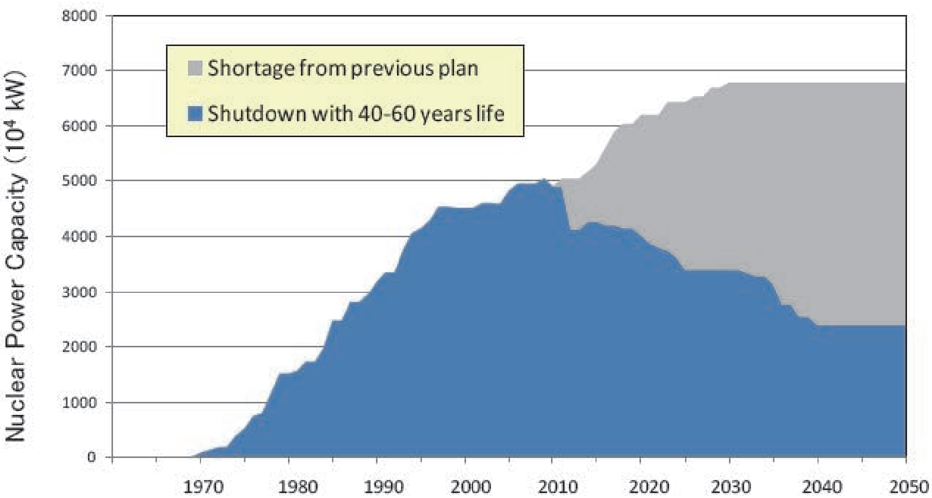
Nuclear power capacity prospect (phase-out with life extension)



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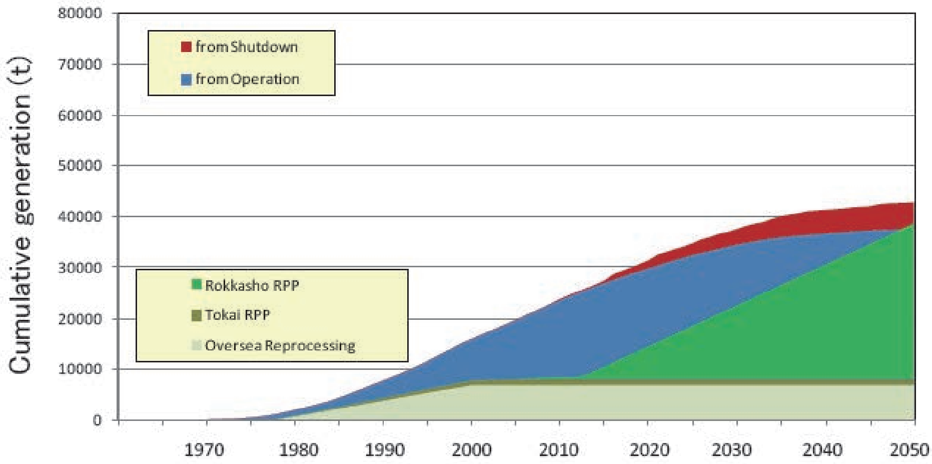
Cumulative generation of spent fuels (phase-out with 40 y lifetime)



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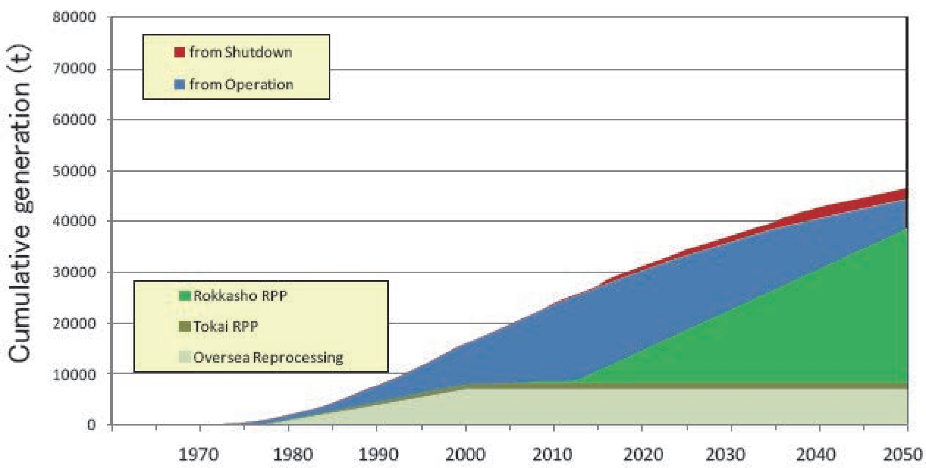
Cumulative generation of spent fuels (phase-out with life extension)



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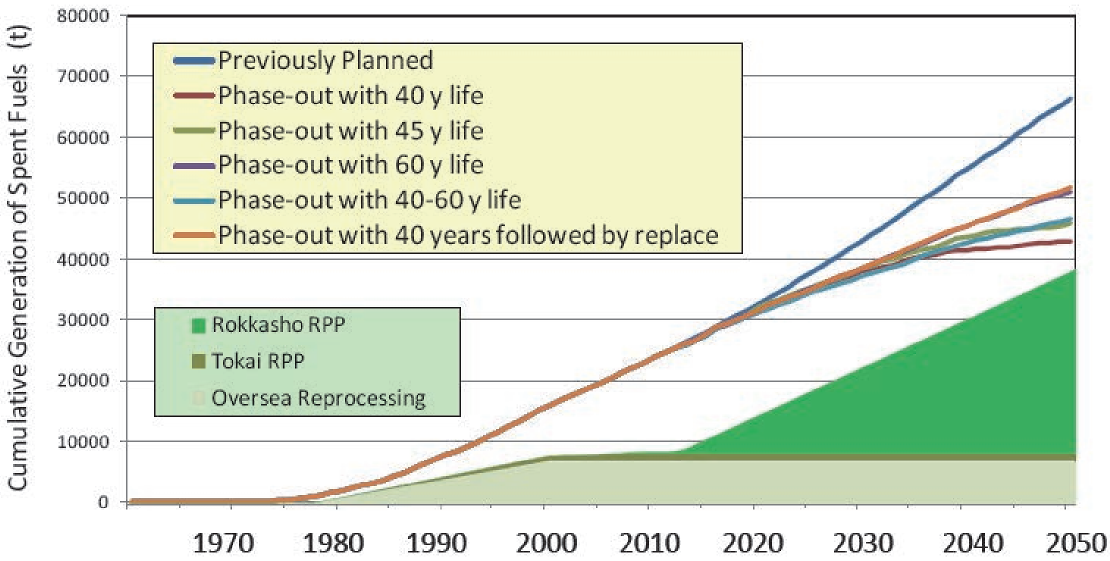
Cumulative generation of spent fuels



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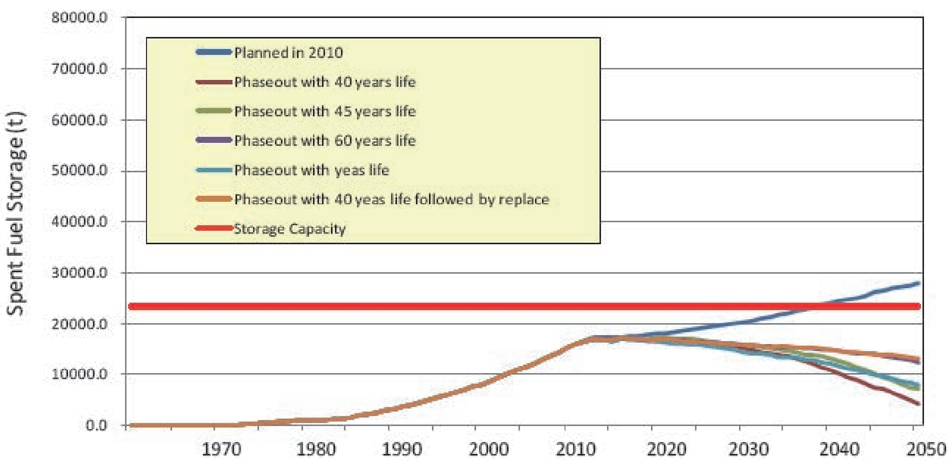
Interim storage prospect (with reprocessing by Rokkasho Plant)



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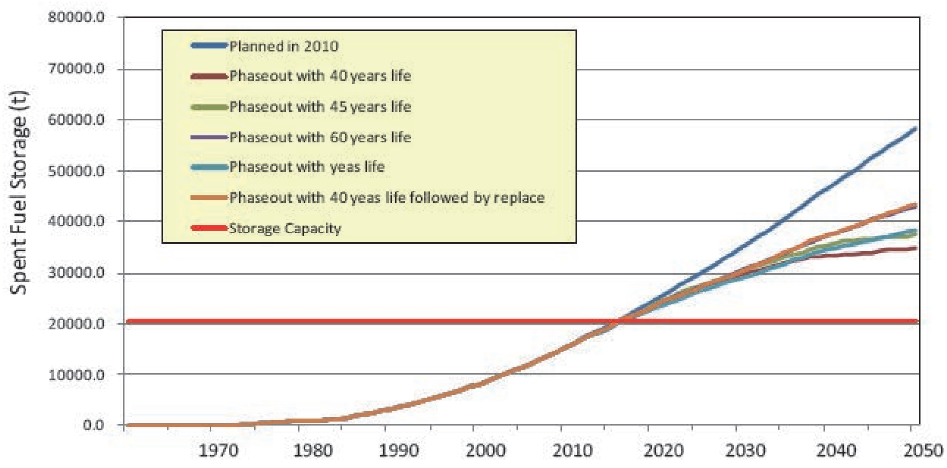
Interim storage prospect (without reprocessing)



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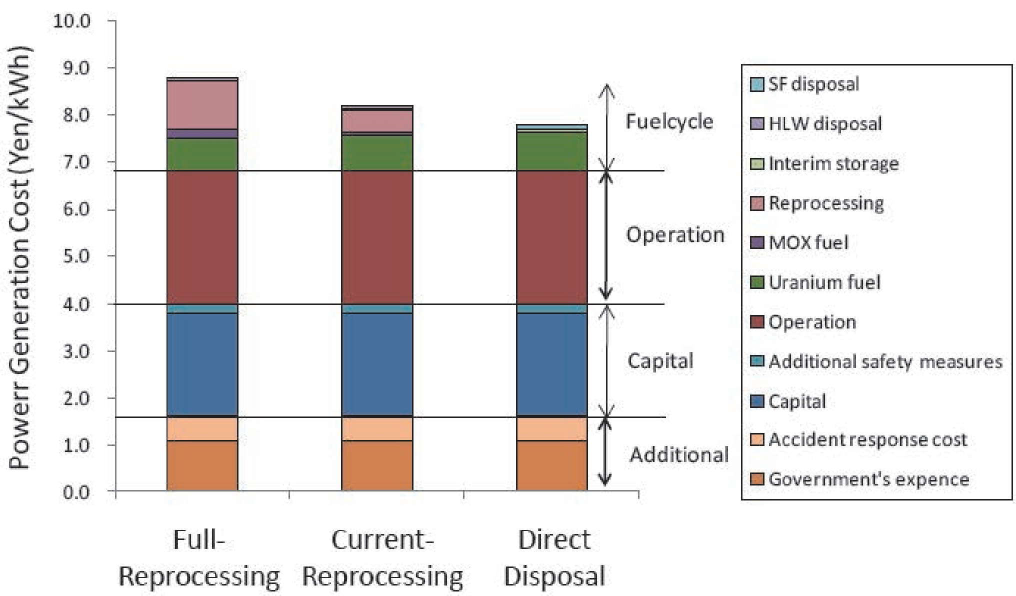
Appraised power generation cost



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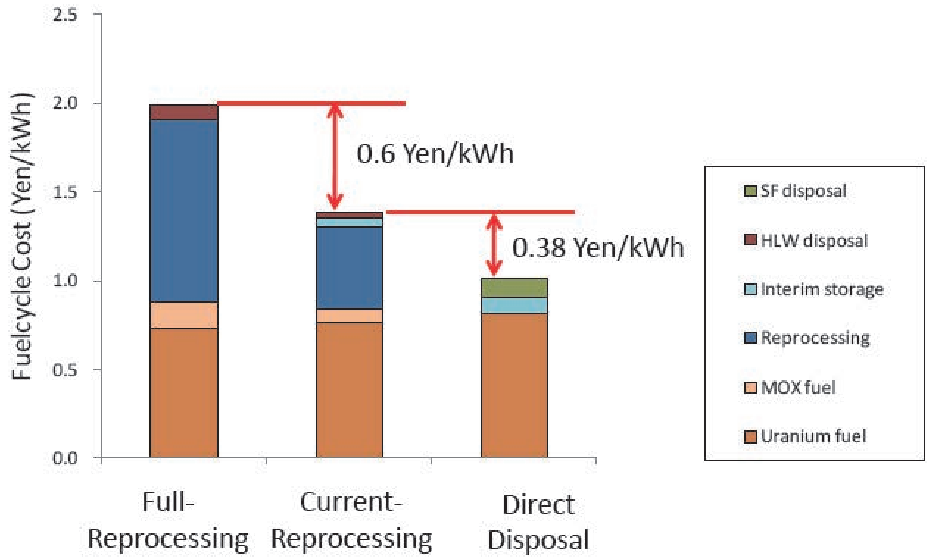
Appraised fuel cycle costs



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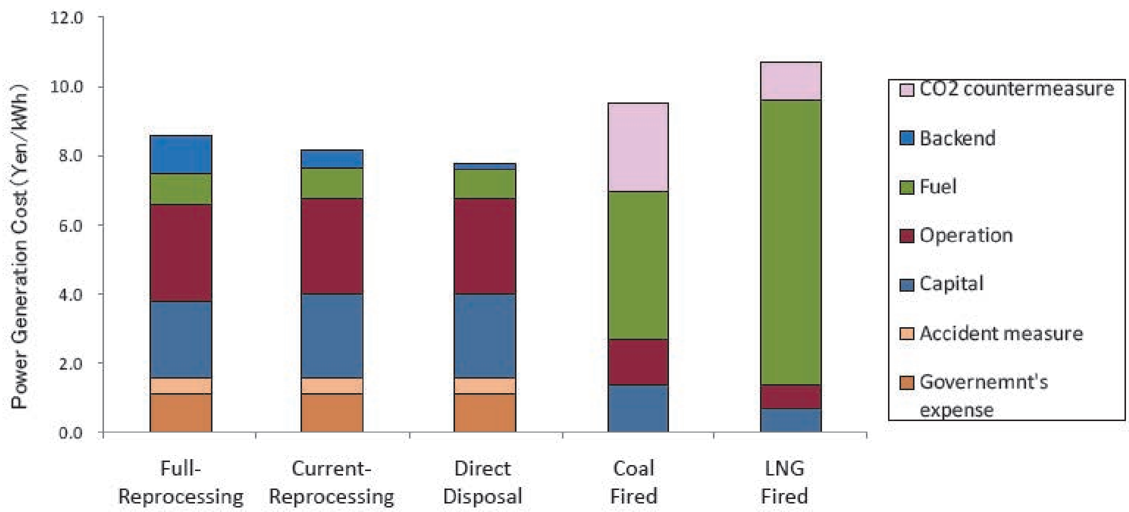
Comparison with thermal power



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Optional fuel cycle scenarios being discussed in AEC

1. **LWR with once-through**
2. **LWR with limited MOX recycling**
3. **LWR with multiple MOX recycling**
4. **LWR with Fast Reactor for transmutation**
5. **Fast Breeder Reactor**

Necessary factors to be taken into considerations

Energy security, stabilization of nuclear power utilization, costs, safety, proliferation resistance, technical readiness, potential hazard management, waste volume and disposal area, exposure risk to public, etc.

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Other issues

- ✓Peoples' distrust to the authority of nuclear safety
- ✓Disturbance and distrust to the radiation safety
- ✓Controversy on the fuel cycle strategy
- ✓Technological issues encountered in Reprocessing and Reactor development
- ✓Less social understanding on the final disposal
- ✓Insufficient budget for future development due to the priority of the restoration for Fukushima site
- ✓Changing JAEA's direction

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Conclusions

1. Japan is re-making the energy policy with a drastic restructuring of nuclear energy policy.
2. Back-end has an importance in this discussion, and heavy discussions are being done on the subjects of /reprocessing or not?/FBR or not?/interim storage?/final disposal feasible?/costly?/society issues/ etc.

   Keeping recycling of spent fuels will be beneficial from view points of robustness of the system and preparation for future.

1. Though it is not explicit now, P&T and ADS developments has a meaning in this discussion, in a sense of "flexibility of the scenario" and of "an technological answer to the publics who has doubts on the safety of nuclear systems".

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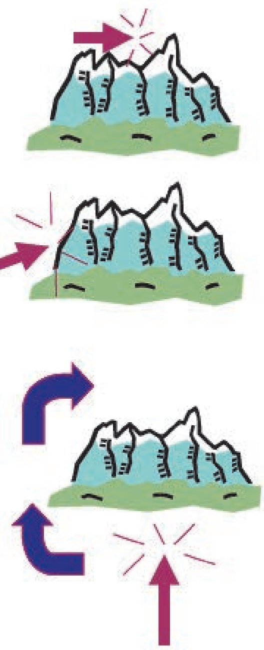
Conclusion

LWR fuel cycle
Economics, PA, minor troubles etc.

FBR fuel cycle
Scientific and technological issues



We need a Stephen Covey approach of ***beginning with the end***

Look beyond the mountain of problems that tend to consume us
How can a more ***integrated assessment*** of the ***nuclear fuel cycle*** allow nuclear energy to take its rightful place in history?

Alan Waltar
Past President, American Nuclear Society

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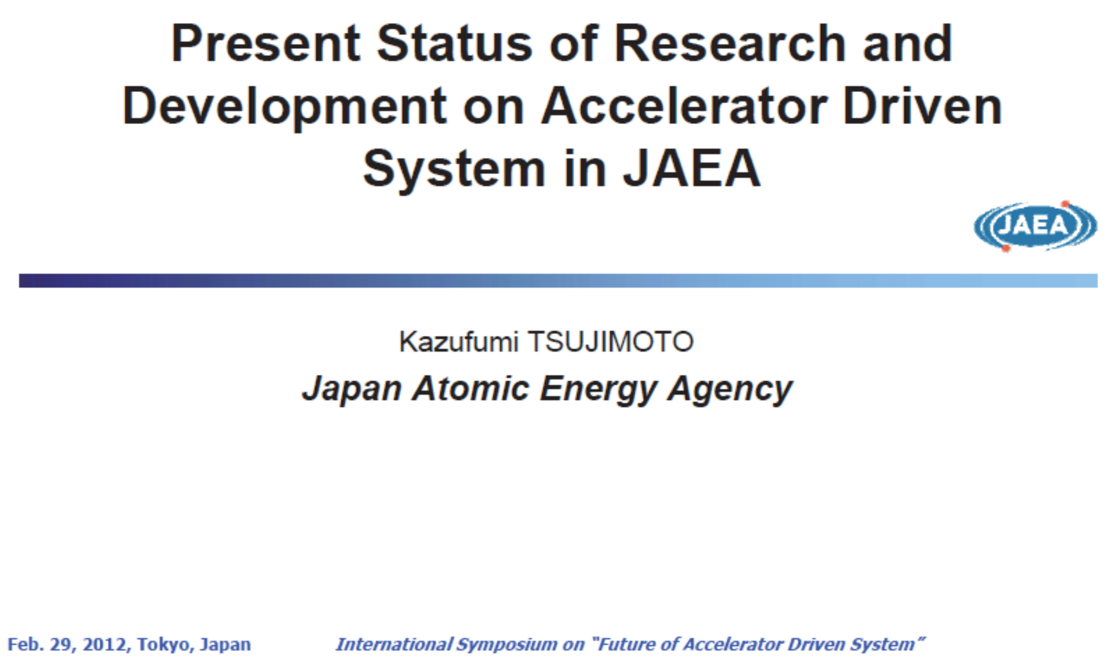
3.3 Present Status of Research and Development on Accelerator Driven System in JAEA

K.Tsujimoto (Nuclear Transmutation Technology Group, JAEA)



Partitioning and Transmutation (P&T) in Japan:
Benefit and role of P&T

☐ Benefits of P&T on Management of High-Level Radioactive Wastes (HLW):

- ✓ Reduction of long-term radiological toxicity
- ✓ Reduction of dose for future inhabitants

→ *To mitigate difficulties caused by long-term nature of radioactivity*

- ✓ Reduction of amount of HLW
- ✓ Reduction of repository size

→ *To extend capacity of a repository*

- ✓ Recovery of valuable materials from wastes, and so on.

- ➢ Steady implementation of **High Level Waste (HLW) disposal** is one of the most important issues even though we select to reduce dependency on nuclear energy.
- ➢ **Partitioning and Transmutation (P&T)** will be a key technology to reduce the environmental burden of HLW.

2

Partitioning and Transmutation (P&T) in Japan:
How can we realize Transmutation ?

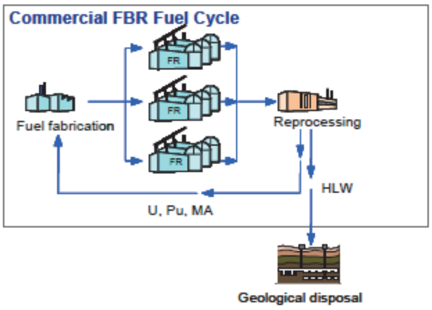
- To transmute MA effectively, fission reactions of MA in fast neutron system fueled with high MA content is desirable.
- Fast "critical" reactor (FR) with high MA content is the most effective "burner" of MA from above viewpoint.
- Operation of such a "critical burner reactor" is, however, not easy because of
  - ✓ ***Small delayed neutron fraction***
  - ✓ ***Large positive reactivity effect by coolant void***
  - ✓ ***Small negative reactivity feedback by Doppler effect***
- To overcome these problems, two methods are conceivable:
  - ➢ ***To reduce the MA concentration → FR with MA (small amount : up to 5%)***
  - ➢ ***To make the core subcritical → ADS***

3

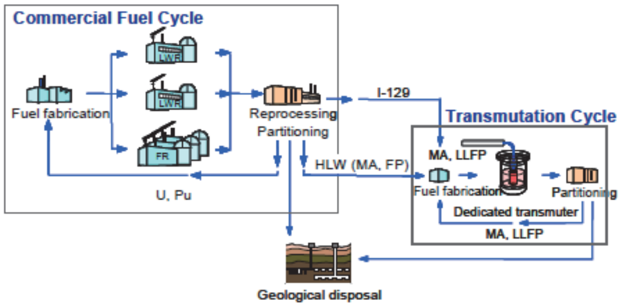
Partitioning and Transmutation (P&T) in Japan:

Fuel cycle concepts for P&T

Homogeneous cycle



Double-Strata (ADS)



- MA is recycled in the next-generation reprocessing plant.
- MA is homogeneously mixed to FBR fuel with small amount up to 5 wt.%.
- **MA transmutation is performed in all electricity generating FBR plant.**

- **Dedicated (second) transmutation fuel cycle with Accelerator-Driven System (ADS) is added to commercial fuel cycle.**
- MA recovered from commercial fuel cycle is confined in the compact transmutation cycle.
- The ADS fuel mainly consists of MA.

R&D for both concepts are being implemented in JAEA.

4

Partitioning and Transmutation (P&T) in Japan:

C&R for P&T in 2009 by JAEC

- **In 2008, the Japan Atomic Energy Commission conducted C&R on P&T technology by setting up a subcommittee. The final report including recommendation reflecting public comments was issued in April 2009.**
  - **Double-strata concept, where dedicated transmutation systems such as ADS will play an important role, should be studied as a part of the whole nuclear system** both in the transient phase of LWR to FBR and the equilibrium state of FBR.
  - **The basic data to judge the feasibility of P&T are insufficient.** It is, therefore, necessary to continue the accumulation of the basic data which are commonly utilized for both FBR and ADS.
  - **R&D of FBR and ADS should be coordinated strongly.**
  - **The required R&D issues on ADS as follows:**
    - ✓ Reliability and economy of the accelerator,
    - ✓ Feasibility of the beam window,
    - ✓ Reactor physics of subcritical core including its control,
    - ✓ Design and safety of LBE cooled core.

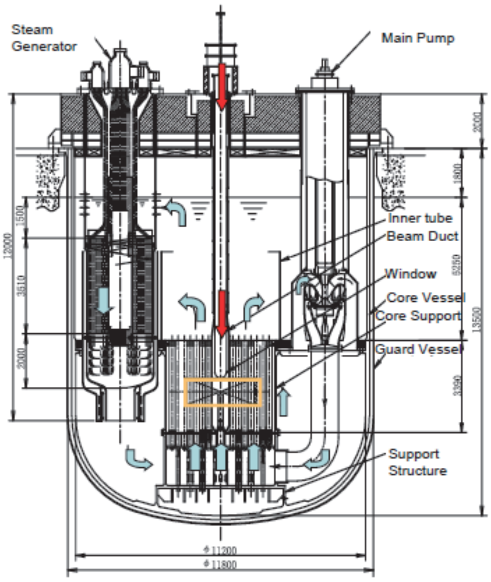
◆ **R&D on ADS in JAEA**

- R&D to resolve the technical challenges in ADS is being continued.
- The activities are included in the 5-year plan (FY2010-2014).

5

ADS Development in JAEA:
Conceptual Design of ADS for MA Transmutation

- Proton beam : 1.5GeV ~20MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : k_{eff} = 0.97
- Thermal output : 800MWt
- Core height : 1000mm
- Core diameter : 2440 mm
- MA initial inventory : 2.5t
- Fuel composition :
  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate :
  10%MA / Year (10 units of LWR)



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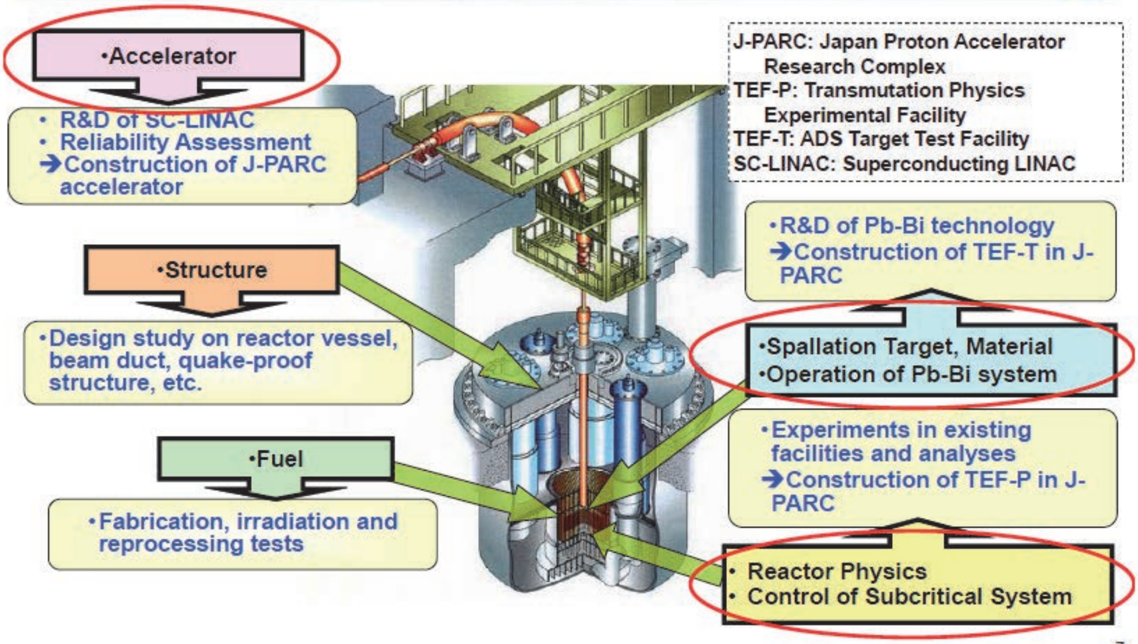
ADS Development in JAEA:
Technical Issues of ADS



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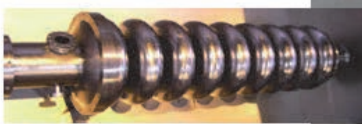
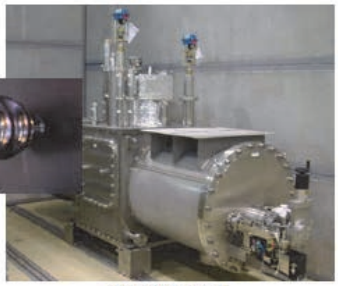
ADS Development in JAEA :
R&D activities of accelerator for ADS

- **Prototype of cryomodule , which was designed to accept 927MHz RF wave, was made and tested.**
  - Two cavity excitation was successfully performed at the design field of 10MV/m, repetition rate of 25Hz and pulse length of 1ms.
- Information on **J-PARC LINAC (181MeV at present, 400MeV in the future)** will be included for the accelerator design study.
  - The LINAC had been operated stably for injection to the following 3 GeV synchrotron since October, 2007.

Photograph of J-PARC LINAC

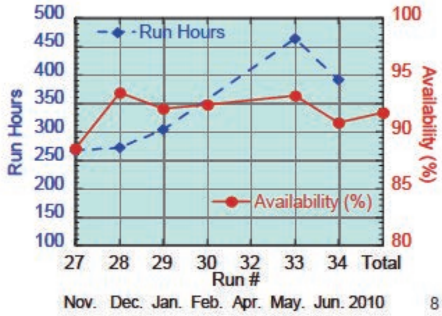


Superconducting cavity



Cryomodule

Statics [Run #27 (Nov. 2009) – #34 (Jun. 2010)]



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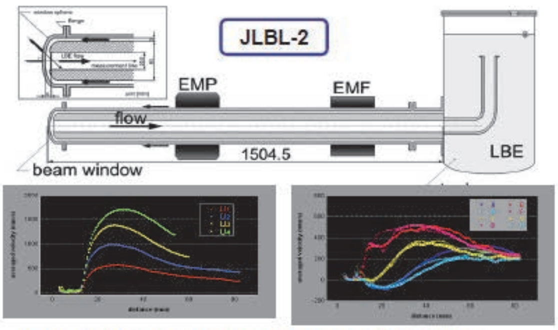
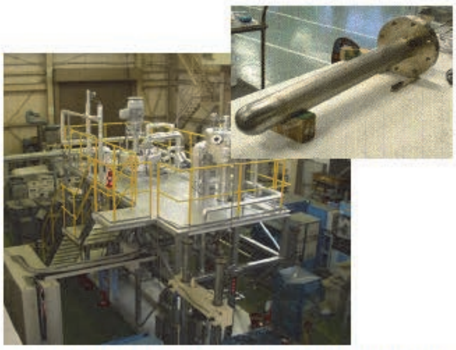
ADS Development in JAEA:
R&D activities for thermal-hydraulic of LBE

- **Basic thermal-hydraulic of LBE using small LBE test loops are proceeding.**
  - The flow velocity measurement by UDM (Ultrasonic Doppler Method) is developed for visualization of the liquid LBE flow.
  - The thermal-hydraulics experiments to investigate the heat transfer coefficients at the beam was performed using a thermal-hydraulic loop (100-500L/min, 330-430°C).
- **The irradiation properties of the beam window material were studied by PIE samples of STIP and MEGAPIE.**



Measurement result by UDM at a centerline and inclined direction



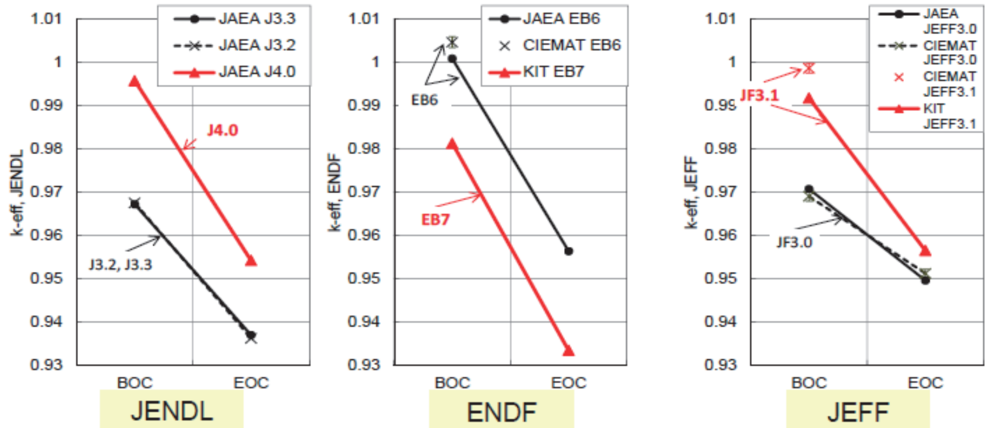
JLBL-3 for thermal-hydraulic test of beam window and results for temperature profile

9

ADS Development in JAEA :

Neutronics design of ADS

- JAEA proposed the comparison of reactor physics parameters calculated by different nuclear data as a benchmark exercise of IAEA-CRP.
- **About 2% discrepancies in k-eff were found among the different nuclear data.** (k-eff disperses from 0.98 to 1.0 at BOC and 0.93 to 0.96 at EOC.)



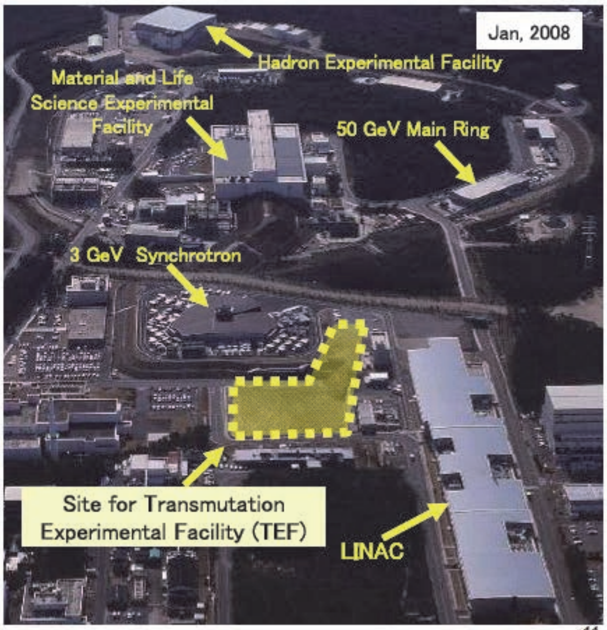
Calculated results for IAEC-CRP benchmark proposed by JAEA (Burnup calculation for the first burnup cycle of 600 EFPD with 800MWth ADS)

10

ADS Development in JAEA:

Transmutation Experimental Facility (TEF)

- Phase-I construction of J-PARC was completed.
- Phase-I facilities had been in service until Mach 2011. Although there were significant damage by the earthquake, the operation was restarted in Dec. 2011.
- The Transmutation Experimental Facility (TEF) is the central project in Phase-2 of J-PARC, however, it is still waiting for the approval of the Government.



- TEF consists of
  - Transmutation Physics Experimental Facility (TEF-P)
  - ADS Target Test Facility (TEF-T)

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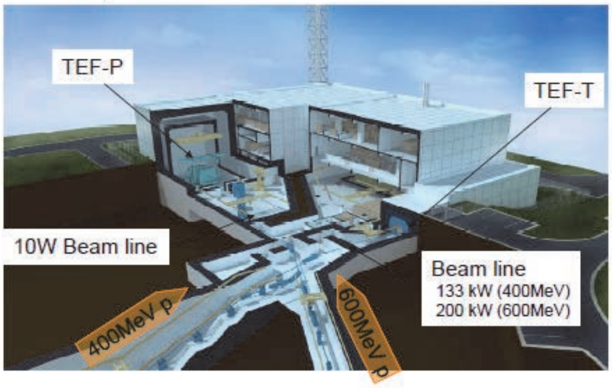
TEF in J-PARC Project :

Image of Transmutation Experimental Facility (TEF)

- **Transmutation Experimental Facility (TEF) is being proposed under the J-PARC project.**
  - TEF-P is critical assembly, and TEF-T is proton target.
  - TEF will be constructed as two individual facilities. TEF-T is radiation facility and TEF-P is nuclear reactor facility.
  - Since it will be expected to take much time for the licensing for TEF-P, the construction of TEF-T will be started prior to TEF-P.



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TEF in J-PARC Project :

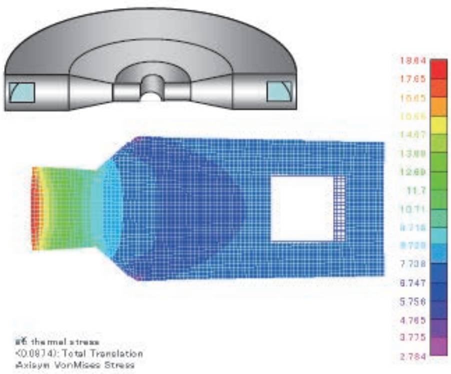
ADS Target Test Facility : TEF-T

- **ADS Target Test Facility (TEF-T)**

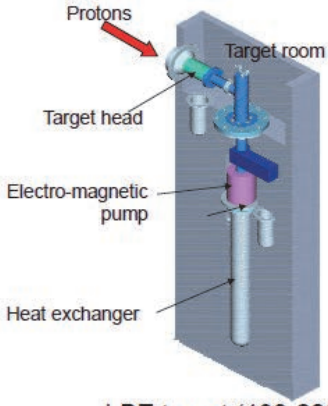
Material Irradiation Test of the material for ADS beam window

- Irradiation damage of material by protons and neutrons
- Compatibility of material with flowing LBE under irradiation

Proton beam power : 30 - 133kW (400MeV), 200kW (600MeV)



Solid target using pure-Cu (30–133kW)



LBE target (133-200kW)

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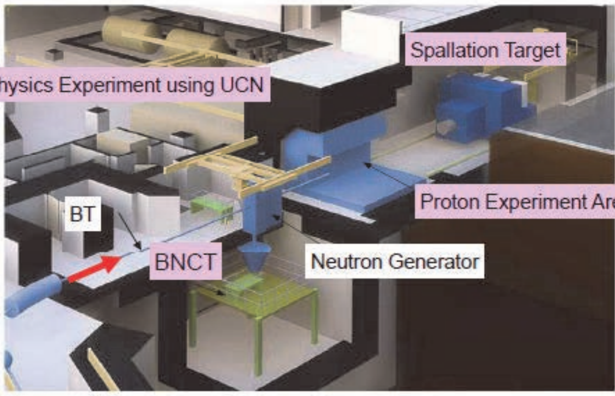
TEF in J-PARC Project :

Multi-purpose utilization of TEF-T

- There is no available facility using proton below 3GeV in J-PARC.
- TEF-T will be designed as multi-purpose experimental facility to satisfy potential needs for proton experiments.



✓ Material Irradiation Test
Irradiation test for ADS window
✓ RI production
Contribution to stable supply of medical RI
✓ BNCT
R&D for practical use of accelerator-based neutron source for cancer therapy
✓ Physics experiment
Physics study using ultra cold neutron source

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TEF in J-PARC Project :

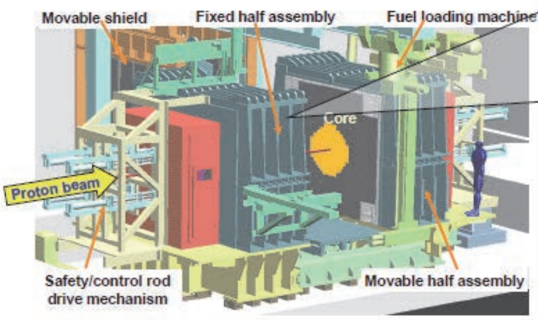
Transmutation Physics Experimental Facility : TEF-P

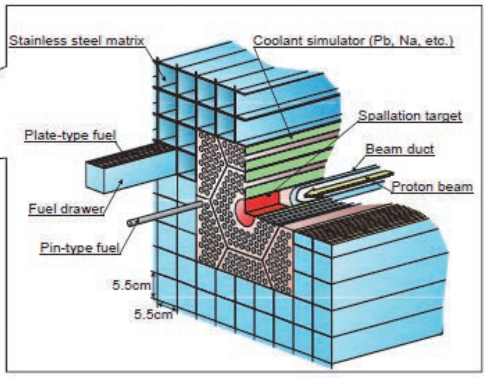
- **Transmutation Physics Experimental Facility (TEF-P)**

Reactor Physics Experiment using Critical Assembly with MA fuel

- TEF-P can include critical and subcritical experiments with proton beam.
- Pin-type MA fuel can be used with remote handling, cooling and radiation shielding.

Maximum fission power : ~ 500W (proton beam power of ~10W)
Proton beam power : ~ 10W (1.5 X 10^{12} Neutrons/s by 600MeV proton)





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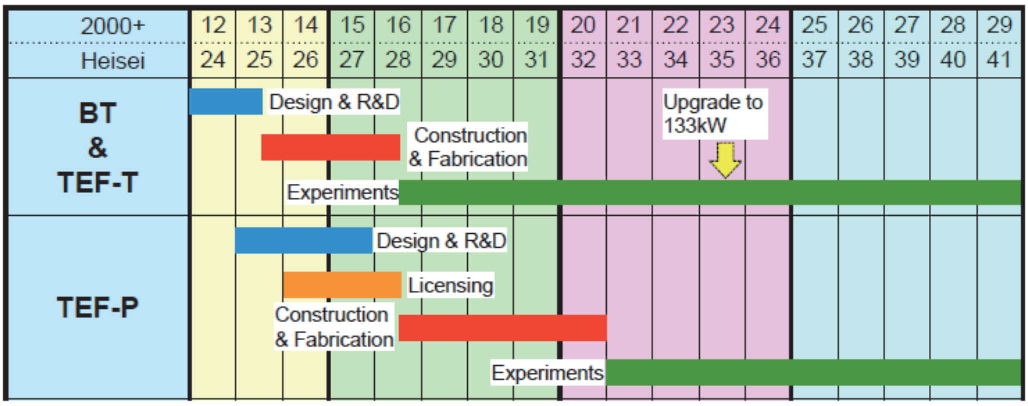
TEF in J-PARC Project :
Preliminary Time Schedule of TEF Program



- The construction of beam transport and TEF-T will be started in 2013. The experiments will be started in 2016.
- To start the construction of TEF in 2016, just after the completion of TEF-T, a few years of licensing activities should be started in 2014.

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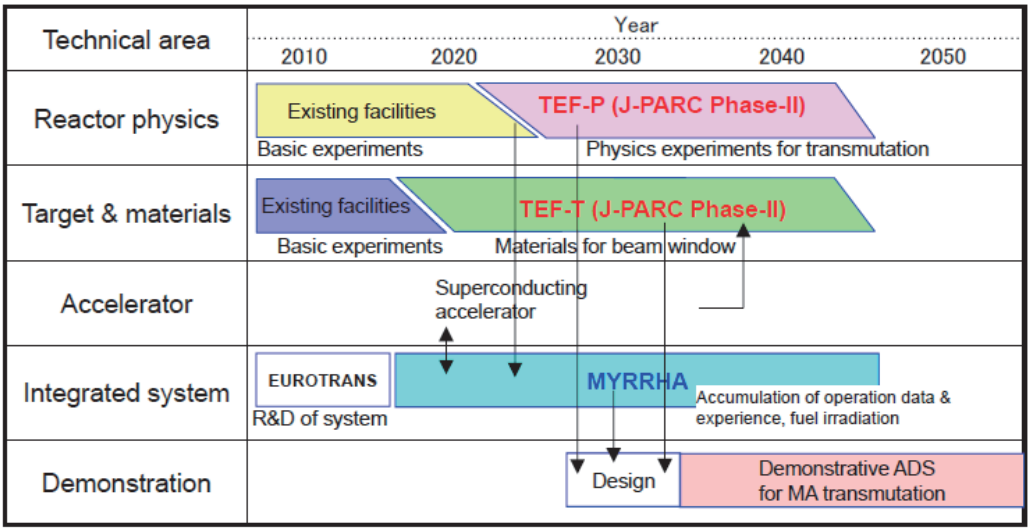
Proposed Outline of International Common Roadmap

- International common roadmap sould be established by **coupling TEF and MYRRHA** as complementary facilities.



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Concluding remarks

- **In Japan, C&R on P&T by AEC was held, and JAEA will continue the R&D activities on P&T technology and ADS.**
- **The accident of Fukushima NPP affects the nuclear energy utilization in Japan.**
  - The discussion to revise the national policy for the utilization of nuclear energy was conducted.
  - Even though we select to reduce dependency on nuclear energy, ***steady implementation of High Level Waste (HLW) disposal is one of the most important issues***.
  - ***Partitioning and Transmutation (P&T) will be a key technology*** to reduce the environmental burden of HLW.
- **International collaboration is important in R&D of ADS.**
  - The ADS and the transmutation technology are increasingly important. However, the technical challenges for ADS spread over wide range.
  - Various basic R&D have been implemented, and **new experimental facility, TEF, is proposed in the J-PARC project in JAEA. TEF is expected to play important roles as an international research facility.**

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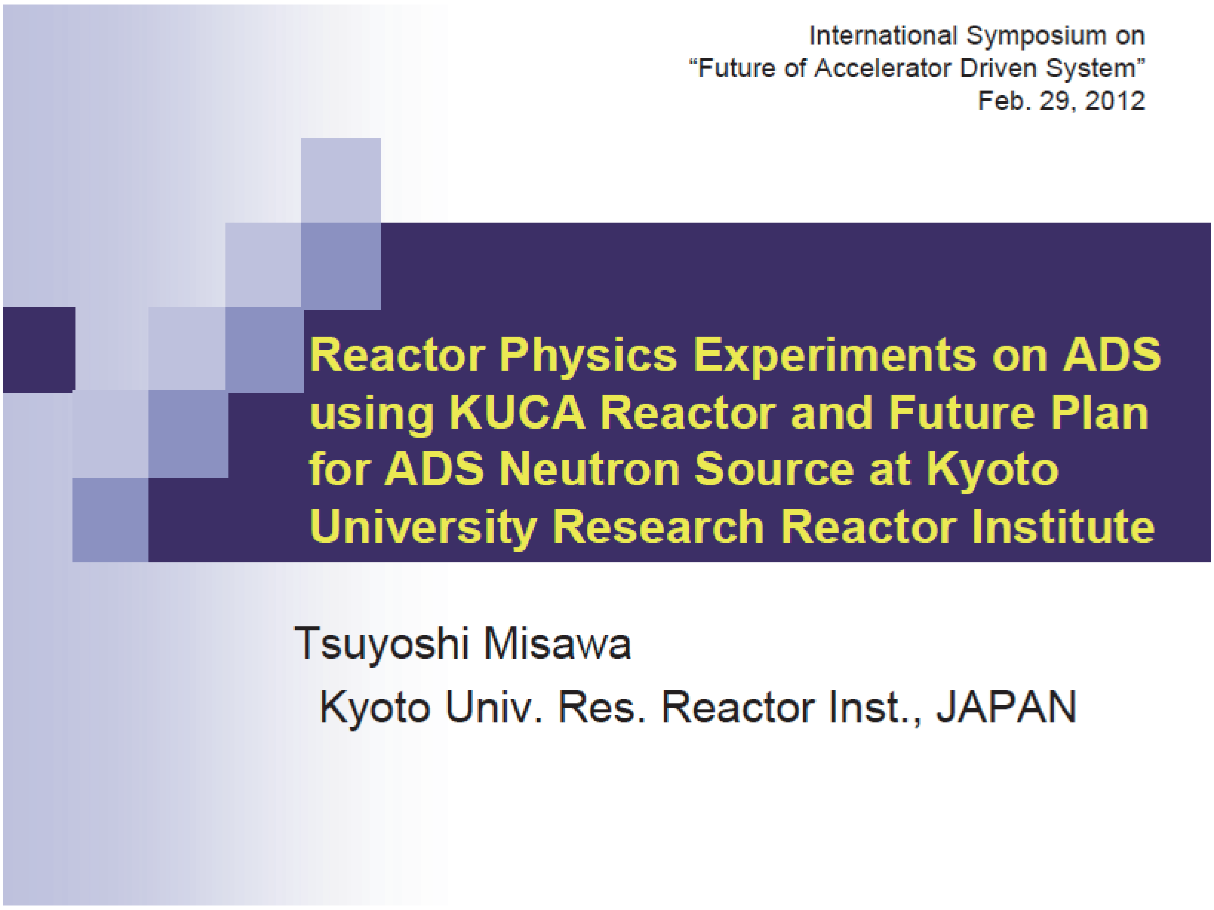
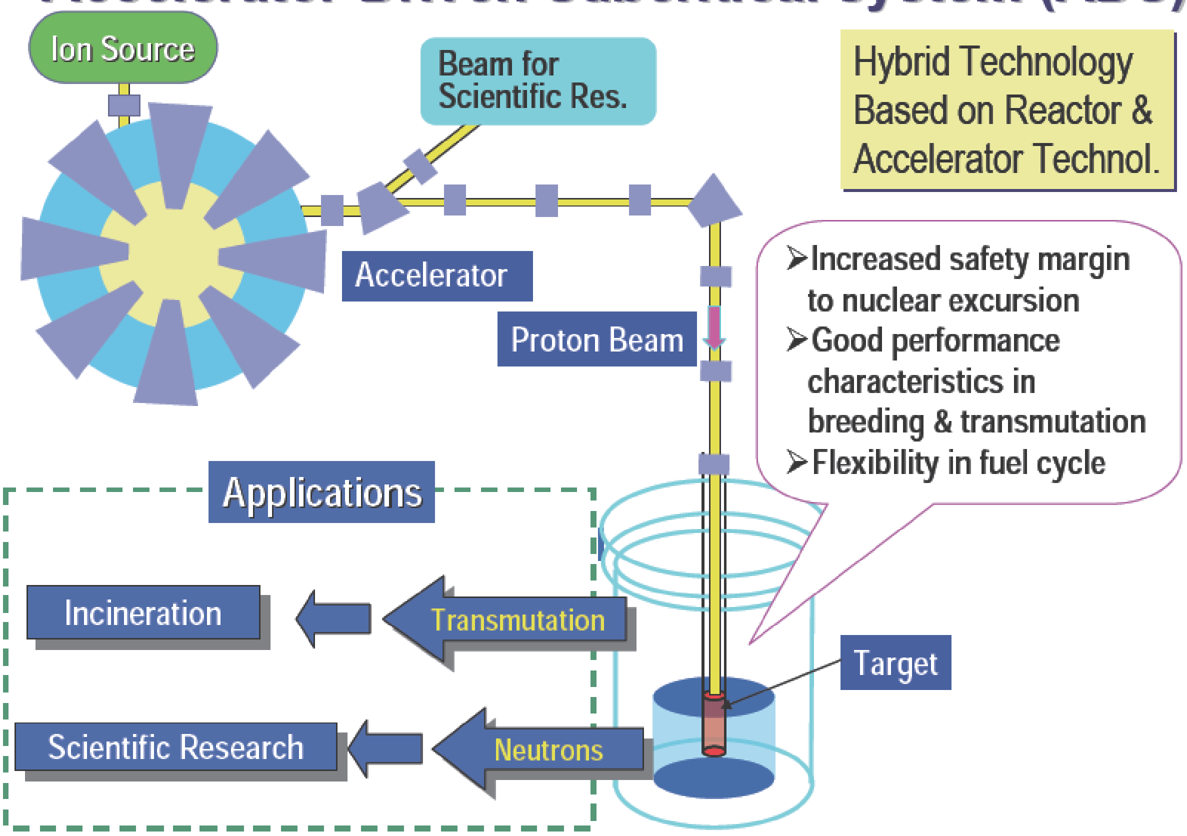
3.4 Reactor Physics Experiments on ADS using KUCA Reactor and Future Plan for ADS Neutron Source at Kyoto University Research Reactor Institute

T. Misawa (Kyoto University)



Kyoto Univ. Research Reactor Institute

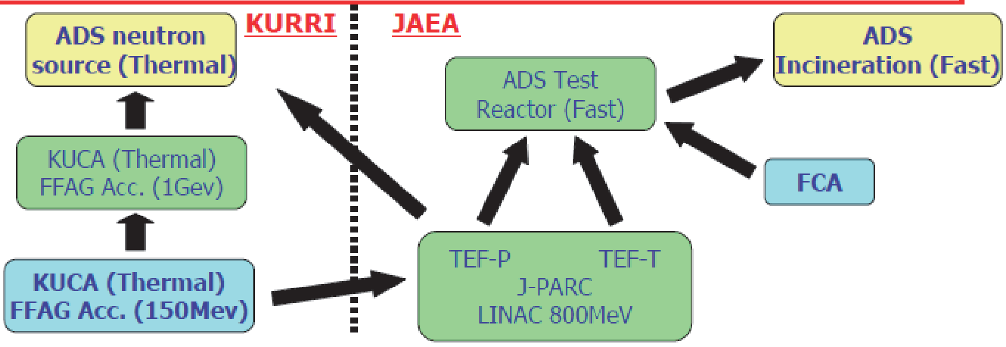
Accelerator-Driven Subcritical system (ADS)



ADS Collaboration Research in Japan

- ◆ **KURRI (Kart & Lab. project): KUCA, FFAG Accelerator**
  Thermal to epi-therma neutron field → Neutron amplifier system
- ◆ **JAEA (J-PARC project): FCA, TEF-P, TEF-T**
  Fast neutron field → Nuclear Transmutation
- ◆ User and support group: Tohoku Univ., Nagoya Univ., Kinki Univ., etc.

✓ Subcriticality measurement (Noise method, NSM method, etc.)
✓ Neutronic characteristics (Neutron flux, Neutron spectrum, etc.)
✓ Nuclear Transmutation (MAs, FPs, etc.)



Contents

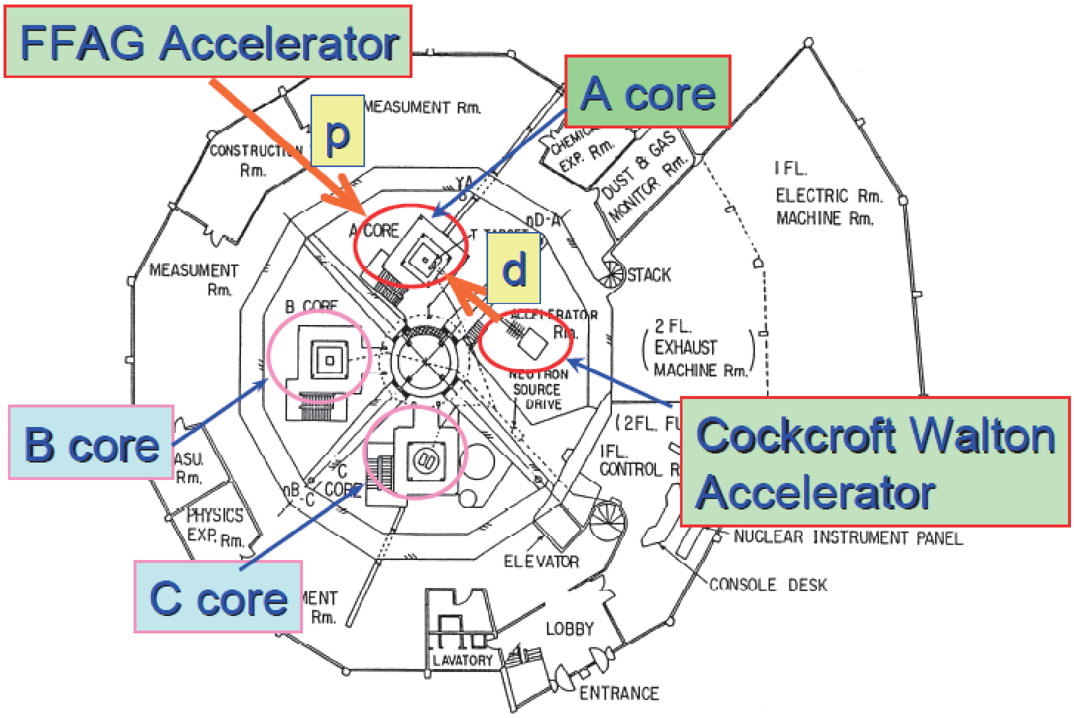
- **Basic Reactor Physics Experiments on ADS**
  - **Combination of KUCA Reactor and FFAG proton accelerator**
- **ADS Neutron Source**
  - **Future plan in Kyoto University Research Reactor Institute (KURRI)**

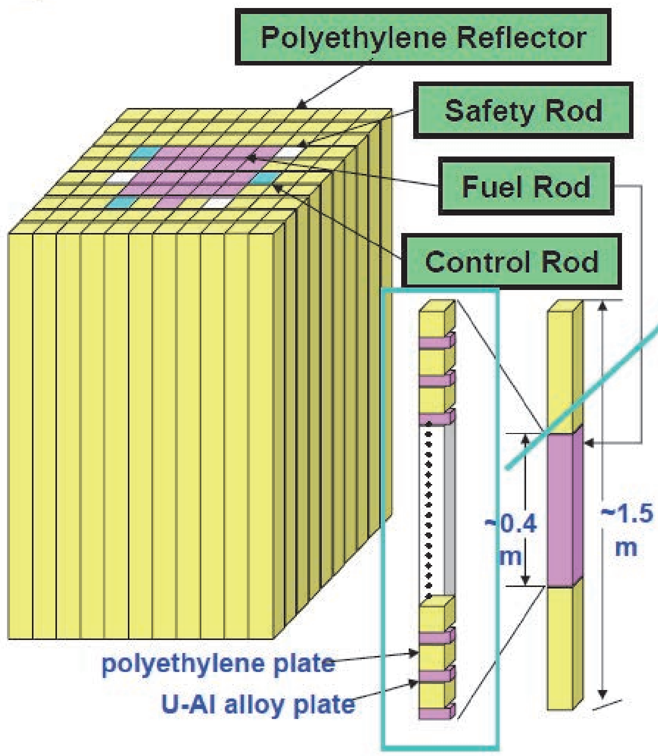
KUCA
(Kyoto University Critical Assembly)

- First Criticality: 1974
- Only one critical assembly owned by university in Japan
- Multiple core type critical assembly
  - Light water moderated core, Solid material (such as polyethylene, graphite, beryllium) moderated core
- Maximum power: 100 W (short time 1kW)
- Accelerator
  - Cockcroft-type to produce 14MeV neutron by DT
  - FFAG-type proton accelerator up to 100 MeV

KUCA Building

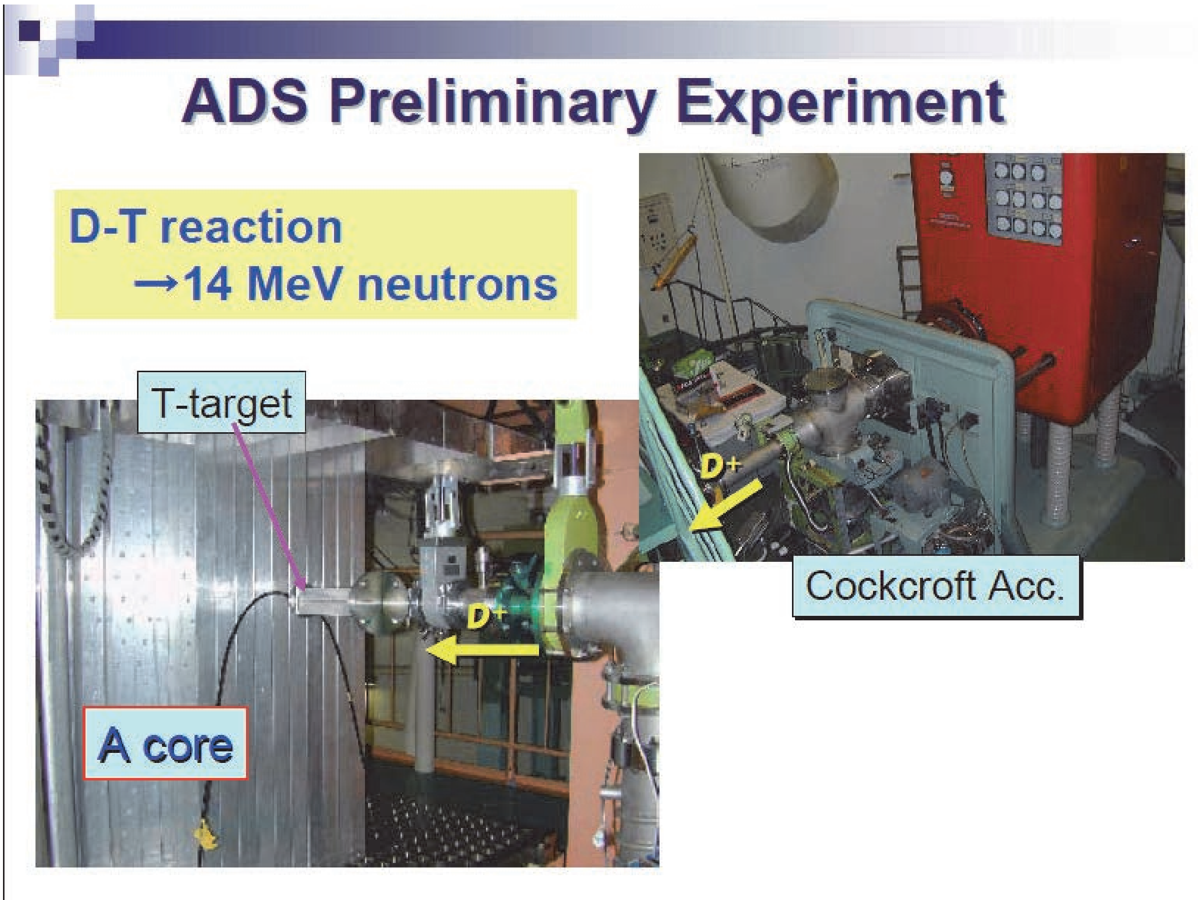
Cross sectional view of KUCA building

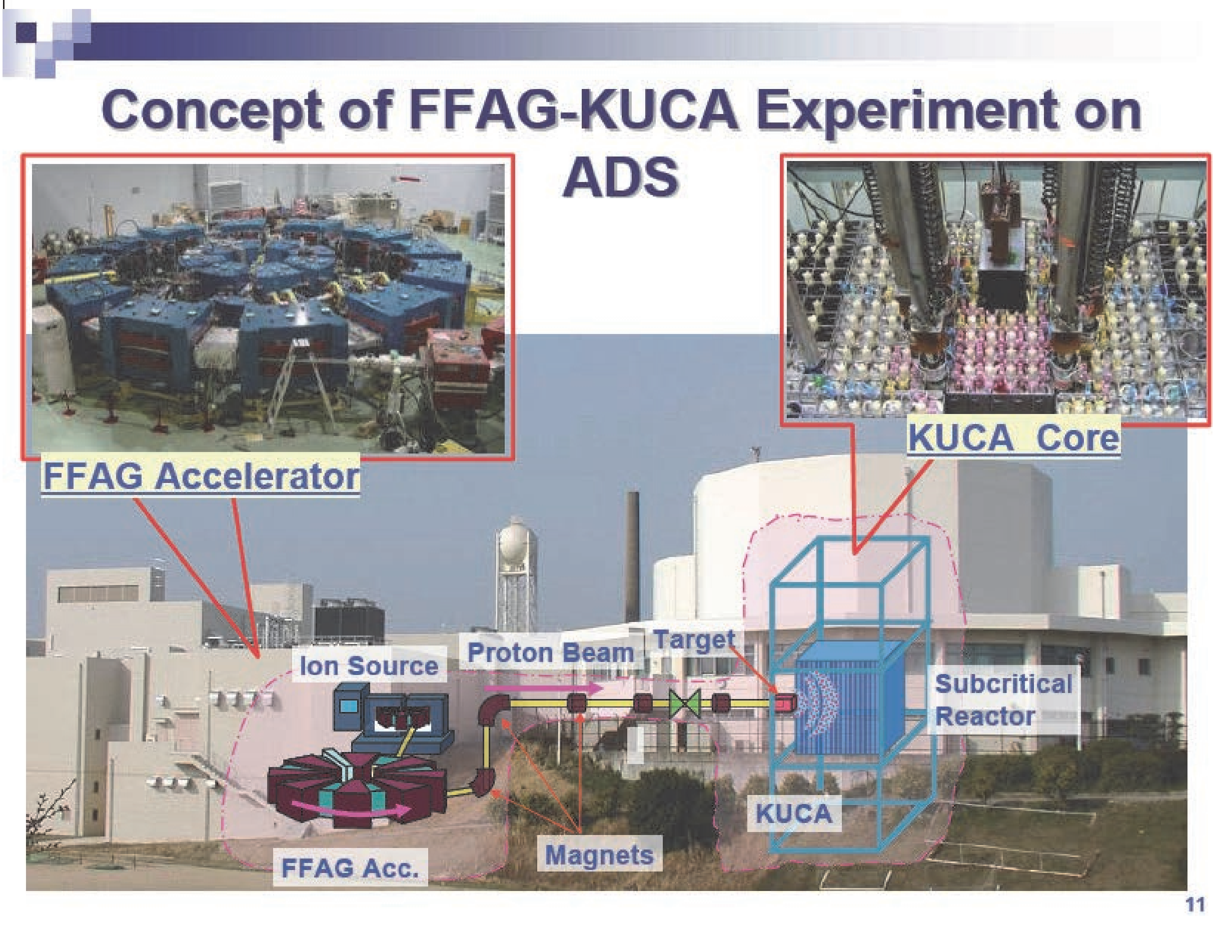




Fuel cell

A-Core View


ADS Preliminary Experiment
D-T reaction
→14 MeV neutrons
T-target
D+
A core
D+
Cockcroft Acc.


Concept of FFAG-KUCA Experiment on ADS
FFAG Accelerator
KUCA Core
Ion Source
Proton Beam
Target
Subcritical
Reactor
KUCA
Magnets
FFAG Acc.
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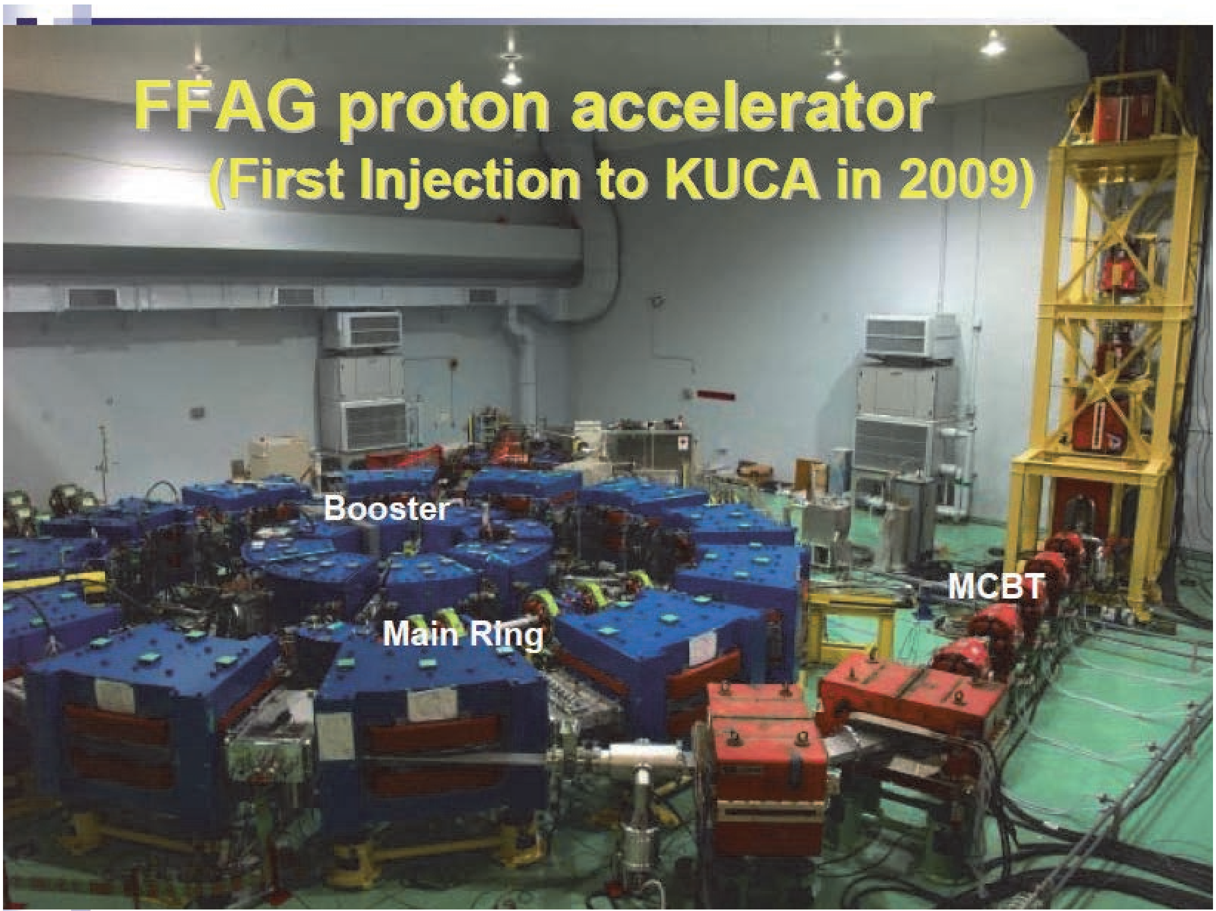
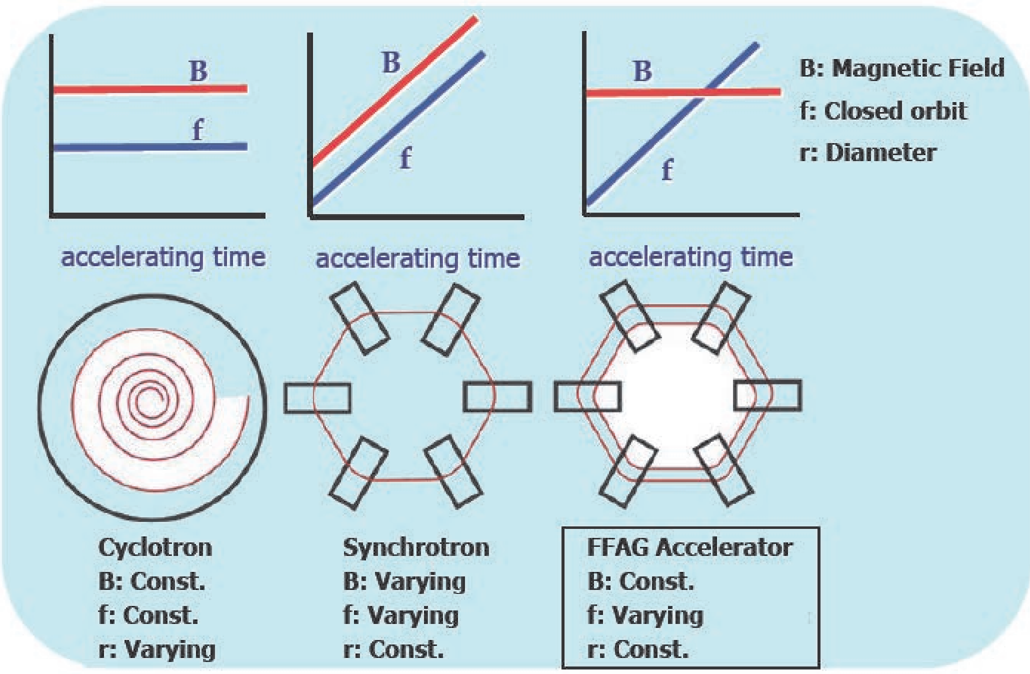
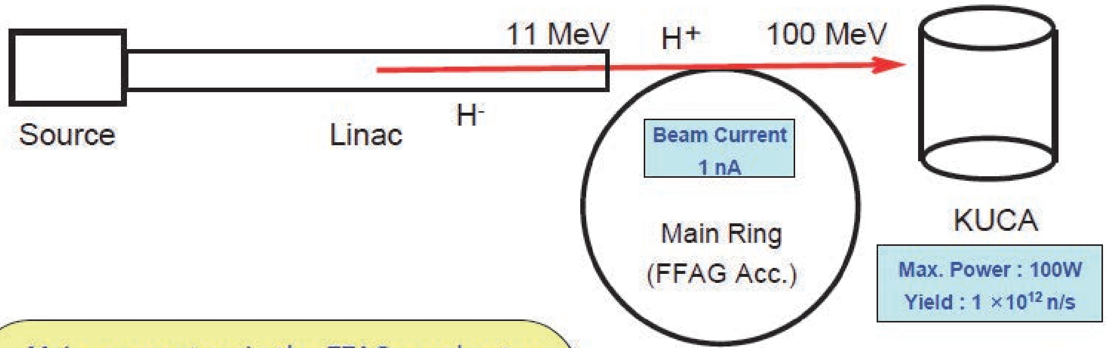


Characteristics of FFAG Accelerator



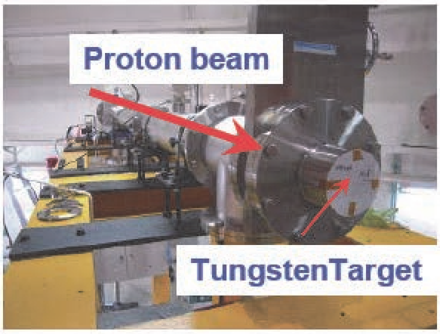
Configuration of present FFAG complex

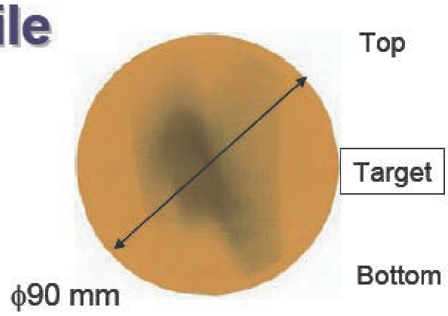


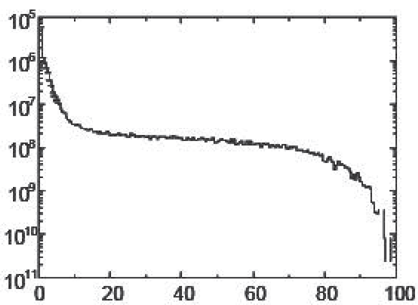
Main parameters in the FFAG accelerator

# of sectors	12
Energy	2.5 - 100MeV
Repetition rate	30 - 120Hz
Average beam current	1nA
Rf frequency	1.5 - 4.6MHz
Field index	7.5
Closed orbit radius	4.4 - 5.3m

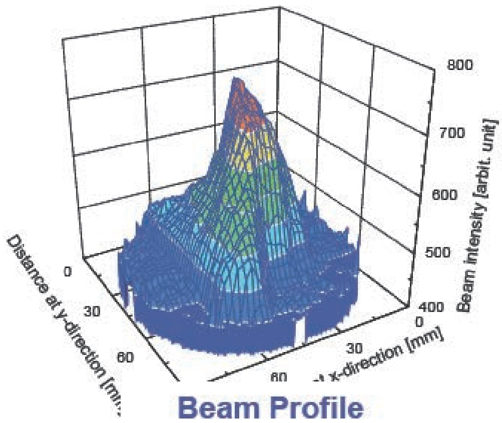
Proton beam profile







Neutron spectrum

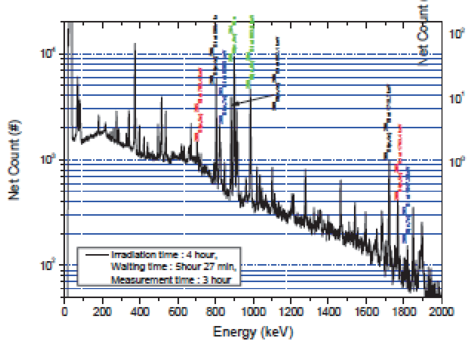


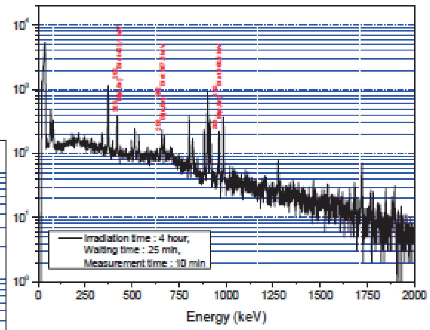
Beam Profile

Spallation Neutron Energy

◆ **Bi Irradiation Experiments**

- Confirmed the production of from 23 MeV to 54 MeV spallation neutrons
- Compared with last Exp. 1 yr ago,
  (n,7n) & (n,8n) reaction could be ascertained because of higher intensity





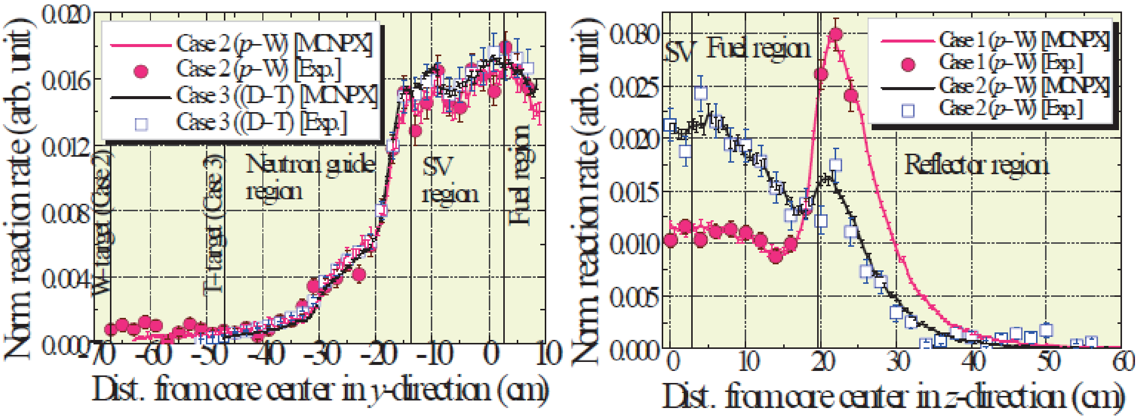
Reaction	Threshold E. (MeV)
^{209}Bi (n, 4n) ^{206}Bi	23
^{209}Bi (n, 5n) ^{205}Bi	30
^{209}Bi (n, 6n) ^{204}Bi	38
^{209}Bi (n, 7n) ^{203}Bi	45
^{209}Bi (n, 8n) ^{202}Bi	54
^{209}Bi (n, 9n) ^{201}Bi	62
^{209}Bi (n,10n) ^{200}Bi	71
^{209}Bi (n,11n) ^{199}Bi	78
^{209}Bi (n,12n) ^{198}Bi	88

Present ADS research topics at KUCA

- **Neutron flux measurement in subcritical state**
  - Optical fiber detector
  - Foil or wire activation method
- **Neutron spectrum measurement**
  - unfolding method by irradiation of with several foils.
  - unfolding method by recoil proton with a liquid scintilator (NE213)
- **Kinetic characteristics measurement**
  - Beam transient
  - Reactivity Change
- **Subcriticality measurement**
  - Pulsed neutron method
  - Noise analysis method
- **Thorium loaded ADS core**
- **Analysis of experiments with Monte Carlo code (MVP, MCNP, and MCNPX) and other deterministic transport codes.**

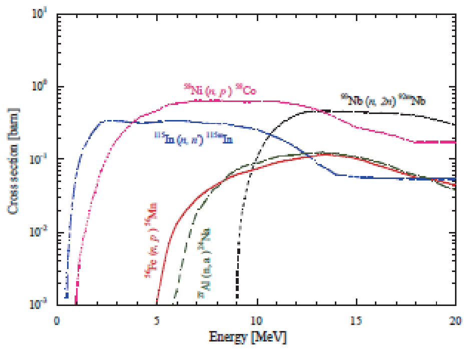
Comparison of k-eff by experiments and calculation (MCNP) at ADS core

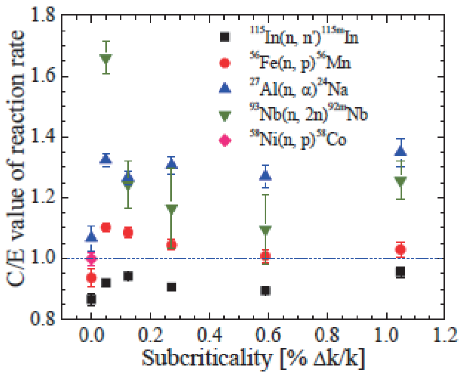
JENDL-3.3		ENDF/B-VI.2	
Experiment $\rho_{exp\text{-}sub}$ (%Δk/k)	Calculation $\rho_{cal\text{-}sub}$ (%Δk/k)	Experiment $\rho_{exp\text{-}sub}$ (%Δk/k)	Calculation $\rho_{cal\text{-}sub}$ (%Δk/k)
-0.68±0.03	-0.69±0.03	-0.68±0.03	-0.71±0.03
-0.89±0.04	-0.84±0.03	-0.89±0.04	-0.86±0.03
-1.34±0.07	-1.35±0.03	-1.34±0.07	-1.40±0.03
-1.76±0.05	-1.71±0.03	-1.76±0.05	-1.72±0.03



Reaction Rate Distribution (experiments and calculation)

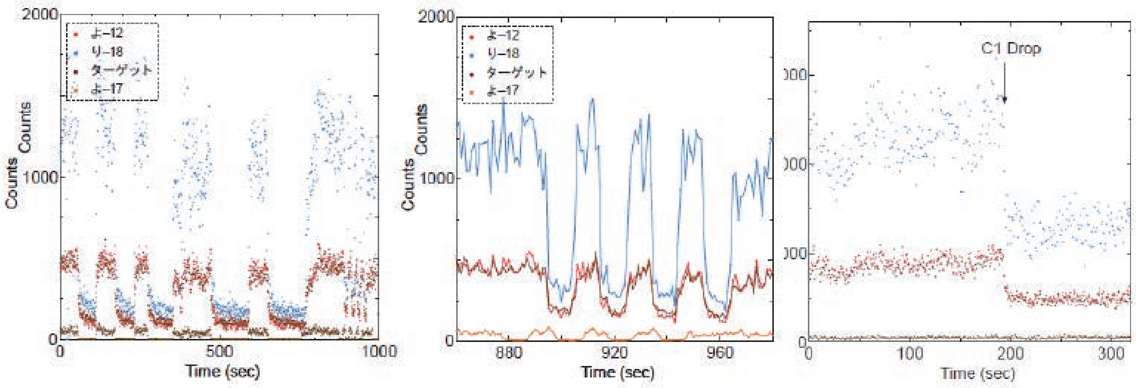
Reaction rate measurement





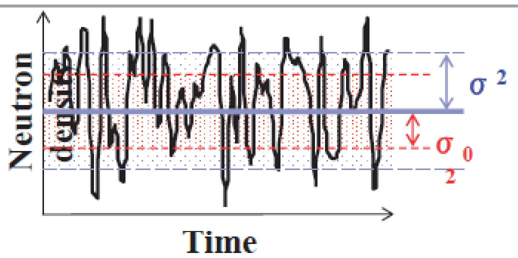
Material	Reaction	C / E [-]
In	$^{115}In\ (n, n')\ ^{115m}In$	0.93 ± 0.01
Ni	$^{58}Ni\ (n, \alpha)\ ^{58}Co$	0.94 ± 0.01
Fe_H (99.99 %)	$^{56}Fe\ (n, p)\ ^{56}Mn$	0.95 ± 0.02
Al	$^{27}Al\ (n, \alpha)\ ^{24}Na$	1.08 ± 0.04

Response of reactor power profile in the case of proton beam on and off



Repetition of beam power change — **Control rod drop**

Neutron Noise Analysis by variance-to-mean ratio method (Feynman-alpha)

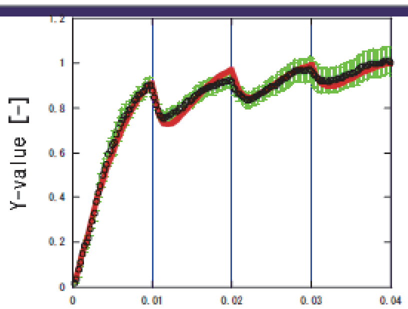


Mean value

σ^2 : Variance

σ_0^2 : Variance of the Poisson distribution

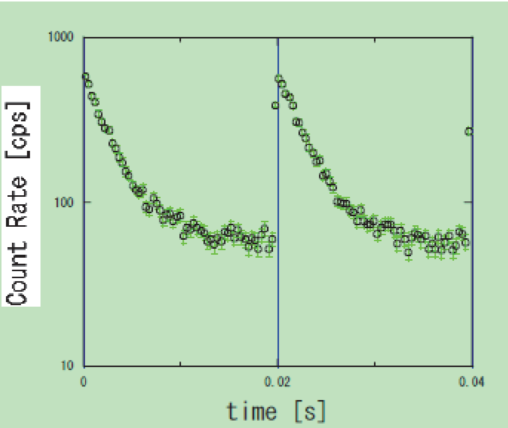
$$Y(T) \equiv \frac{\frac{1}{N}\sum_{k=1}^{N} Z_k(T)^2 - \left\{\frac{1}{N}\sum_{k=1}^{N} Z_k(T)\right\}^2}{\frac{1}{N}\sum_{k=1}^{N} Z_k(T)} - 1$$

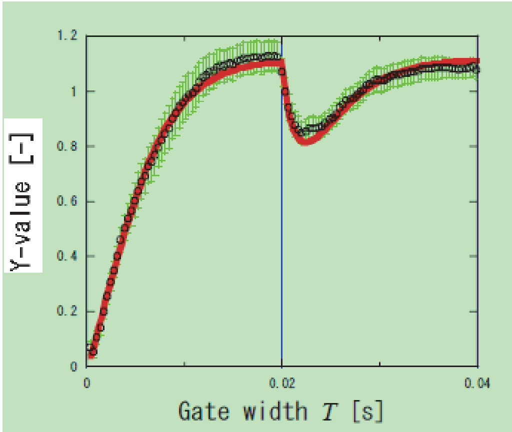


New formulation of Y-value with pulsed neutron source

$$Y_{\mathrm{syn}}(T) = Y_0 \frac{\left\{\begin{array}{l}\sum_{L=1}^{M[T]}\left\{\begin{array}{l}(\delta+1)+(\delta-1)e^{-2\alpha(T-L\tau)} \\ -2\delta e^{-\alpha(T-L\tau)}-2\alpha(T-L\tau)e^{-\alpha(T-L\tau)}\end{array}\right\} \\ +(\delta-1)\frac{1}{1-e^{-2\alpha\tau}}\left(1-e^{-\alpha T}\right)^2+2\frac{1-(1+\alpha T)e^{-\alpha T}}{1-e^{-\alpha\tau}}\end{array}\right\}}{\sum_{L=1}^{M[T]}\left\{1-e^{-\alpha(T-L\tau)}\right\}+\frac{1}{1-e^{-\alpha\tau}}\left(1-e^{-\alpha T}\right)}$$

Subcriticality measurement by neutron noise analysis





Pulsed neutron method (Area-ratio method)		V-to-variable-M method	Comparison of α -value
$-\rho$ [\$]	α_0 [1/s]	α [1/s]	$(\alpha - \alpha_0)/\alpha_0$
1.597 ± 0.012	357.8 ± 0.9	359 ± 16	0.005 ± 0.045

Some results were accepted by ADS benchmark problem at IAEA

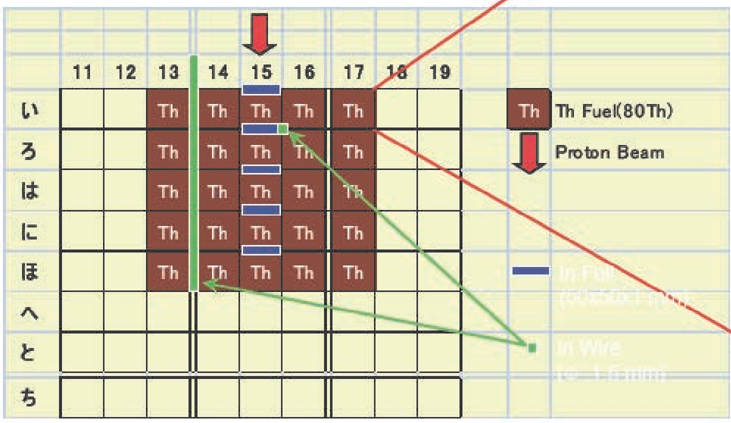
- **Phase I: Static experiments (14MeV neutrons)**
  Reaction rates , Neutron spectrum, Reactivity
- Phase II: Kinetic experiments (14MeV neutrons)
  Neutron multiplication, Subcriticality measurement method
  (Rossi-α, Feynman-α, Pulsed neutrons and
  Neutron source multiplication (NSM) methods)
- Phase III: Static and Dynamic experiments (150MeV protons)
  Above topics, γ-ray distribution, Power monitoring, etc.

- Fuel: Highly enriched ^{235}U, ^{232}Th, Natural Uranium
- Reflector: Polyethylene, Graphite, Aluminum, Beryllium
- Core: Any combinations of Fuel & Reflector

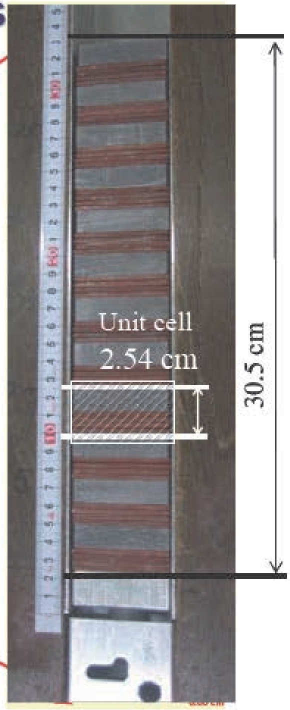
Thorium-loaded ADS Experiments

◆ **Thorium-loaded core**

- 5 by 5 fuel assembly with 80 Th plate & No moderator
- Th plate dimension : 2" x 2" x ¼"
- To analyze Th fission R.R, In foil/wire were installed

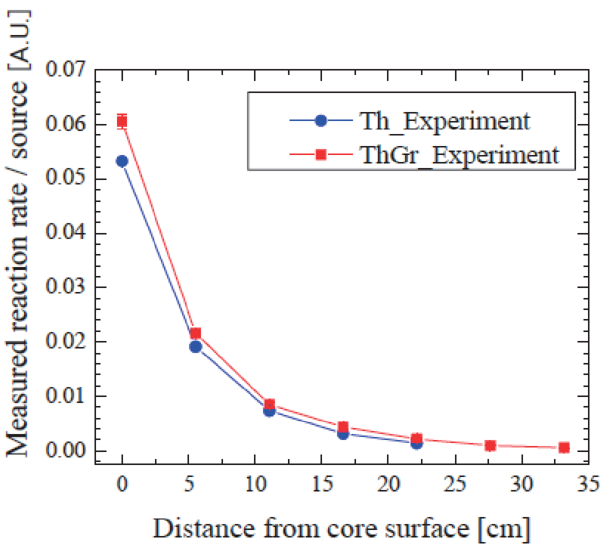


KUCA A-core (5 by 5 F.A.)



Configuration of F.A. with 80 Th fuel plate

Reaction rate measurement



Dis. [cm]	(ThGr/Th)
0	1.14 ±0.03
5.53	1.13 ±0.03
11.06	1.15 ±0.05
16.59	1.39 ±0.08
22.12	1.56 ±0.11

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Study of Materials Irradiation Effects by proton beam

New Materials irradiation chamber for FFAG

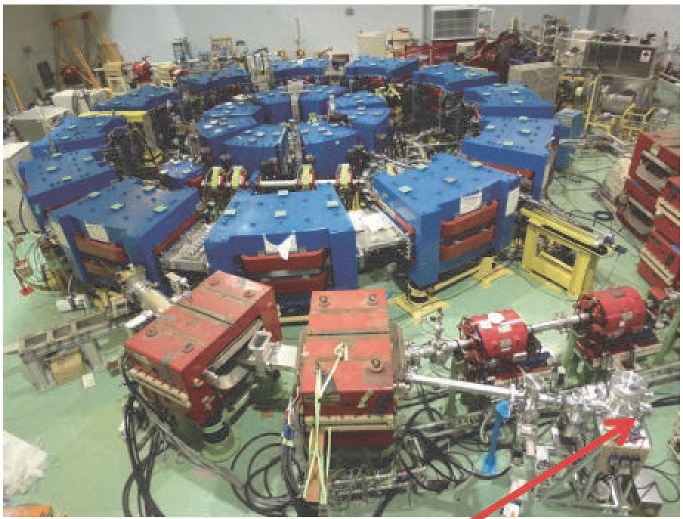
Irradiation temperatures: 6K - 700 K

In-situ fatigue test

Post irradiation test

Positron annihilation lifetime measurements

Electrical resistivity measurement

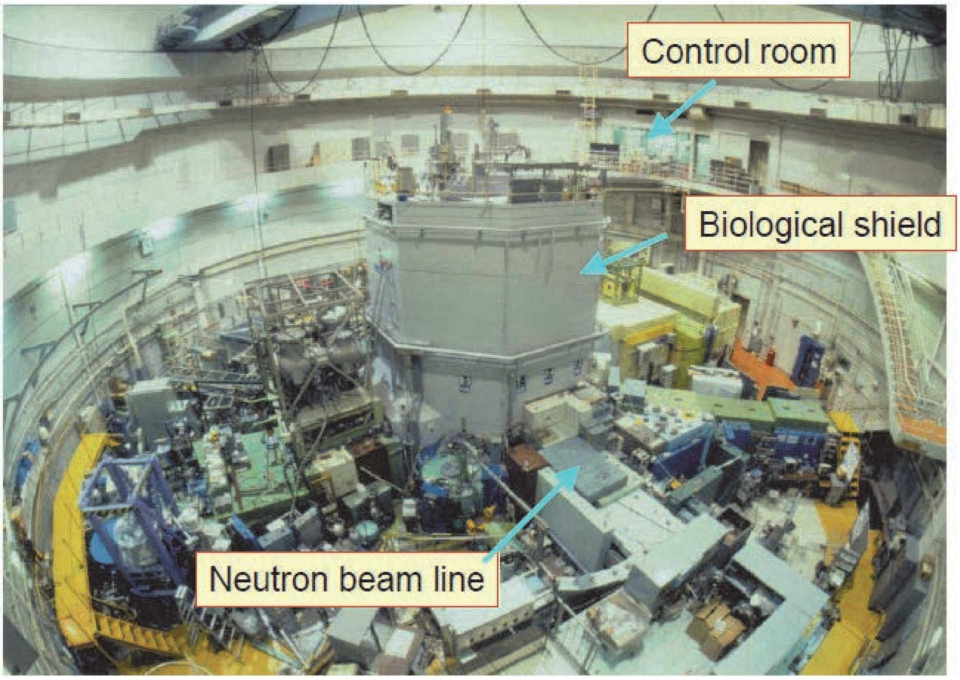


Materials Irradiation Chamber

Future Plans for KUCA ADS exp.

- **Upgrade FFAG system: Proton beam energy and current**
  - Energy: 100 MeV to 150 MeV (hopefully up to 200 MeV)
  - Current: 1 nA to 10 nA (hopefully up to 100 nA)
- **ADS experiments (Hard spectrum cores) by varying neutron spectrum and external neutron source**
  - Hard spectrum core loaded with Pb or Pb-Bi which can be achieved by 2-zone core with test and driver regions
  - Pb sample worth measurement
  - Reaction rate measurement of ^{237}Np and ^{241}Am
- **Th-loaded and Th-U-loaded ADS experiments**
  - Reaction rate or Conversion ratio measurement
    - Capture of ^{232}Th, Fission of ^{233}U, etc.
  - Experiments by varying neutron spectrum, outer source, subcriticality
- **Establish subcriticality measurement techniques in actual ADS operation mode (less than keff=0.95)**
- **Make ADS benchmarks based on KUCA exp. (U, Th, Th-U)**

KUR
(5MW thermal reactor operated from 1964)



Neutron source after KUR

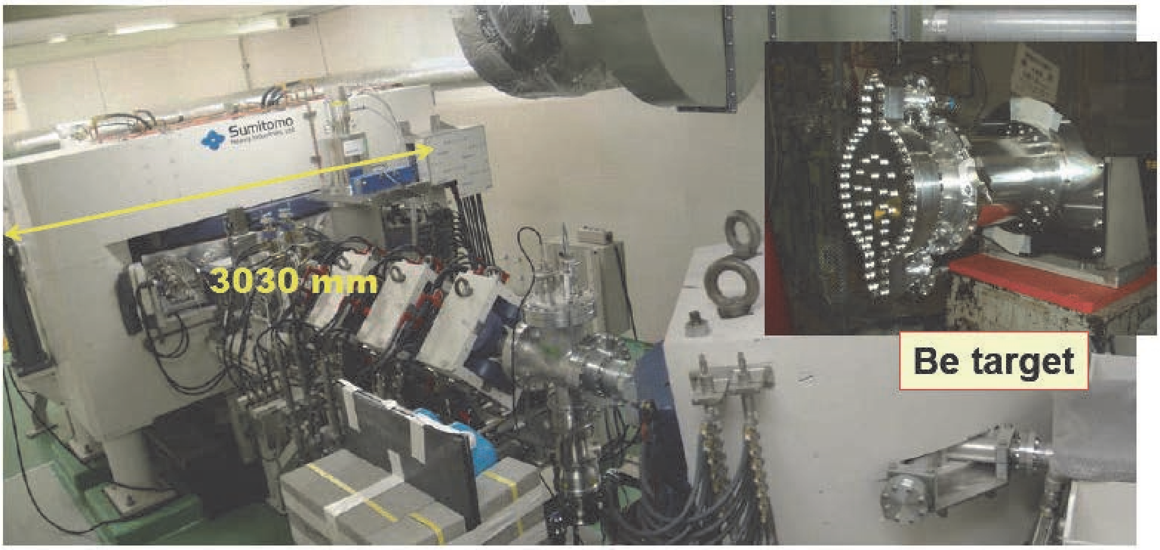
- KUR was operated for more than 1000 hours in Fy 2011 without any trouble
- However, KUR will be shutdown in the future since it has been operated for 47 years
- Future plan of KURRI for neutron source
  - Accelerator (FFAG ?)
    - Pulsed neutron source
  - Accelerator (cyclotron ?)
    - Continuous neutron source
  - ADS
    - Continuous neutron source
    - Neutron irradiation exp. & neutron beam exp.

ADS neutron source

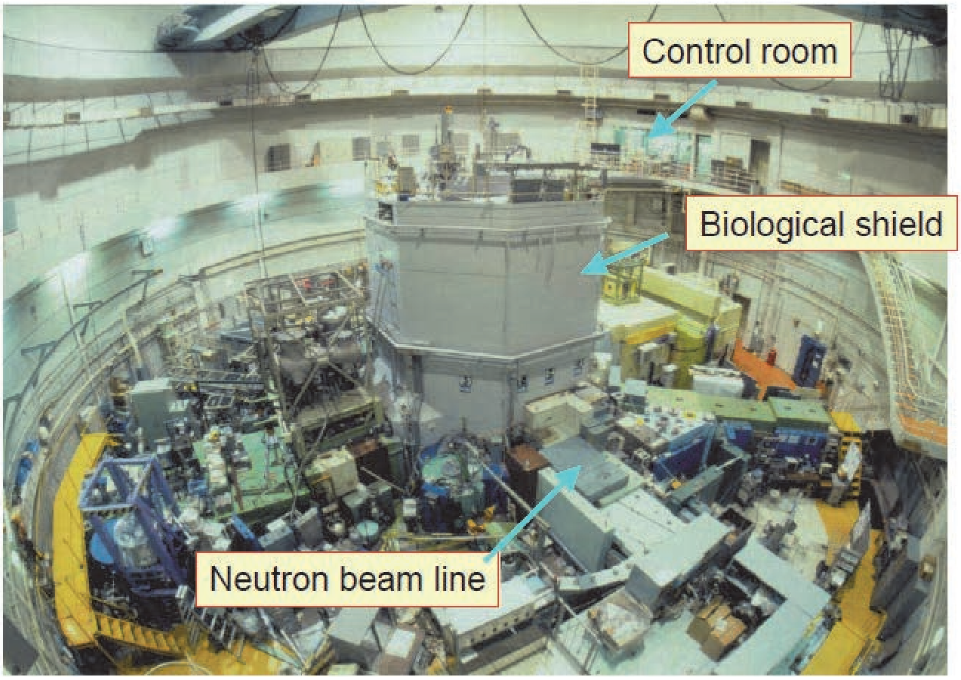
- Fuel
  - Pin type fuel with Zr cladding
  - Enrichment: less than 5 %
  - UO_2 or U-metal
- Multiplication
  - k-eff : less than 0.95
    - not categorized as nuclear reactor (hopefully)
- Accelerator
  - Cyclotron
    - already developed for BNCT

Cyclotron for BCNT (boron neutron capture therapy) at KURRI

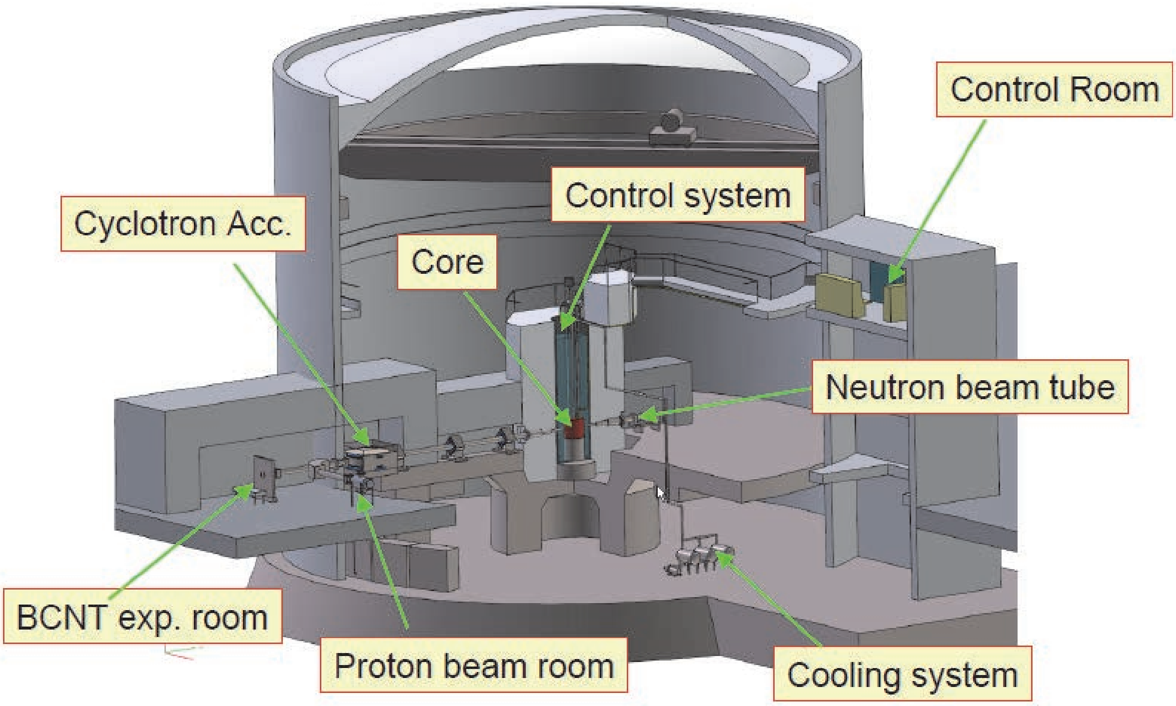
Proton Beam: 30 MeV, 1 mA
N production rate : 1.9×10^{14} (n/sec)



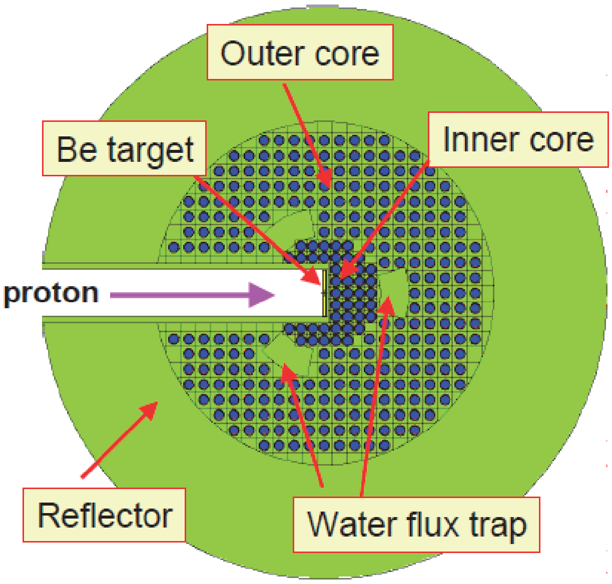
KUR reactor room



ADS in the KUR building



Core configuration



Horizontal cross section of the core

- Core : (pin fuel + H_2O)
  - Inner (hard spectrum)
  - Outer (soft spectrum)
  - Core height: 100 cm
- Irradiation hole (with pneumatc system)
  - water flux trap (3 positions)
  - center core
- Neutron beam line
  - from center core
- proton beam tube (10cm dia.)
  - Be metal target
  - with H_2O target cooling line

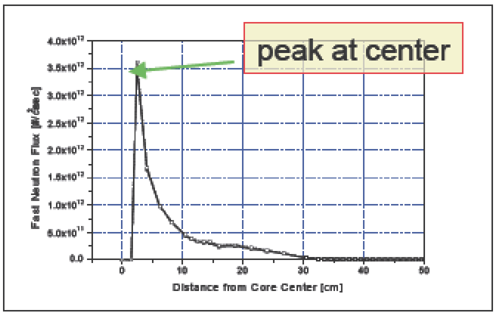
Feature of ADS neutron source

- Highest thermal flux to power ratio
  - present ADS: 3.4×10^{10} (1/cm²/sec/kW)
  - KUR: 0.40×10^{10} (1/cm²/sec/kW)
  - JRR-3: 0.48×10^{10} (1/cm²/sec/kW)
- Low production of spent fuel
- Allowance of positive reactivity coeff.
  - Insertion of water trap region inside the core will cause positive temperature or void coeff.
- No limitation for irradiation material in the view point of reactivity
  - Unbounded design for irradiation system

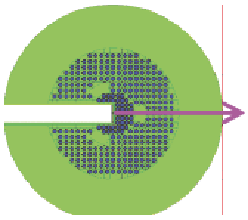
Neutron Flux at the present ADS

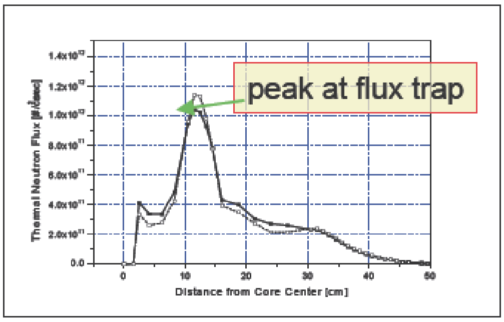
Fuel	UO_2	U-metal
Core Diam.	60	60
Enrichment (%)	1.49	1.16
k-eff	0.9	0.9
Thermal power (kW)	35	40
Max. Thermal flux ($n/cm^2/s$)	1.2E+12	1.2E+12
Max. Fast flux ($n/cm^2/s$)	3.5E+12	3.6E+12

ref. : thermal flux at KUR in 1MW is 4.0E12



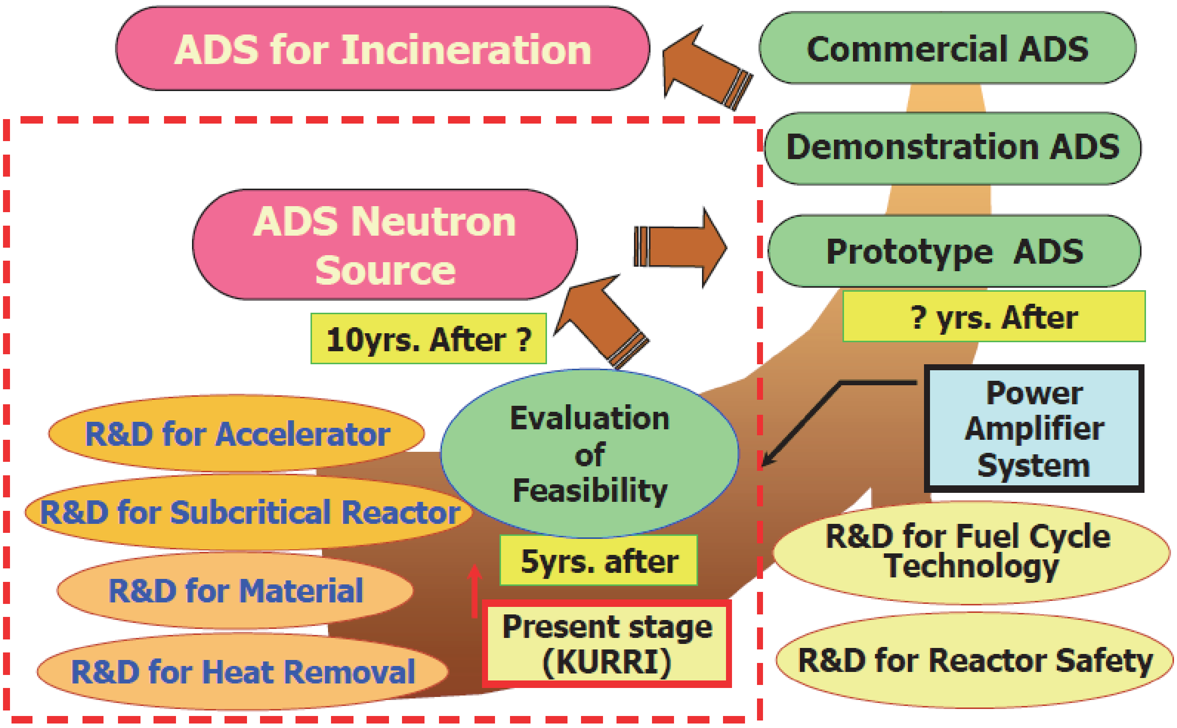
fast neutron flux





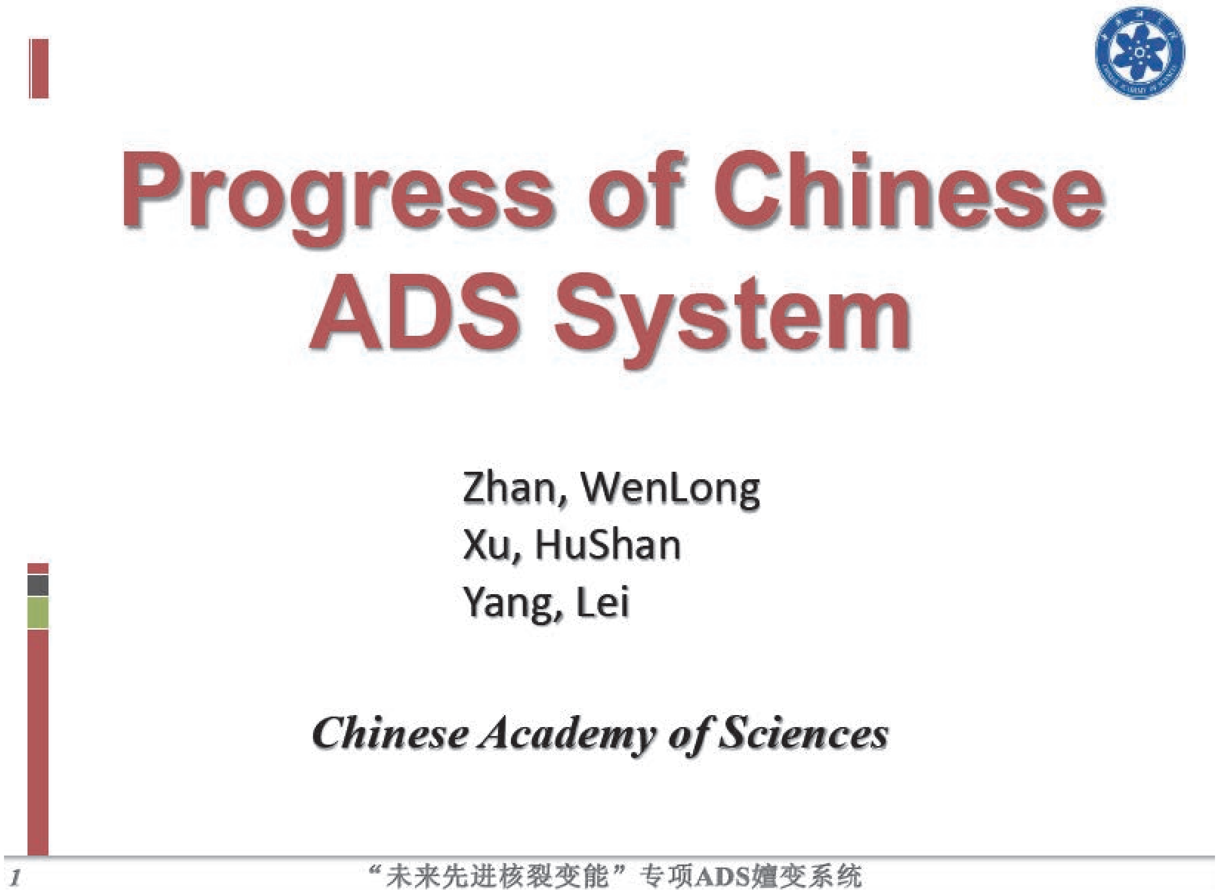
thermal neutron flux

Road Map of ADS Research Program

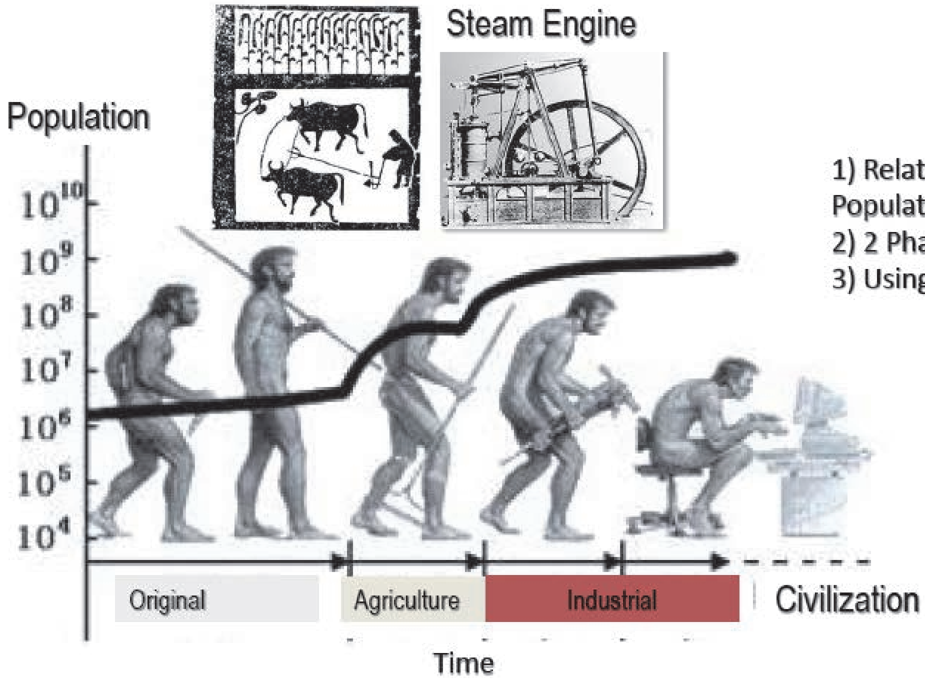


3.5 Progress of Chinese ADS System

L. Yang (CAS, China)



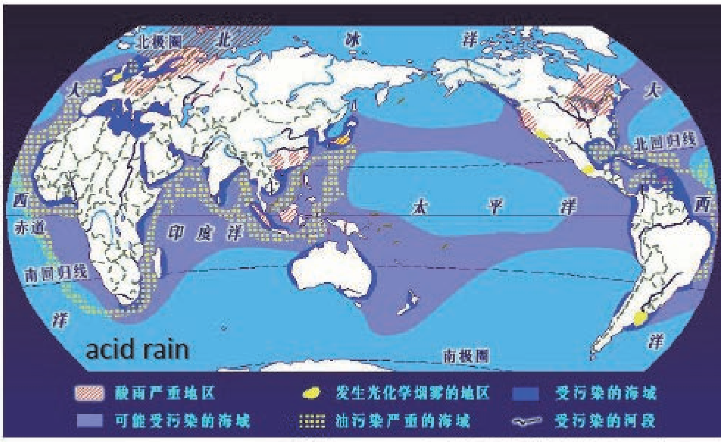
Energy Revolution



1) Relation between Population and Time
2) 2 Phase transition
3) Using Non-manpower

Global environment pollution by chemical energy

Fossil fuels remain indispensable to the global economy, but it is increasingly produced in places that present big commercial, environmental, and geopolitical risks; greenhouse gases continue to accumulate in the atmosphere; and the odds that the world will face catastrophic climate change are increasing.



2004年全国环境污染损失占当年GDP的3.05%

Three per cent loss of GDP

Renewable energy

Hydroelectric power plant

地理
季节
传输
问题

Solar/wind power plants

Wind power is plentiful, renewable, widely distributed, clean, and produces no greenhouse gas emissions during operation.

improve inherent safety

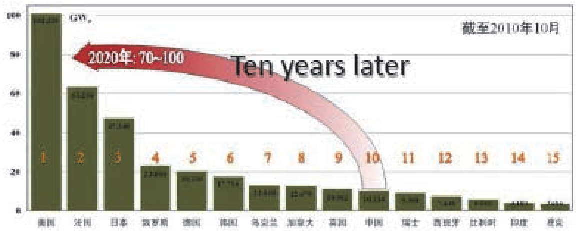
AP1000 Sodium fast reactor

Now, the nuclear power plant stands on the border between humanity's greatest hopes and its deepest fears for the future. Atomic energy offers a clean energy with huge demand.

4 “未来先进核裂变能”专项ADS嬗变系统

Nuclear Power in China

Operation:	10.234GW$_e$/11 reactors
Constructing:	25.90GW$_e$/23 reactors
Designing:	44.27GW$_e$/39 reactors
Planning:	120.0GW$_e$/120reactors



Westinghouse Electric Com. Third G.R.

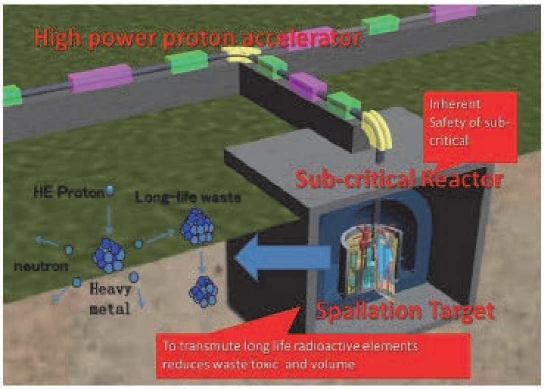
Heavy water R.

5 “未来先进核裂变能”专项ADS嬗变系统

Nuclear waste disposal in China

- 1GW nuclear plant (PWR) produces several 10 tons waste per year.
- In the past 30 years, most of 100s nuclear reactors use the way to disposal the waste in USA. At present, 45k tons waste has been produced and still increases 2k tons per year.
- In China, the pressure of waste disposal will be heavier in around 2030. At that time, it will be 3200 tons high-level waste per year according the long term plan.

- Report of 《 ADS and FR in Advanced Nuclear Fuel Cycles 》 NEA/ OECD
  - ADS is better at burning waste than fast reactors
  - ADS employing a <u>fast neutron spectrum and solid, could support more PWR waste transmutation to transmute transuranics or minor actinides</u>



ADS in China

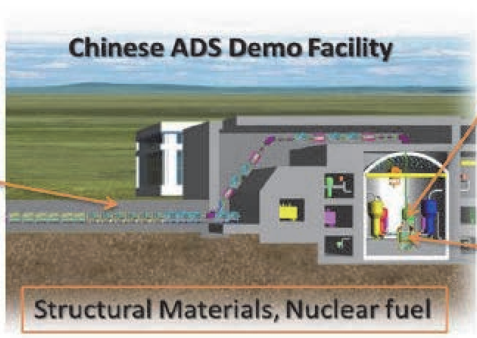
In China, the result of sustainable fission energy development strategy consulted by experts and academicians is:
- SFR is used for breeding and ADS for transmutation, it is suitable for China

ADS R&D in China

- – 1999, Conceptual Study on ADS
- 2000 – 2010, 2 R&D projects of 973 supported by the department of Science and Technology
- 2011 – , ADS R&D facility constructing

CAS; China Institute of Atomic Energy; Tsinghua University and etc.

High Power Proton accelerator: 15MW=1.5GeV@10mA



Subcritical core: 1-3m wide、2-4m high

Beam target coupled region: ~15cm wide、~50cm high

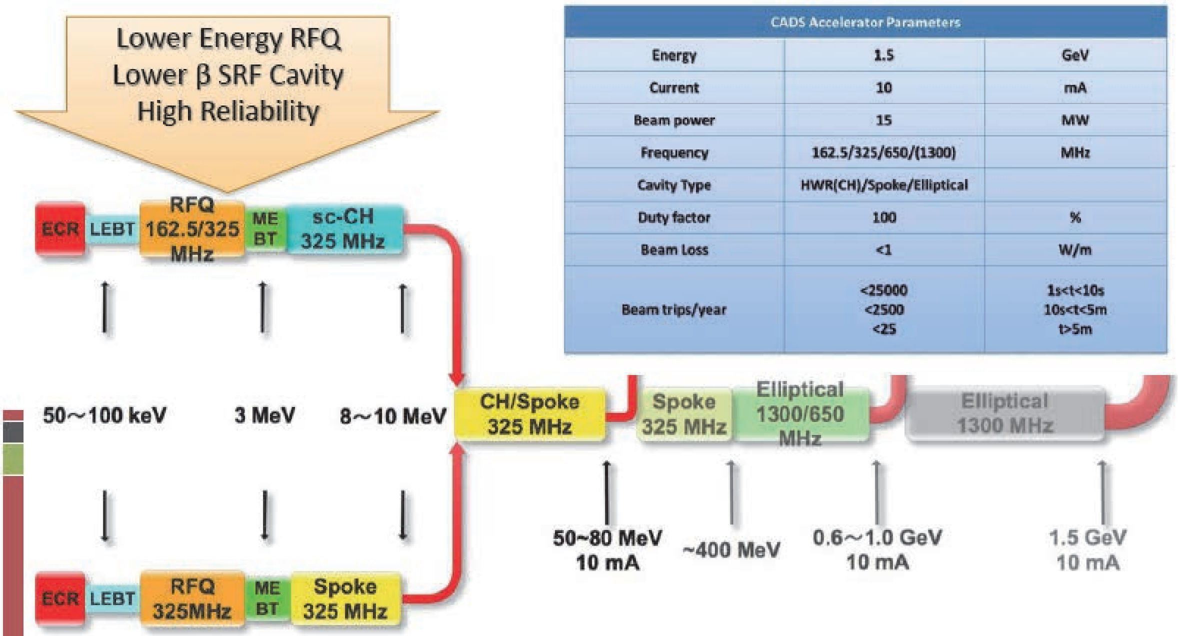
Progress for CADS HPPA

Open questions in HPPA for >10 MW (cw) beam power

- One of the most challenging technical aspects of any ADS accelerator system, the Front-End Injector (ECR+LEBT+RFQ+MEBT+LBSRF).
  - improve the reliability of front-end system
  - control of beam halo generated in front-end systems
- Superconducting radio-frequency accelerating structures appropriate for the acceleration of tens of MW of beam power have been designed, built and tested; some structure types are in routinely operating accelerator facilities.
  - Robust and reliable for year-round uninterrupted operation
  - Operates with minimum beam loss (beam loss 1 nA/m) in accelerator

8 “未来先进核裂变能”专项ADS嬗变系统

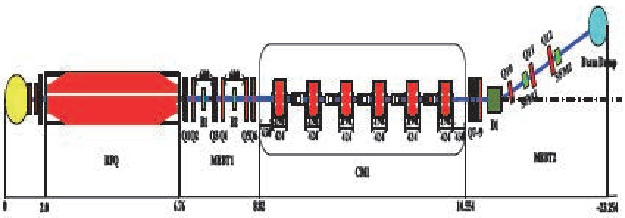
Conceptual design of Accelerator

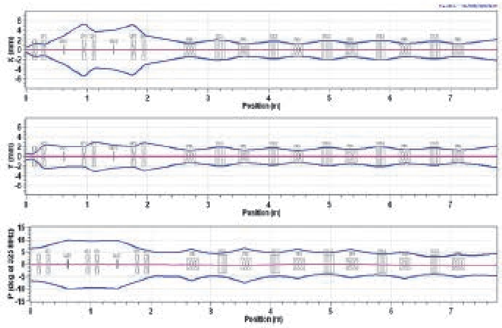


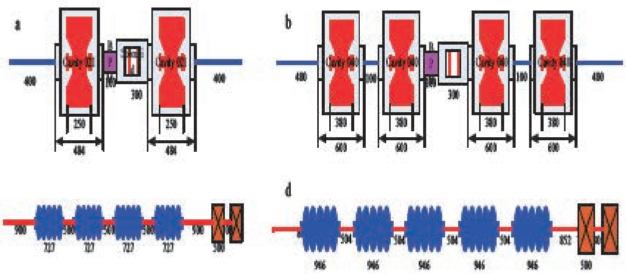
CADS Accelerator Parameters		
Energy	1.5	GeV
Current	10	mA
Beam power	15	MW
Frequency	162.5/325/650/(1300)	MHz
Cavity Type	HWR(CH)/Spoke/Elliptical	
Duty factor	100	%
Beam Loss	<1	W/m
Beam trips/year	<25000 <2500 <25	1s<t<10s 10s<t<5m t>5m

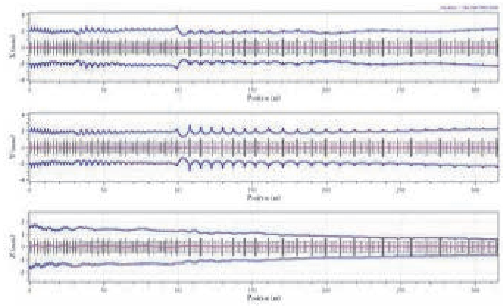
9 “未来先进核裂变能”专项ADS嬗变系统

Beam Dynamics

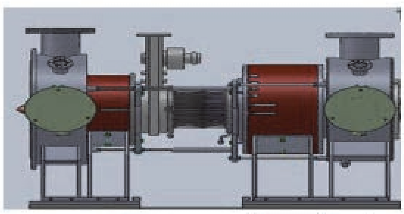


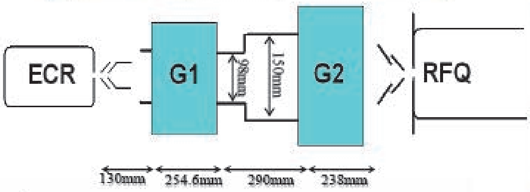


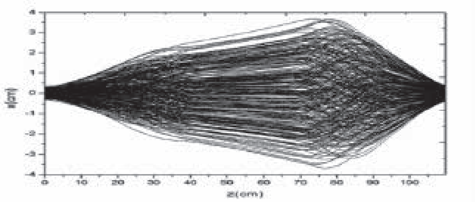




ECR & LEBT (0.035MeV)

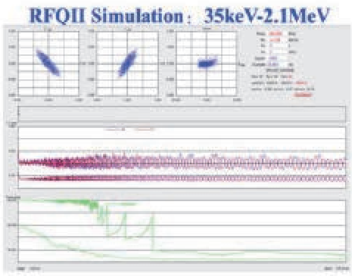


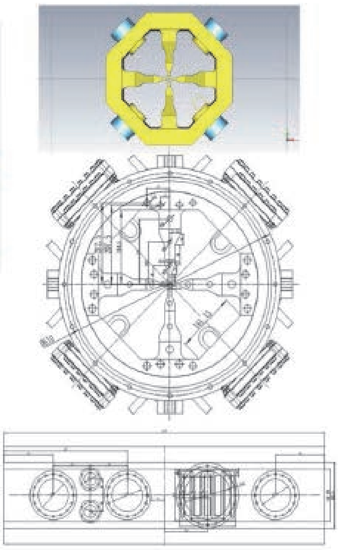


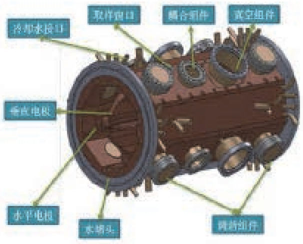


Assemble

Radio Frequency Quadrupole



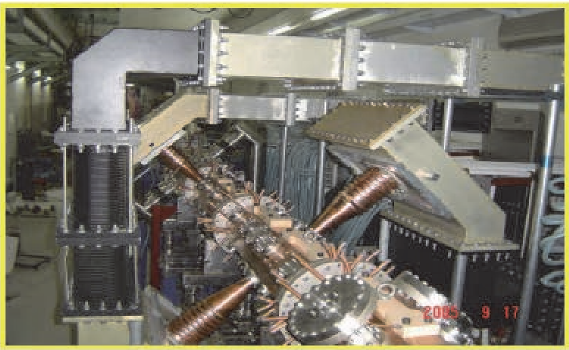




Mechanical Design

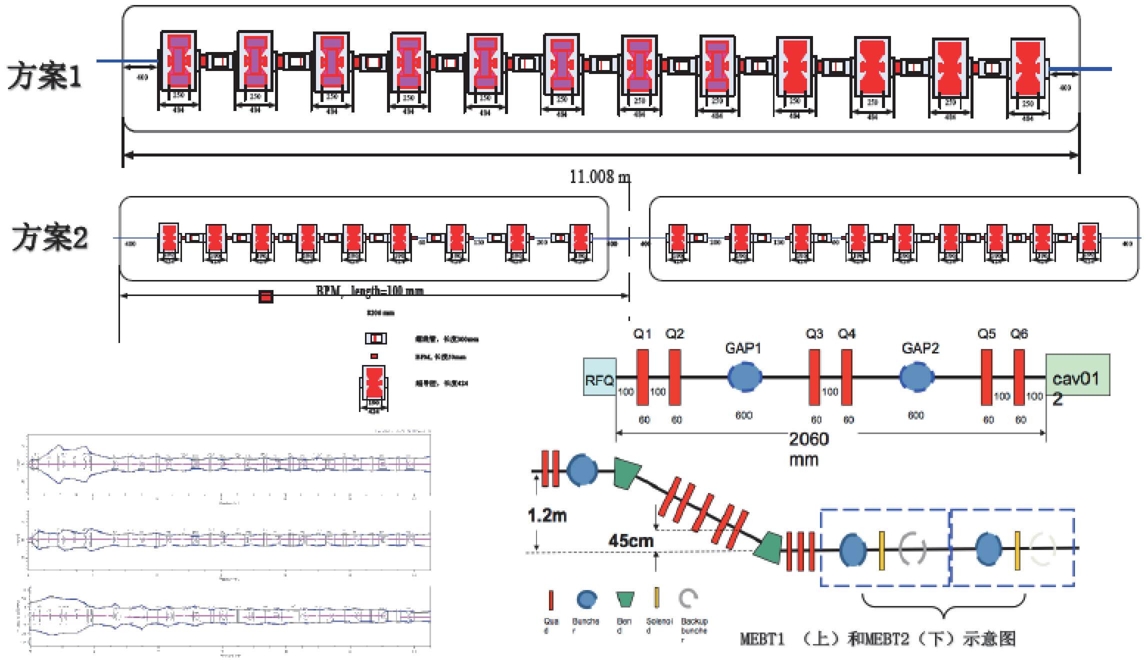
Manufacture

Radio Frequency Quadrupole (IHEP-CIAE)



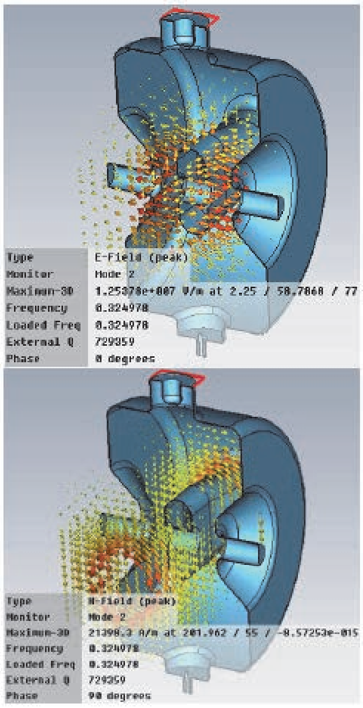
3MeV@6mA

MEBT



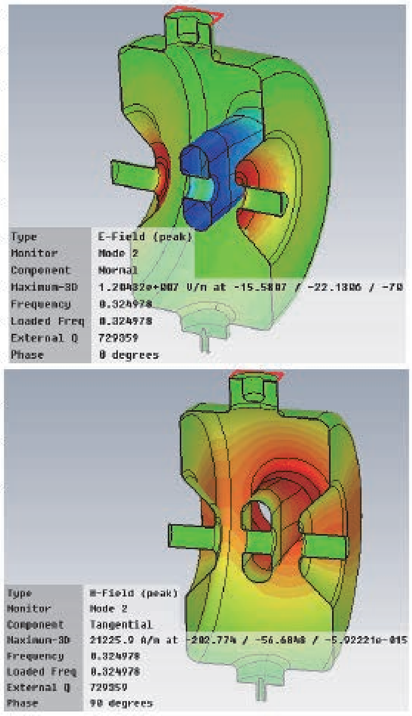
14 “未来先进核裂变能”专项ADS嬗变系统

Superconducting cavity



Para.	
E_p/E_{acc} /(void)	3.88
H_p/E_{acc} /mT/(MV/m)	8.13
β_{opt}	0.246
r/Q /Ω	206
G /Ω	87
Df/dL /kHz/mm	632
R_{BCS} /nΩ	0.68
Q0@Rres=5nΩ	1.38E10
$Q_{e,opt}$	7.28E5
Le @$Q_{e,opt}$ /mm	22.3

Para.	
E_p /MV/m @1J	12.04
H_p /kA/m @1J	21.22
Vc @32.5MV/m /MV	1.75
Vc @65mT /MV /MV	1.58



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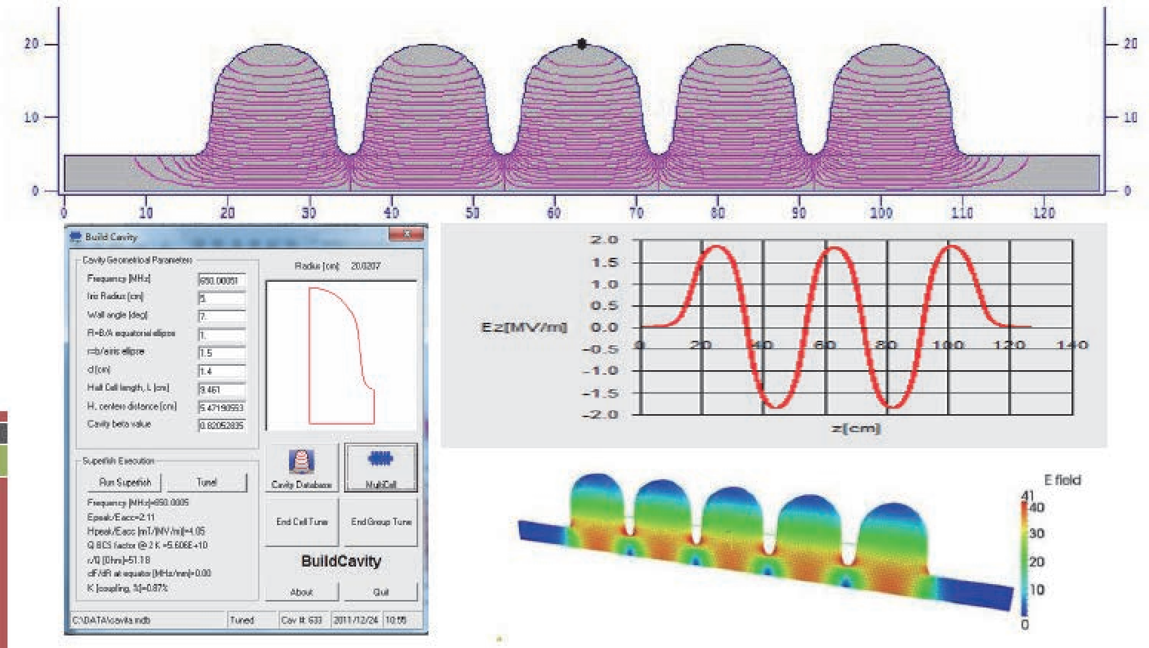
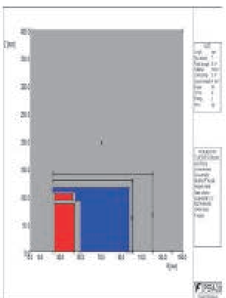
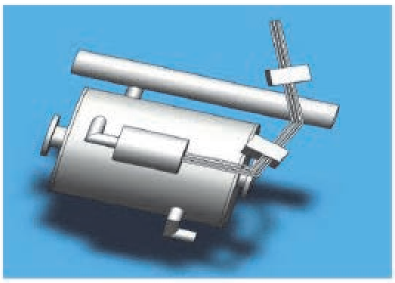
High Beta Superconducting cavity

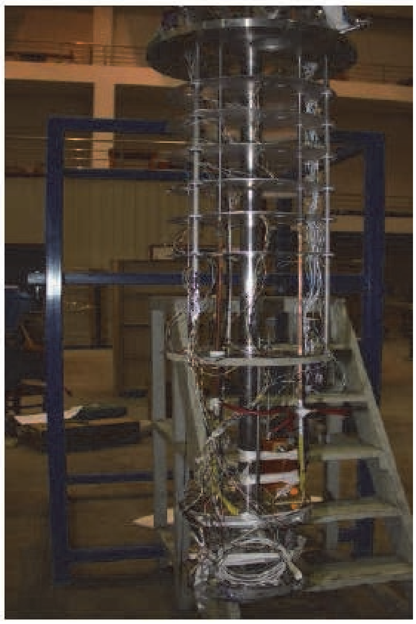


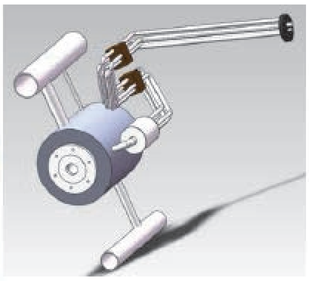
Superconducting magnet



2D model for calculation

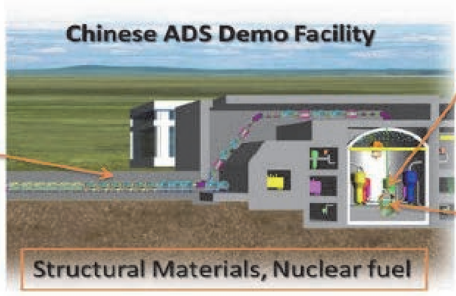






Progress for CADS Spallation Target

High Power Proton accelerator: 15MW=1.5GeV@10mA



Subcritical core: 1-3m wide、2-4m high

Beam target coupled region: ~15cm wide、~50cm high

Open questions in ADS Spallation target

With the demand of neutron flux，how to transfer effectively heat deposition for the spallation target?

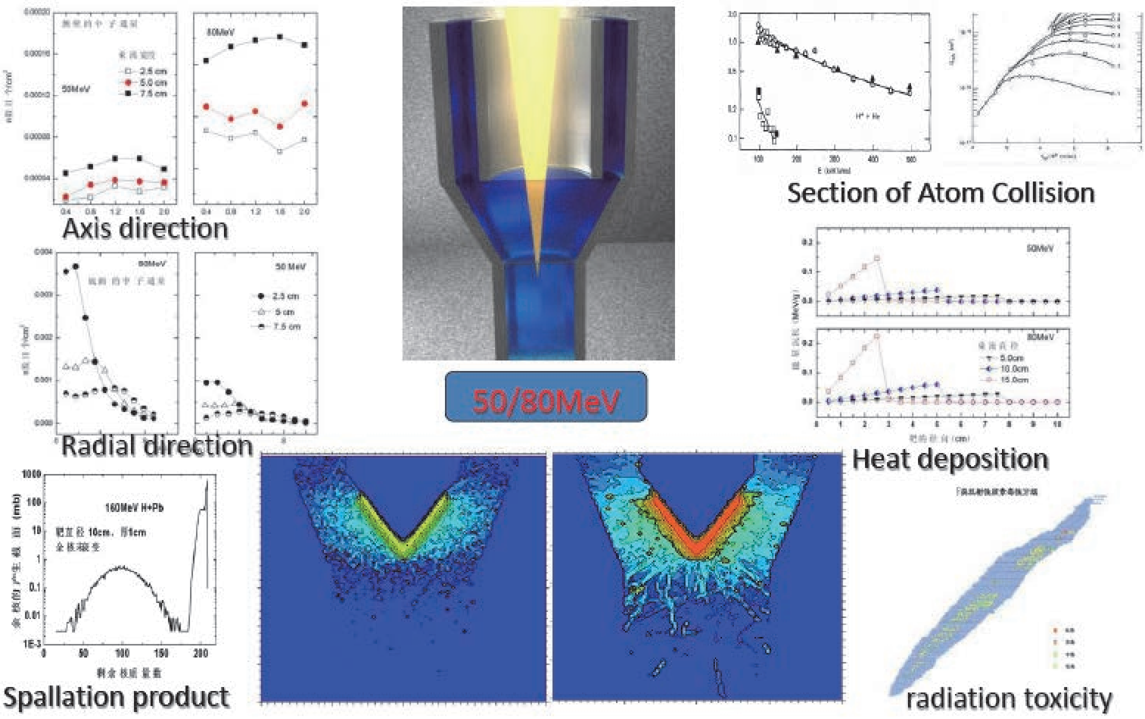
(a) Has high spallation neutron yield at 1 GeV proton beam (neutron/proton20–40).

(b) Has capability to dissipate very high heat flux without vaporizing (heat flux of the order ~kW/cubic centimeter).

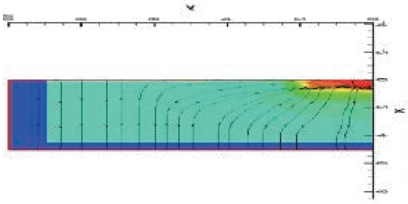
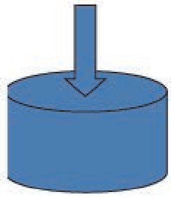
(c) Withstands irradiation and thermal effects along with its container.

Better understanding for strong coupled of the beam and liquid metal.

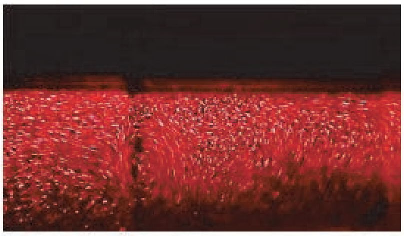
Calculation of Spallation process and Neutronic

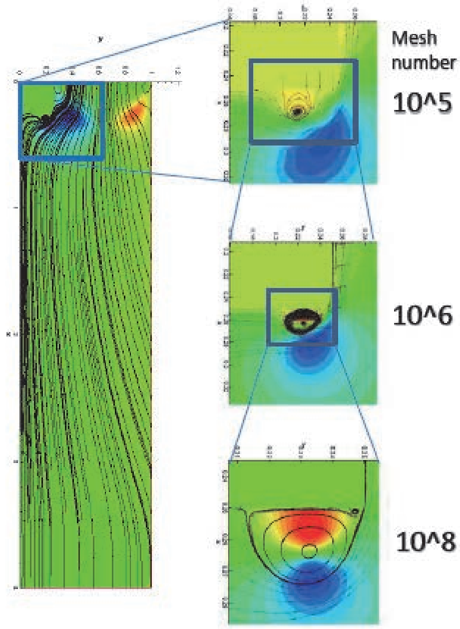


Beam-Fluid coupling model and Mass-Parallel CFD

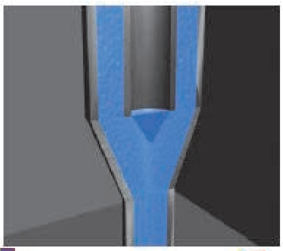
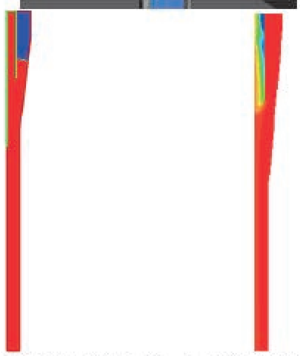
benchmark test Beam-Fluid coupling model and algorithm



Beam-target interaction region simulation, 15360 cores, Speedup ~3000.

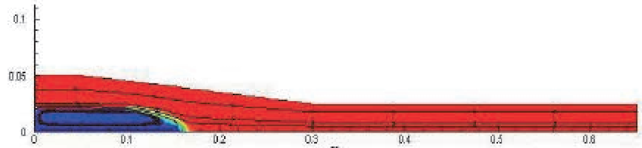
Beam-target coupling study for windowless target

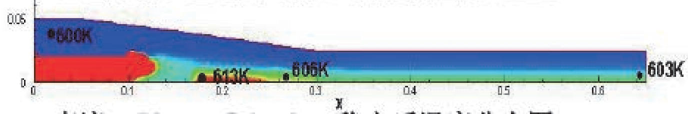
液态Pb稳定自由液面的形成

flux	Radius 1	Radius 2	slope
5-20L/s	5-12cm	10-25cm	90-20 Degree

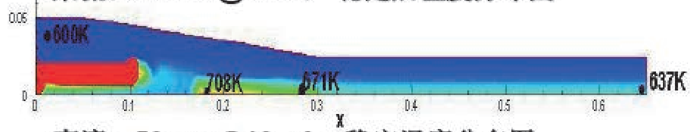
22050种几何结构扫秒



红色为铅，蓝色为气体，铅的流量为10L/S



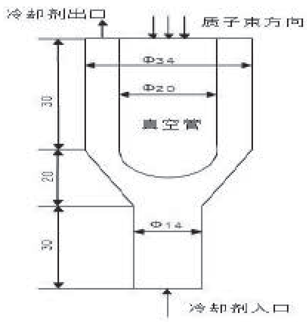
束流：50mev@1mA，稳定后温度分布图

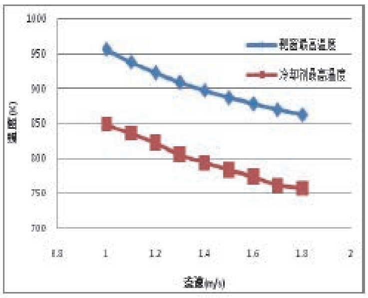


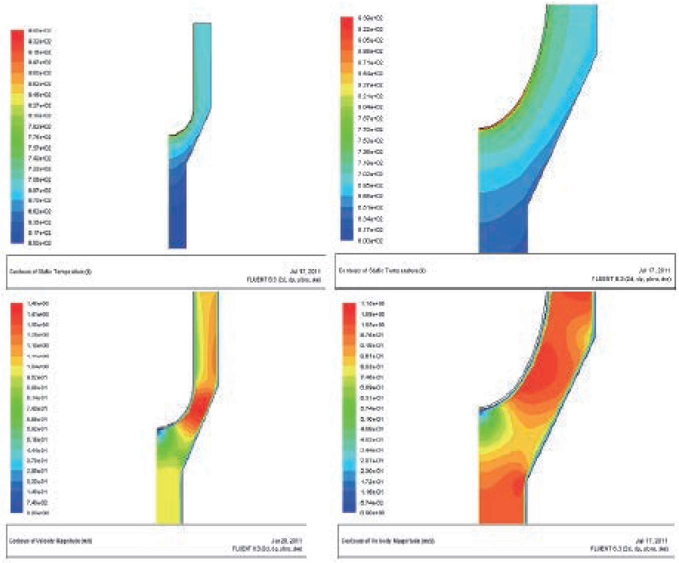
束流：50mev@10mA，稳定温度分布图

~50MeV → ~250MeV

A widow target design (IMP-Tsinghua University)

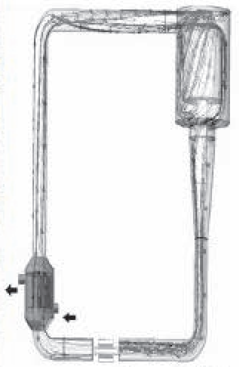




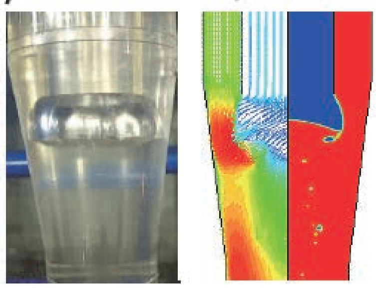


23 “未来先进核裂变能”专项ADS嬗变系统

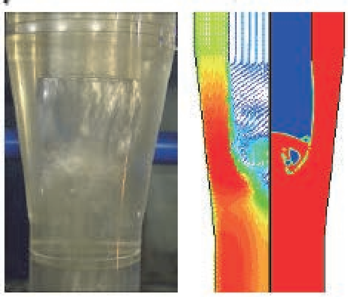
Water loop to study interface of windowless target



Reynolds number（Re≈3500）



Reynolds number（Re≈8000）



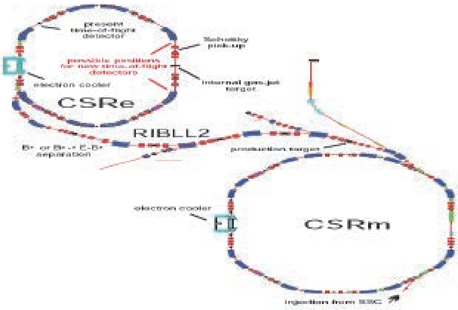
Using water simulation loop to study stability of interface for the windowless target.

24 “未来先进核裂变能”专项ADS嬗变系统

Spallation target neutronics measurement

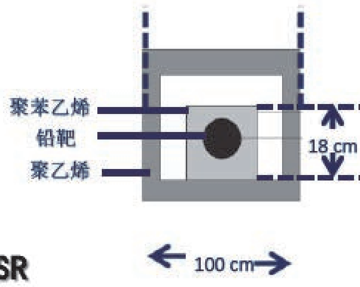
- Measurement object
  - Neutron yield
  - Neutron Flux
  - Spallation products
  - Energy spectrum
  - Reaction cross section

Detectors, electronics, acquisition system

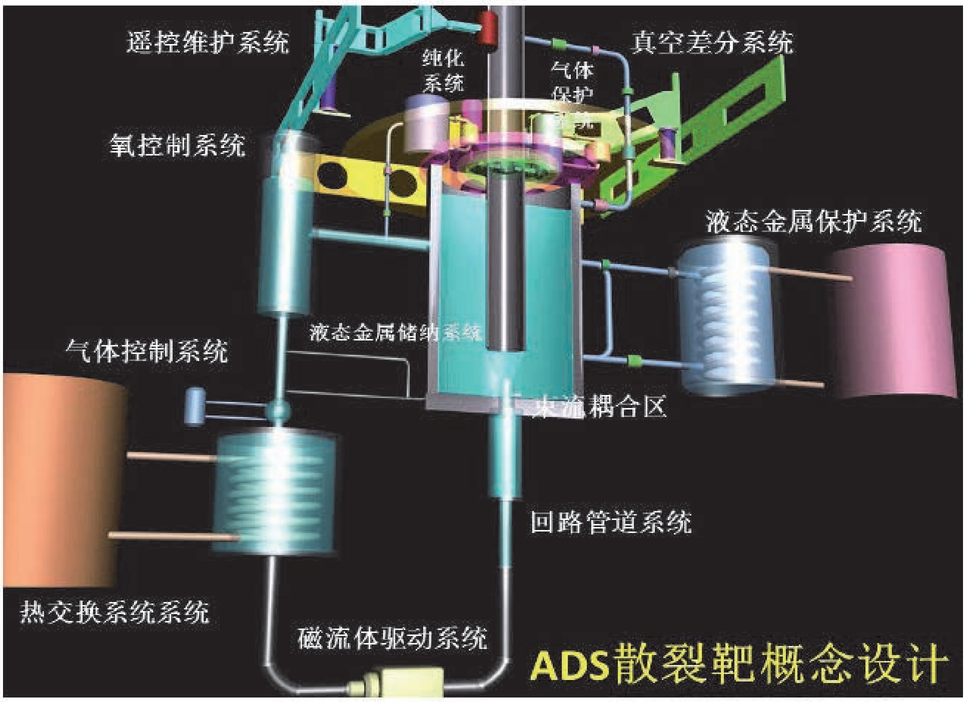


Proton energy < 800MeV in CSR

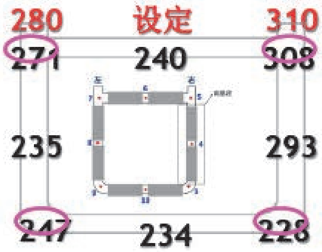
PISA

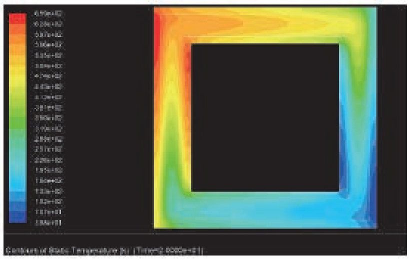


Windowless Target Test loop Conceptual Figure

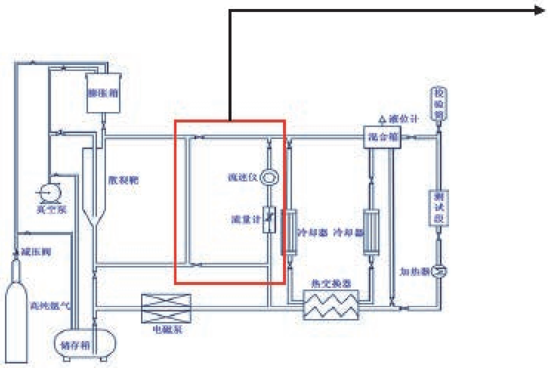


Loop testing for liquid metal

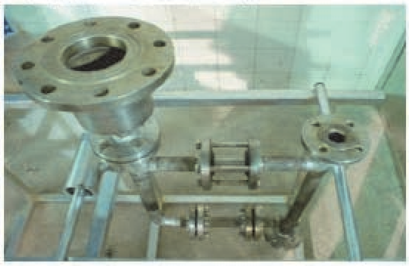




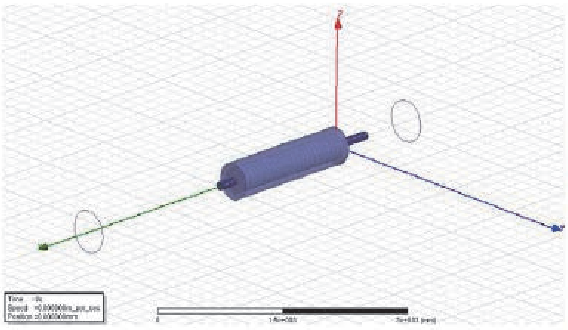
液态金属自然对流回路　　液态金属自然对流回路实验与数值模拟

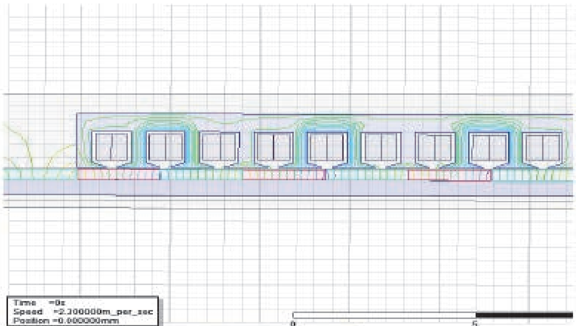


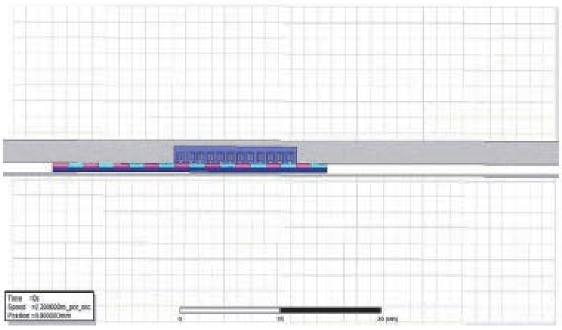
●自然对流回路



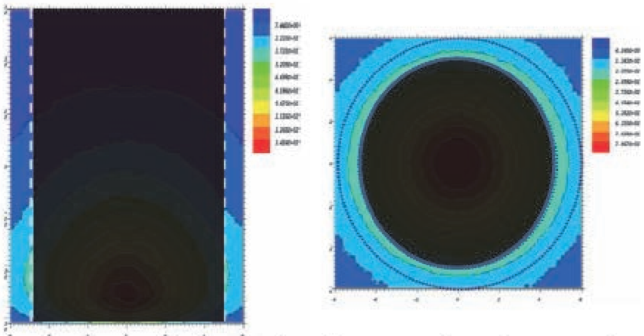
Electromagnetic Pump Design



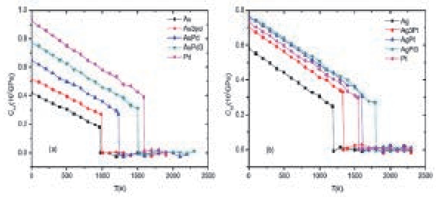




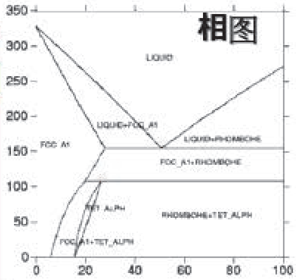
Material calcaulation of spallation target structure

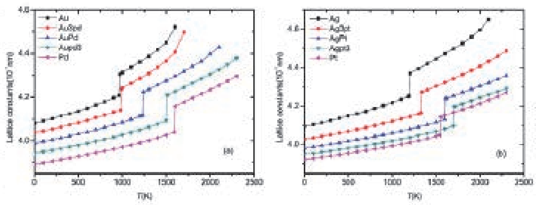


Neutron irradiation-induced structural steel materials DPA distribution along the target

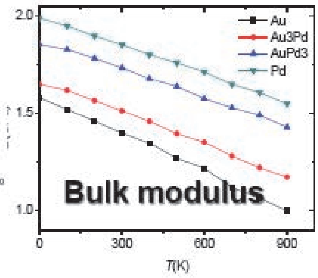


Structural mechanics and thermal properties of alloys calculation





Lattice parameter and Thermal expansion coefficient



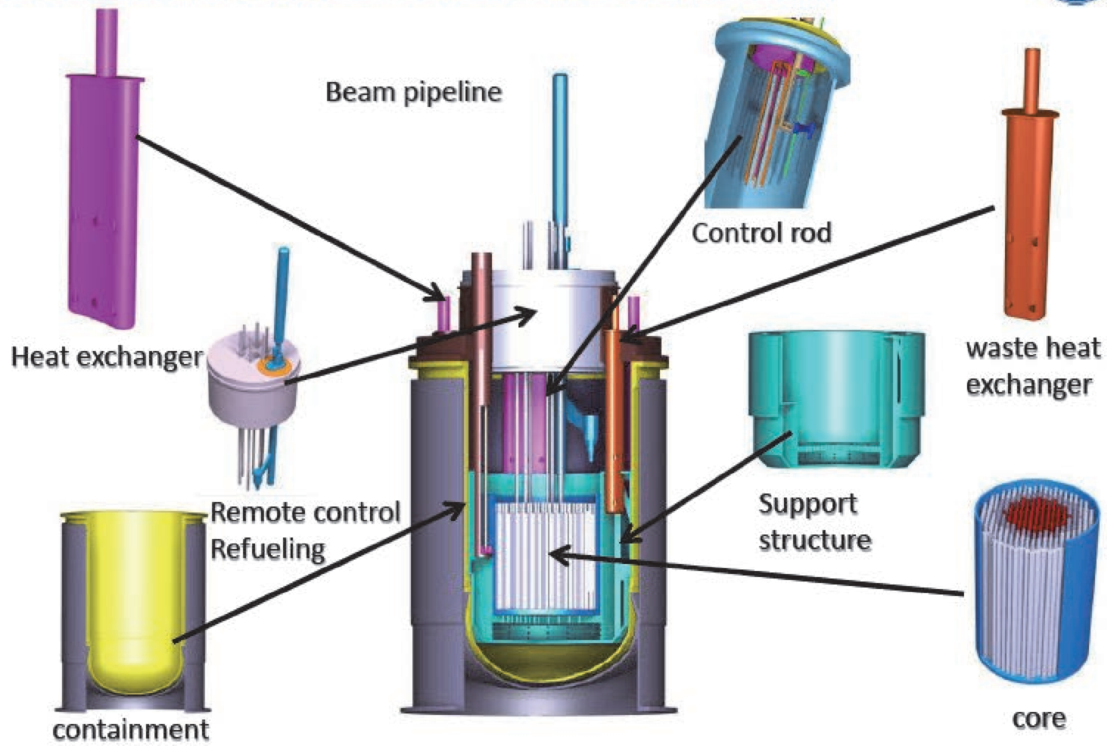
Progress for CADS Subcritical Core

Open questions in ADS subcritical core

Soviet submarine

- The production of α-radioactive Polonium (210Po) having 138 days half-life undergoes α-decay, some problems are caused by bismuth because of its migration from the coolant to the cover gas and formation of aerosols. 210Po is volatile, so that the leakage from the cover gas poses some hazard to the plant operators.
- Netronics in subcritical core.

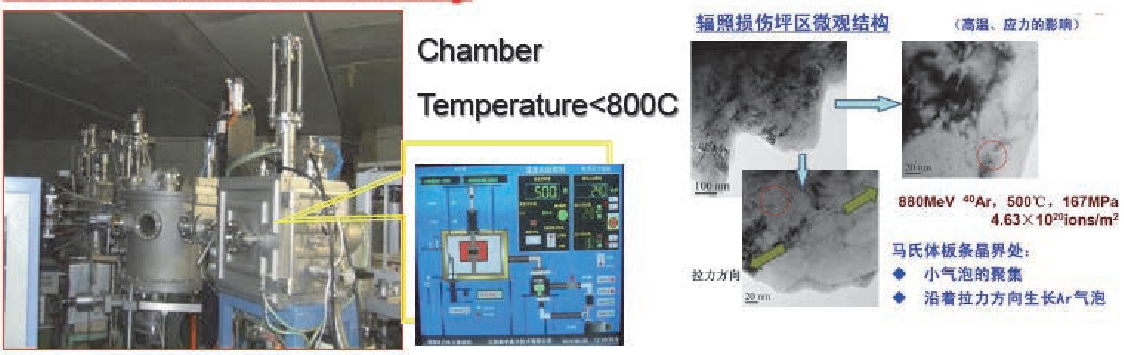
Conceptual design of Subcritical Core (10MW)



31 “未来先进核裂变能”专项ADS嬗变系统

Progress for Materials & etc.

Stress & irradiation facility



LBE corrosion device

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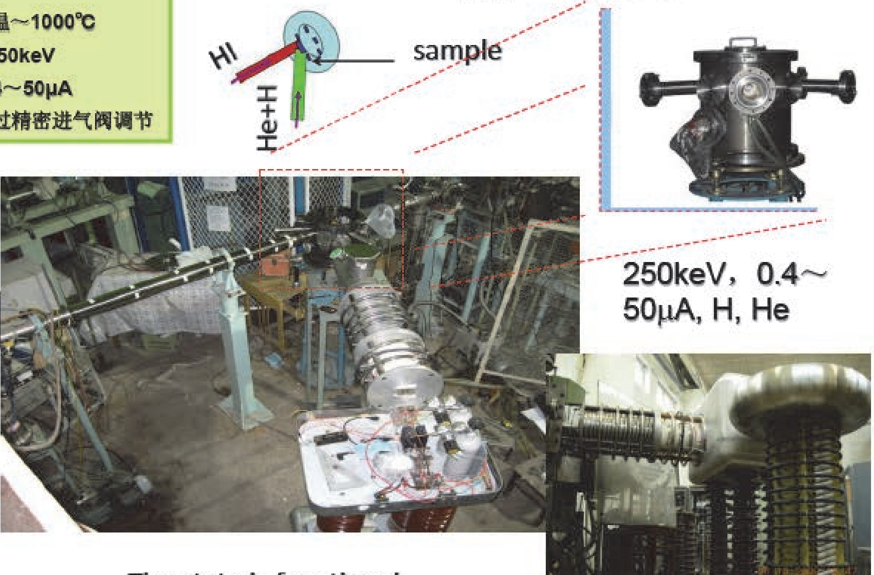
Three beams irradiation facility (CIAE)

三束同时辐照实验装置：
由重离子辐照靶室，氢、氦注入系统组成
重要参数：
辐照温度：室温～1000℃
能量：≥250keV
流强：0.4～50μA
H^+和He^+比例：通过精密进气阀调节

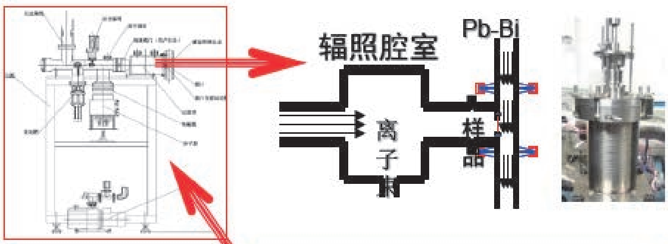
Irradiation Chamber

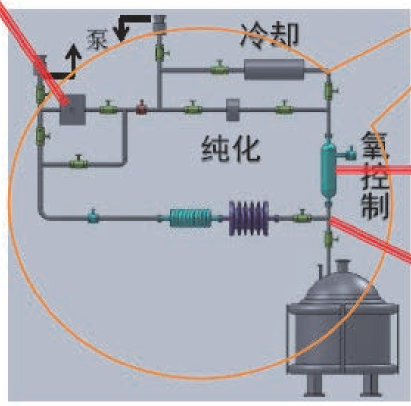
RT～1000℃

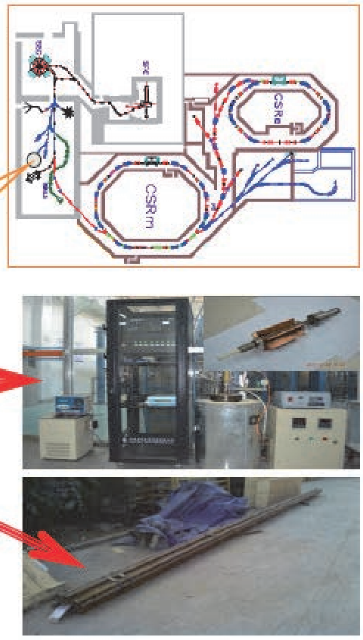


The state is functional.

LBE corrosion & irradiation facility





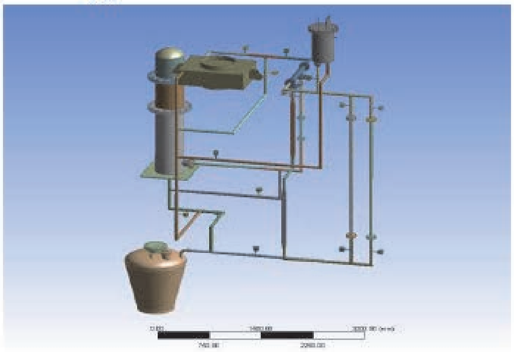


温度：≤ 550℃
流速：≤ 2 m/s
LBE体积： ～12 L
回路高度：～1.8 m
回路温差：～100℃

Under construction

LBE Thermal-hydraulic and Materials Test Loop (CIAE)

- Maximum temperature 550 ℃
- Maximum flow rate 6m³/h, (velocity 3 m/s)
- Pressure 0.3 MPa
- LBE volume ～200 l
- Height of Loop ～ 5 m
- Number of test sections 2
- Test sections height ～ 1.5 m
- Temperature difference ～100 ℃
- Oxygen sensor Yes
- Oxygen control Yes



Under construction

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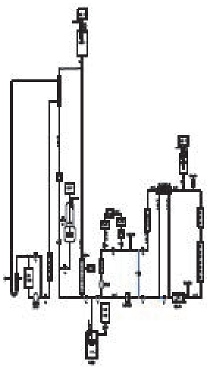
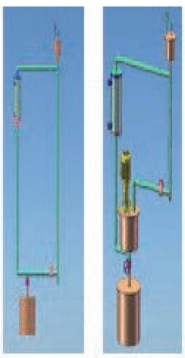
LBE Thermal-hydraulic and Materials Test Lab.

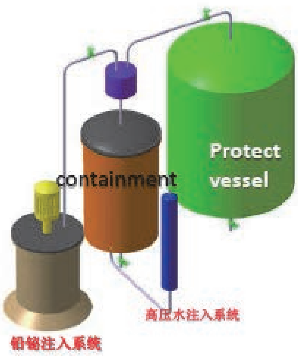
Function:

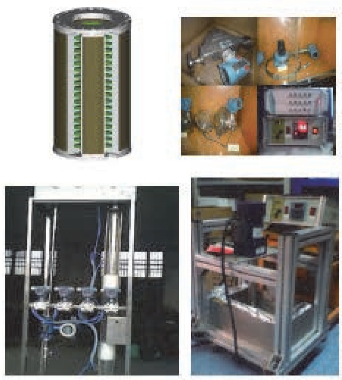
1. Materials test for LBE
2. Thermal-hydraulic test
3. Safety test

铅铋回路实验大厅与配套建设建筑效果图









To be functional in next year

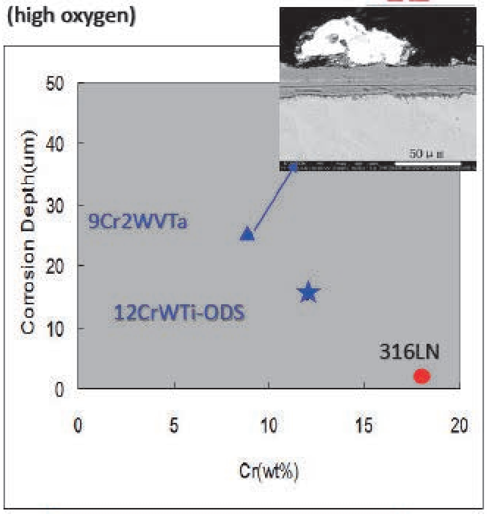
39 "未来先进核裂变能" 专项ADS嬗变系统

Evaluation of candidate materials for ADS (CIAE)

	1×10^{-7} wt.% (low oxygen) Weight loss ($\times 10^{-3}$g/m² . h)	10^{-4}-10^{-6} wt.% (high oxygen) oxide (μm)
316LN (Fe-18Cr-12Ni)	2.0	1.86
12CrWTi-ODS	0.25	15
9Cr2WVTa	0.89	25

Corrosion depth with Oxygen

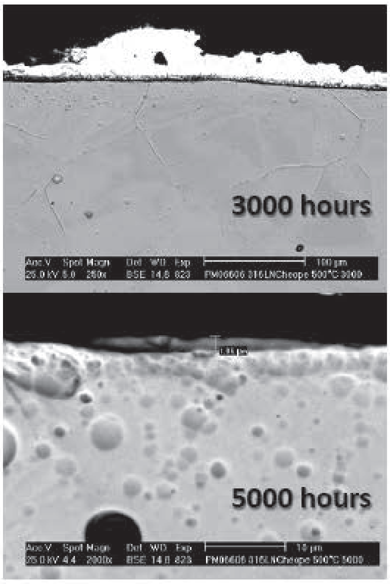
10^{-4}x10^{-6} wt.% (high oxygen)



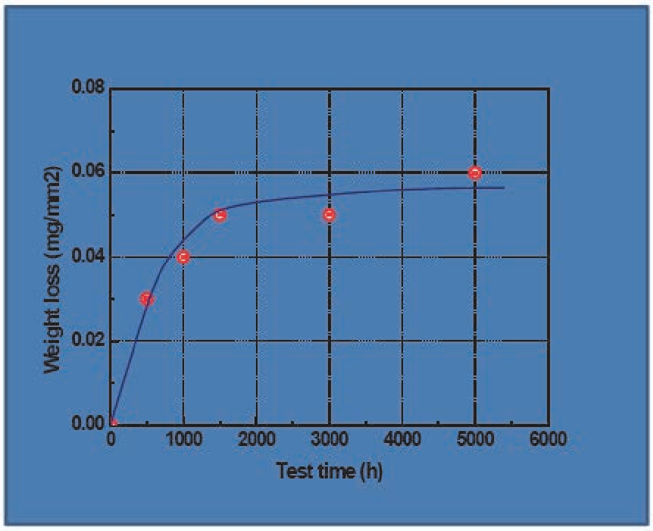
Corrosion depth decreased with Cr

316LN in flowing LBE (CIAE)

Test conditions: 500°C, 3000h, 5000h in LBE with Co_2=10^{-4}-10^{-6}wt.% velocity: 1m/s



SEM observations



Corrosion of 316LN in LBE

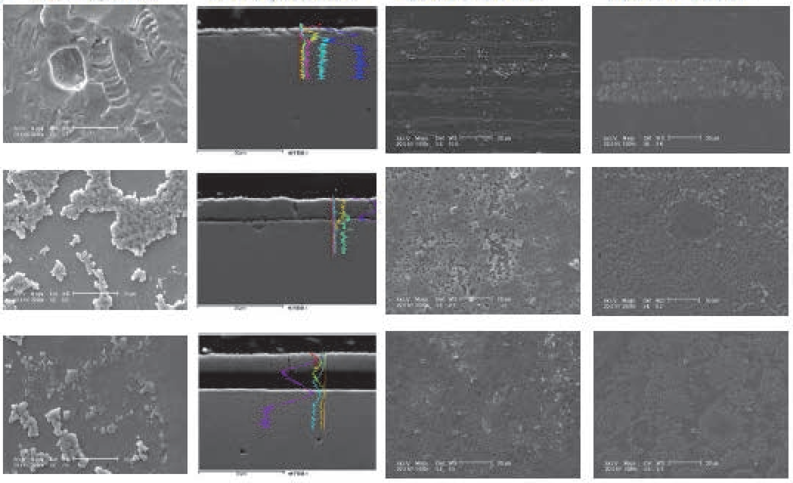
Evaluation of candidate materials for ADS

Test conditions: 450℃, 1m/s | 480℃, 0.14m/s | 450ºC，1000h | 450ºC，2000h

316L

T91

CLAM



SIMP

SEM observations

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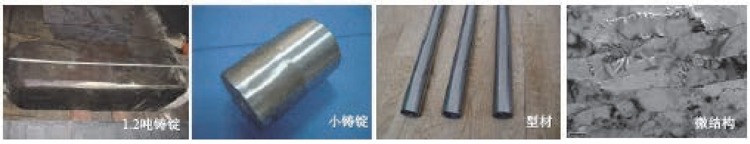
China Low Activation Martensitic Steel （CLAM）

- Anti-radiation structure materials for ADS;
- CLAM steel production is 4.5 tons;
- CLAM steel is evaluated as the structure materials of the subcritical core.



- Neutron irradiation evaluation
（PSI~20dpa，高通量堆~1dpa）
- Also for TBM

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High-temperature & strength Martensitic Steel （SIMP）

Chemical composition of SIMP

C	Si	Cr	Mn	W	Ta	V	Nb
0.20~ 0.30	1.0 ~1.5	11.0 ~13.0	0.4 ~0.6	1.0 ~1.5	0.15 ~0.45	0.20 ~0.30	< 0.001

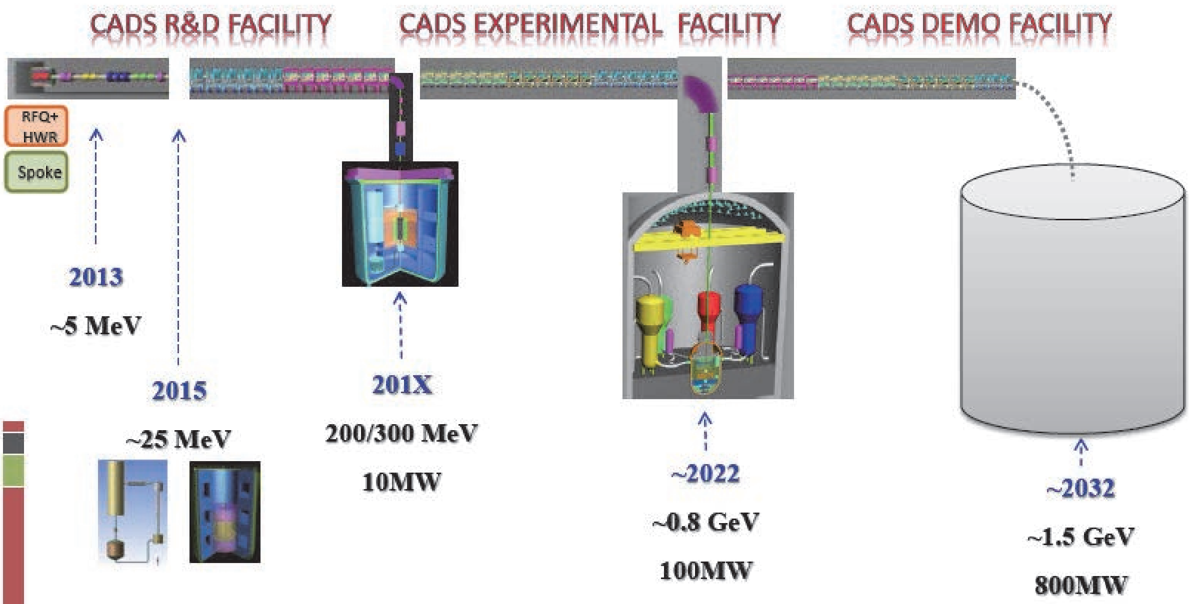

微观组织：全马氏体组织，且组织较细



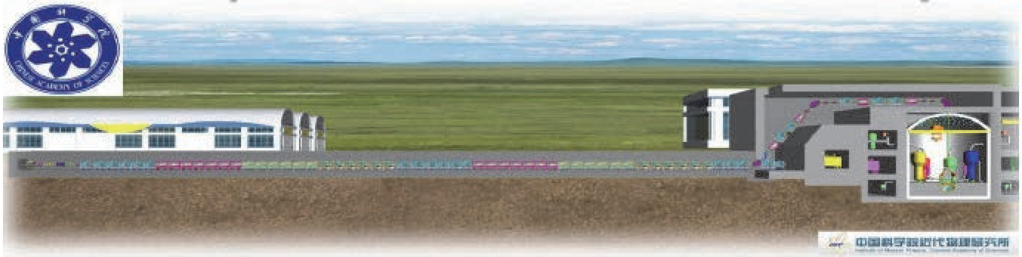
600℃ tensile properties

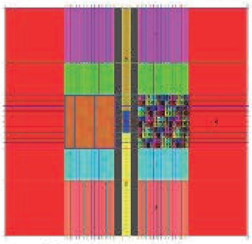
	Yield strength (MPa)	Tensile strength (MPa)	Elongation rate A%
SIMP	**310.5**	**393.6**	**44.4**
EUROFER97	277	292	29.3
CLAM	293	334	29.0
EP823	----	310	22
T91(ASME)	215	255	----

CADS Facility RoadMap

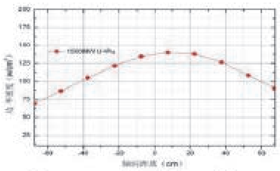


Prospect for CADS DEMO Facility

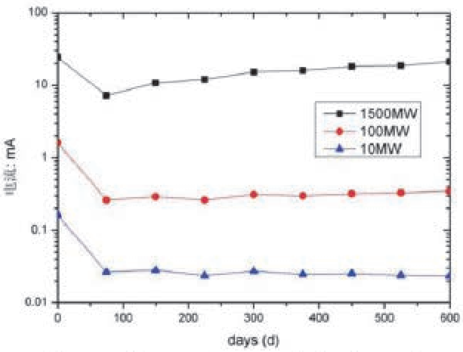




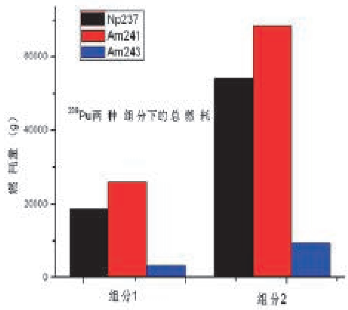
Core structure



Power distribution



Current requirement for burning 600D in different power of core



MA transmutation ~130kg/year in 800MW

Site Candidate of CADS


Thank you !

3.6 R&D status of ADS in Korea

S. W. Hong (Sungkyunkwan University, Korea)

R&D Status of ADS in Korea

Seung-Woo Hong

Dept of Physics
Dept of Energy Science
Sungkyunkwan University

Materials are prepared with help from
S. I. Bak, M. Behzad, F. Carminati, I. S. Hwang,
Y. Kadi, H. Kim, V. Manchanda, T.-S. Park, C. Tenreiro

Contents

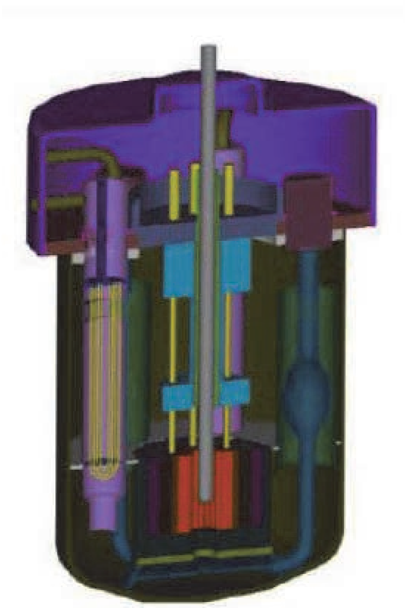
I. Work by KAERI

KAERI's 10 year ADS Project

HYPER (**HY**brid **P**ower **E**xtraction **R**eactor)

1st Phase (1997~2000)	2nd Phase (2001~2003)	3rd Phase (2004~2006)
• Establish basic concept of HYPER • Development of computer codes • Basic experiments	• Upgrade the core design • Research on the key technologies (Pb-Bi, Fuel) • Participation in MEGAPIE	• Complete conceptual design of code • Complete basic research of key technologies

HYPER (**HY**brid **P**ower **E**xtraction **R**eactor)



Item	Value
Capacity	1000 MW_{th}
K_{eff}	0.98
Proton Beam	1 GeV, 10.6/16.4 mA (BOC/EOC)
Fuel Type	TRU Zr-Metal Alloy
Coolant/Target	Pb-Bi (Not separated target)
Transmutation	TRU, FP(Tc-99, I-129)
TRU Tran. Rate	282 kg/yr
FP Tran. Rate	27 Kg/yr (Tc-99), 7 kg/yr (I-129)
Support Ratio	3.2
Temperature	Inlet = 340, Outlet = 470, Max. = 542 ℃

Conceptual Design of HYPER core

T. Y. Song*, J. E. Cha, C. H. Cho, C. H. Cho, Y. Kim,
B. O. Lee, B. S. Lee, W. S. Park, M. J. Shin

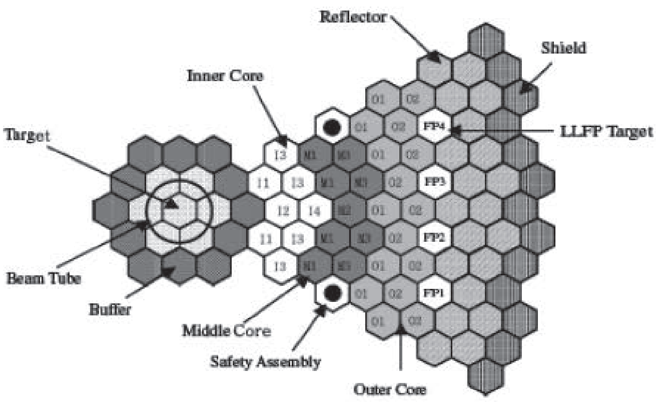


Fig. 1. HYPER core assemblies.

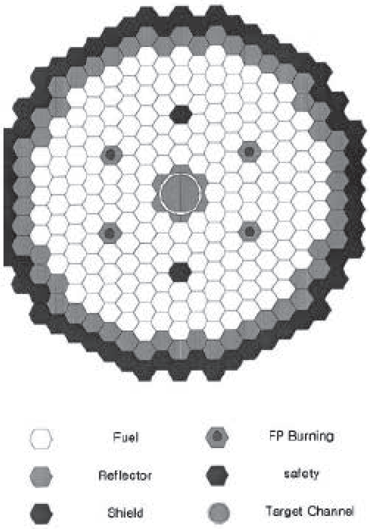
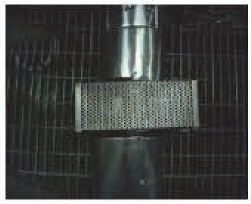
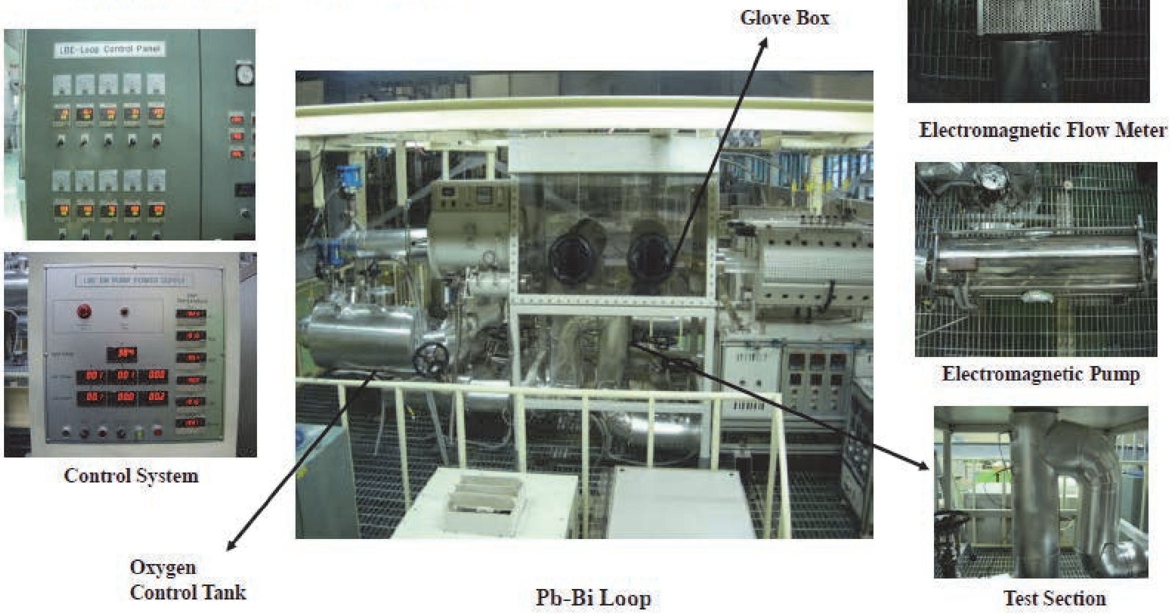


Fig. 2. Reference HYPER core.

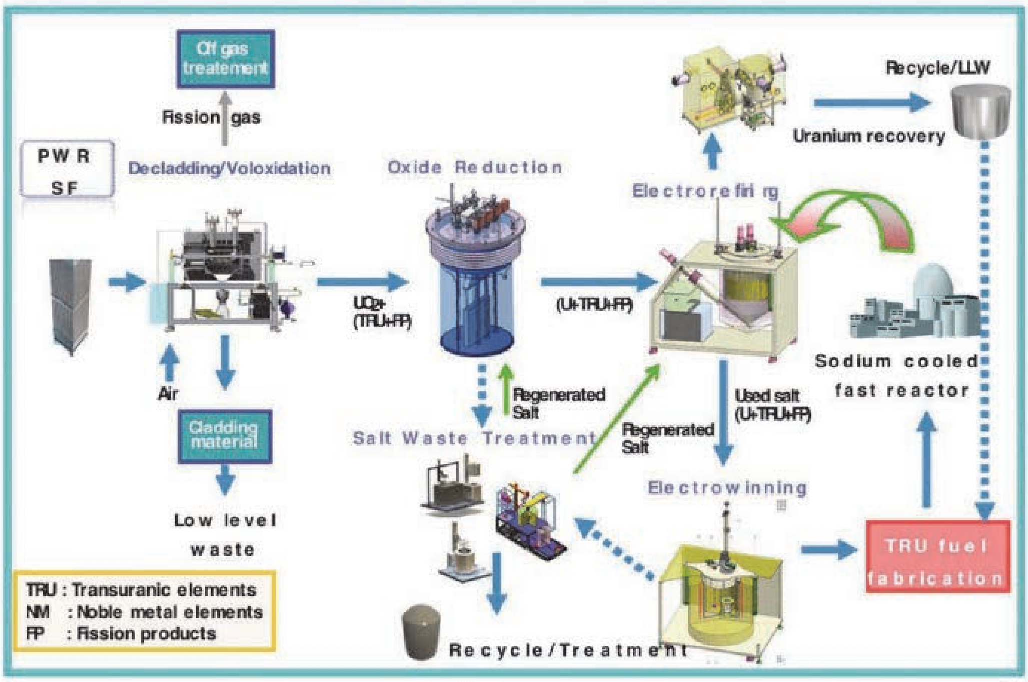
Pb-Bi corrosion experiment loop

Development & operation of Pb-Bi corrosion test loop
Max. velocity : 2 m/s
Temperature : 450 ~ 550℃





Pyroprocessing

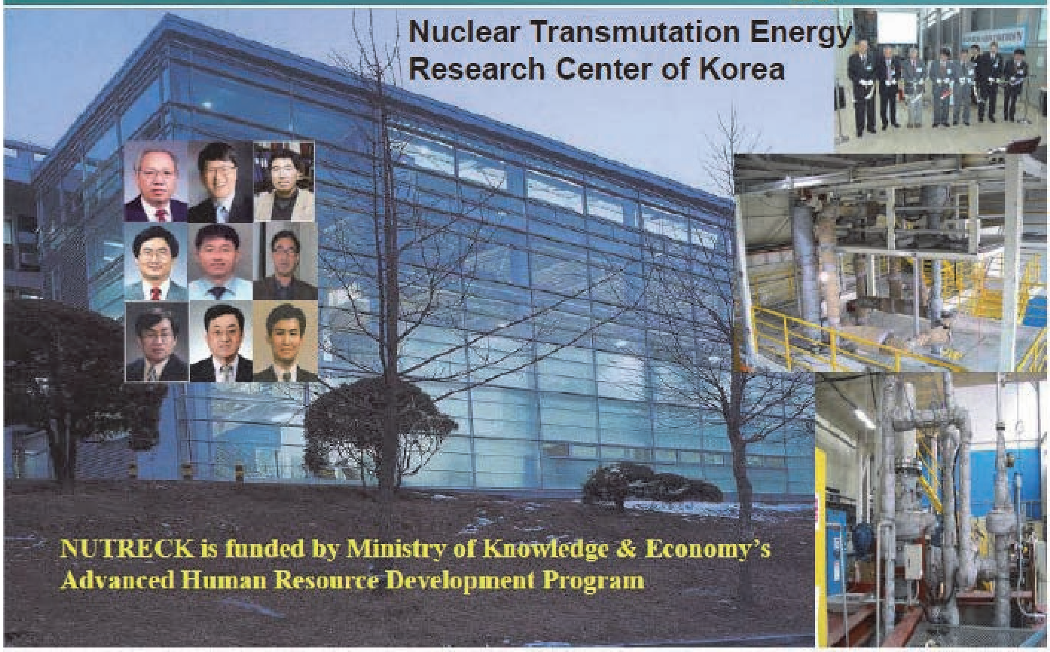


Process Flow Diagram of Pyroprocessing

HANSOO LEE, GEUN-IL PARK, KWEON-HO KANG, JIN-MOK HUR, JEONG-GUK KIM, DO-HEE AHN, YUNG-ZUN CHO, and EUNG HO KIM   NUCL ENG AND TECH, VOL.43 317 2011

II. NUTRECK at Seoul National Univ.

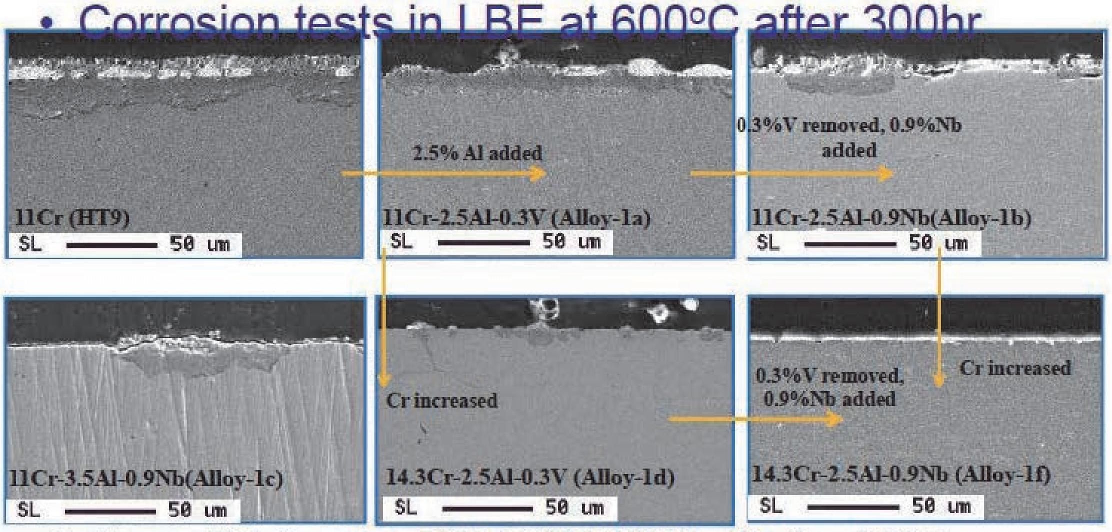
Nuclear Transmutation Technology



Courtesy of Il Soon Hwang

Development of Corrosion Resistant Materials

- Corrosion tests in LBE at 600°C after 300hr

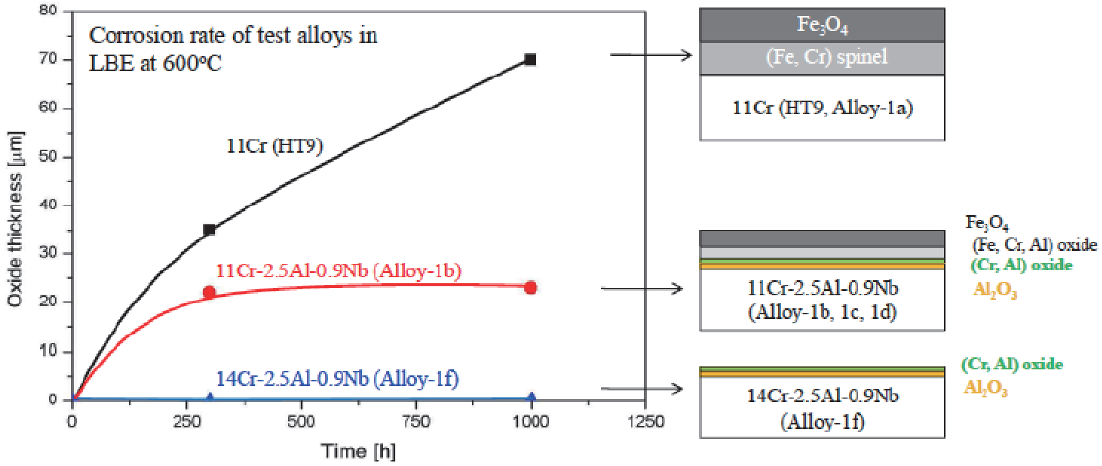


- Continuous Al_2O_3 formed on 14.3Cr-2.5Al-0.9Nb(Alloy-1f) alloy at 600°C
- Nb addition promote Al_2O_3 formation

Courtesy of Il Soon Hwang

NUTRECK: Development of Corrosion Resistant Materials

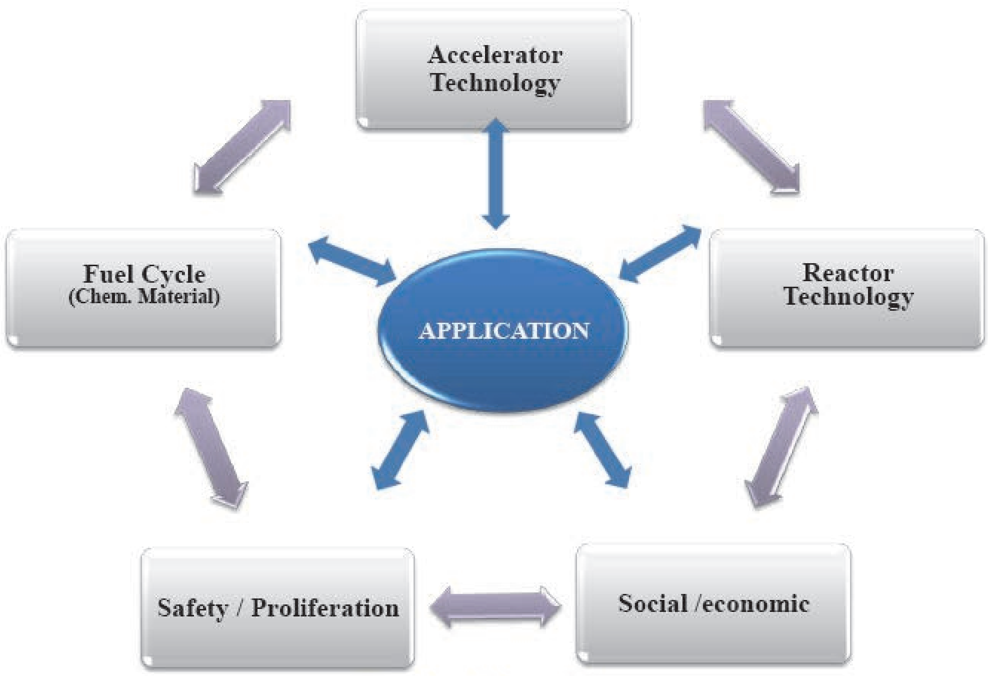
- Summary of corrosion test results at 600°C



Courtesy of Il Soon Hwang

III. Dept of Energy Science, SKKU

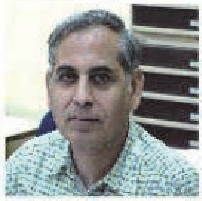
University-level R&D as a World Class University Program



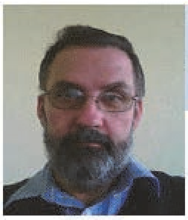
Technology Map

Group Members
(Chemistry, Physics, Material Science, and Engineering)

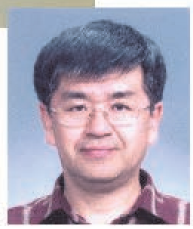
Yacine KADI
[CERN/SKKU: Nuclear Physics/Engineering



Vijay MANCHANDA
[BARC/SKKU: Radiochemist]



Claudio TENREIRO
[University of Talca/SKKU: Nuclear Physics]



CHAI, Jong Seo
[SKKU: Accelerator]

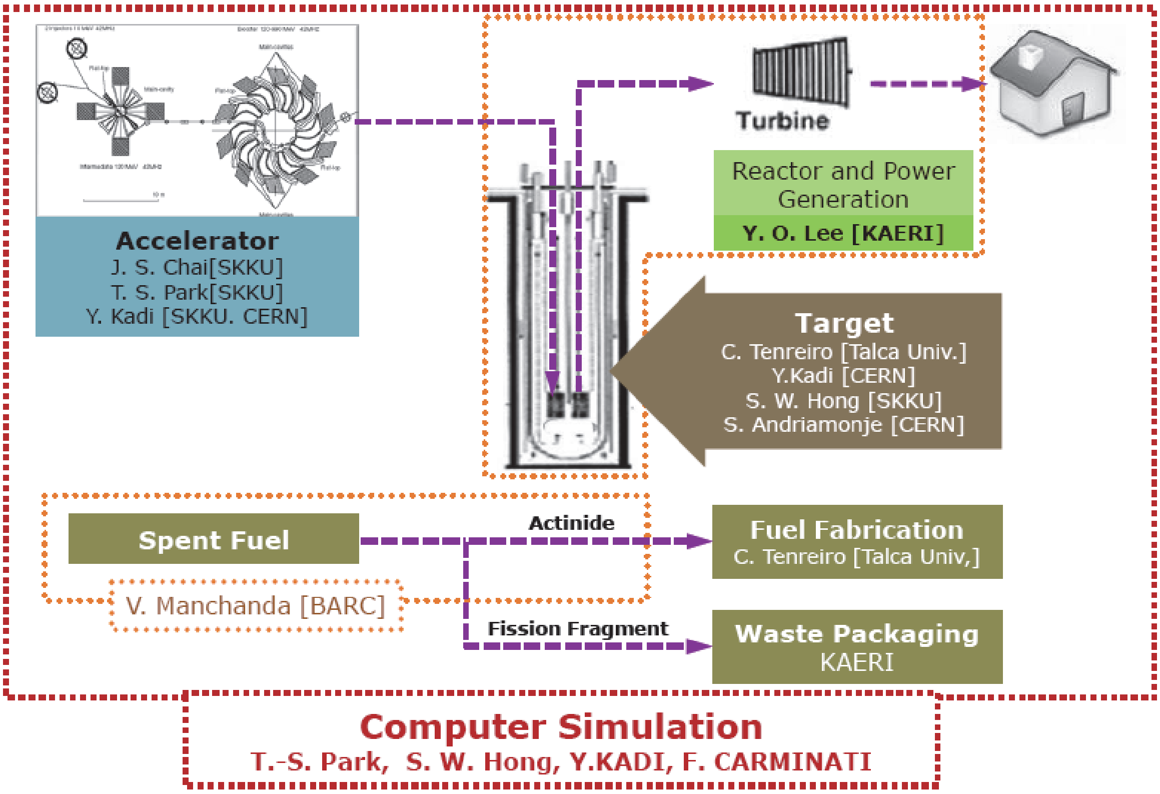
Hong, Seung-Woo
[SKKU: Nuclear Physics]

Park, Tae Sun
[SKKU: Nuclear Physics & Accelerator]

Federico CARMINATI
[CERN: Nuclear and Particle Physics]

Samuel Andriamonje
[CNRS/CERN: Nuclear Physics]

R&D on ADS in SKKU



Topics of R&D in SKKU

University-level, small-scale R&D

1. Computational modeling: ^{T}Nudy
2. Partitioning
3. Transmutation of LLFP's
4. Design of compact reactor core
5. Life Cycle Assessment of ADS
6. Applications (detectors, medical, etc)

1. ^{T}Nudy

(ROOT Nuclear Data Library)

- **A C++ library, powered by ROOT, to read, process and visualize ENDF nuclear data**
- ENDF= Evaluated Nuclear Data Format
  - Nuclear reaction data for E ≤ 20 MeV, including cross sections and neutron yields
  - Written in ASCII, and can be read most conveniently by FORTRAN (i.e., fixed length records and so on)
  - Most popular version=6, recent version=7

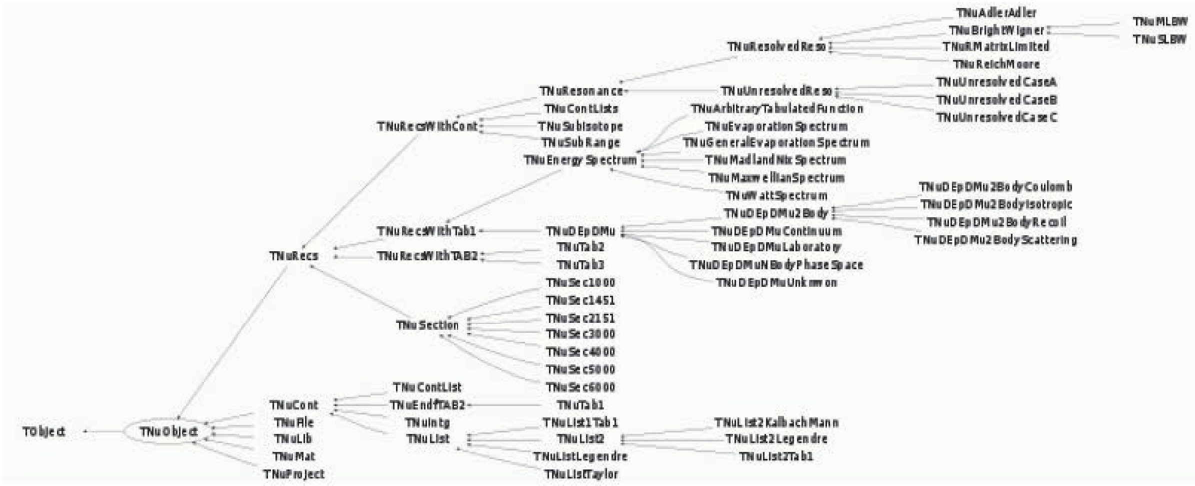
An example of ENDF file

```
 … …
 4.009300+4 9.210840+1          0          0          0          04034 3 17     0
-1.537640+7-1.537640+7          0          0          1          74034 3 17     1
          7          2                                            4034 3 17     2
 1.554330+7 0.000000+0 1.575580+7 8.802450-5 1.600000+7 2.610420-34034 3 17     3
 1.700000+7 9.111520-2 1.800000+7 2.766320-1 1.900000+7 4.673160-14034 3 17     4
 2.000000+7 6.148280-1                                            4034 3 17     5
 0.000000+0 0.000000+0          0          0          0          04034 3  099999
 4.009300+4 9.210840+1          0          0          0          04034 3 22     0
… …
```

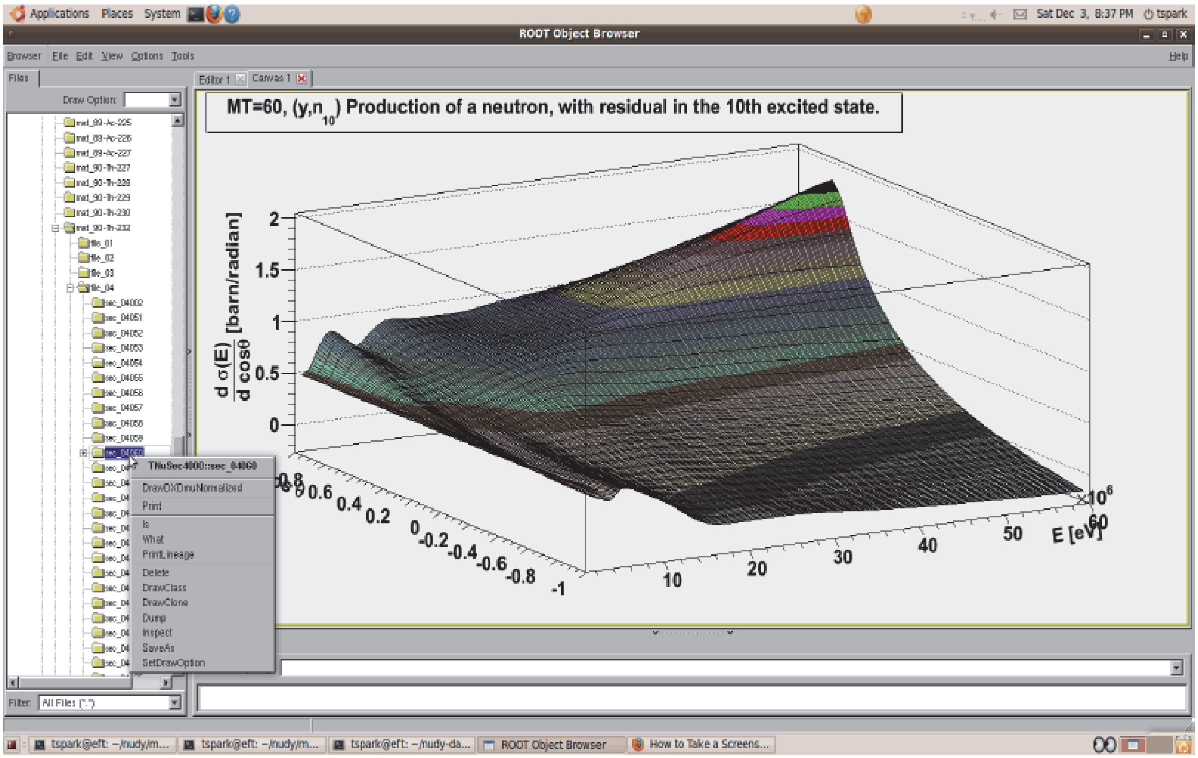
Motivations for ^{T}Nudy

- C++ is now a major computational language, and **it is useful to have C++ library of ENDF**, which is relevant for ADS and many other nuclear applications.
- ENDF= **set of "objects"**, and OOP will be the most natural choice
- Large amount of data -> advanced memory handling is needed
  (dynamic memory allocation/deallocation)
- Aims: Provide a standard C++ library
  - User-friendly graphic user interface in an integrated frame (ROOT)
  - Fast enough for realistic Monte Carlo simulations
  - Easy/flexible enough to be useful for education

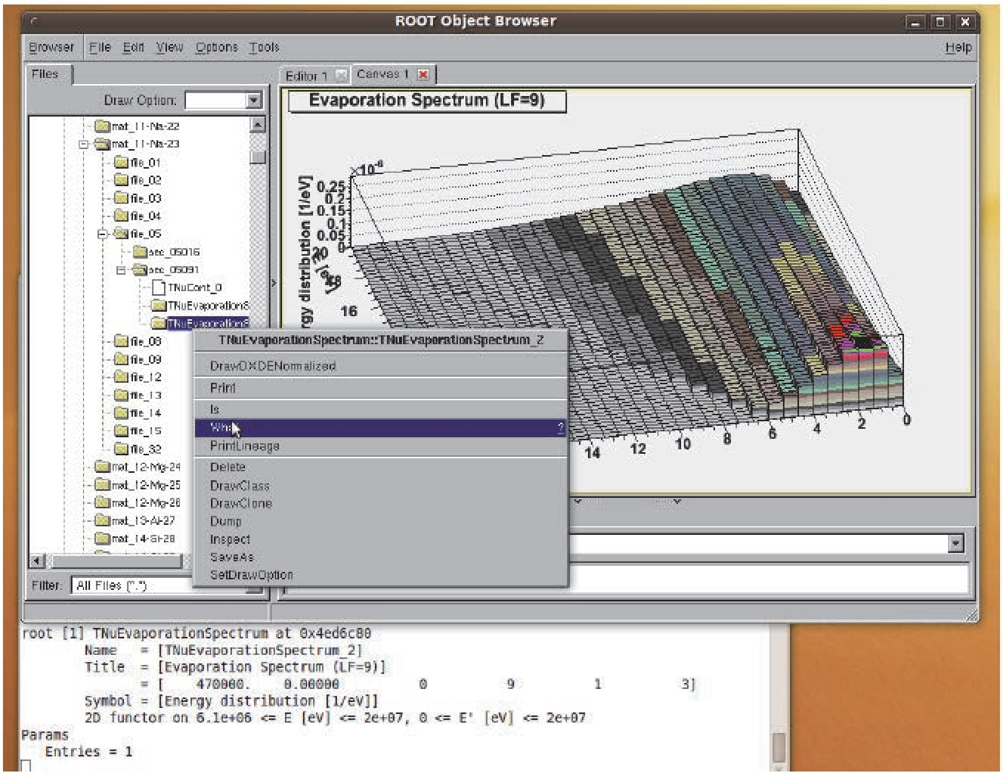
TNudy classes (still expanding)



ENDF data displayed as you like



ENDF data displayed as you like



Current status of ^{T}Nudy

- It's still a very early stage of development.
- Routines for the data with MF=1~28 have been implemented
  - MF=1 (neutron yields)
  - MF=2 (resonance data)
  - MF=3 (total cross section), MF=4 (dσ/dμ), MF=5 (dσ/dE'),
  - MF=6 (d^2σ/dμ/dE') , ….
- Covariance data (MF= 30~40) are in progress
- In preparation of the first release
- Eventually, ^{T}Nudy will be extended to include
  Monte-Carlo sampling routines for burn-up simulations

2. Partitioning

- Actinide partitioning (using PS-TODGA)
- Extraction of Sr-90 from Th-232
- On-line detection of α-radiations
  (using CR-39 based fiber optic sensor)

- **Actinide Partitioning (A.P.)**

A.P. is a strategy for the management of High Level Nuclear Waste (HLW). Green extractants are designed and deployed for the separation of long lived radionuclides which include actinides like Am-241/243, Np-237and Pa-231 from HLW.

- **Radiochemistry of Th**

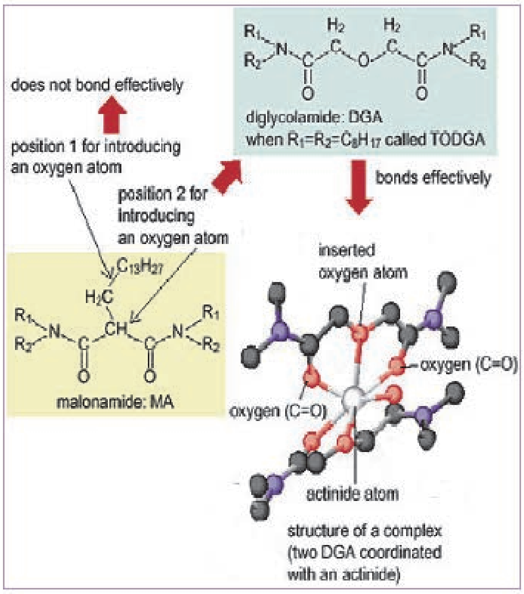
Nuclear data like cross sections of neutron capture and fast neutron fission of Th -232 and activation products like Pa-233 and U-233 are pivotal to the use of Th as Energy Amplifier. There is also a need to develop efficient procedures to separate valuables like Cs-137 ,Sr-90 and Mo-99 from irradiated Th.

- **Solid State Nuclear Track Detectors**

There is a need to intensify efforts to efficiently monitor online the presence of alpha emitting radionuclides in the surroundings of nuclear facilities.

Actinide Partitioning

- Actinide Partitioning is a strategy for the management of High Level Nuclear Waste (HLW). There is growing interest to design and deploy green extractants.
- Tetraoctil diglycolamide (TODGA) is
  - a green extractant (made of only C, H, N, O)
  - effective for the separation of long lived radionuclides (Am-241/243, Cm-245, Np-237 and Pa-231) from HLW,
  - and has been investigated extensively in leading laboratories for Actinide Partitioning.
- A novel nano composite material, Polystyrene-TODGA (PS-TODGA) was prepared and characterized. The uptake behaviour of Am(III) from nitric acid by this material was investigated.
- Effect of diluent and ionic strength was investigated on the extraction behaviour of La(III), Eu(III) and Yb(III) with TODGA.



Chemistry of diglycolamides: Promising extractants for actinide partitioning, Chem. Rev., in press (2011).

Preferential recovery of ^{90}Sr from $(Sr,Th)O_2$

- ^{90}Sr is a generator of ^{90}Y that is of medical importance

  ^{90}Sr (29 years) $\rightarrow ^{90}Y + \beta^-$,

  ^{90}Y (64 hours) $\rightarrow ^{90}Zr + \beta^-$

- Cumulative yield of ^{90}Sr during fast fission of ^{232}Th (7.32± 0.36%) and of ^{233}U (6.39±0.33%) are large.
- In nitric/perchloric acid, SrO is highly soluble, while ThO_2 and other FPs are inert.

Element	% Dissolution (1M HNO_3)	% Dissolution (1M $HClO_4$)
Th	0.13	0.08
Sr	~100	~100
Y	2.0	0.4
Pd	7.0	4.0
Zr	7.0	0.8
(50 mg of sample, 10mL,10 min., 120 C)		

- 1st step of Sr-separation
  - Thus, by using dilute nitric acid/perchloric acid, preferential leaching of Sr over Pd, Y, Zr and Th from mixed thorium oxide is possible.
- 2nd step of separation
  - Medical application requires high level of decontamination factor (D.F.)
  - Sr-selective extraction chromatographic resin was employed for further purification of Sr from ^{232}Th and other fission products like ^{137}Cs and ^{152}Eu.

Solid State Nuclear Track Detectors

There is a need to intensify efforts to efficiently monitor the release of alpha emitting radionuclides caused by the core melt down or loss of coolant in a spent fuel pond.As a consequence of the exposure of diethylene-glycol bis(allycarbonate) (CR-3 9) to alpha radiations (emitted from ^{232}Th), radiation damage causes modification of its physico–chemical properties like absorbanc e, surface roughness and reflectance which could be correlated with the chemically etc hed track density, conventionally followed for the quantification of α-radiations offline .In this context, CR-39 based Fiber Optic S ensor (CRFOS) based on the reflectance m easurement has been developed with an ai m to monitor online the presence of α-emitt ing radionuclides (in / around a nuclear faci lity).

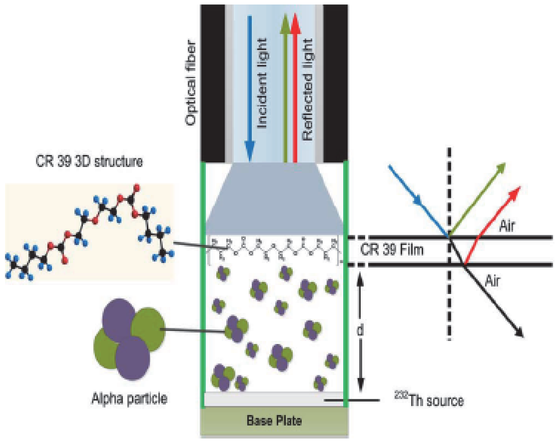


Figure 1: Proposed scheme of CRFOS for detection of alpha particle radiations from ^{232}Th source. Reflected light form CR-39, as indicated in the ray diagram, is measured using photo-detector and reflected-absorbance is measured by spectrometer. The distance "d" is varied from 10 to 50 mm to evaluate the effect of irradiation distance. The distance between optical fiber and CR 39 film is kept constant @ 10 mm

AFM 3D image of CR 39 film: Before & After

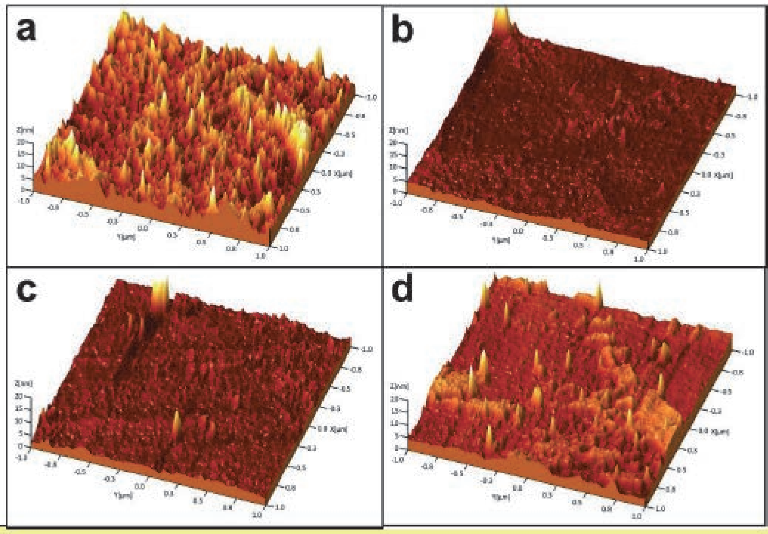


Figure 2: AFM 3D image of CR 39 film before (a) and after alpha particle irradiation at various distances of 10 mm (b), 20 mm (c) and 50 mm (d) from the ^{232}Th source for 60 minutes of irradiation time. The surface topology for irradiation distance of 10 and 20 mm show distinct changes whereas that for 50 mm shows little change with respect to the original surface topology. The RMS roughness for 10, 20 and 50 mm irradiation distance is 0.91, 0.90 and 1.2 nm respectively whereas the RMS roughness of blank film (without alpha particle irradiation) is 1.3 nm.

Reflectance indicates alpha particles

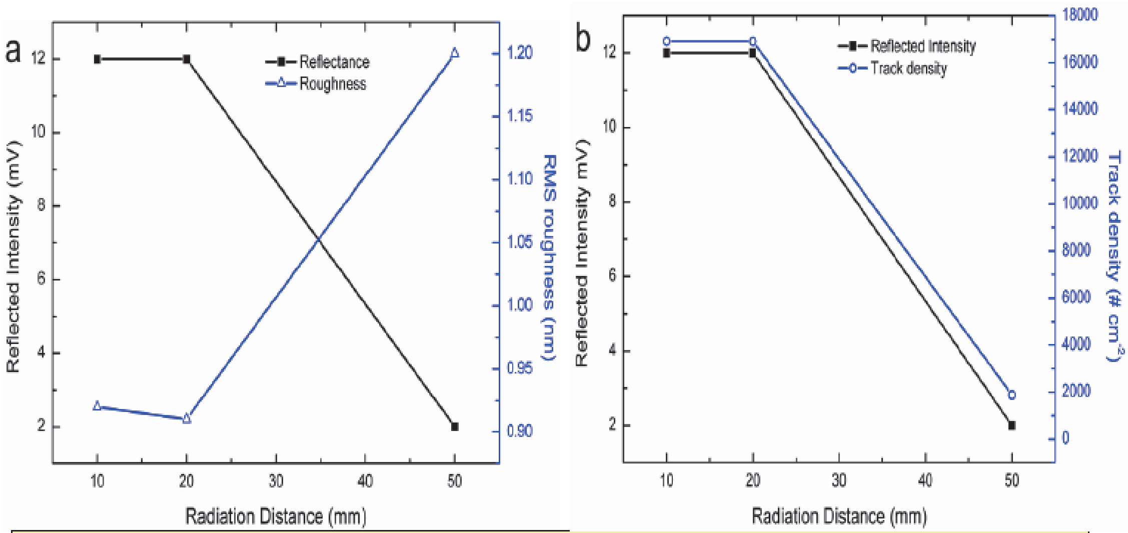


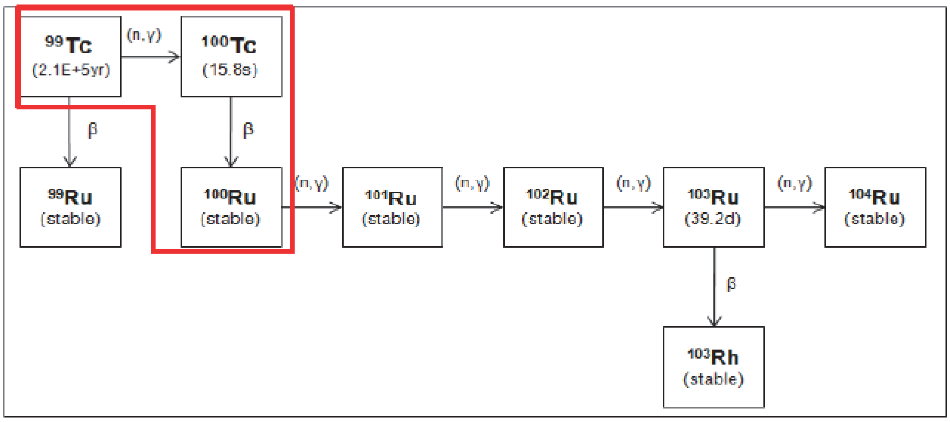
Figure 3: Comparison of CRFOS reflected intensity with the change in RMS roughness (a) and with measured track density (b). Beyond the irradiation distance of 20 mm the reflected intensity drops down whereas the RMS roughness increases steeply. It is also seen that the track density measured after chemical etching of CR-39 has direct relationship with the reflected intensity.

Online Optical Monitor of Alpha Radiations using a Polymeric Solid State Nuclear Track Detector CR-39 , Sensors and Actuators ,B: Chemical , in press (2011)

3. Transmutation of LLFPs

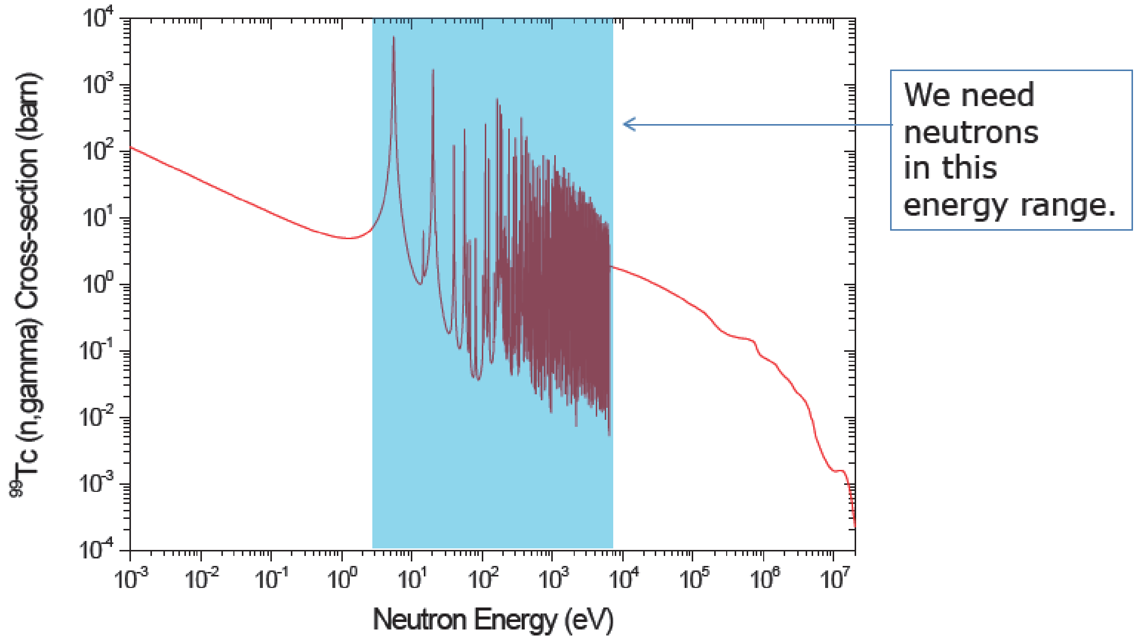
- Long-Lived Fission Products(LLFPs) are the main concern of the long-term radio-toxicity and risk of nuclear plants.
- Among other FPs, Tc-99 is
  - one of the major LLFPs (8.54 kg/GW/year for PWRs with 3.2% ^{235}U),
  - long-lived ($T_{1/2}$ = 211,000 years),
  - water-soluble,
  - Suitable for using **Adiabatic Resonance Crossing** method
- Simulations of transmutation of Tc-99 for an experiment with KIRAMS MC-50 proton cyclotron

- ^{99}Tc can be transmuted by neutron induced reaction.



To transmute ^{99}Tc to ^{100}Ru, we need lots of neutrons, but not all neutrons are effective for the transmutation.

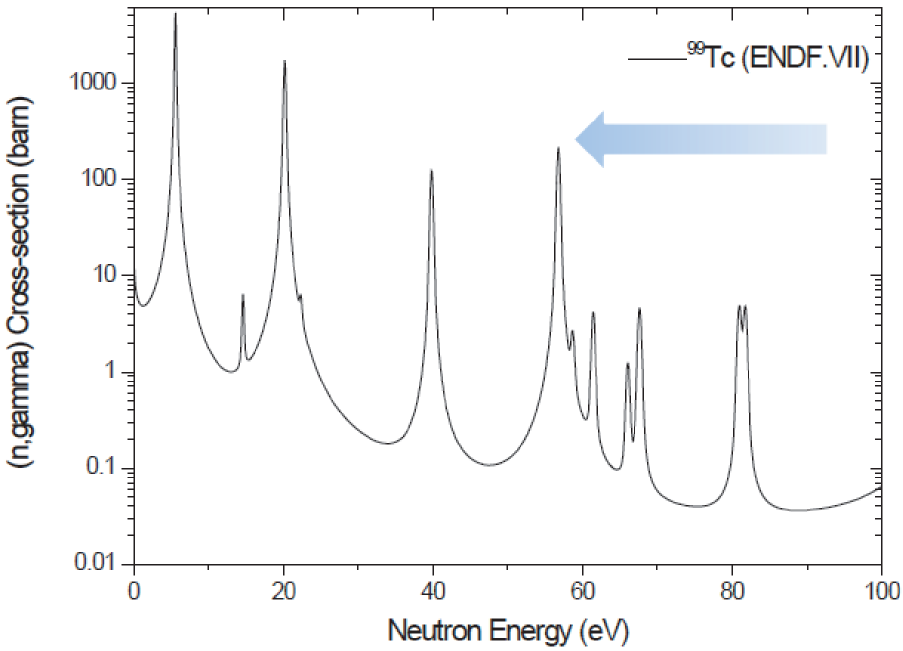
Neutron Capture Cross-Section of ^{99}Tc

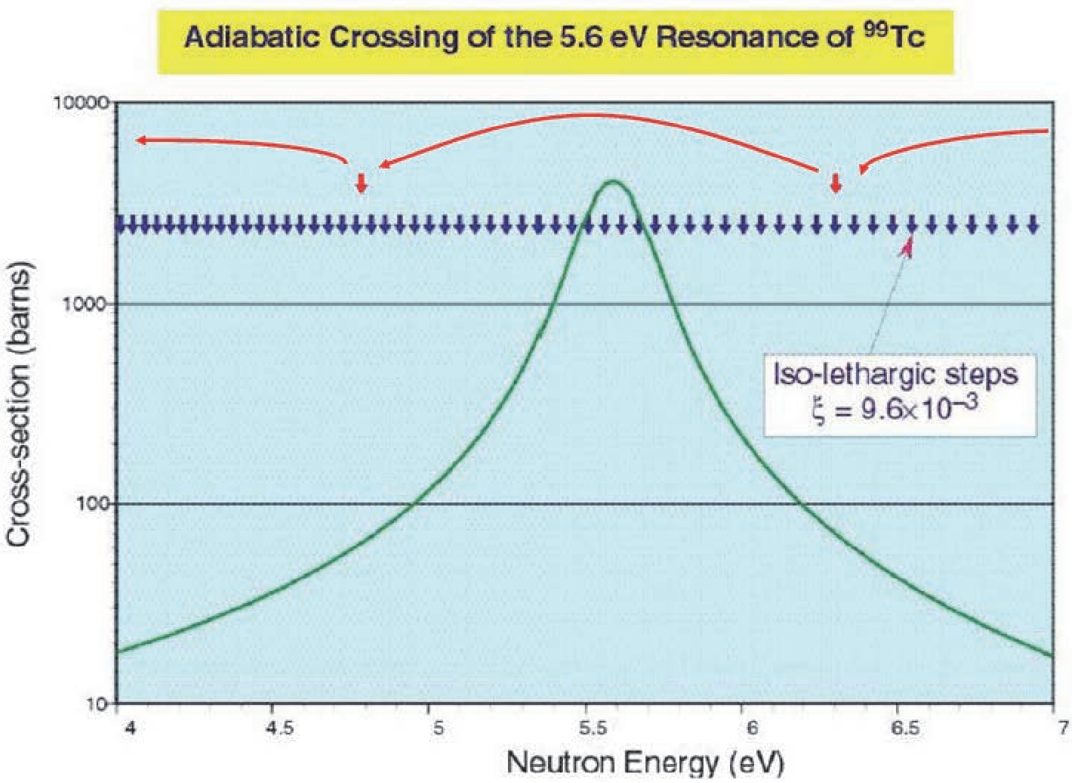


(n, gamma) cross-section data from ENDF-VII.0

- Some resonances are very narrow with large cross sections. (5297 barns at 5.58 eV, 1693 barns at 20.21 eV, etc)

Adiabatic Resonance Crossing Method

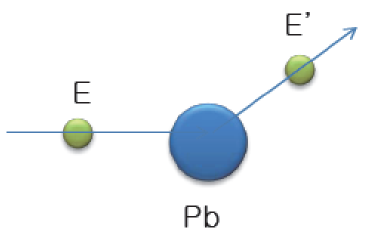


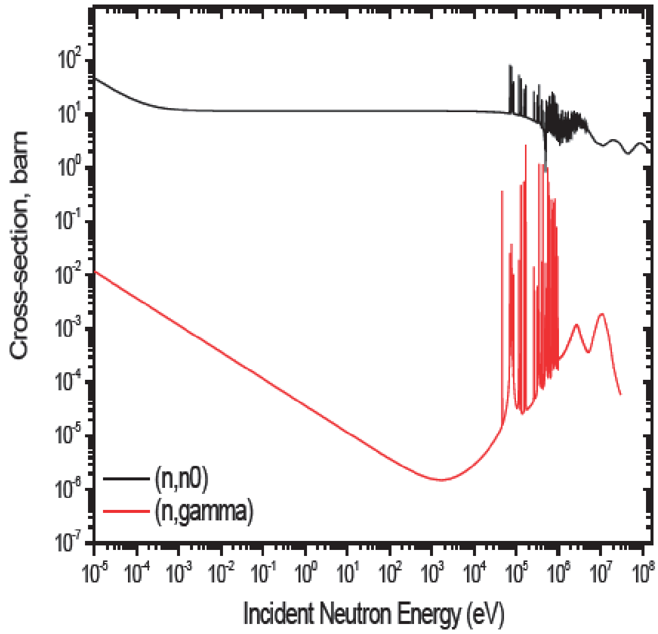


Use of lead (^{208}Pb) block for ARC

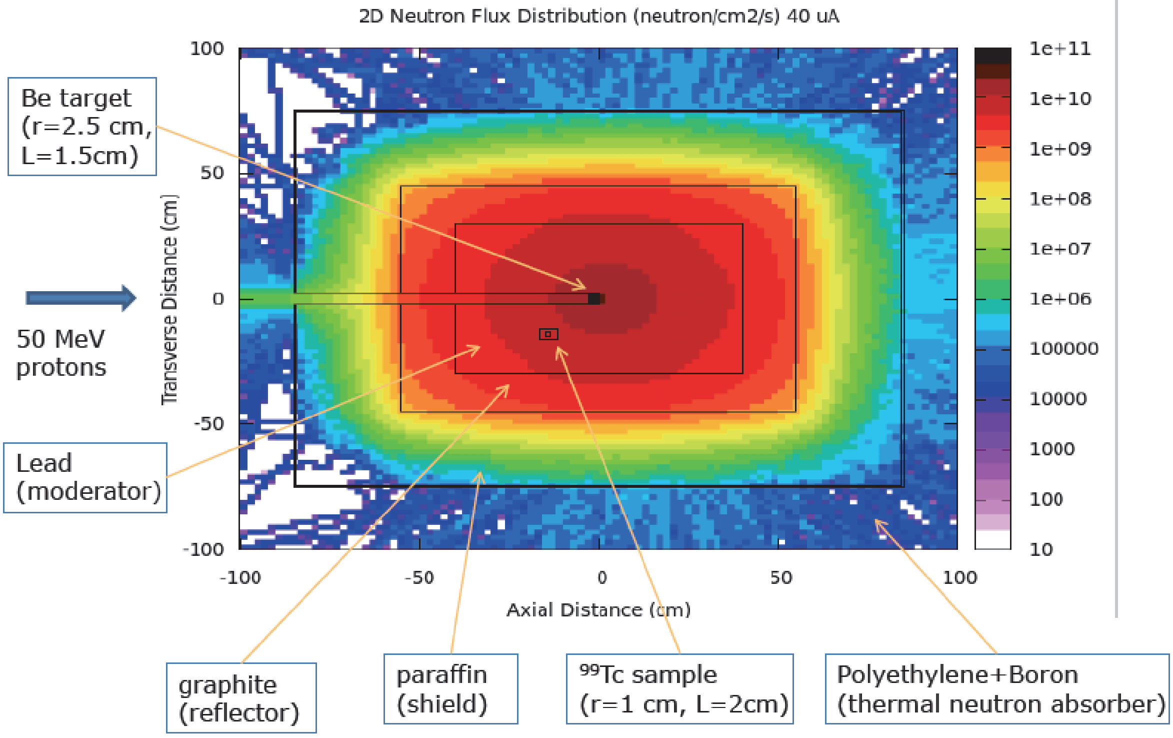
- Large elastic cross section
- Small capture cross section
- Large mass (A=208) insures small energy loss per collision

$\Delta E/E \approx 2\, M(n)/M(Pb) \approx 0.01$



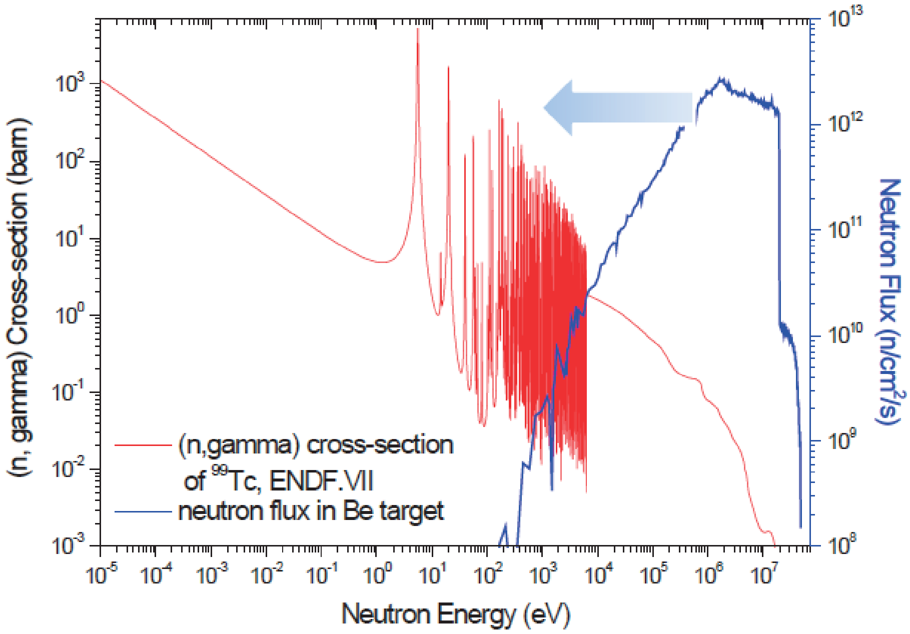


Simulation for designing lead block

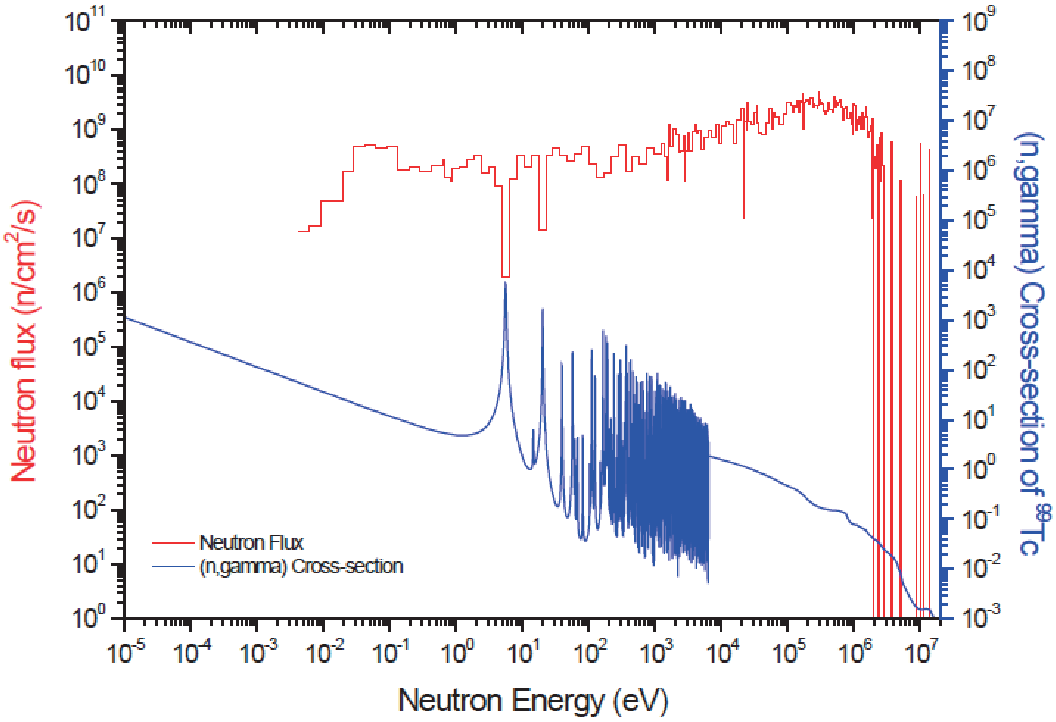


Neutron spectrum at the Be target

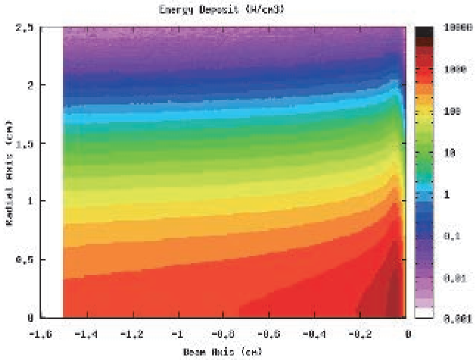
- Most of Neutrons are in high energy region.
  (50MeV 40μA proton beam, Be target: r = 2.5cm, thickness = 1.5cm)
- These neutrons should be moderated to resonance region.

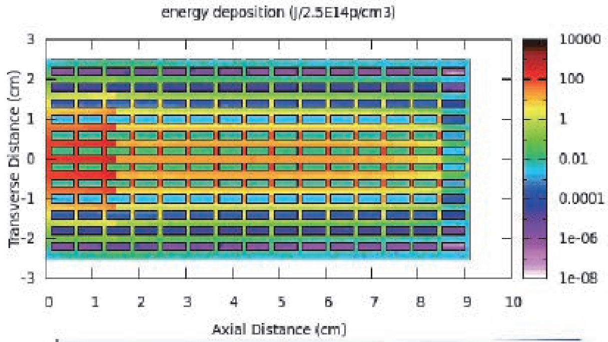


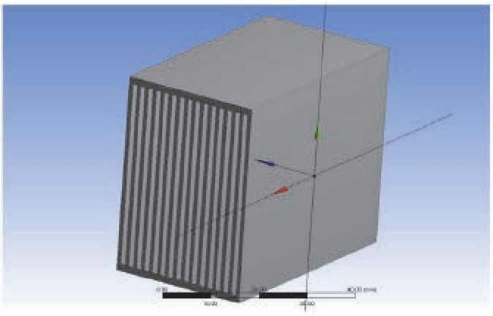
Neutron spectrum at the ^{99}Tc sample

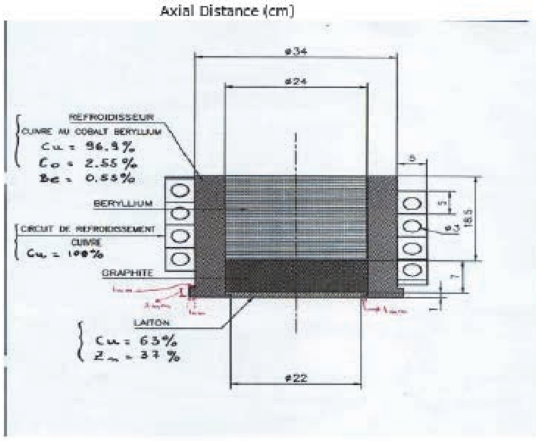


Thermal analysis for Be target design





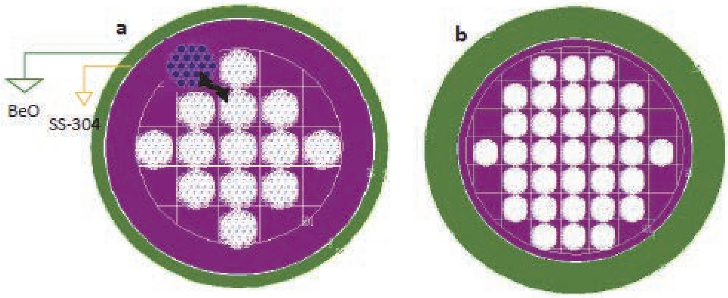




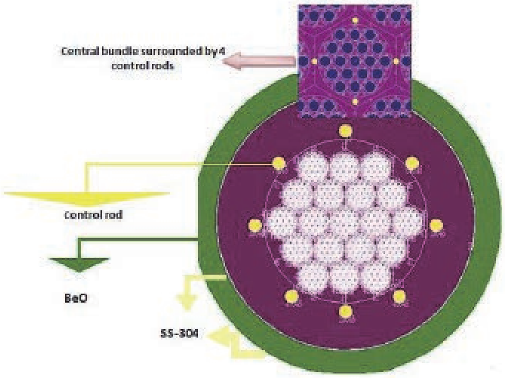
4. Design of Compact Reactor Core

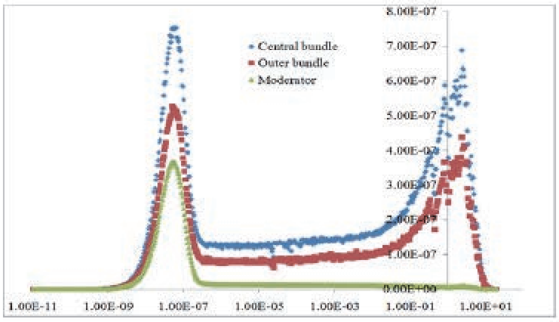
To make an existing Reactor Core compact, we chose a CANDU, thermal reactor configuration.

2 configurations: 13 and 33 bundles, 19 fuel elements each, with enrichments of 2.1% and 2.5% respectively and subcritical configuration k_{eff} = 0.98



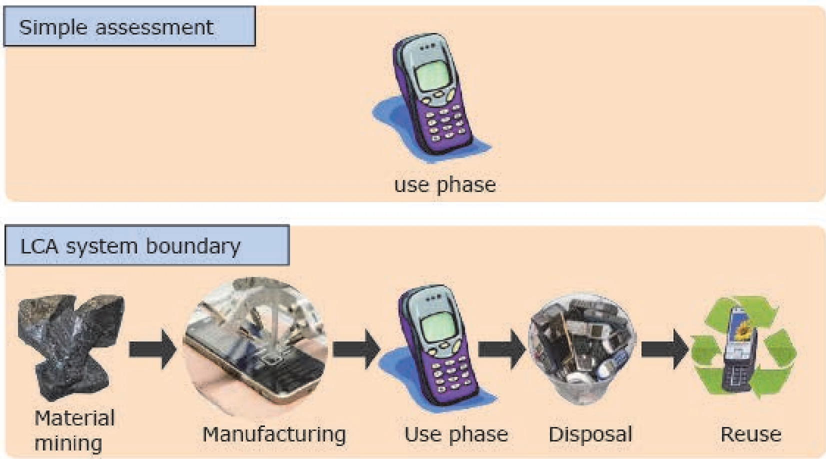
New design tailoring the MA transmutation
Fuel: (^{232}Th, ^{235}U)O_2
Neutron distribution is tailored for MA burning





5. Life Cycle Assessment for ADS

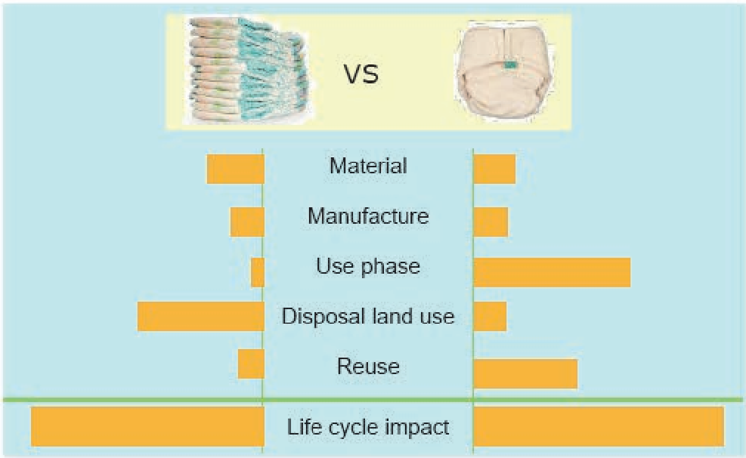
- LCA is useful tool considering life cycle time scale with various point of view

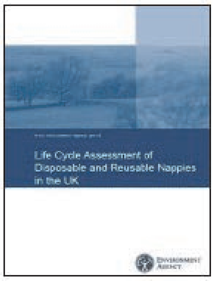


ISO 14044, Environmental management – life cycle assessment – Requirements and guidelines, International Organization for Standardization, 2006.

Why do we need "Life Cycle" Consideration? - example of diapers-

- LCA gives us right and comprehensive result.
  - An environmental study of nappies revealed that there was **no difference** between reusable and disposable nappies, when it comes to whole life cycle environmental damage.





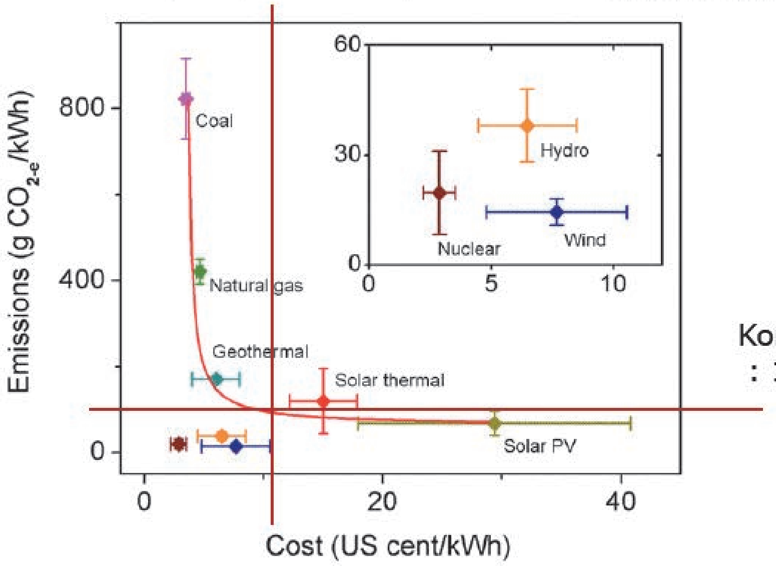
Aumonier, S. and M. Collins (2005). Life Cycle Assessment of Disposable and Reusable Nappies in the UK. E. Agency.

Results (GHG vs Cost)

- Correlation between GHG emissions and cost

Grid parity : 11 cent /kWh

$$\text{GHG emissions} = 72.53 + \frac{228.95}{\text{Cost} - 3.18}$$



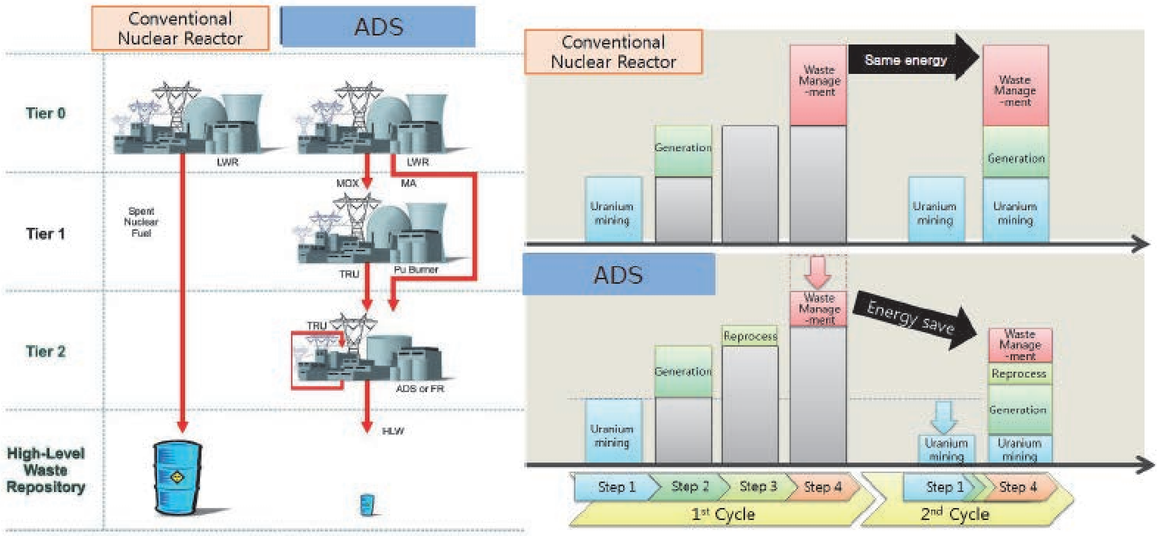
Korean energy target
: 110 g CO2 /kWh

- GHG emissions and cost are in inverse proportion

Heetae Kim and Claudio Tenreiro, "Energy Policy", Submitted

Application of LCA to ADS

- Energy systemic impact of ADS
  - 35.5% of total energy balance in Korea
  - next generation nuclear technology
  - can reduce nuclear waste and reuse it
  - no impact data of energy amplifier so far



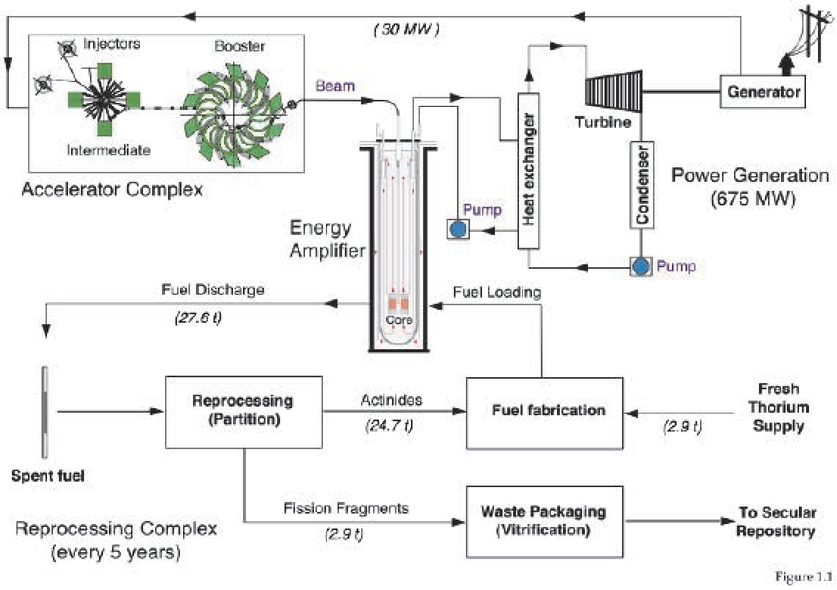
LCA on Th based ADS

• Life Cycle Analysis (LCA) for ADS:
One of the fundamental problems in nuclear power is the MA burning for waste reduction. This imply two steps, namely partitioning and transmutation, both have to be correctly evaluated from the LCA

• Th-fuel based cores: Another challenge and opportunity is to shift from U fuelled reactors to Th ones.
Good opportunity to study and perform core design physics.

• ADS core analysis: In order to get more local experience in ADS, several lines of research are currently under consideration regarding the target and core distribution of MA

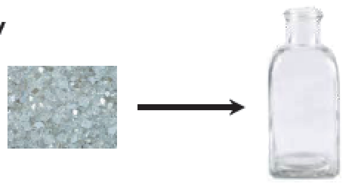
General lay-out of an ADS



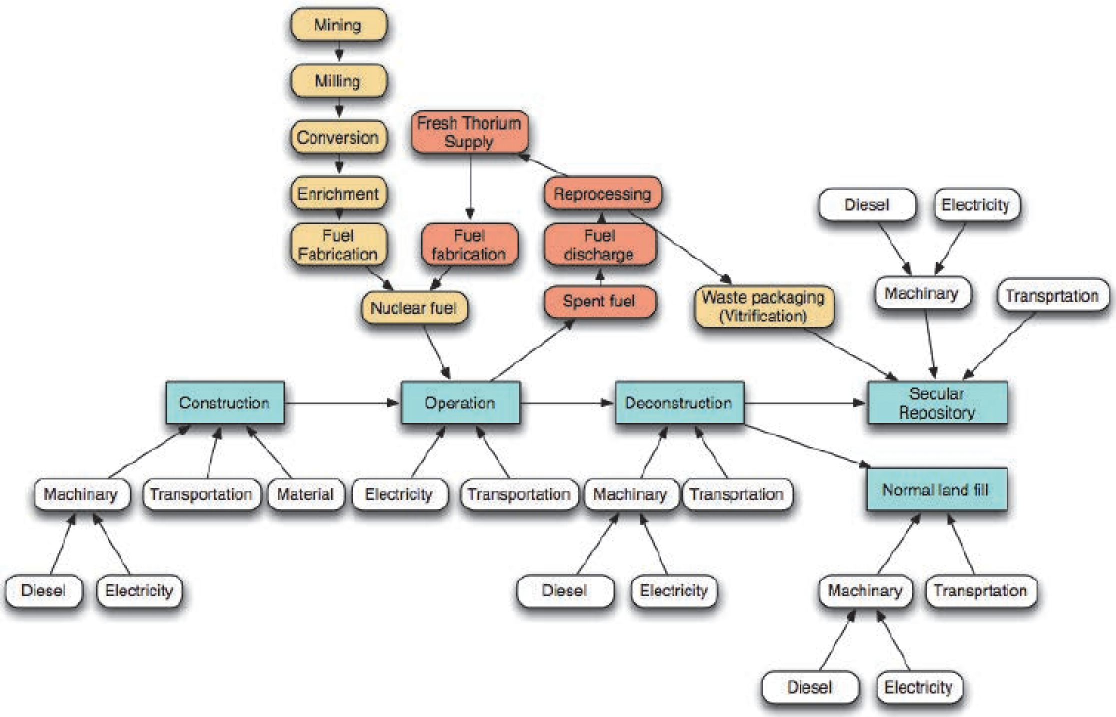
Rubbia, C., Buono, S., Gonzalez, E., Kadi, Y., & Rubio, J. A. (2011). A REALISTIC PLUTONIUM ELIMINATION SCHEME WITH FAST ENERGY AMPLIFIERS AND THORIUM-PLUTONIUM FUEL, 1–49.

System boundary

- The system boundary determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal of the study.
- Simple system boundary
  - production w/o building (factory)
  - consider materials and energy input only
- ADS case
  = production + building (power plant)
- Cut off parameters on
  - mass, energy or environmental significance

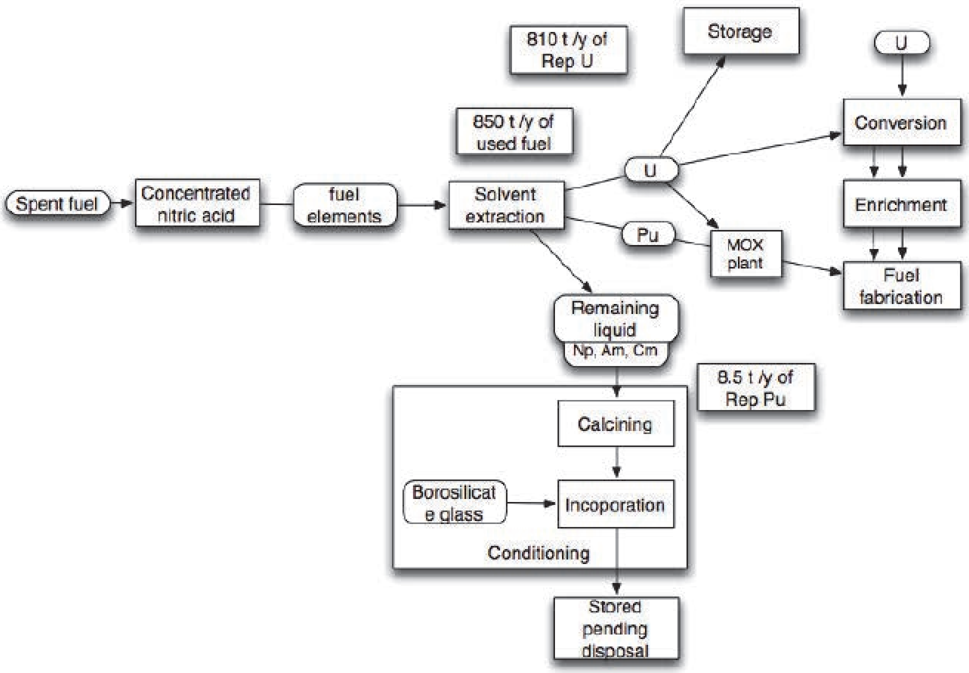


System boundary for ADS



Heetae Kim and Claudio Tenreiro "ADS model for LCA energy system analysis.", (in preparation)

System boundary for reprocess



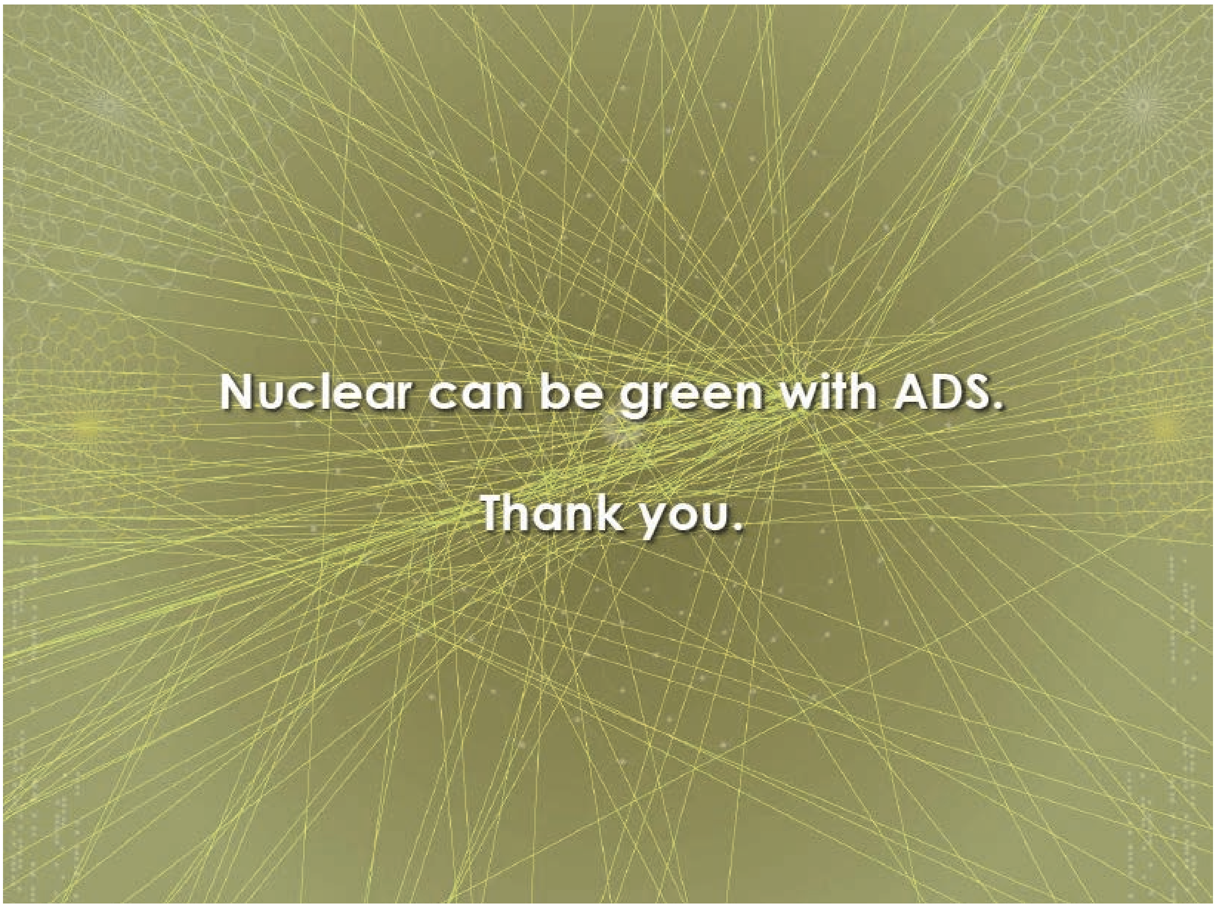
Heetae Kim and Claudio Tenreiro, "LCA energy system analysis for ADS model" (in preparation)

"Asian Working Group for ADS and its Applications"

- Goal: To summarize what has been accomplishe d in this field and what needs to be further stud ied in the future for realizing the ADS. This wor k does not necessarily involve research activitie s but aims to **produce a roadmap** which can b e presented to **the society/governments** for policy making.
- Modules:
  - Accelerator
  - Reactor core design
  - Material
  - Nuclear data and nuclear physics
  - Thorium
  - Education

Possible Scope of Task

- List the options for technological elements.
  (Dr. Yano: One 20 MW linac, or ten 2 MW cyclotrons?)
- List the pros and cons of each technology.
- Consensus or Roadmaps: How to approach or invest
  (Not necessarily research efforts)
- International roadmap: Not prejudiced.
- Present the roadmap to the societies/governments of different countries to facilitate policy making
- Plan the next steps
  (Dr. Yamana: Steve Covey's approach? Or Big Project?)


Nuclear can be green with ADS.
Thank you.

3.7 Accelerator Driven System: Plans & Present Status in India

P. K. Nema (BARC, India)

Nuclear Energy Growth Constraints

- Fuel Resources
  - -Uranium versus thorium.
  - - Fuel re-cycling (U-Pu)
  - - Thorium (fuel recycle in R&D stages).
- Technology
  - - Plant safety.
  - - Breeders (for optimum resource utilization).
- Environmental impact- Disposal of wastes.
- Economics & proliferation concerns.

Nuclear Power Programme in India

Constraints:

- ➢ Uranium resource crunch (for existing "once through" technology).
- ➢ Vast and easily exploitable thorium fuel resource.

Evolving 3-stage technology developments:

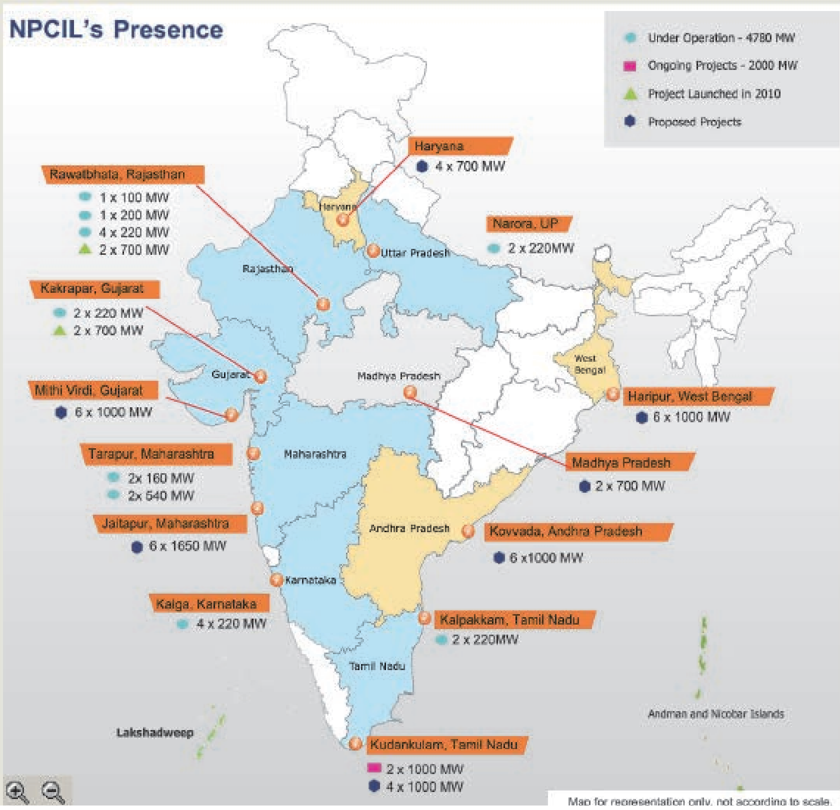
1. PHWR- Natural uranium + heavy water
2. FBR with U-Pu recycle- sodium cooled reactor & fuel reprocessing.
3. Thorium fuel cycle (driven by stage-2).

ADS applications can usher in early onset of stage-3….?

Indian Nuclear Power Programme - 2020

REACTOR TYPE AND CAPACITIES	CAPACITY (MWe)	CUMULATIVE CAPACITY (MWe)
> 20 reactors at 6 sites in operation PHWR at Tarapur, Rawatbhata, Kalpakkam, Narora, Kakrapar and Kaiga	4,780	4,780
➢ 2 LWRs under construction at Kudankulam (2x1000 MWe)	2,000	6,780
➢ PFBR under construction at Kalpakkam (1 X 500 MWe)	500	7,280
> Projects planned till 2020 PHWRs (8x700 MWe), FBRs (4x500 MWe), AHWR (1x300 MWe)	7,900	15,180
➢ Additional LWRs through international cooperation	~ 20000	~ 35000

Power Reactor locations- planned and operating



Why ADS for India…?

- **Indian interest in ADS is primarily for thorium fuel applications.**
- This is taken up as an additional path to ongoing 3-stage nuclear power programme.
- Fuel re-cycling (U-Pu) programme already existing. Thorium fuel recycle is in R&D stages.
- Heavy liquid metal technology- shared also for High-Temperature Reactor (HTR) systems.
- **High power proton accelerator is the main thrust area for ADS programme.**

ADS Programme: Ongoing Activities

List of main activities:

1. Reactor physics code and nuclear data upgrades.
2. Fuel cycle studies with typical (HWR/MSR) ADS configurations.
3. Experimental sub-critical assembly driven by DD and DT source neutrons.
4. Studies on target spallation reactions & thermal hydraulics studies for heavy liquid metal (HLM).
5. Development of high power proton accelerator.

Facilities planned & constructed for R&D:

1. Sub-critical experimental facility driven with DD/DT neutrons.
2. Experimental LBE loop facility.
3. LBE loop with 30 MeV proton beam irradiation.
4. Low-Energy High Intensity Proton Accelerator (LEHIPA).
5. Design studies for ADS demonstration facility with research reactor.

Ongoing R&D on ADS Technology

1. Development of sub-systems of high power proton accelerator (HPPA) planned in step-wise modules.
2. LEHIPA is first module of HPPA and under construction in BARC. R&D phase for other modules.
3. Heavy Liquid Metal target system for ADS demo facility & for industrial-scale facility to be developed.
4. Components of experimental LBE loop and an irradiation module are getting ready.
5. Experimental sub-critical facility under preparation.
6. DD/DT Neutron generator is made functional and targets of Titanium deuteride and tritide (5-20 Ci) are developed.

Reactor Physics Developments

- **Development of Computer Codes for Analysis of ADS**

BurnTran: Burn-up code based on 2D Transport theory.

McBurn : Developed a Burn-up module & coupled with MC algorithm for analyzing batch fueling.

- **Nuclear data**

Usage of available data files and also that generated from ENDF data processing.

- **Experimental studies and Code calculations validation:**

Planned in the proposed sub-critical experiment using DD & DT neutron facility.

- **Conceptual Design Studies**

Fuelling schemes of thorium for ADS in MSR and heavy water reactors

ADS Studies for Thorium Fuel

1. Studies for PHWR/MSR ADS : initially fuelled with Nat. U+Th; and, eventually operating with only thorium fuel feeds.
2. Thorium fuel cycles in thermal spectrum ADS:

- Self sustaining cycles
- Very difficult for critical reactors : resulting in very low burn-ups.
  - Quite feasible for ADS mode:
    - Gain is 30-40,
    - At K_{eff}~0.95 burn-up of over 40 GWd/t possible.
- Breeding cycles
  - K_{eff} comes down further to about 0.93 &
    - Gain is down to about 25,
  - Burn-up goes up to about 60 GWd/t .

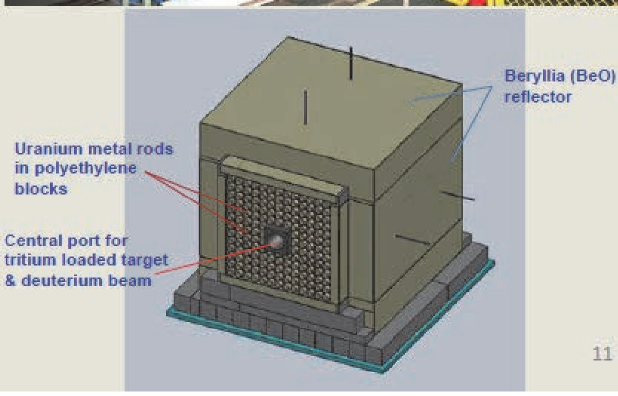
3. Thorium fuel cycles in Fast ADS:

- Self sustaining cycles and offers slow breeding potential.
- Large burn (> 100 GWt/T) up with metallic fuel, HLM coolant : Suitable for once through thorium utilization.
- Requires large start up mass of fissile ^{233}U.

DD/DT Neutron-Driven ADS (BARC) Facility

- For experiments on physics of ADS and validation of simulations. Sub-critical assembly (k_{eff}=0.89) of natural uranium in polyethylene with BeO reflector is chosen.
- To make use of fast neutrons (≈ 10^{9-10} n/s) produced by 400 kV, 100-250 μA DC accelerator in D+D/T reaction.
- *Solid target of titanium deuteride/tritide on copper substrate for nuclear reactions.*

1. Fuel moderator combination allowed dispensing with criticality accident scenario and safety audit.
2. DD neutron source strength 10^{10} and DT neutron strength of 10^9 n/s would be allowed due to thickness of shielding walls of room.



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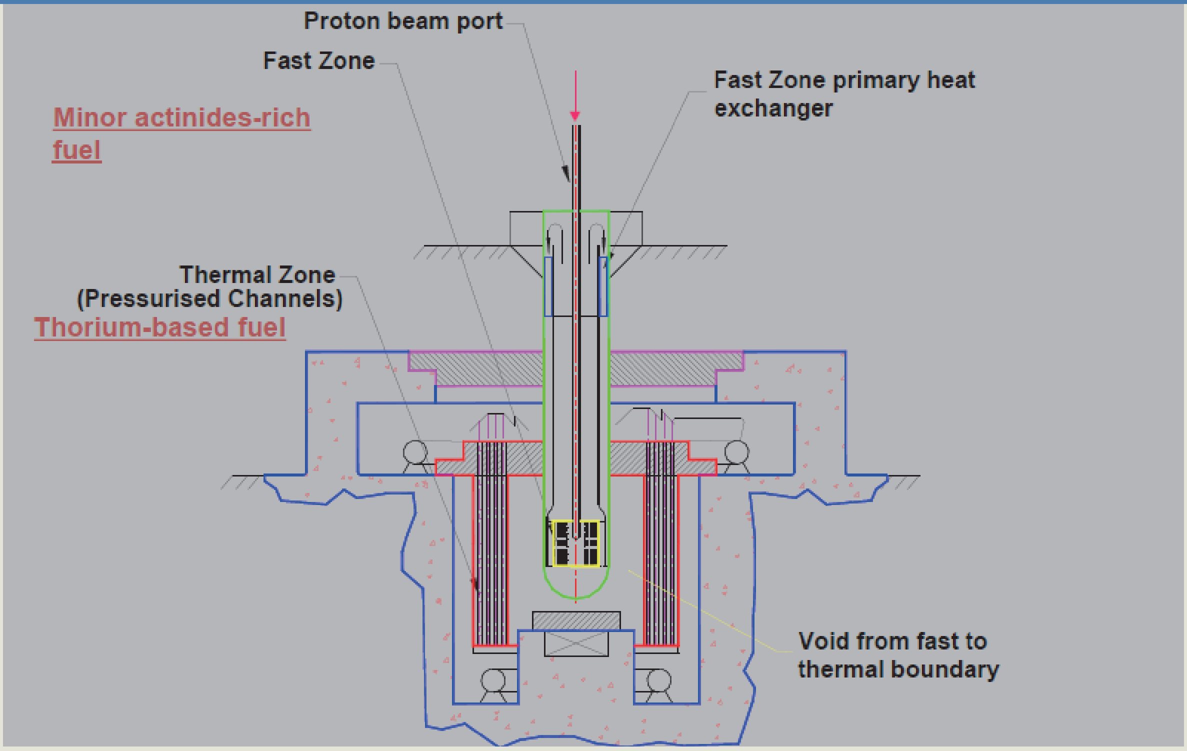
One-way Coupled ADS Scheme for Thorium Utilization & Actinides Transmutation



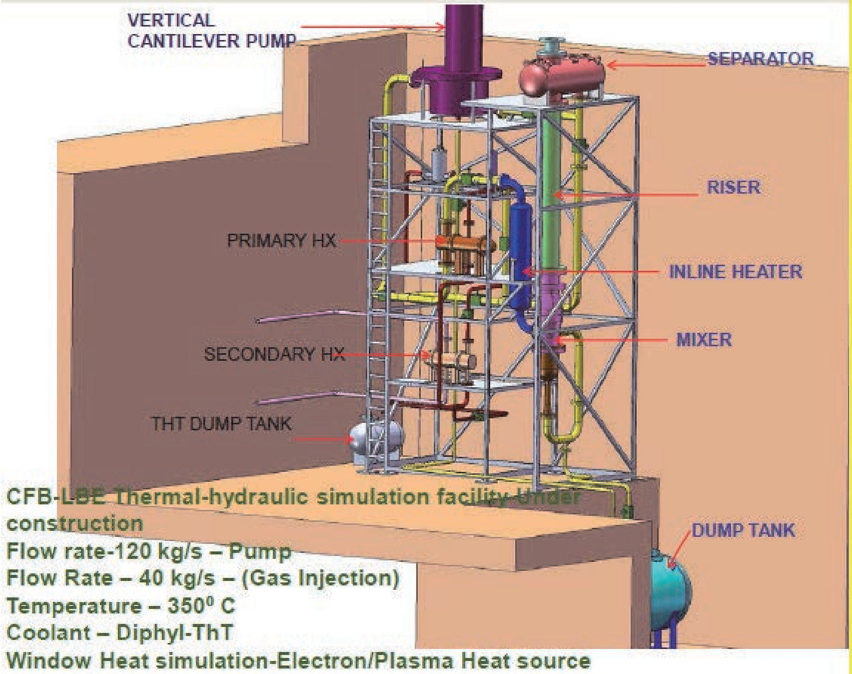
Target & Reactor Physics R&D

- Design and analysis for HLM target for nuclear reactions, neutron yield, residues and heat deposition by using CASCADE & FLUKA codes.
- Neutron transport and coupling with ADS reactor core, reactor calculations using McBurn and BurnTran Programmes.
- Possibility of including fresh nuclear data and cross section library.
- Shielding calculations and fuel cycle estimates.

Capability for Preliminary design and estimates for thorium utilizing ADS configurations.

LBE Experimental Test Facility

(Non-radiological hazards facility)



Facility safety audit

Operation temp. limited to 350^{0}C so that lead vapor pressure is within chemical safety concentration requirement for lead vapours.

Only thermal hydraulics code validation, instrumentation and material corrosion studies.

There are no planned tests that involve radiological safety aspects.

LBE Irradiation Facility

LBE liquid metal target irradiation with 30-MeV proton beam.

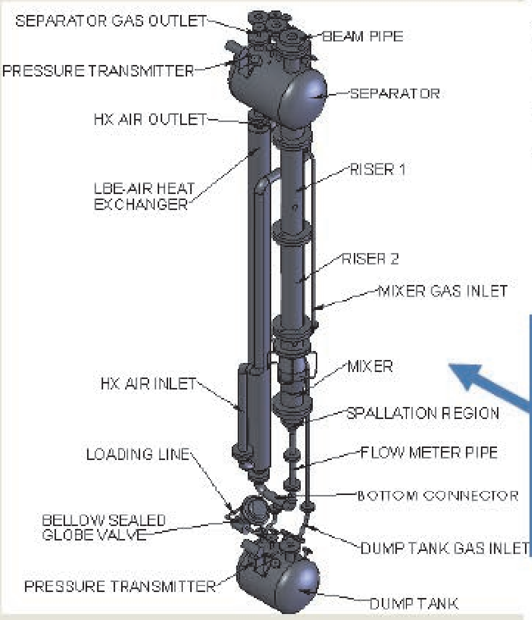
- **High current proton beam irradiation though thin T91 material beam window.**
- **LBE activation and polonium formation to be validated.**
- **To test with gas-injection for enhanced convective circulation of heavy liquid metal LBE at 220^{0}C.**

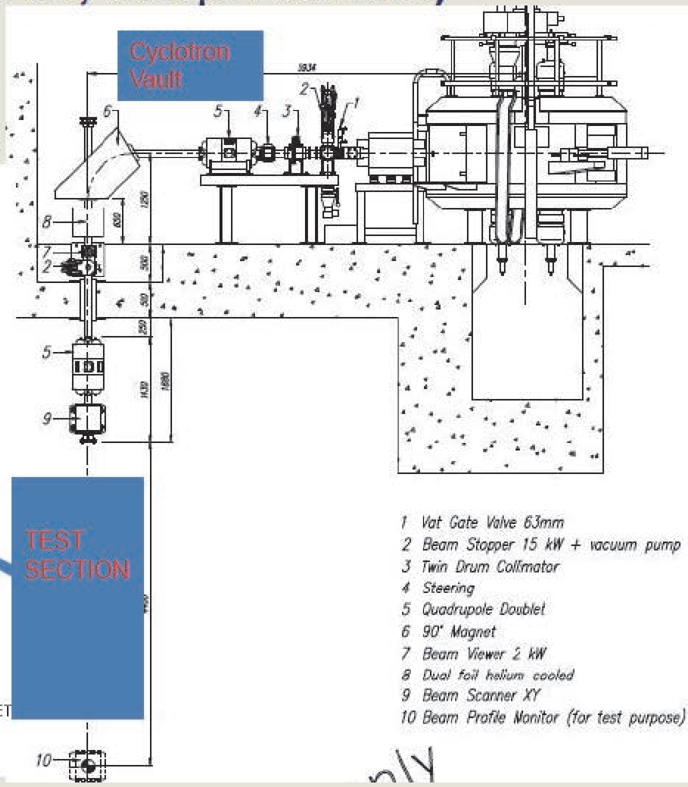
Basis for Safety audit:

Spillage of ~ 1500 Kgs. LBE irradiated for 400 hours in 15 kW proton beam power :

- **Saturation polonium activity (estimate by FLUKA), of which 97% retained as lead-polonide and 3% escapes in room air.**
- **Concentration of polonium in air remains within allowable limits.**

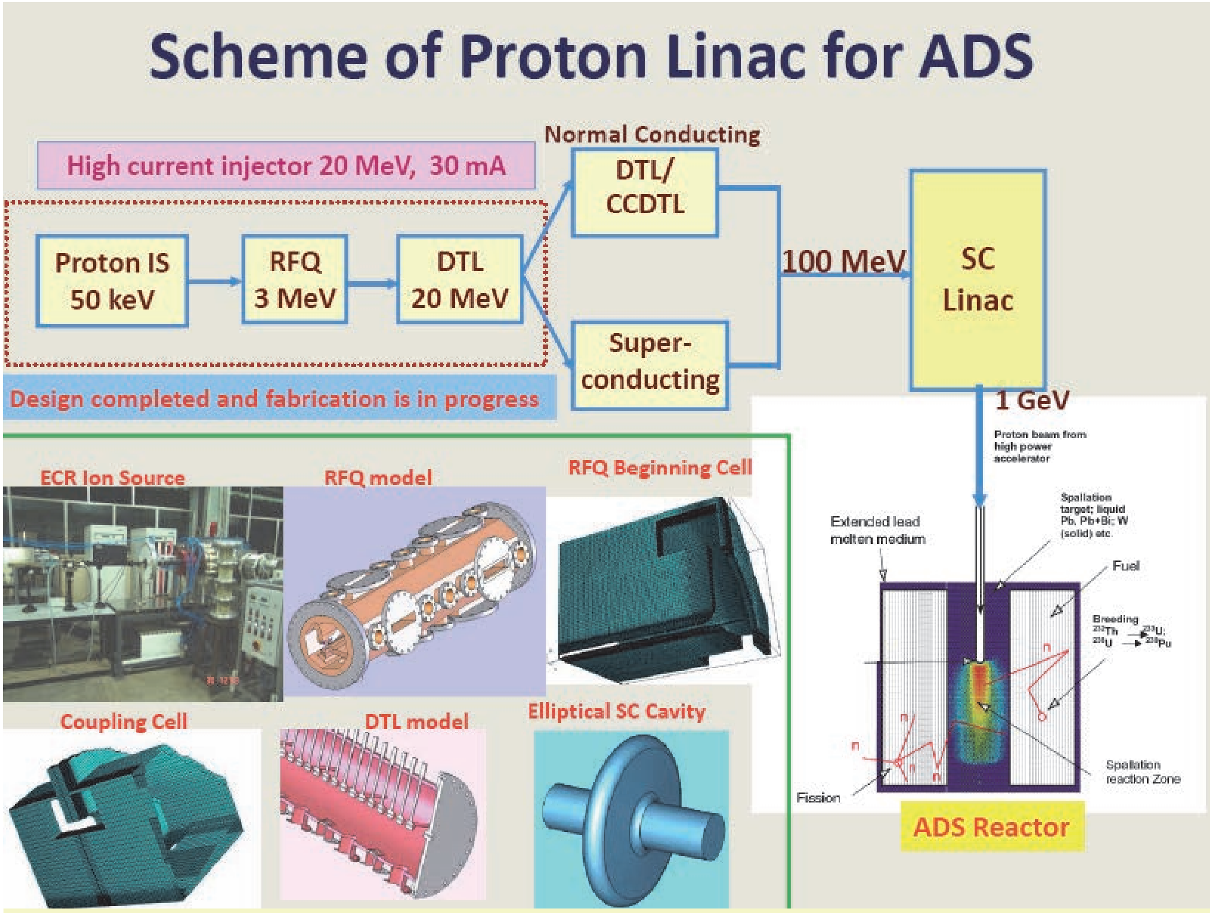
LBE Target Studies with Beam Irradiation
(30 MeV Cyclotron, 500 μA current)

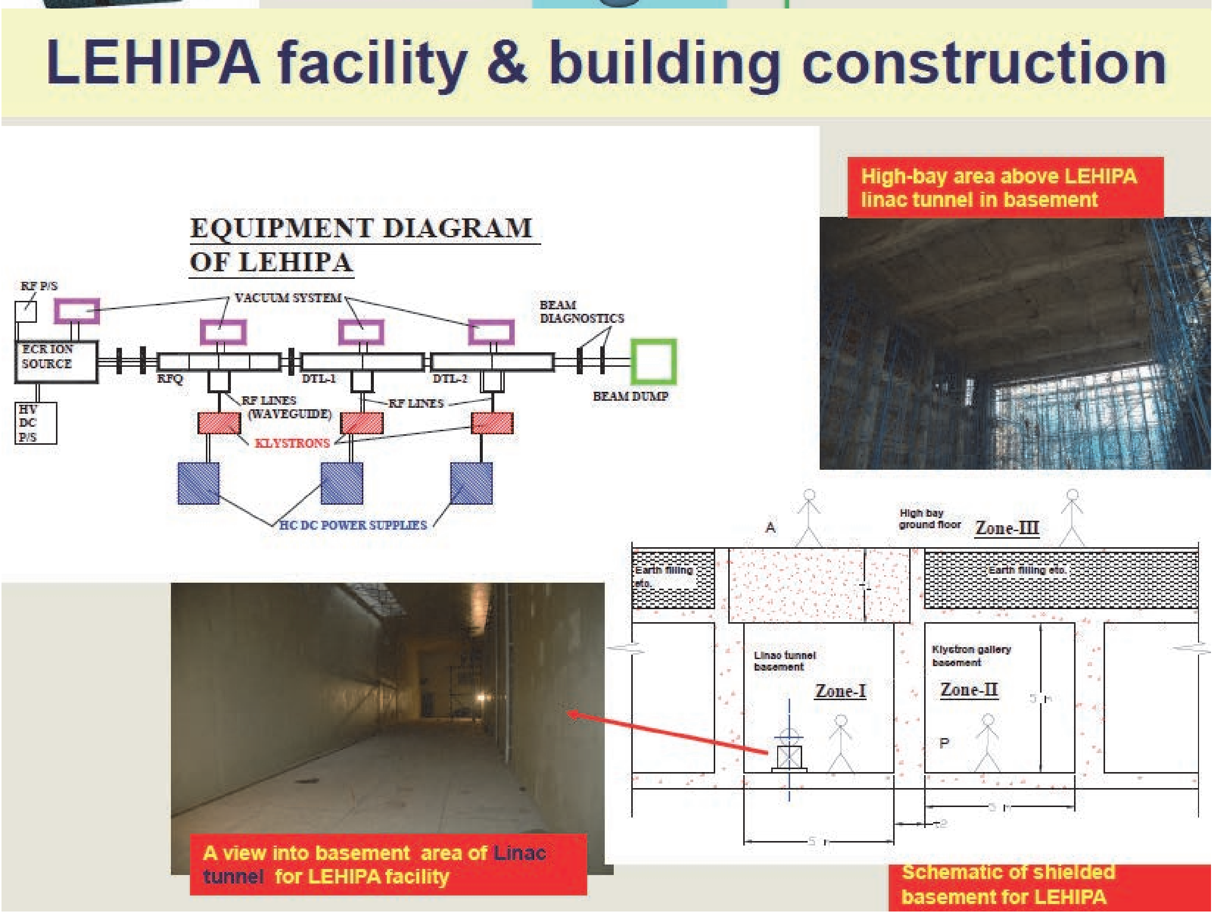




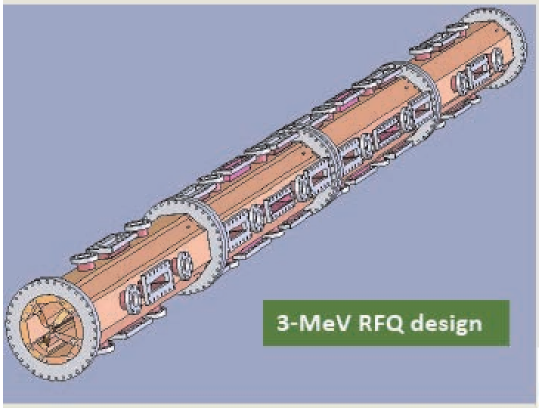
Developing Target Technology

- Thermal hydraulics simulations in HLM target-window cooling. (**But, stable regime for windowless target flow geometry could not be realized so far**).
- Gas-injection assisted HLM convection loop: two phase, 1-dimensional circulation system code available - validated in N_2-Hg loop.
- Window material for prototype target module will be T91 (characterized for FBR applications).
- LBE Target module testing rig has been set up to verify functionality.

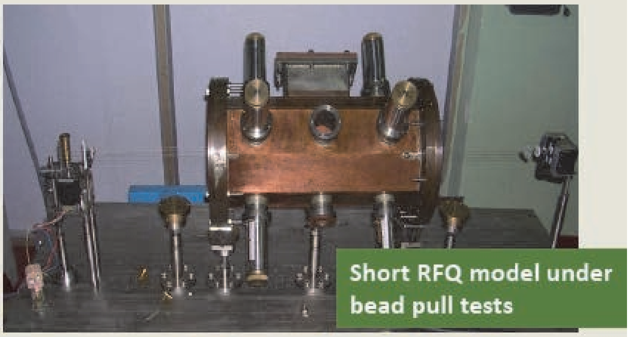

Scheme of Proton Linac for ADS
High current injector 20 MeV, 30 mA
Normal Conducting
DTL/
CCDTL
Proton IS
50 keV
RFQ
3 MeV
DTL
20 MeV
100 MeV
SC
Linac
Super-
conducting
Design completed and fabrication is in progress
1 GeV
Proton beam from high power accelerator
Spallation target; liquid Pb, Pb+Bi; W (solid) etc.
Extended lead molten medium
Fuel
Breeding
Fission
Spallation reaction Zone
ADS Reactor
ECR Ion Source
RFQ model
RFQ Beginning Cell
Coupling Cell
DTL model
Elliptical SC Cavity


LEHIPA facility & building construction
EQUIPMENT DIAGRAM
OF LEHIPA
RF P/S
VACUUM SYSTEM
BEAM
DIAGNOSTICS
ECR ION
SOURCE
RFQ
DTL-1
DTL-2
BEAM DUMP
HV
DC
P/S
RF LINES
(WAVEGUIDE)
RF LINES
KLYSTRONS
HC DC POWER SUPPLIES
High-bay area above LEHIPA
linac tunnel in basement
A
High bay
ground floor
Zone-III
Earth filling etc.
Earth filling etc.
Linac tunnel
basement
Zone-I
Klystron gallery
basement
Zone-II
P
A view into basement area of Linac
tunnel for LEHIPA facility
Schematic of shielded
basement for LEHIPA

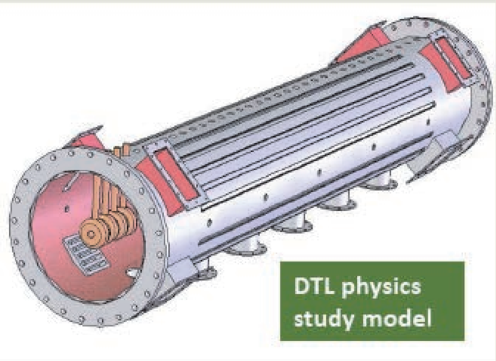
Construction of LEHIPA



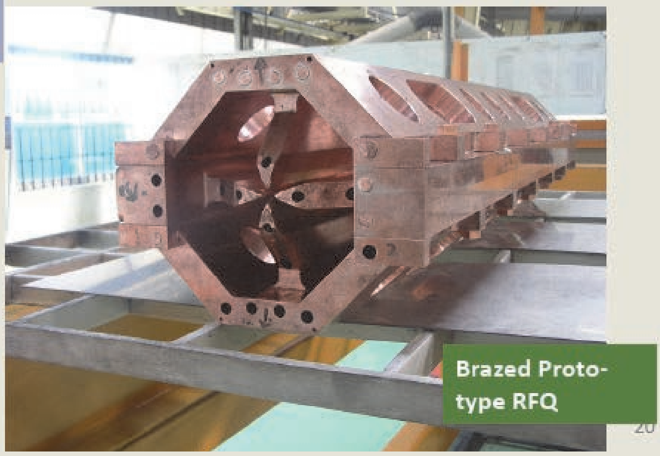
3-MeV RFQ design



Short RFQ model under bead pull tests



DTL physics study model



Brazed Proto-type RFQ

20

RF Power System : Prototypes

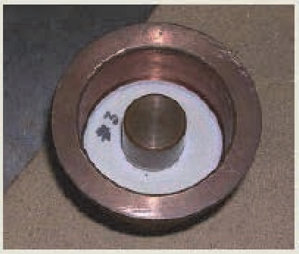
RF System for 400 keV prototype RFQ
(35 kW tetrode-tube based RF power supply using 1 kW intermediate driver).

New Driver stage : 350 MHz, 2.5 kW

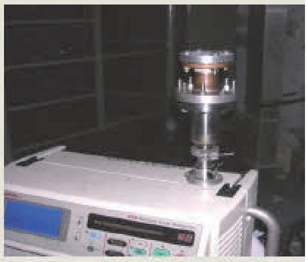
Development of Coaxial Coupler for prototype 400 keV RFQ (deuteron accelerator)

Coaxial coupler connected to RFQ Cavity

Alumina tubes metallized in BARC



First RF window prototype after vacuum brazing

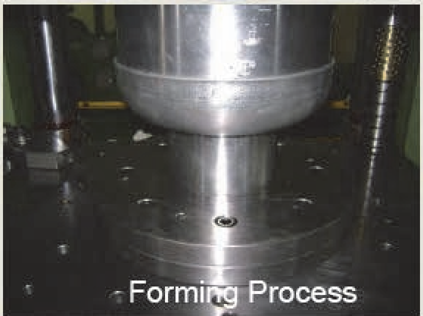


RF Coupler prototype being tested for vacuum

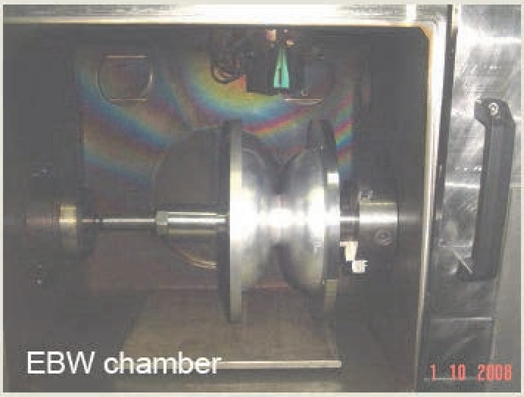
Coaxial adapters under RF Chracterization

350 MHz RF cavity developed for Coupler conditioning

Developing Technique for SC RF Cavity Fabrication



Formed Niobium Half Cell



Welded dumbell

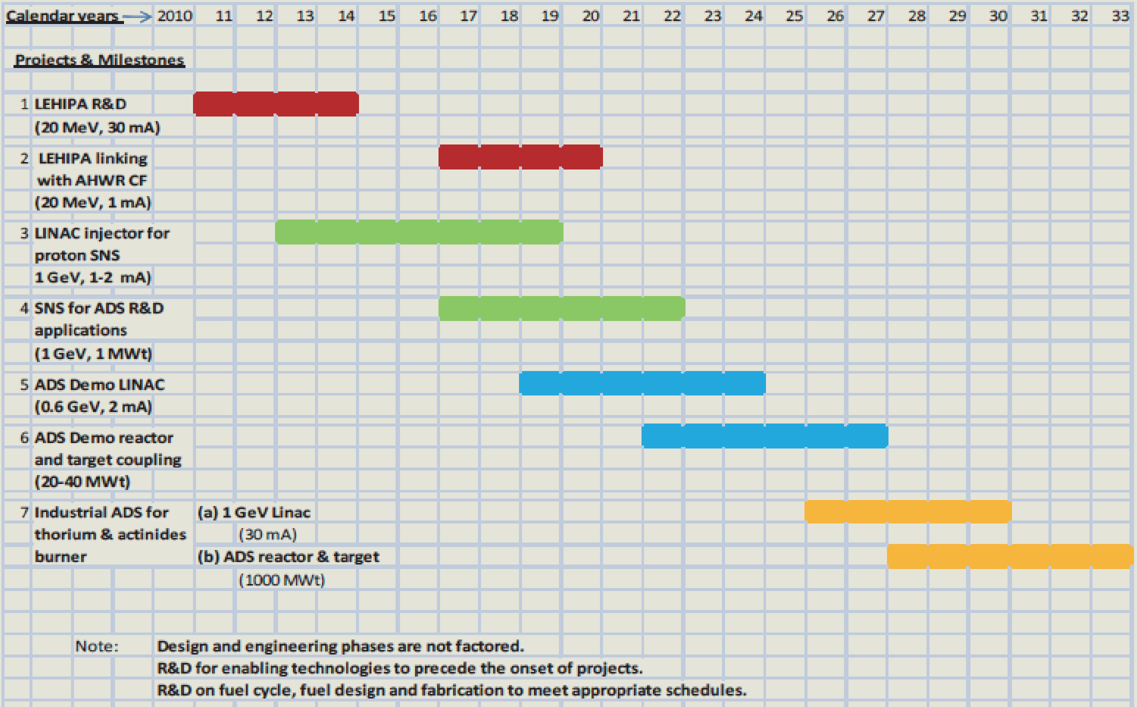
23

Visionary Roadmap for ADS Development in India			
S. no.	**Tasks in the form of project**	**Rationale**	**Timeline**
1.	**LEHIPA** at BARC- 20 MeV, 30 mA (Av.) proton linac	It is an ongoing project for enabling accelerator technology, facility is useable as neutron facility in BARC.	2010-14
2.	Linking beam from **LEHIPA with AHWR** Critical facility in BARC. LEHIPA in 20 MeV, 1 mA mode of operation.	To deliver beam on a target in heavy water moderated criticality facility, with fuel lattice formations: for ADS experimental reactor physics studies.	2017-21
3.	Linac + proton **SNS** as neutron source: design and development by RRCAT, Indore.	Sequential development of high duty-cycle proton (or H^-) linac and pulse compression proton accumulator ring for intense spallation neutron facility.	2013-19 (Linac) and, 2017-23 (SNS)
4.	Proton Linac as neutron source & to drive a **demo ADS** in research reactor at Visakhapattanam campus of BARC.	Proton (not H^-) linac with cw operation between 0.6-0.8 GeV and 1.6 mA. When coupled to sub-critical reactor, fission power would be 20-40 MWt for ADS demonstration facility.	2019-24 (Linac) and, 2023-28 (reactor)
5.	Multi-purpose 1-GeV proton linac complex, eventually coupled with ^{233}U production ADS: baseline design in AHWR as well as MSR (site-independent **conceptual design**).	Based on design and construction experience & technology developments of proton linacs, a 1 GeV accelerator coupled with 1000 MWt ADS reactor could be designed as a project for approval of construction.	20025-26 (Enginneering Design & R&D phase)
6.	**Industrial ADS** construction as minor actinides burner device to incinerate long-lived waste from spent nuclear fuel, or Pu+Th for breeder modes etc. (PWR/BWR and safeguarded PHWR, FBR).	By upgrading proton linac of demo-ADS, and coupling its beam with this first-of-kind ADS will utilize reactor fuel in various combinations. Fission power would be desireable at 1000 MWt (≈300 MWe).	2027-33
7.	Power generating ADS for thorium utilization with high reliability driver proton accelerator.	Third-stage nuclear power ADS device of operation with Th+U fuel in fully self sustainable mode and capacity up to 1 GWe.	unspecified

Essential R&D Areas for ADS

- ✓ High power proton beam handling.
- ✓ High power RF sources.
- ✓ RF power couplers, circulators
- ✓ Superconducting niobium material & cavities.
- ✓ Liquid Helium cryogenics system.
- ✓ Materials for liquid Lead & LBE systems.
- ✓ Windowless target system
- ✓ Fuel reprocessing and re-fabrication.

Roadmap for ADS Developments



Summary, Experience & Lessons

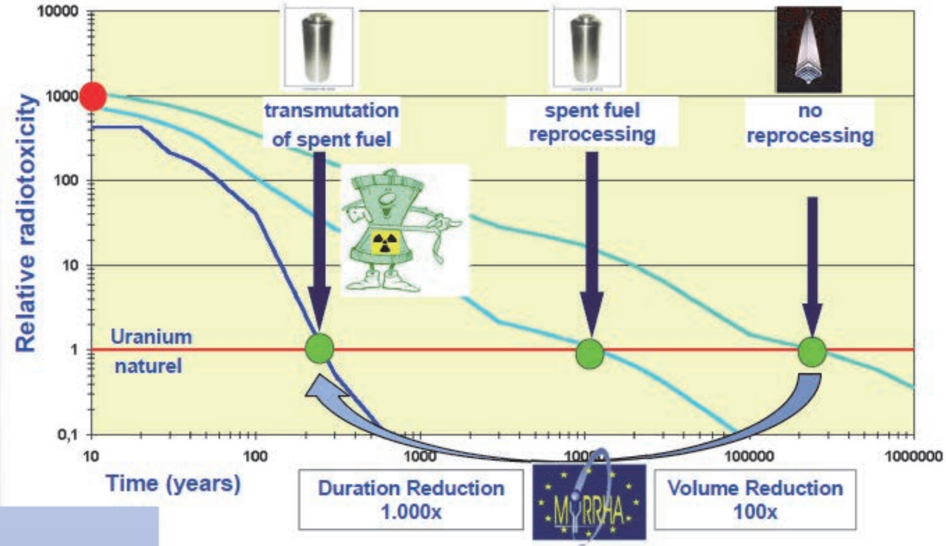
1. ADS would sustain thorium utilization in ^{233}U recycle mode for thermal, and with high fuel burn up in one-through mode in fast reactors.
2. The objective of actinides waste transmutation is not very high priority in our ADS plans, but we understand that same configuration is usable for such applications, when required in future.
3. Key enabling technology developments in RF power, superconducting RF cavities and cryogenics are pre-requisites for high power proton accelerator. We have to go a long way to master these.
4. Accelerator for ADS should co-exist to also support other applications by sharing beams for radiotherapy, materials irradiation, research using neutron beam for material science and nuclear data etc. Then, its cost in nuclear power application would be justifiable.
5. We have made beginning for R&D on ADS sub-systems, but the integrated project would be started after overcoming technological constraints.
6. We are proceeding for a few bilateral collaborations with Fermi & Jefferson Labs, USA for accelerators and with SCK-CEN for MYRRHA.


Thank You !
For your kind attention
28

3.8 Advanced Nuclear Systems with P&T in Europe and Role of MYRRHA

P. Baeten (SCK-CEN, Belgium)

Motivation for transmutation



2

FP6-PATEROS
European Strategy for P&T

- **The implementation of P&T of a large part of the high-level nuclear wastes in Europe needs the demonstration of its feasibility at an "engineering" level. The respective R&D activities could be arranged in four "building blocks":**

1. Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA),
2. Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter,
3. Design and construction of one or more dedicated transmuters,
4. Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.

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FP6-PATEROS
A European approach to P&T

- P&T useful for countries
  - in phase out
  - with active nuclear programme
- Reduction of volume & heat load of waste
- P&T should be seen at a regional/European level
- Scenario studies: 4 country groups
  - A: stagnant or phase-out
  - B: continuation and Pu optimisation for FRs
  - C: subset of A in "nuclear renaissance"
  - D: non-nuclear to go nuclear

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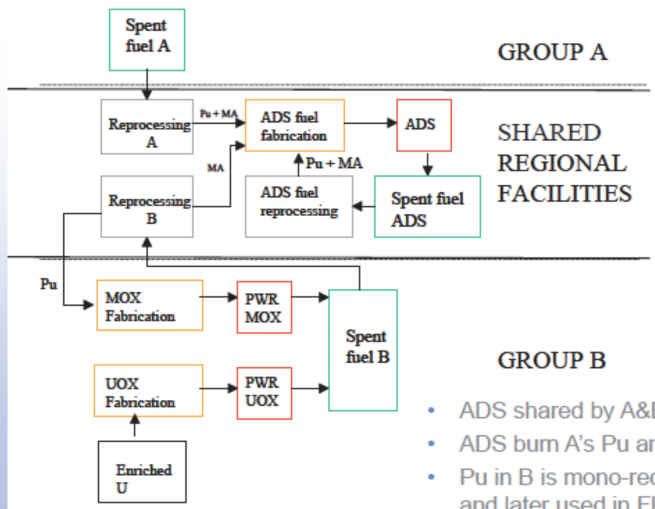
FP6-PATEROS
A European approach to P&T

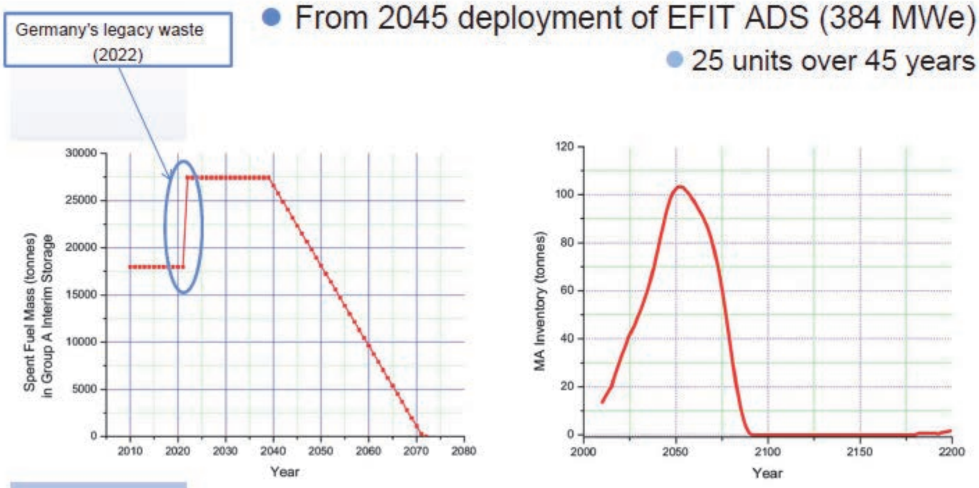


- ADS shared by A&B
- ADS burn A's Pu and A&B's MA
- Pu in B is mono-recycled PWR and later used in FR

Scenario 1 objective: elimination of A's spent fuel by 2100

FP6-PATEROS
A European approach to P&T

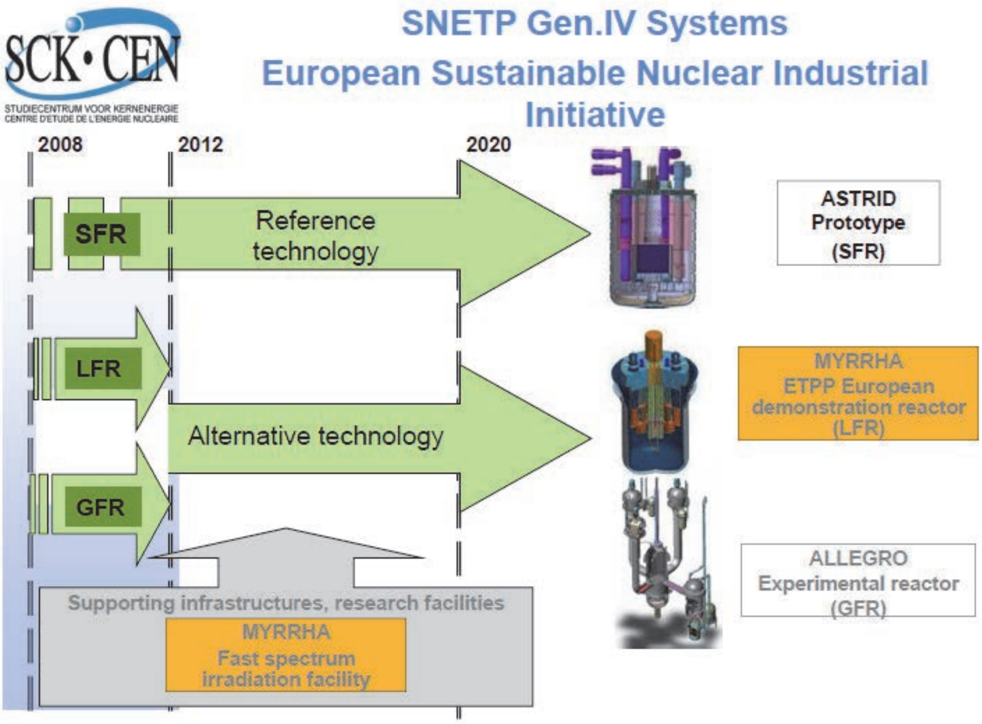
- From 2045 deployment of EFIT ADS (384 MWe)
  - 25 units over 45 years



Spent fuel and MA inventory in Group A

FP6-PATEROS
A European approach to P&T

- This scenario is only efficient on a European level
  - EFIT ADS was tuned to maximize MA burning
  - Consequence: "Pu-neutral"
- Pu from group A used
  - in ADS fuel for start-up cores
  - in FR fuel for group B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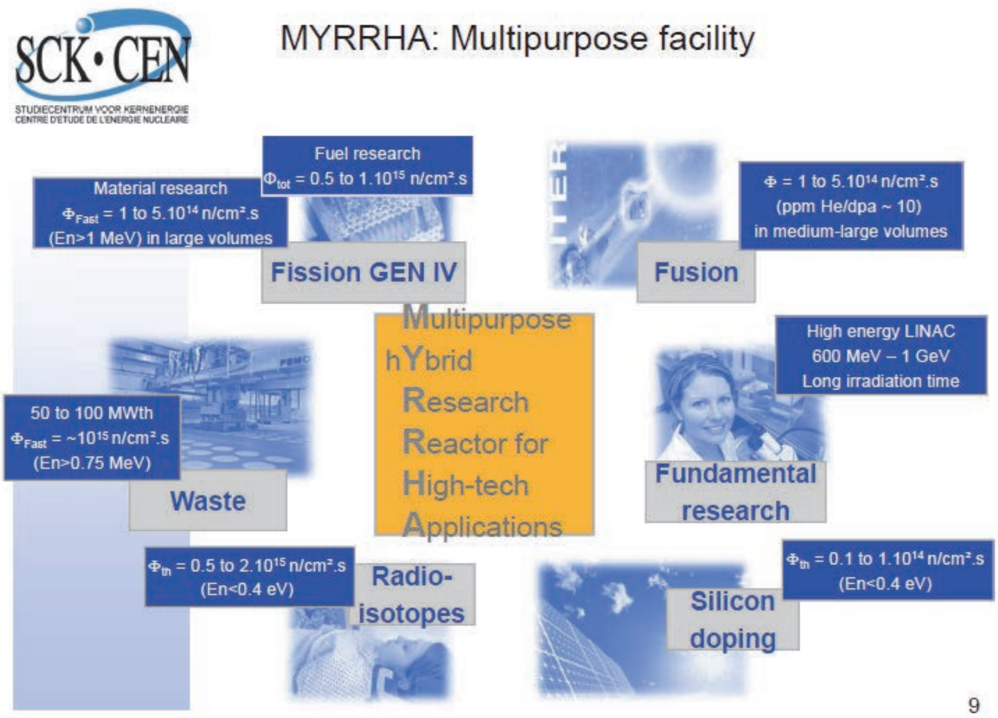
SNETP Gen.IV Systems
European Sustainable Nuclear Industrial Initiative
2008
2012
2020
SFR
Reference technology
LFR
GFR
Alternative technology
Supporting infrastructures, research facilities
MYRRHA
Fast spectrum irradiation facility
ASTRID Prototype (SFR)
MYRRHA
ETPP European demonstration reactor (LFR)
ALLEGRO
Experimental reactor (GFR)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MYRRHA: Multipurpose facility
Material research
Φ_Fast = 1 to 5.10^14 n/cm².s
(En>1 MeV) in large volumes
Fuel research
Φ_tot = 0.5 to 1.10^15 n/cm².s
Fission GEN IV
Φ = 1 to 5.10^14 n/cm².s
(ppm He/dpa ~ 10)
in medium-large volumes
Fusion
Multipurpose
hYbrid
Research
Reactor for
High-tech
Applications
High energy LINAC
600 MeV – 1 GeV
Long irradiation time
Fundamental research
50 to 100 MWth
Φ_Fast = ~10^15 n/cm².s
(En>0.75 MeV)
Waste
Φ_th = 0.5 to 2.10^15 n/cm².s
(En<0.4 eV)
Radio-isotopes
Φ_th = 0.1 to 1.10^14 n/cm².s
(En<0.4 eV)
Silicon doping
9

MYRRHA international reviewing

2001: International Strategic Guidance Committee

2002: International Technical Guidance Committee

2003: Review by Russian Lead Reactor Technology Experts (ISTC#2552p project)

2005: Conclusions of the European Commission FP5 Project PDS-XADS (2001-2004)

2006: European Commission FP6 Project EUROTRANS (2005-2009): Conclusions of Review and Justification of the main options of XT-ADS starting from MYRRHA

2007: International Assessment Meeting of the Advanced Nuclear Systems Institute

2008: European Commission FP7 Project Central Design Team (CDT) at Mol for MYRRHA detailed design

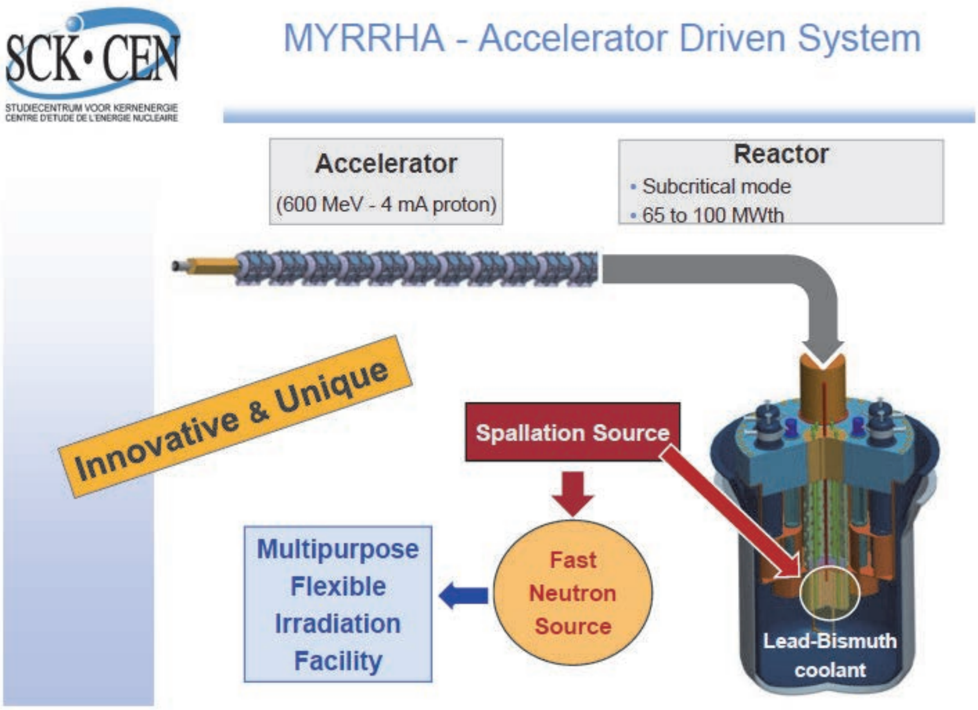
2009: MIRT of OECD/NEA on request of Belgian Government

Europe and future nuclear energy

ESFRI
European Strategic Forum for Research Infrastructure

SET Plan
European Strategic Energy Plan

11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STUDIECENTRUM VOOR KERNENERGIE
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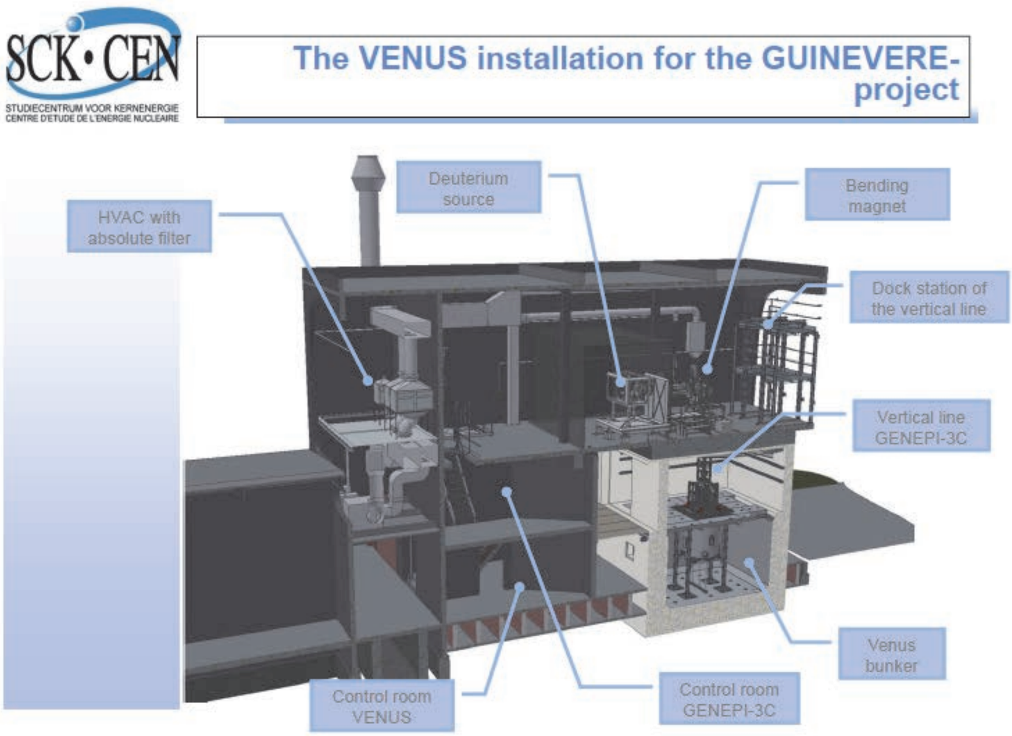
MYRRHA - Accelerator Driven System
Accelerator
(600 MeV - 4 mA proton)
Reactor
• Subcritical mode
• 65 to 100 MWth
Innovative & Unique
Spallation Source
Fast Neutron Source
Multipurpose Flexible Irradiation Facility
Lead-Bismuth coolant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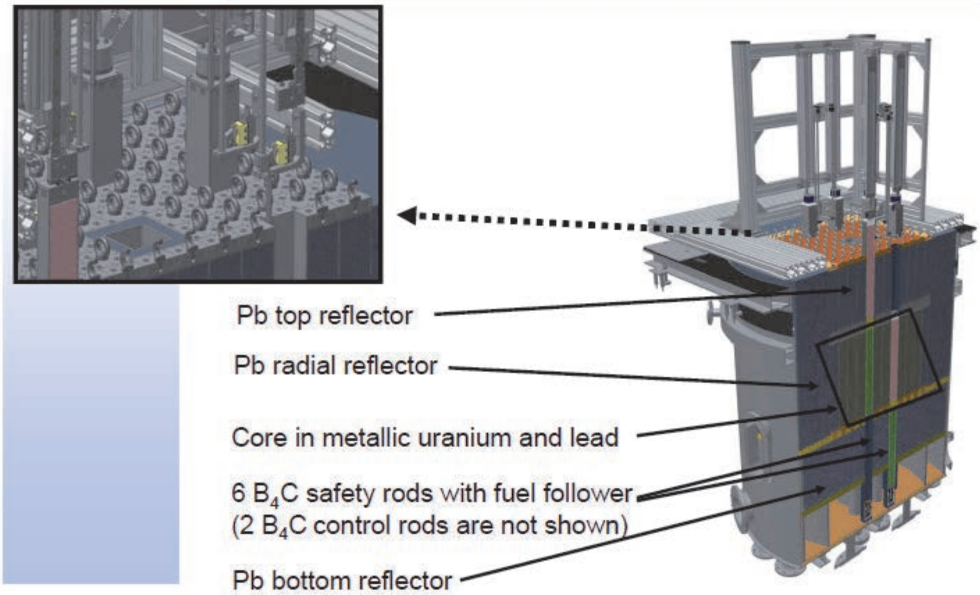
The VENUS installation for the GUINEVERE-project
HVAC with absolute filter
Deuterium source
Bending magnet
Dock station of the vertical line
Vertical line GENEPI-3C
Venus bunker
Control room GENEPI-3C
Control room VENUS

The VENUS-F configuration for GUINEVERE



MYRRHA Accelerator Challenge

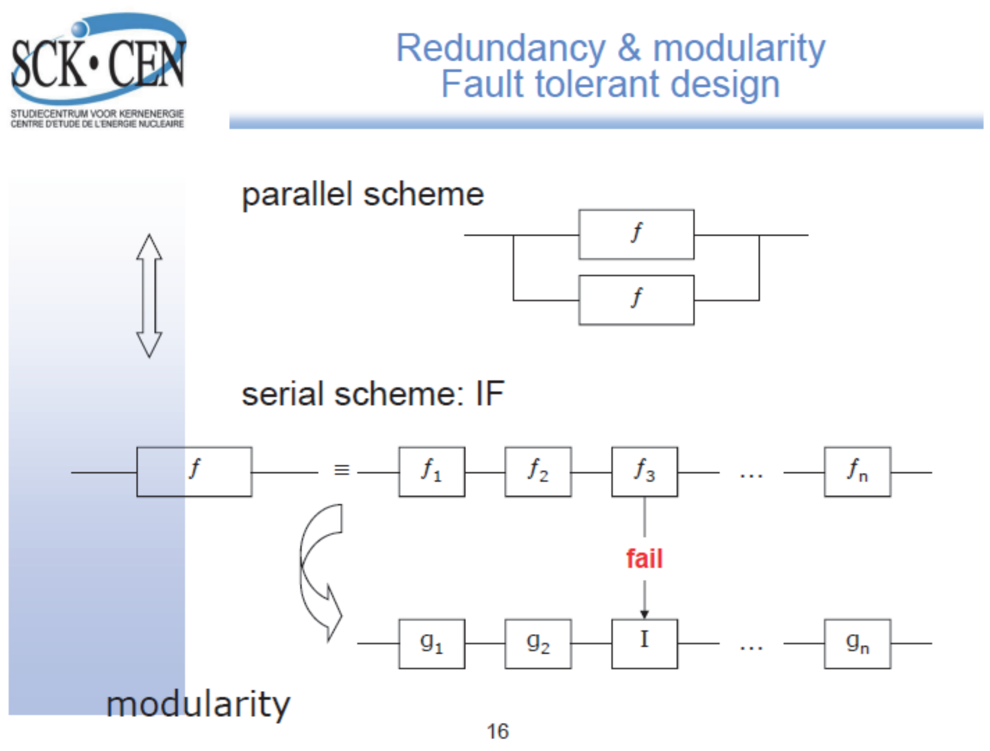
fundamental parameters (ADS)	
particle	p
beam energy	600 MeV
beam current	4 mA
mode	CW
MTBF	> 250 h

challenge !

failure = beam trip > 3 s

implementation	
superconducting linac	
frequency	176.1 / 352.2 / 704.4 MHz
reliability = redundancy	double injector
	“fault tolerant” scheme

15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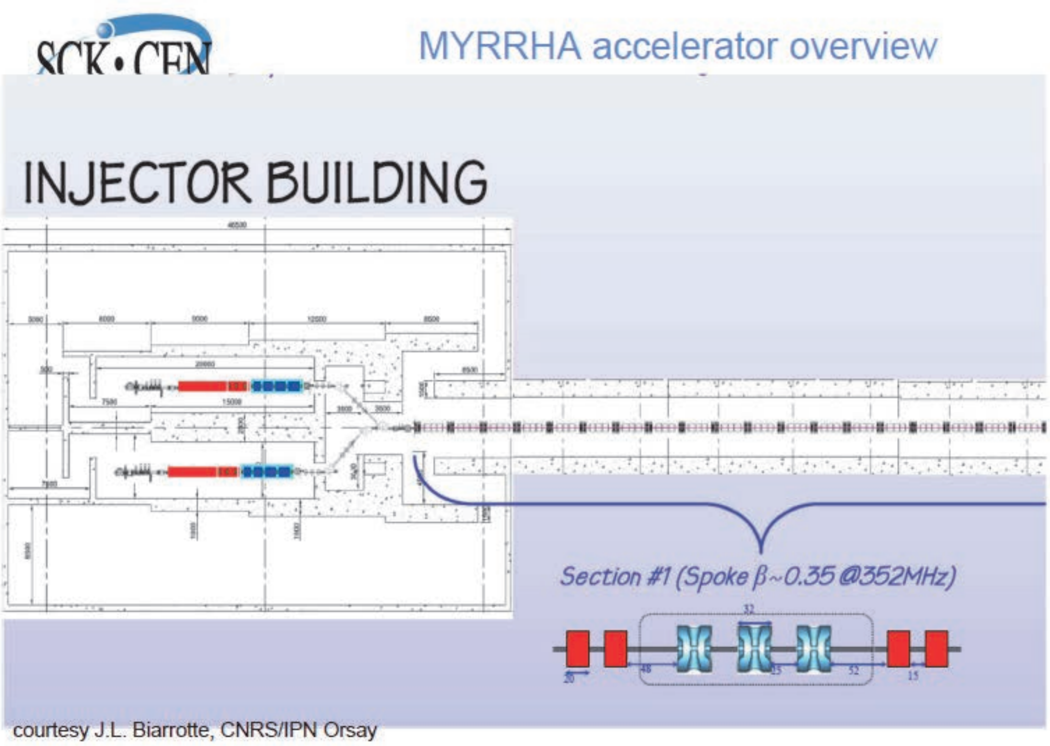
Redundancy & modularity
Fault tolerant design
parallel scheme
f
f
serial scheme: IF
f
≡
f_1
f_2
f_3
…
f_n
fail
g_1
g_2
I
…
g_n
modularity
16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MYRRHA accelerator overview
INJECTOR BUILDING
Section #1 (Spoke β~0.35 @352MHz)
courtesy J.L. Biarrotte, CNRS/IPN Orsay

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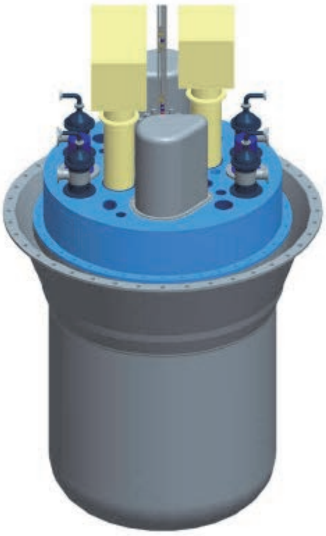
Reactor layout

- Reactor Vessel
- Reactor Cover
- Core Support Structure
  - Core Barrel
  - Core Support Plate
  - Jacket
- Core
  - Reflector Assemblies
  - Dummy Assemblies
  - Fuel Assemblies
- Spallation Target Assembly and Beam Line
- Above Core Structure
  - Core Plug
  - Multifunctional Channels
  - Core Restraint System
- Control Rods, Safety Rods, Mo-99 production units
- Primary Heat Exchangers
- Primary Pumps
- Si-doping Facility
- Diaphragm
  - IVFS
- IVFHS
  - IVFHM



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MYRRHA design parameters

General design parameters	MYRRHA rev. 1.4
Maximum core power	100 MW_{th}
Reactor power	110 MW_{th}
Temperatures	
Cold shutdown state	200 °C
Maximum core inlet temperature	270 °C
Maximum average core ΔT	140 °C
Average core outlet temperature	410 °C
Maximum hot plenum temperature	350 °C
Maximum fuel cladding temperature	466 °C
Spallation target	
Type	Loopless spallation window
Number of core positions	One core position
Material	T91
Operating temperature	416 °C – 466 °C

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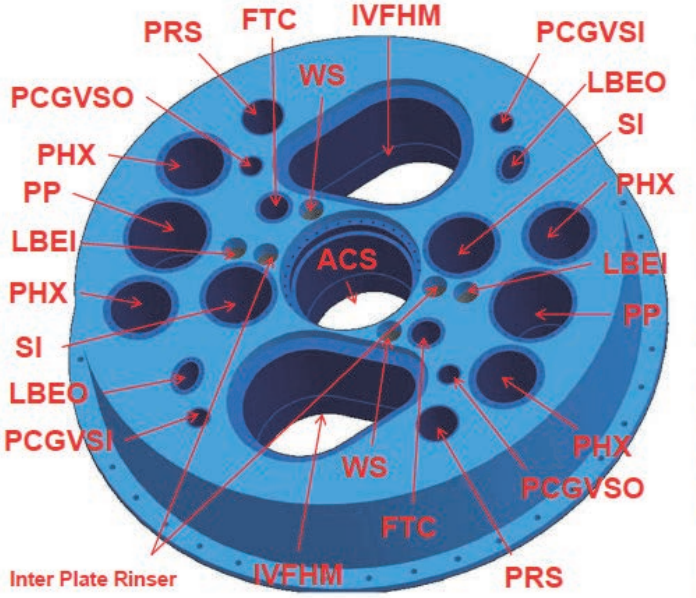
Reactor Cover



List of penetrations

ACS: Above Core Structure (1)

PP: Primary Pump (2)

PHX: Primary Heat Exchanger (4)

IVFHM: In Vessel Fuel Hand. Mach. (2)

SI: Silicium Doping (2)

LBEI: LBE Inlet (2)

LBEO: LBE Outlet (2)

PCGVSI: Primary Cover Gas & Ventilation System inlet (2)

PCGVSO: Primary Cover Gas & Ventilation System Outlet (2)
(These penetrations shall be moved near the ACS)

Inter Plate Rinser (2)

WS: Wet Sipping (2)

FTC: Fuel transfer channel (2)

PRS: Pressure Relief System (2)

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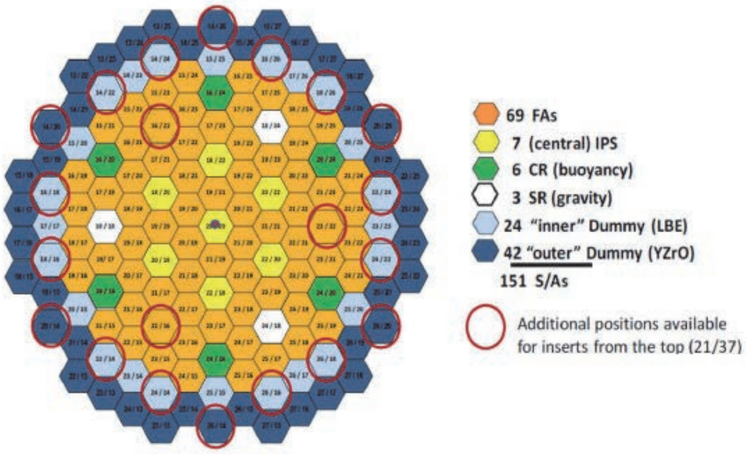
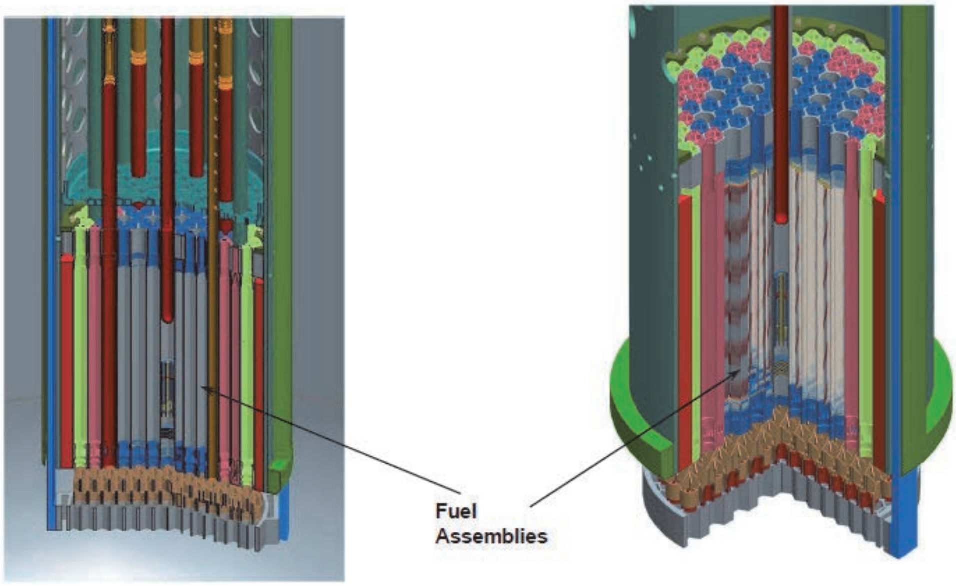
Core and Fuel Assemblies

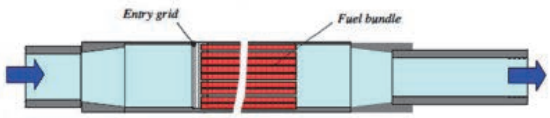
- 151 positions
- 37 multifunctional plugs



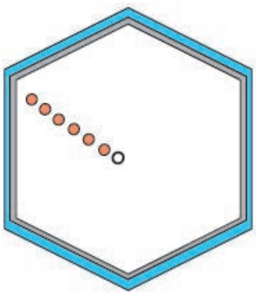
Core and Fuel Assemblies

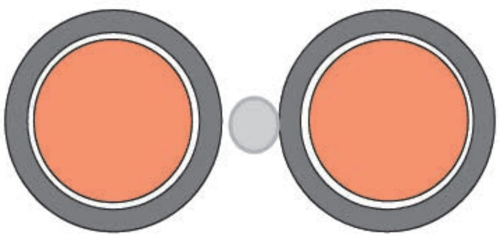


Core and Fuel Assemblies



- Fuel
  - Cladding in 15-15 Ti
  - Wire wrap
  - Wrapper in T91





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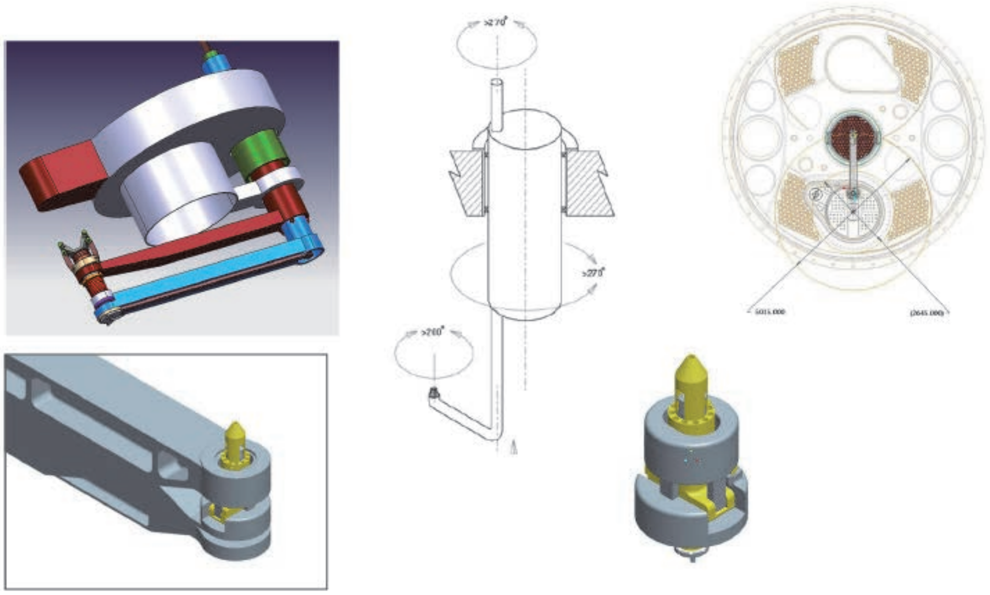
In-Vessel Fuel Handling Machine (IFHVM)



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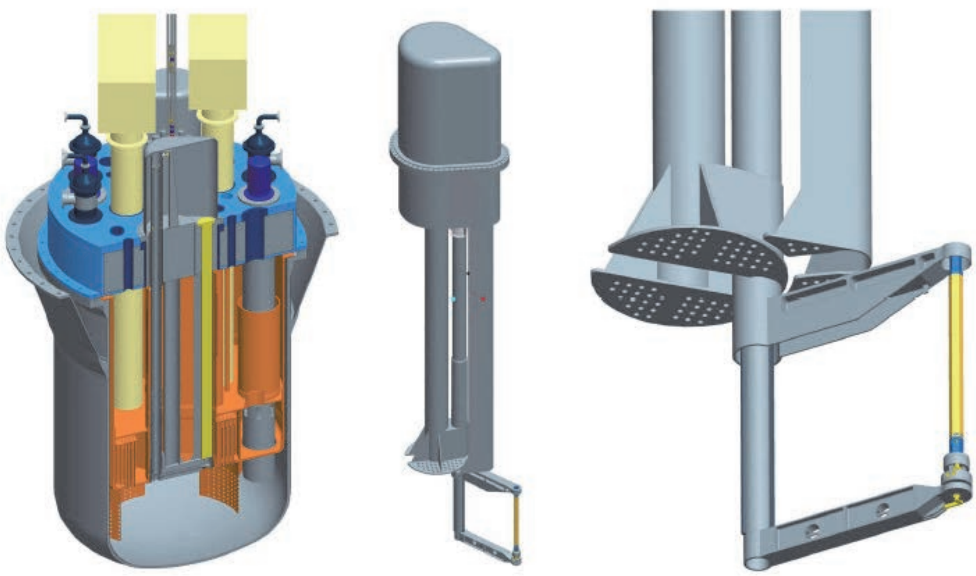
In-Vessel Fuel Handling Machine (IFHVM)



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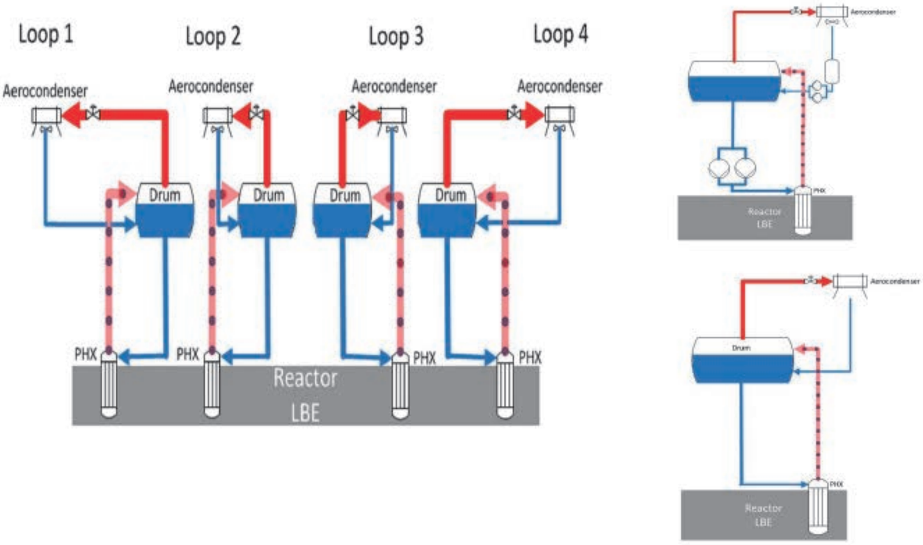
Cooling systems



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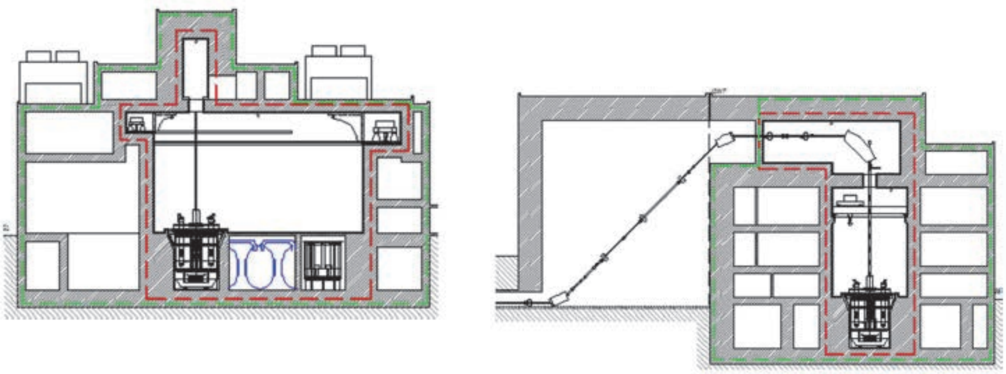
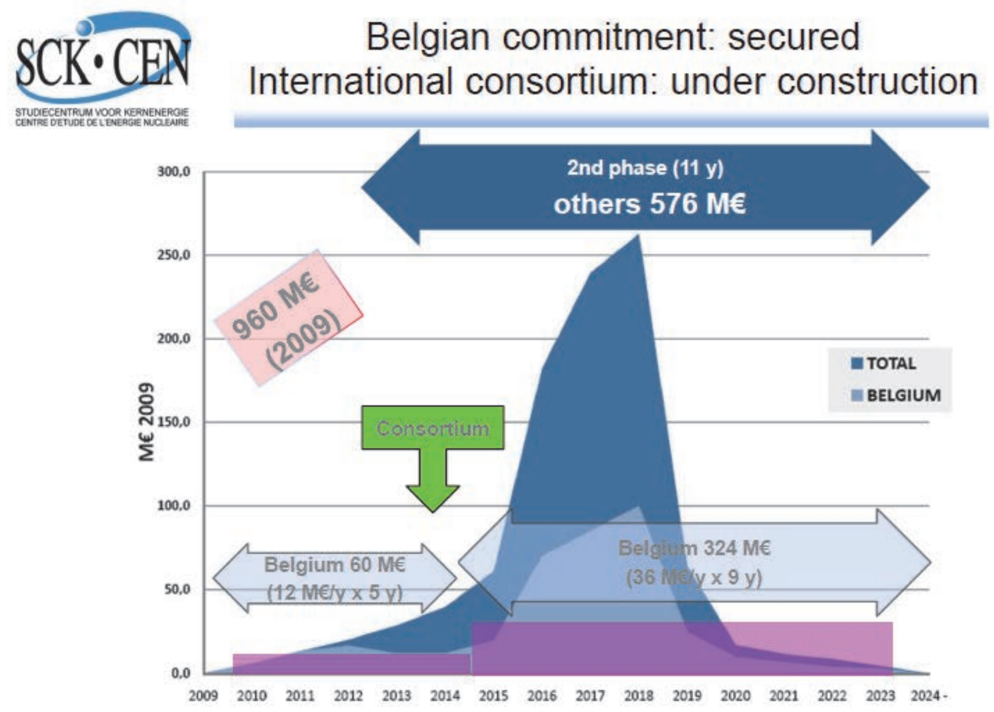
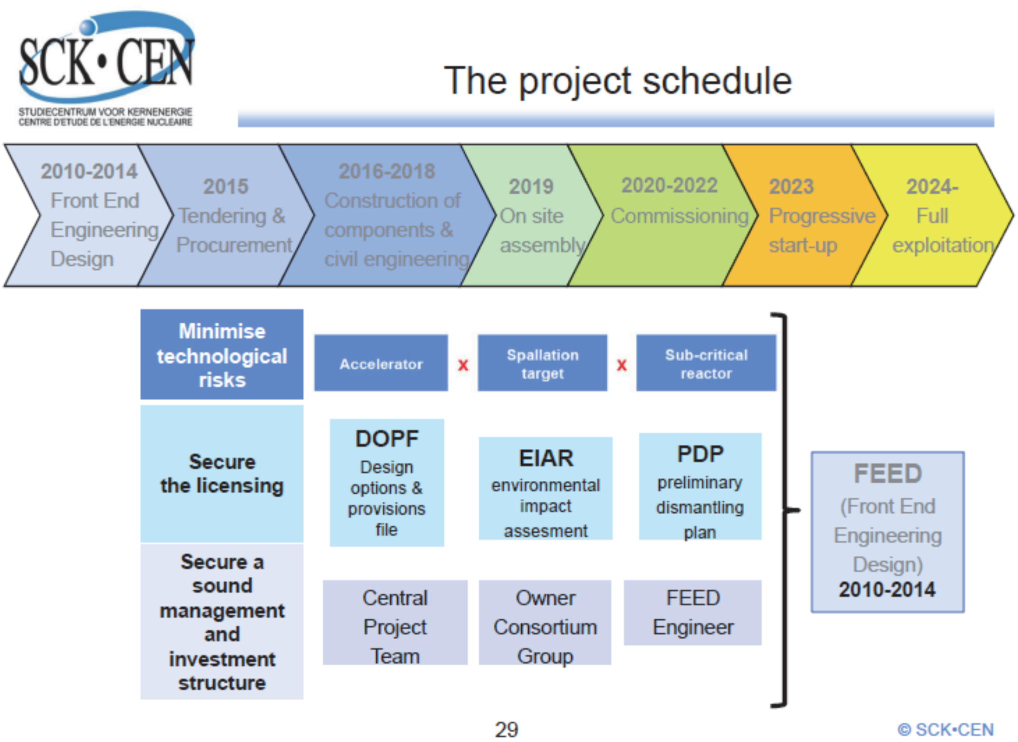
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Integration into building




SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
Belgian commitment: secured
International consortium: under construction
2nd phase (11 y)
others 576 M€
960 M€
(2009)
Consortium
Belgium 60 M€
(12 M€/y x 5 y)
Belgium 324 M€
(36 M€/y x 9 y)
TOTAL
BELGIUM
M€ 2009
300,0
250,0
200,0
150,0
100,0
50,0
0,0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024 -


SCK•CEN
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CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
The project schedule
2010-2014 Front End Engineering Design
2015 Tendering & Procurement
2016-2018 Construction of components & civil engineering
2019 On site assembly
2020-2022 Commissioning
2023 Progressive start-up
2024- Full exploitation
Minimise technological risks
Accelerator
Spallation target
Sub-critical reactor
Secure the licensing
DOPF Design options & provisions file
EIAR environmental impact assesment
PDP preliminary dismantling plan
Secure a sound management and investment structure
Central Project Team
Owner Consortium Group
FEED Engineer
FEED (Front End Engineering Design) 2010-2014
29
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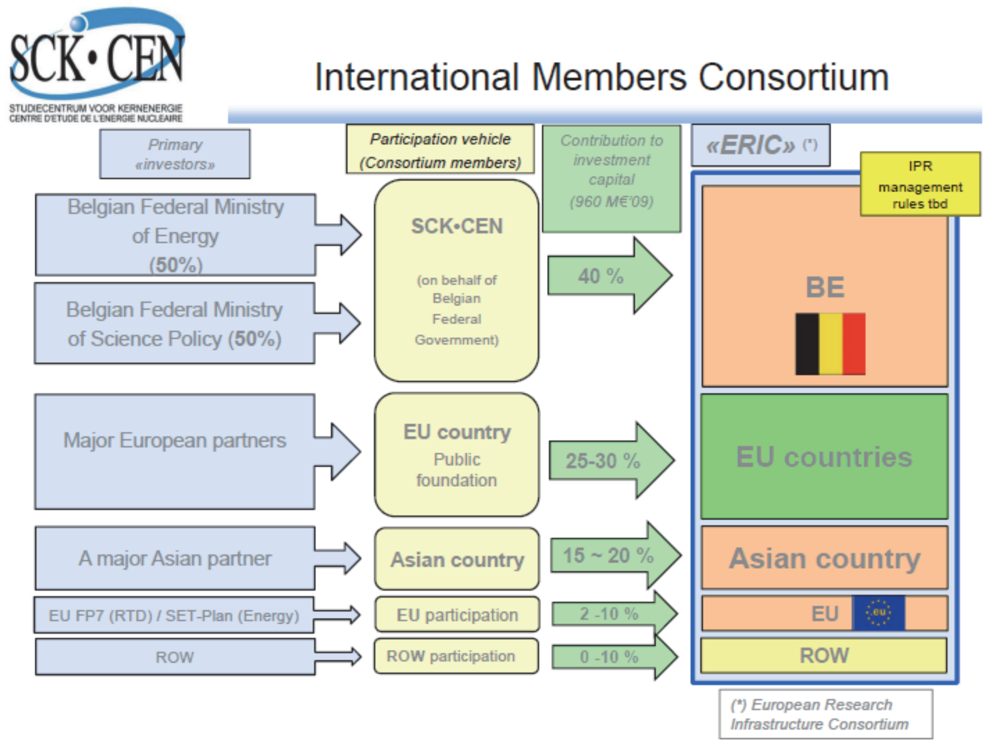
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
MYRRHA: an international project
JAEA
中国科学院
CHINESE ACADEMY OF SCIENCES
NATIONAL NUCLEAR CENTER OF THE REPUBLIC OF KAZAKHSTAN
KAZATOMPROM
НАЦИОНАЛЬНАЯ АТОМНАЯ КОМПАНИЯ
AnsaldoNucleare
Una Società Finmeccanica
EMPRESARIOS AGRUPADOS
AREVA
iba
OXFORD TECHNOLOGIES
TRACTEBEL Engineering
GDF SUEZ
NNC
SENER
ADEX
Adaptive Predictive Expert Control
SCK•CEN
CSIC
KIT
ith
cnrs
cea
ENEA
NRG
PAUL SCHERRER INSTITUT
PSI
ÚJV
INRNE
JRC
Ciemat
Forschungszentrum Jülich
FZR
Forschungszentrum Rossendorf
INFN
ULg
KTH
UPPSALA UNIVERSITET
UCL
LEUVEN
GSI
enen
UNIVERSIDAD POLITECNICA DE VALENCIA
USC
TUDelft
TU WIEN
UNIVERSITÄT FRANKFURT AM MAIN
AGH


SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
International Members Consortium
Primary «investors»
Participation vehicle (Consortium members)
Contribution to investment capital (960 M€'09)
«ERIC» (*)
IPR management rules tbd
Belgian Federal Ministry of Energy (50%)
Belgian Federal Ministry of Science Policy (50%)
SCK•CEN
(on behalf of Belgian Federal Government)
40 %
BE
Major European partners
EU country
Public foundation
25-30 %
EU countries
A major Asian partner
Asian country
15 ~ 20 %
Asian country
EU FP7 (RTD) / SET-Plan (Energy)
EU participation
2 -10 %
EU
ROW
ROW participation
0 -10 %
ROW
(*) European Research Infrastructure Consortium

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

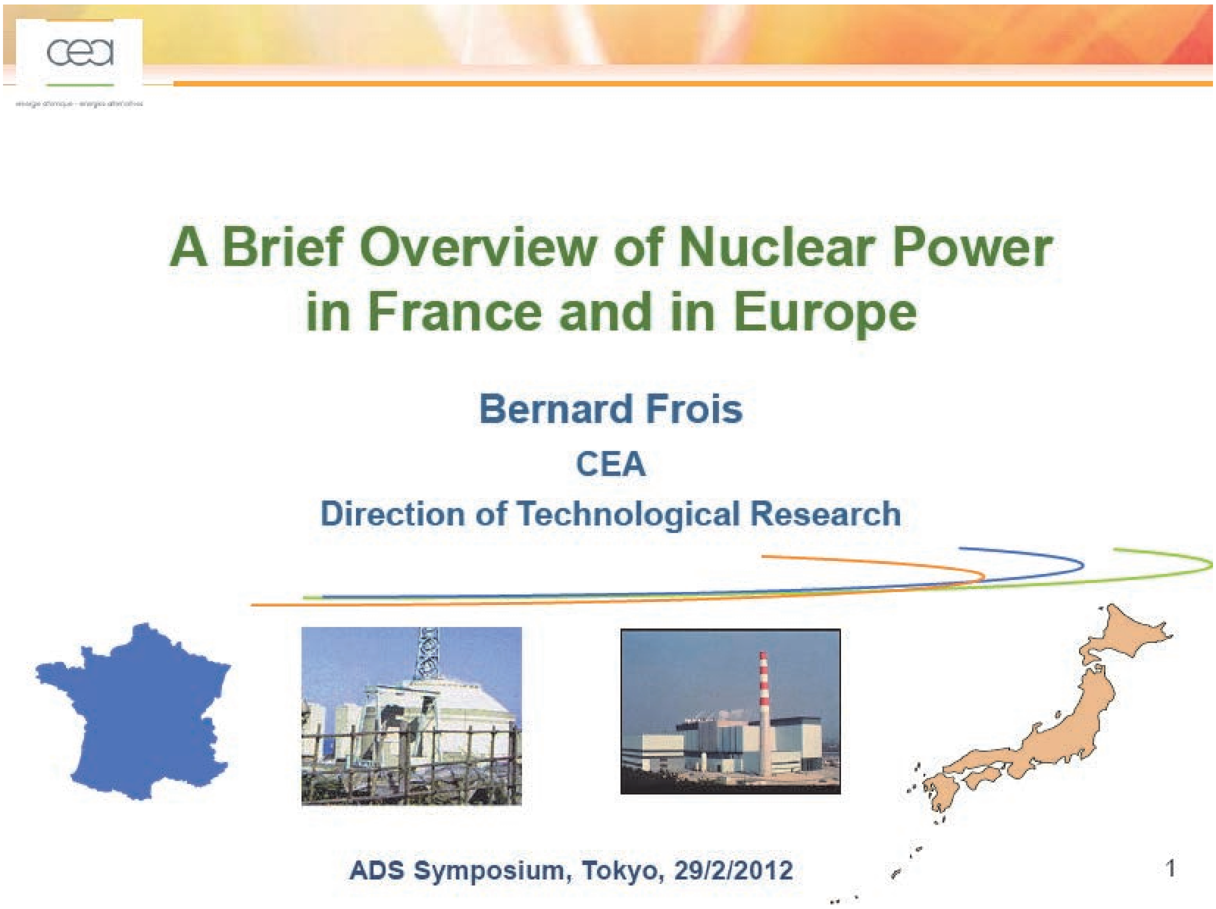
Joining the MYRRHA project

- Belgium is welcoming international participation in the MYRRHA consortium
- Membership eligibility for the international MYRRHA consortium is based on a balanced in-cash/in-kind contribution

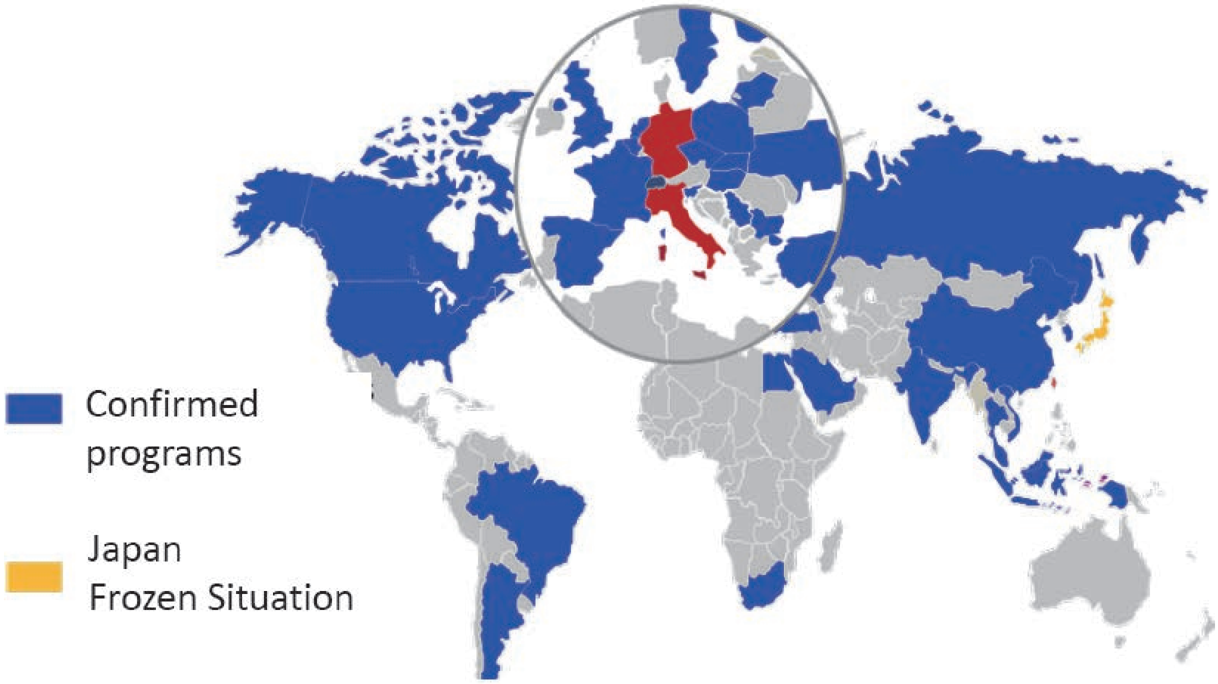
- Until end 2014, our objectives are:
  - to collect **Letters of Intent** for participation in the MYRRHA International Consortium (deadline 2012)
  - to sign **Memoranda of Understanding** for collaboration in MYRRHA with international partners (deadline mid 2014)
  - To finalise the **Consortium legal framework** (deadline end 2014)

3.9 A Brief Overview of Nuclear Power in France and in Europe

B. Frois (Scientific adviser, CEA, France)



World Nuclear Power Situation 2012

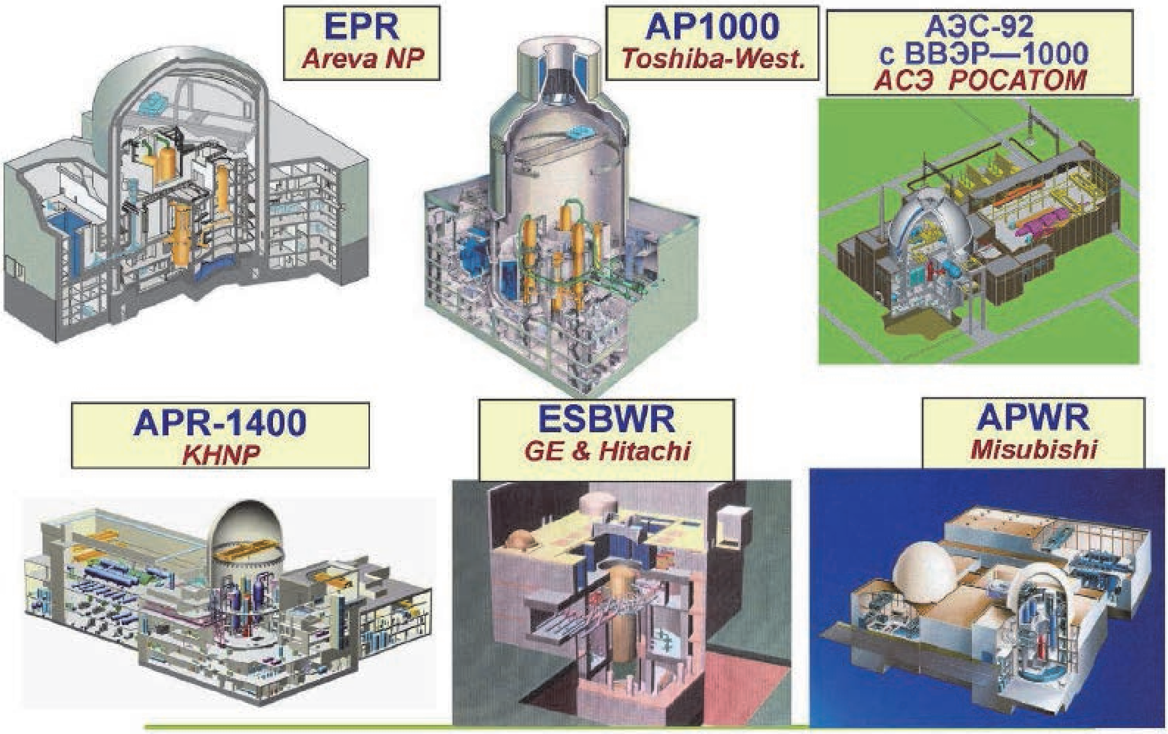


From WANO organization

"Following the Fukushima Daiichi accident, there was speculation that the expansion in interest in nuclear power seen in recent years could come to an end. However, it is clear that there will, in fact, be continuous and significant growth in the use of nuclear power in the next two decades, although at a slower rate than in our previous projections. We expect the number of operating nuclear reactors in the world to increase by about 90 to 350 by 2030, in our low to high projections, from the current total of 432 reactors."

Opening Talk of Yukiya Amano, Director General of IAEA on the 19/9/2011 at the 55th session of the General Assembly of the AIEA.

ALWRs from the USA, Japan, Russia & Europe



B.Frois, ADS Symposium, Tokyo 29 February 2012 4

The current nuclear power fleet in France

63 GWe installed

58 PWR units

900 MWe	1300 MWe	1500 MWe
34	20	4
■	▲	●

19 sites ; 1 single technology

A fleet :

- Young : average age = 23 years old
- Mature : > 1250 cumulated reactor-years

In 2017, 60 units and 66 GWe installed

B.Frois, ADS Symposium, Tokyo 29 February 2012 5

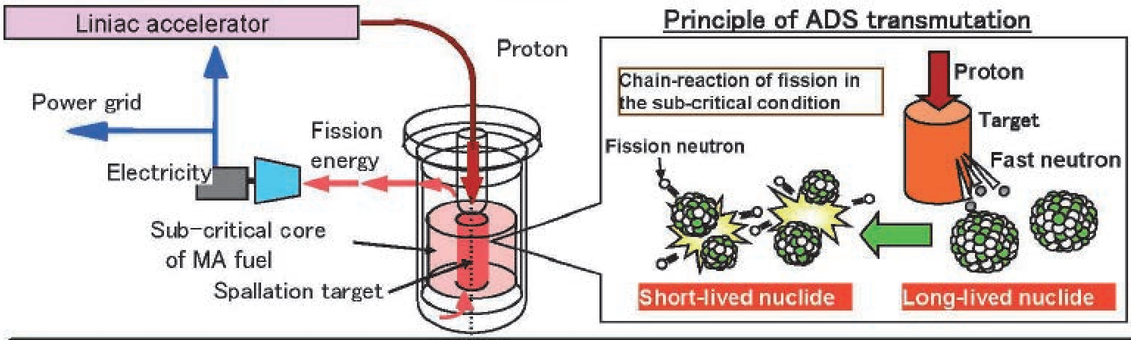
French Industry and Energy Minister Eric Besson became the first foreign politician to enter the crippled Fukushima plant since last year's disaster, telling workers they must revive atomic energy in Japan. Besson, who was accompanied on his tour of the plant by an AFP journalist, said nuclear power was too important a source of energy to abandon

Picture: AFP/GETTY

Courtesy: Tsujimoto, Oigawa

Accelerator-Driven System (ADS)

JPARC Project

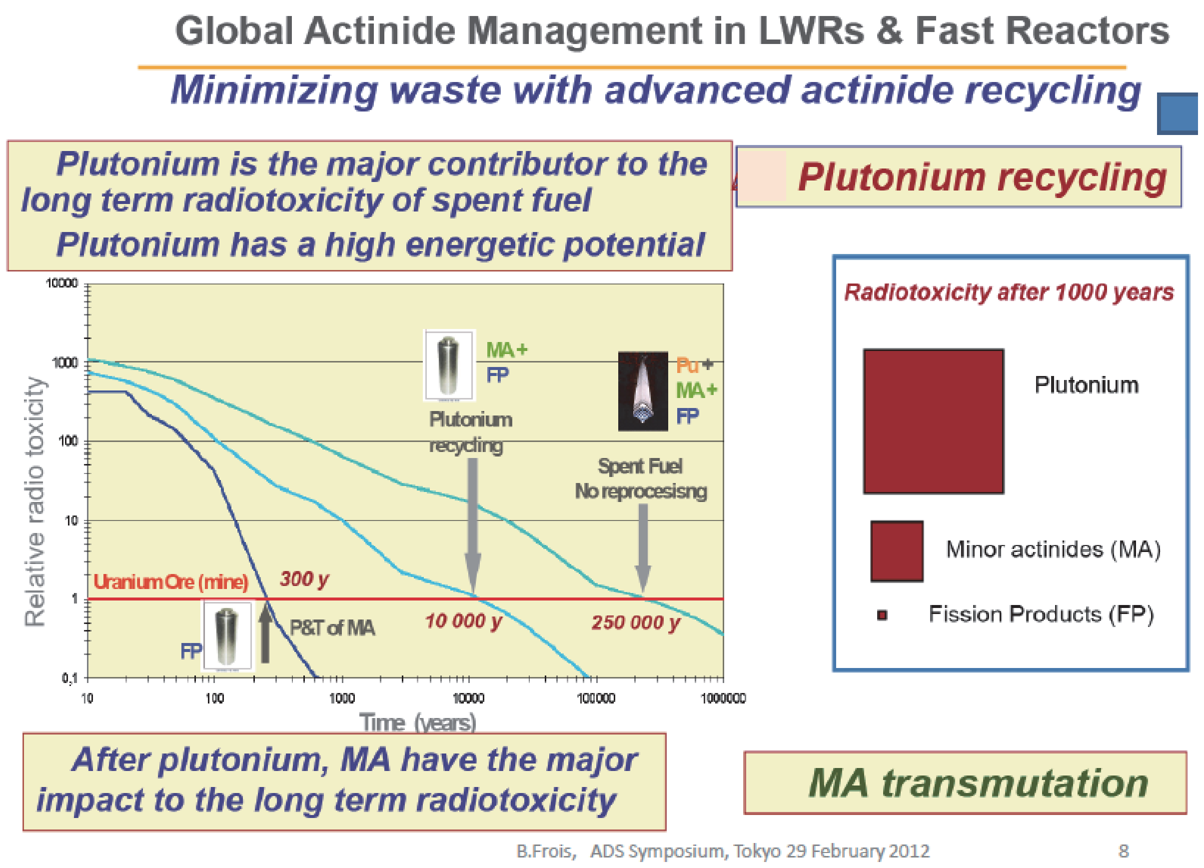


Mechanism of ADS

- Proton beam which is accelerated by the **superconducting LINAC** is injected to ADS.
- High intensity proton generates massive neutrons by **spallation reaction** with **heavy metal target** (~30neutrons/proton).
- Fission reactions of **MA** are caused by spallation neutrons. Neutrons by fission reactions lead to the next transmutation.

  →Number of neutron is increased 20-times by the **chain-reaction**.

B.Frois, ADS Symposium, Tokyo 29 February 2012 7


Global Actinide Management in LWRs & Fast Reactors
Minimizing waste with advanced actinide recycling
Plutonium is the major contributor to the long term radiotoxicity of spent fuel
Plutonium has a high energetic potential
Plutonium recycling
Relative radio toxicity
10000
1000
100
10
1
0,1
10
100
1000
10000
100000
1000000
Time (years)
MA+
FP
Plutonium recycling
Pu+
MA+
FP
Spent Fuel
No reprocesisng
Uranium Ore (mine)
300 y
10 000 y
250 000 y
P&T of MA
FP
Radiotoxicity after 1000 years
Plutonium
Minor actinides (MA)
Fission Products (FP)
After plutonium, MA have the major impact to the long term radiotoxicity
MA transmutation
B.Frois, ADS Symposium, Tokyo 29 February 2012
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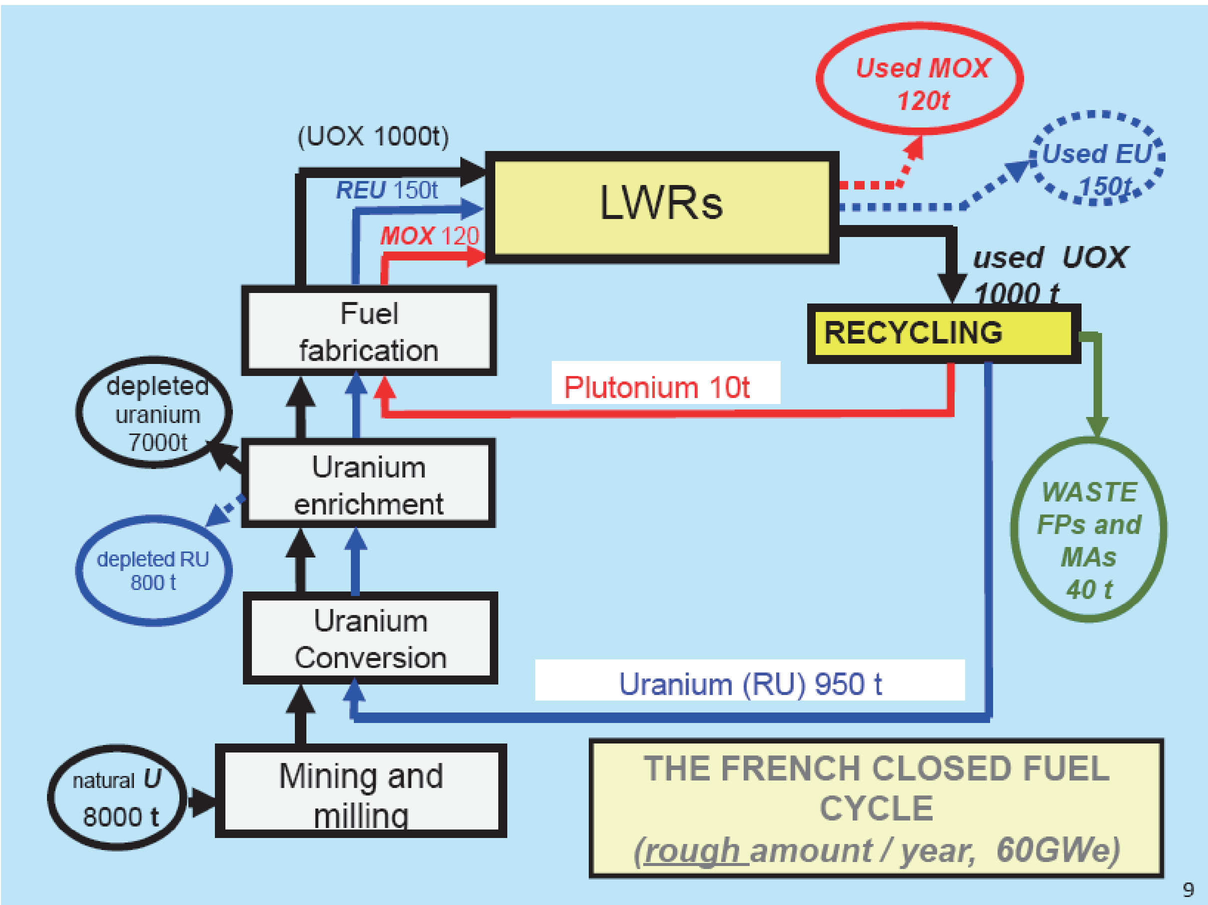
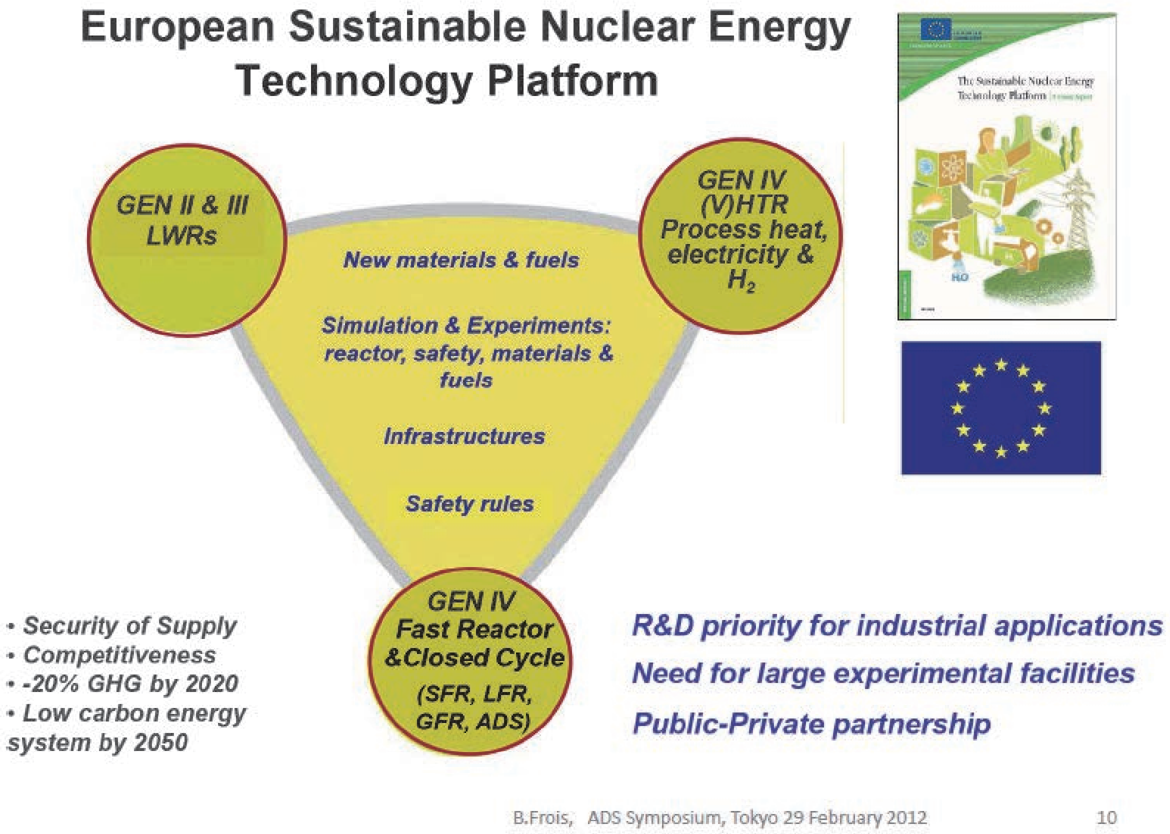
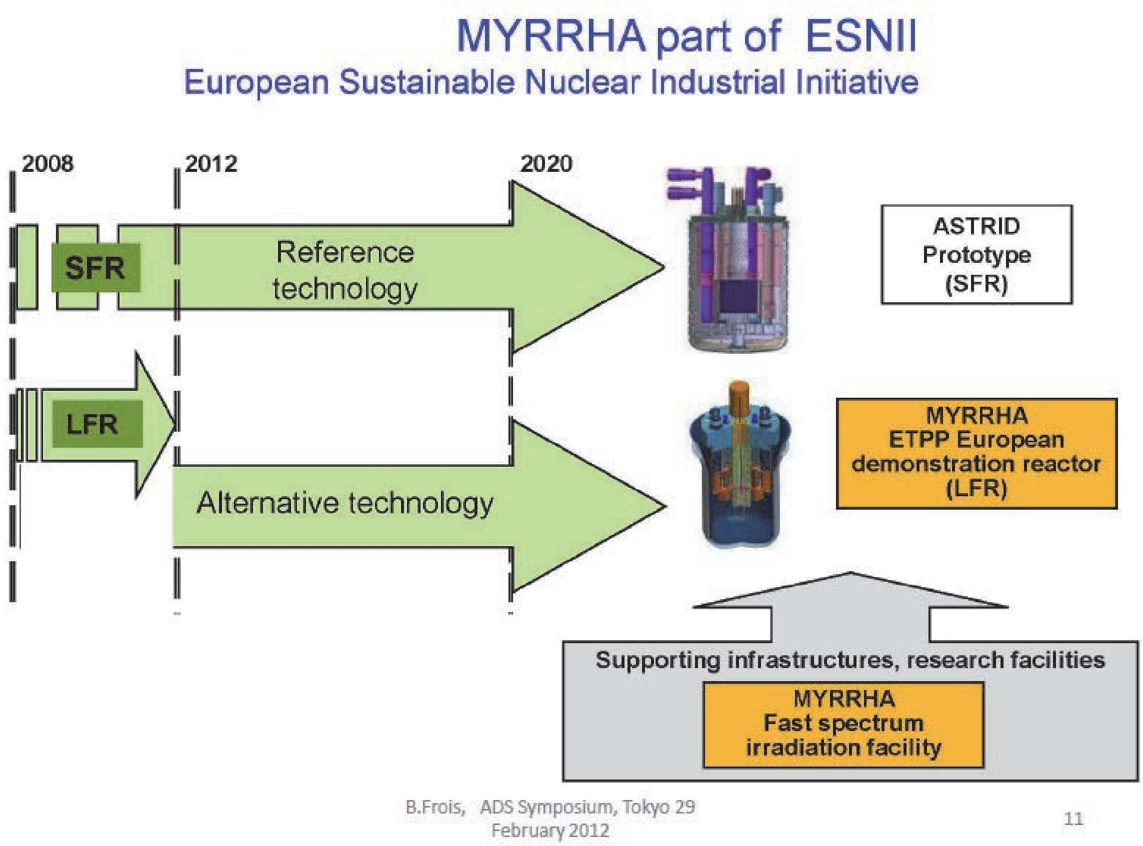
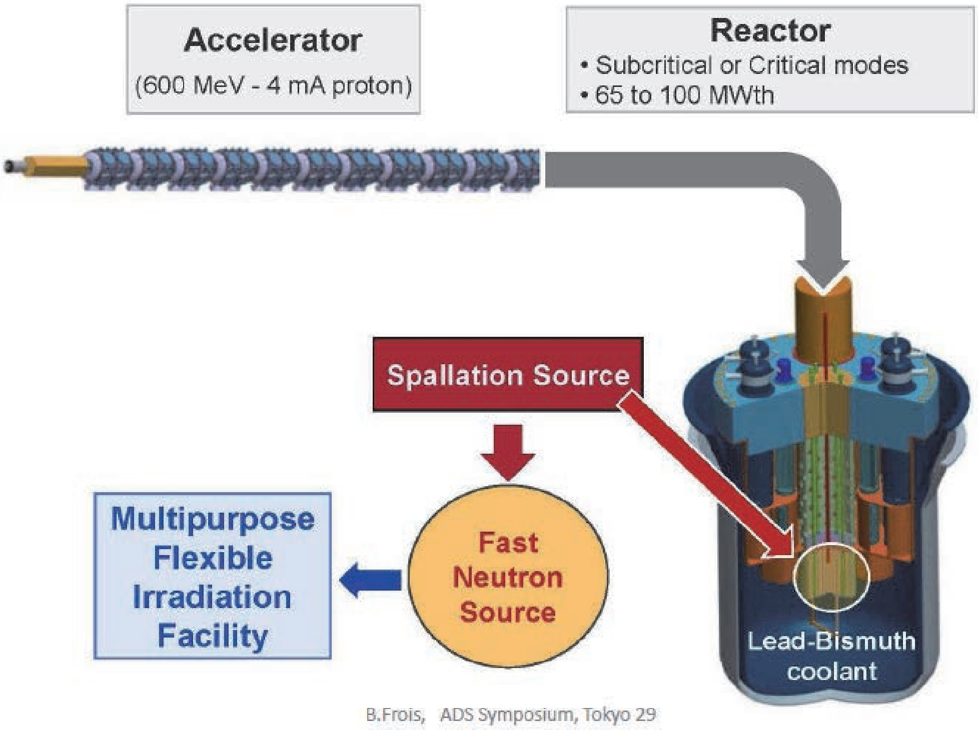

Used MOX
120t
(UOX 1000t)
Used EU
150t
REU 150t
MOX 120
LWRs
used UOX
1000 t
RECYCLING
Fuel
fabrication
Plutonium 10t
depleted
uranium
7000t
Uranium
enrichment
depleted RU
800 t
WASTE
FPs and
MAs
40 t
Uranium
Conversion
Uranium (RU) 950 t
natural U
8000 t
Mining and
milling
THE FRENCH CLOSED FUEL
CYCLE
(rough amount / year, 60GWe)
9


European Sustainable Nuclear Energy Technology Platform
GEN II & III LWRs
GEN IV (V)HTR Process heat, electricity & H2
New materials & fuels
Simulation & Experiments: reactor, safety, materials & fuels
Infrastructures
Safety rules
GEN IV Fast Reactor &Closed Cycle (SFR, LFR, GFR, ADS)
• Security of Supply
• Competitiveness
• -20% GHG by 2020
• Low carbon energy system by 2050
R&D priority for industrial applications
Need for large experimental facilities
Public-Private partnership
B.Frois, ADS Symposium, Tokyo 29 February 2012
10


MYRRHA part of ESNII
European Sustainable Nuclear Industrial Initiative
2008
2012
2020
SFR
Reference technology
LFR
Alternative technology
ASTRID Prototype (SFR)
MYRRHA ETPP European demonstration reactor (LFR)
Supporting infrastructures, research facilities
MYRRHA Fast spectrum irradiation facility
B.Frois, ADS Symposium, Tokyo 29 February 2012
11

MYRRHA - Accelerator Driven System



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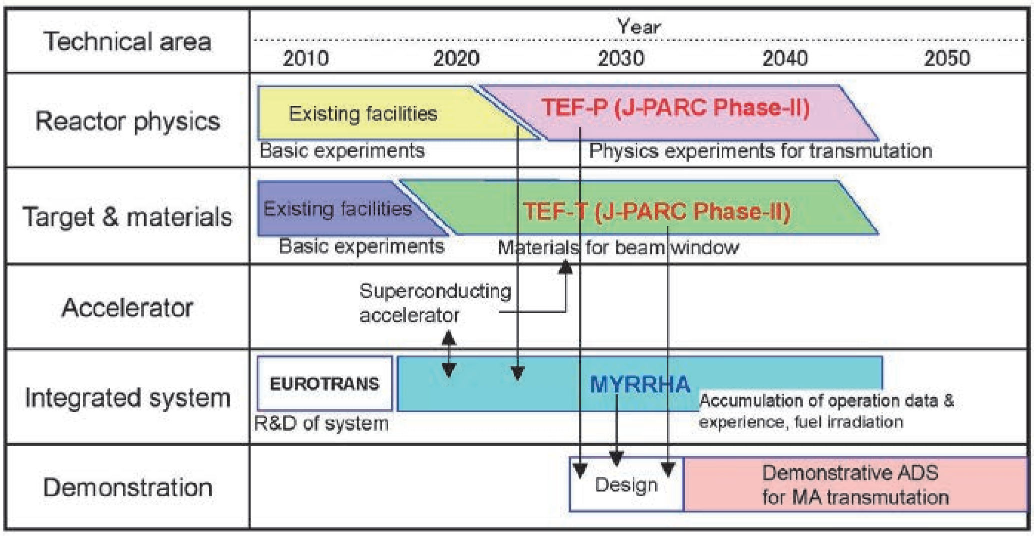
International Collaboration between JPARC and MYHRRA is important



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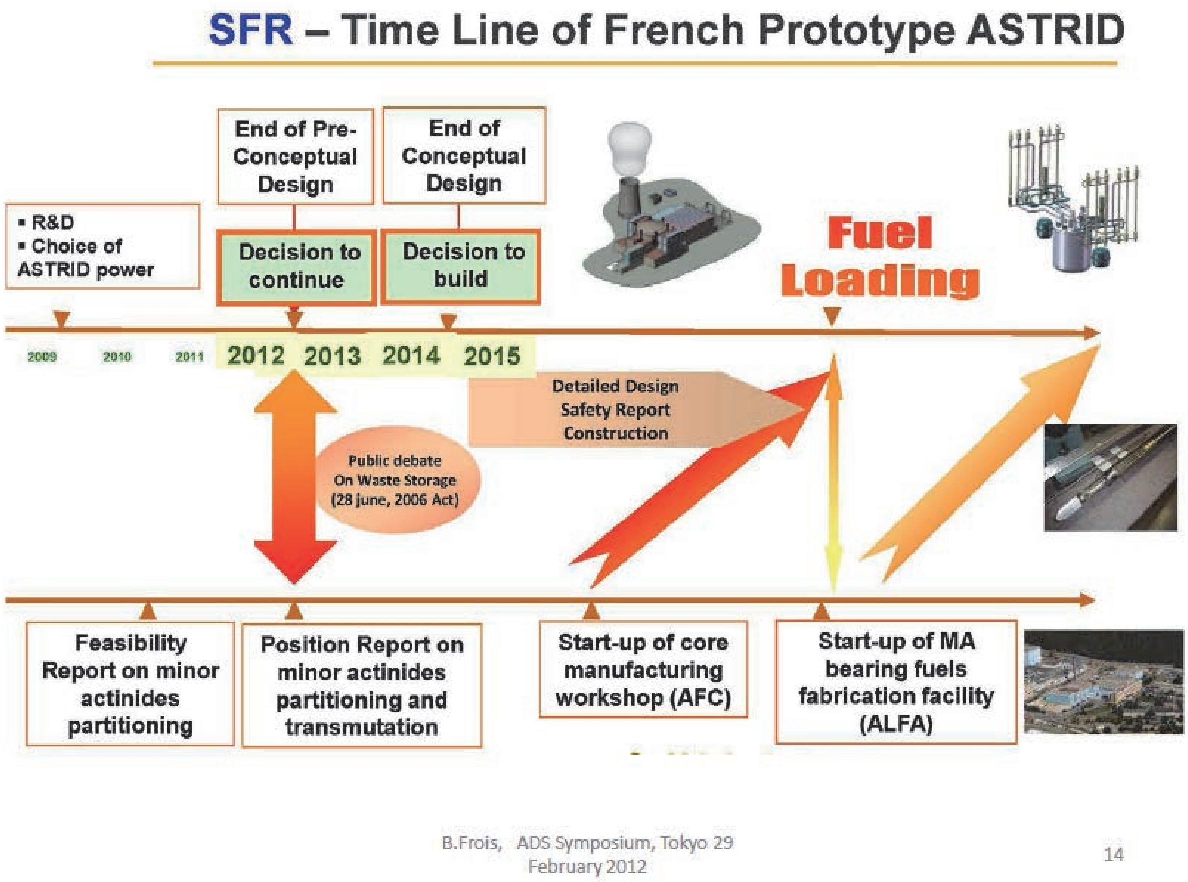
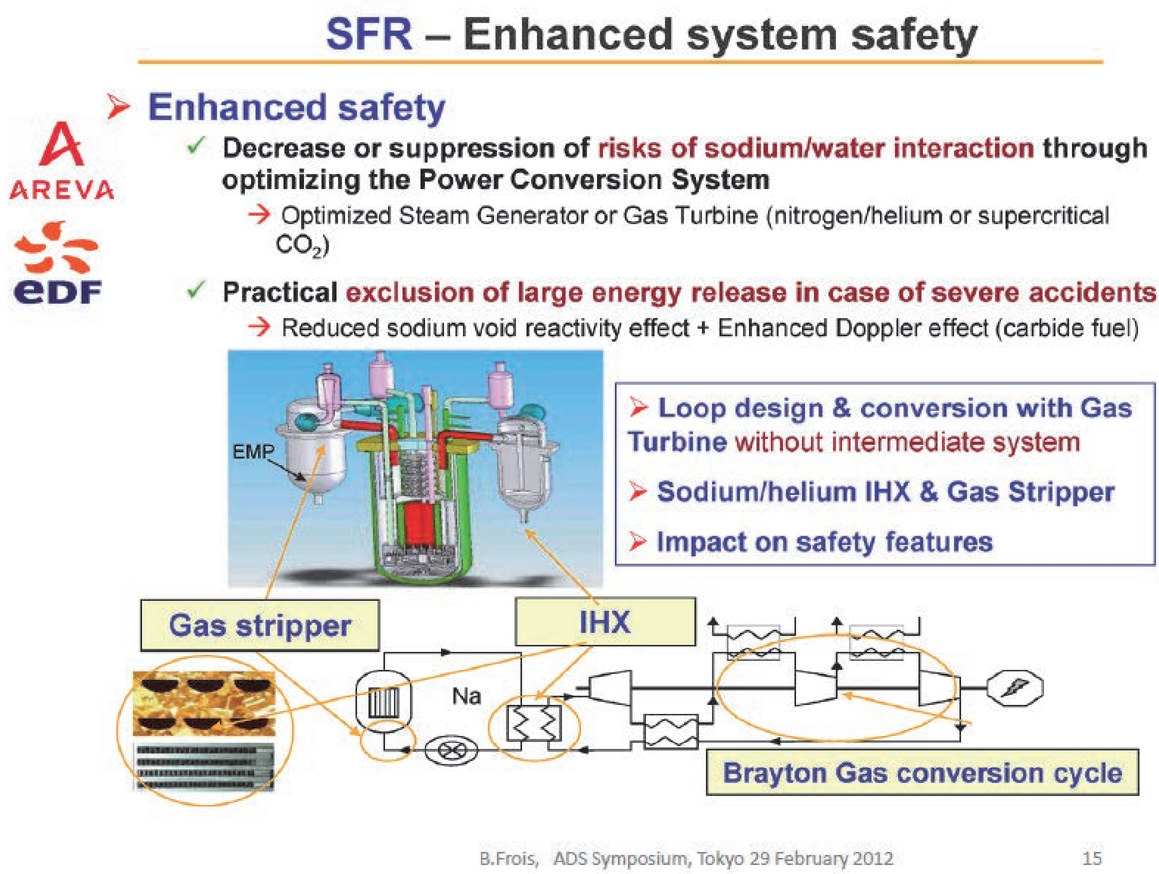

SFR – Time Line of French Prototype ASTRID
End of Pre-Conceptual Design
End of Conceptual Design
▪ R&D
▪ Choice of ASTRID power
Decision to continue
Decision to build
Fuel Loading
2009
2010
2011
2012
2013
2014
2015
Detailed Design
Safety Report
Construction
Public debate
On Waste Storage
(28 june, 2006 Act)
Feasibility Report on minor actinides partitioning
Position Report on minor actinides partitioning and transmutation
Start-up of core manufacturing workshop (AFC)
Start-up of MA bearing fuels fabrication facility (ALFA)
B.Frois, ADS Symposium, Tokyo 29 February 2012
14


SFR – Enhanced system safety
Enhanced safety
AREVA
eDF
Decrease or suppression of risks of sodium/water interaction through optimizing the Power Conversion System
→ Optimized Steam Generator or Gas Turbine (nitrogen/helium or supercritical CO2)
Practical exclusion of large energy release in case of severe accidents
→ Reduced sodium void reactivity effect + Enhanced Doppler effect (carbide fuel)
EMP
Loop design & conversion with Gas Turbine without intermediate system
Sodium/helium IHX & Gas Stripper
Impact on safety features
Gas stripper
IHX
Na
Brayton Gas conversion cycle
B.Frois, ADS Symposium, Tokyo 29 February 2012
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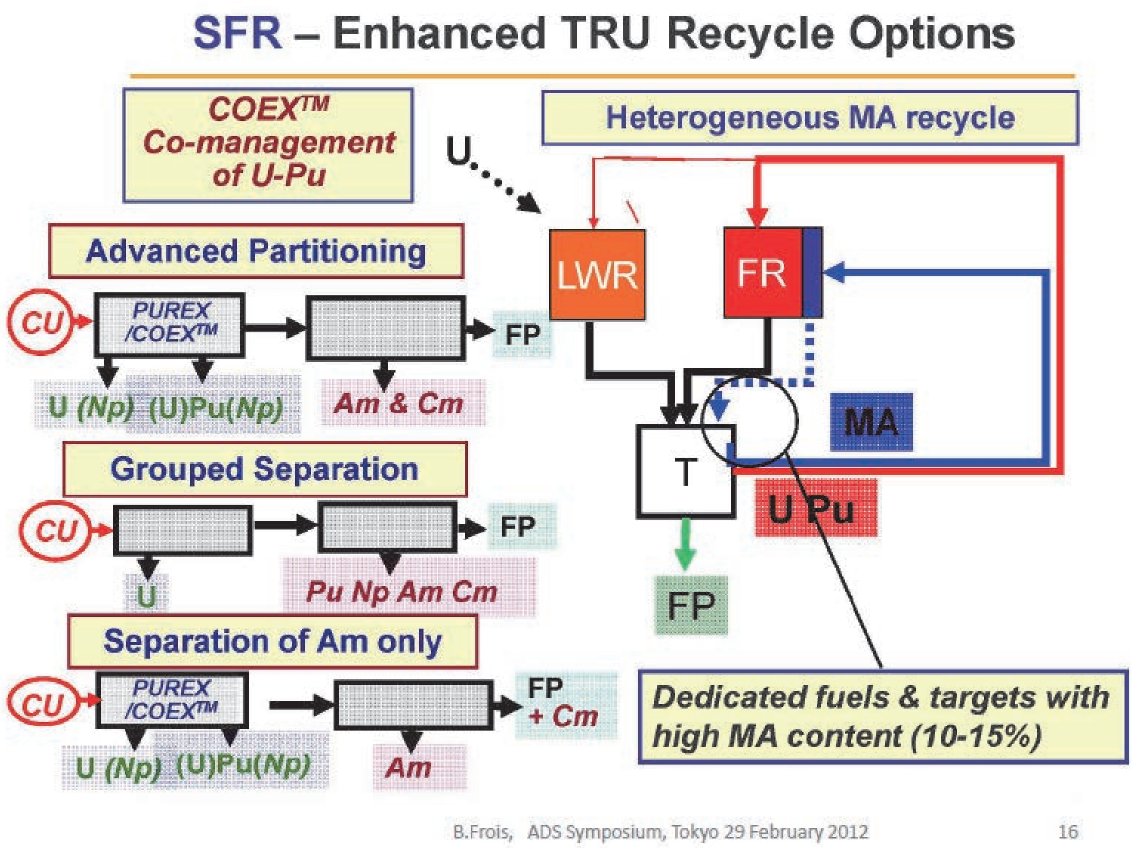
SFR – Enhanced TRU Recycle Options
COEX™ Co-management of U-Pu
U
Heterogeneous MA recycle
Advanced Partitioning
LWR
FR
CU
PUREX /COEX™
FP
U (Np) (U)Pu(Np)
Am & Cm
MA
Grouped Separation
T
U Pu
CU
FP
U
Pu Np Am Cm
FP
Separation of Am only
CU
PUREX /COEX™
FP + Cm
Dedicated fuels & targets with high MA content (10-15%)
U (Np) (U)Pu(Np)
Am
B.Frois, ADS Symposium, Tokyo 29 February 2012
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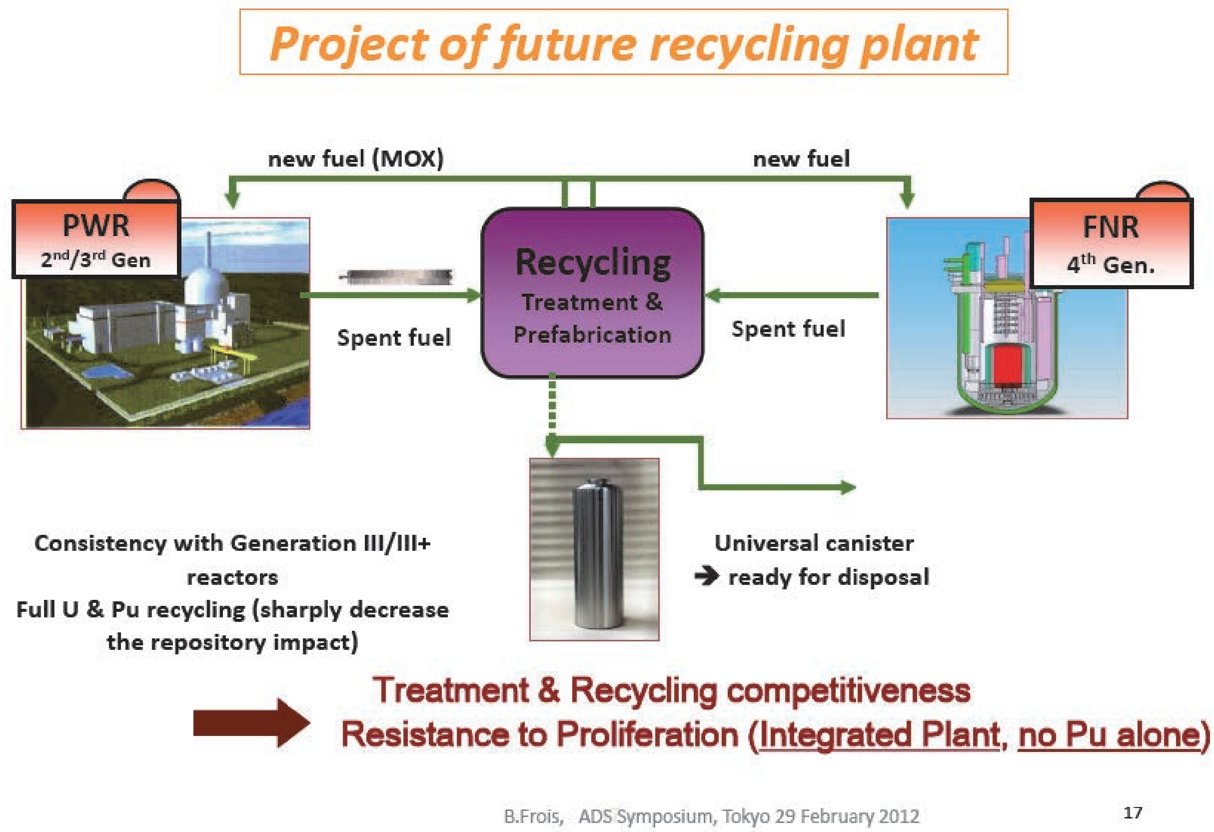
Project of future recycling plant
new fuel (MOX)
new fuel
PWR 2nd/3rd Gen
FNR 4th Gen.
Recycling
Treatment & Prefabrication
Spent fuel
Spent fuel
Consistency with Generation III/III+ reactors
Full U & Pu recycling (sharply decrease the repository impact)
Universal canister
➔ ready for disposal
Treatment & Recycling competitiveness
Resistance to Proliferation (Integrated Plant, no Pu alone)
B.Frois, ADS Symposium, Tokyo 29 February 2012
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December 30, 1991
June 28, 2006

The 1991 and 2006 French Waste Laws

- Recycle by P and T to decrease waste amount and toxicity
- Geological deep repository, retrievable
- Confinement and interim storage

2012 Industrial potentialities of the diverse recycling options

2020 Decision to build a prototype for transmutation tests, operation

2015 Repository defined and licensed

2025 Repository in operation

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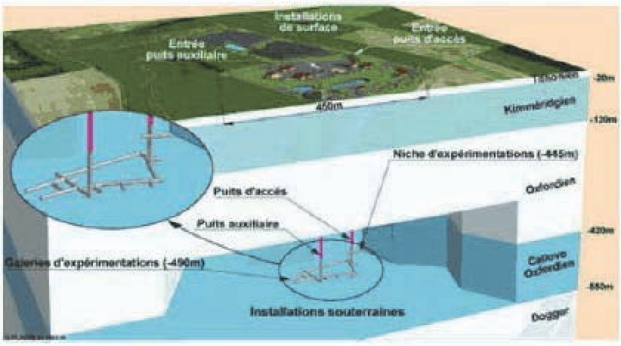
Assessment of the Site of Bure in France as Potential Geological HLLL Waste Repository

⇨ **French Act of June 28, 2006 for a sustainable management of nuclear materials and waste**

⇨ **Satisfactory containment properties of clay for the radionuclides**

⇨ **Feasibility of a geological disposal in this formation**



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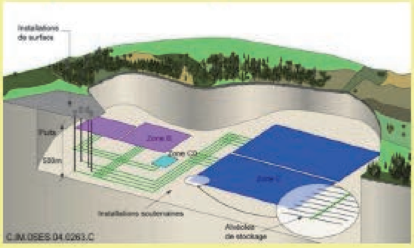
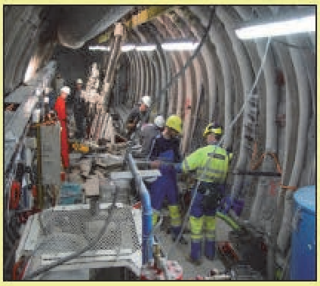
Sustainable management of nuclear materials and waste French Law of June 28, 2006

- ✓ France has a National Plan managed by ANDRA
- ✓ Stepwise program for Long-Lived Waste ; P&T , geological repository and interim storage
- ✓ Specifies the roadmap to have a retrievable geological repository in operation by 2025



*Design project for HLL waste disposal, **in progress***

*Research from Underground laboratory (URL), **in operation***



- ✓ Secured long term funding

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EPR in Flamandville

A mature concept, based on current PWR's feedback

Significant improvements in safety and economy

- 2005: French Energy Policy Act
  → *A Gen III plant by 2012*
- 2007: First concrete
- 2012 : Connection to the grid

... and announced for Penly...

- 2009 : Announcement
- 2017 : Connection to the grid

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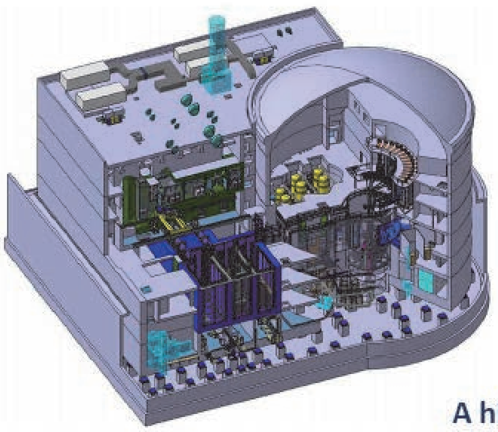
JHR : a high performance material resarch reactor under construction in Cadarache



- 100 MW electric
- International partnership
  - CEA, EDF, AREVA
  - EU, Belgium, Czech Republic, Finland, Spain, India, Japan, Sweden ...

A high performance and flexible reactor to address Gen II, Gen III and Gen IV materials testing needs & radioisotope production :

- High level neutronic flux
- Increasing instrumentation
- Capability to simulate different environments

- *September 2007* – Building permit
- *July 2009* – First concrete
- 2014 – Expected operation

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Conclusions

- Fukushima is a terrible accident. All nations have realized the need for a new approach to safety and sustainability.
- Germany will stop nuclear power. But this has already a significant economic impact. Grid stability is a problem.
- Japan needs time to find the best way.
- Most nations continue to follow their plans
- France and Europe have defined their plans for the future
- Nuclear fuel cycle is one of the most important issue
- ADS has a major window of opportunity. Many countries are interested (China, India, etc.)
- United States has recently published important reports on nuclear power and on the future of nuclear fuel cycle.

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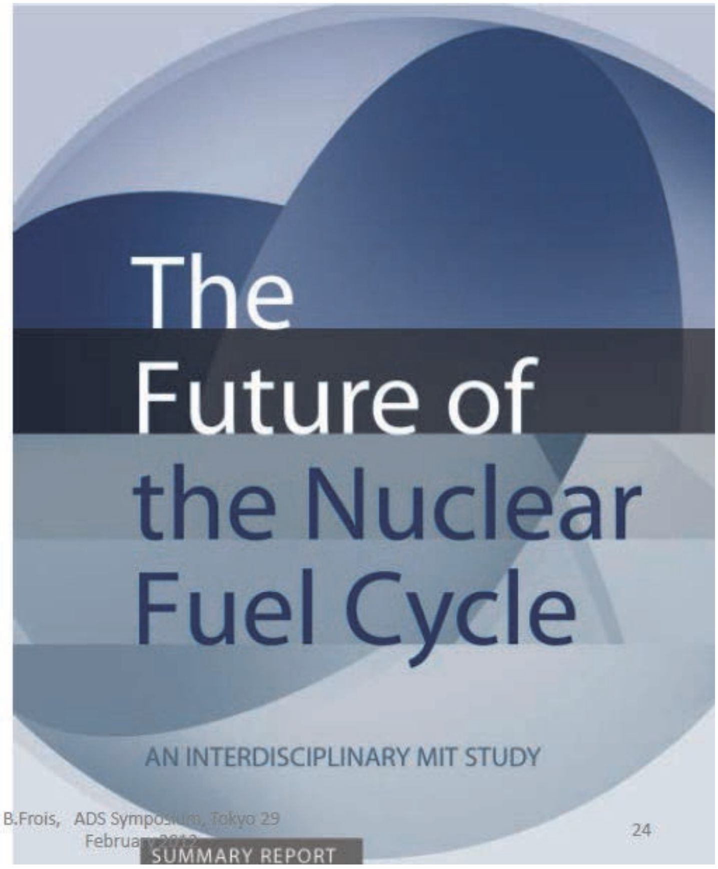
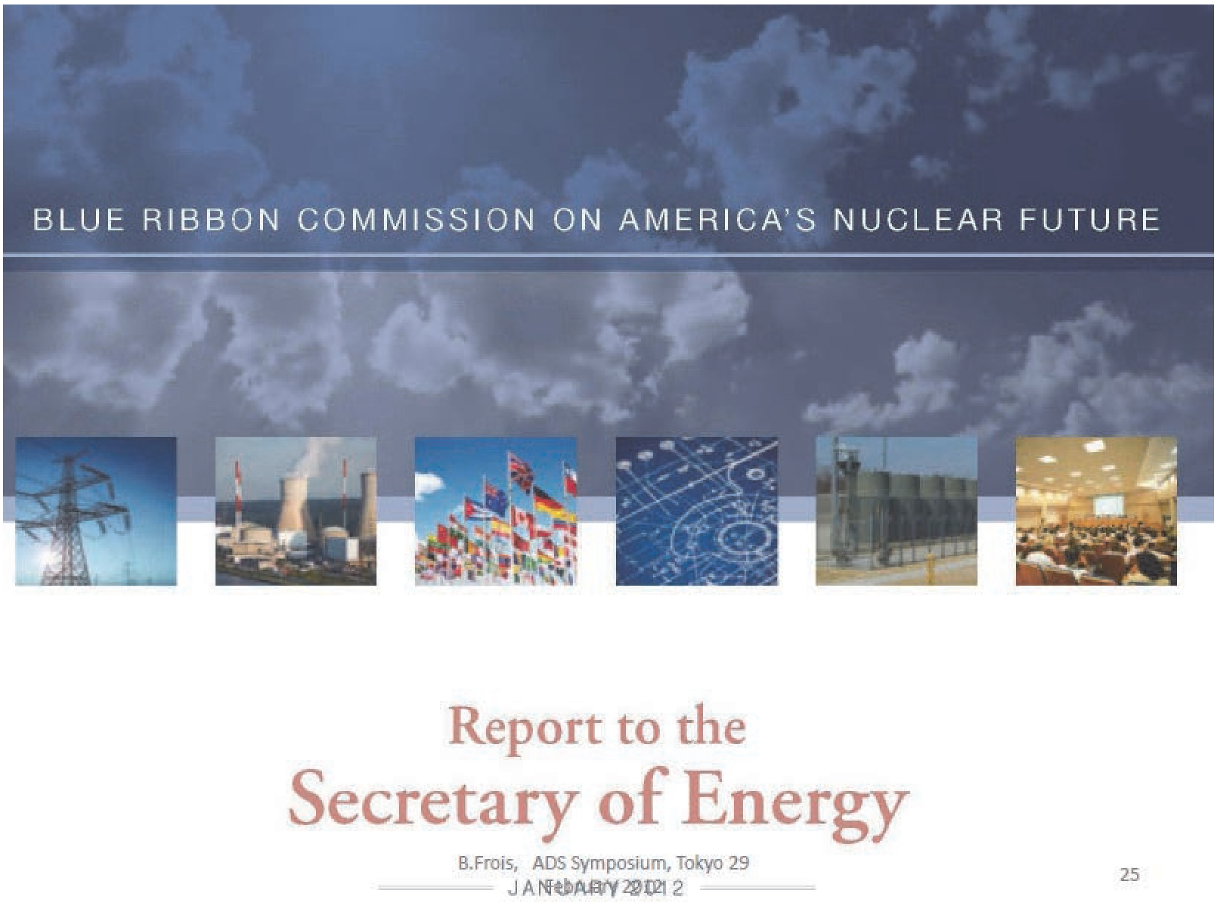

The
Future of
the Nuclear
Fuel Cycle
AN INTERDISCIPLINARY MIT STUDY
SUMMARY REPORT
B.Frois, ADS Symposium, Tokyo 29 February 2012
24


BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE
Report to the
Secretary of Energy
JANUARY 2012
B.Frois, ADS Symposium, Tokyo 29 February 2012
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With my warmest thanks, for their precious contributions, to:

- Bernard Boullis, Frank Carré, Daniel Iracane, Dominique Ochem, Dominique Warin, Alain Zaetta, CEA, France
- Alex Mueller, CNRS, France
- Andrew Hutton, JLAB, United States
- Ernest Moniz, MIT, United States

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3.10 Cooperation – The Way to realize ADS

H. Xia (SNPTC, China)

国家核电 SNPTC

1. Why

2. How

STATE NUCLEAR POWER TECHNOLOGY CORP.

Why

国家核电 SNPTC

- During the Fukushima accident, disablement of spent fuel pool cooling and the possibility of earthquake-induced damage to the pools were the cause of great concern. P&T would reduce the spent fuel inventory at the NPP.
- The ADS is the most efficient transmutation technology. It's very important to close the fuel cycle which is key for the sustainable large scale utilization of nuclear energy.

STATE NUCLEAR POWER TECHNOLOGY CORP.

Why

国家核电 SNPTC

- The technical challenges for ADS spread over very wide range of scientific and engineering fields, however, the ADS society is small.
- It is very important to share the information, experience and R&D efforts in a well organized way by interesting countries.
- We have a good start.

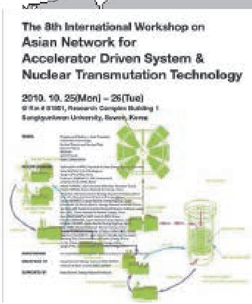
STATE NUCLEAR POWER TECHNOLOGY CORP.

Brief Review of ADS Asian Network

In 2003, JAERI initiated “Asia ADS Network”
with Korean and Chinese colleagues at the same place.

Heng Yang

University of South China (南华大学)



Curtsy to Dr.H.Oigawa

J-PARC

EURATOM-CAEA COOPERATION IN NUCLEAR FISSION RESEARCH WORKSHOP

国家核电 SNPTC

Template no 5 - "co-ordinated call for parallel projects"

Session 1: Innovative nuclear systems (GEN IV) and fuel cycles (P&T)

Template drafted by S. VAN DIJCK (Euratom) and HaiHong XIA (China) – 2009

Review by Mario CARTA, Steven VAN DYCK, Maurizio BOELLA (EURATOM), Haihong Xia and Wang Zhiguang (China) -2011

SUBJECT TITLE: Physics and materials for accelerator driven systems

STATE NUCLEAR POWER TECHNOLOGY CORP. 6

OBJECTIVES

国家核电 SNPTC

- Reactor physics: zero and low power ADS core studies
- Study of materials to be used in ADS installations
- Study of Pb and Pb-Bi coolant and its technology

STATE NUCLEAR POWER TECHNOLOGY CORP. 7

SCOPE

国家核电 SNPTC

Reactor physics: special emphasis on spallation source characteristics, flux space - energy profiles and reactivity monitoring techniques.

Materials: characterisation of the behaviour of structural materials, exposed to heavy liquid metal and neutron and –or ion irradiation. The goal of the charaterisation is to compose a database on industrial materials and prototype advanced materials.

Pb and Pb-Bi coolant studies in loops for the development of heavy liquid metal coolant technology.

IMPACT FOR ALL PARTIES CONCERNED

国家核电 SNPTC

Create synergy between the parallel roadmaps to ADS development in China and Europe.

Enhance ADS safety by better understanding of spallation source and core physics through comparison of complementary experiments.

Extend material behaviour database for ADS design efforts through complementary experiments.

Increase transnational access to heavy liquid metal coolant test infrastructures.

RESPONSIBLE CONTACT EXPERTS :

China: Xia Haihong, Euratom: Steven Van Dijck

How

国家核电 SNPTC

Share information and experience is a good start, but not enough!

More real cooperation are expected:

- ◆Benchmark the tools and data
- ◆Design
- ◆Licensing
- ◆Development and Construction
- ◆Operation and utilization etc.

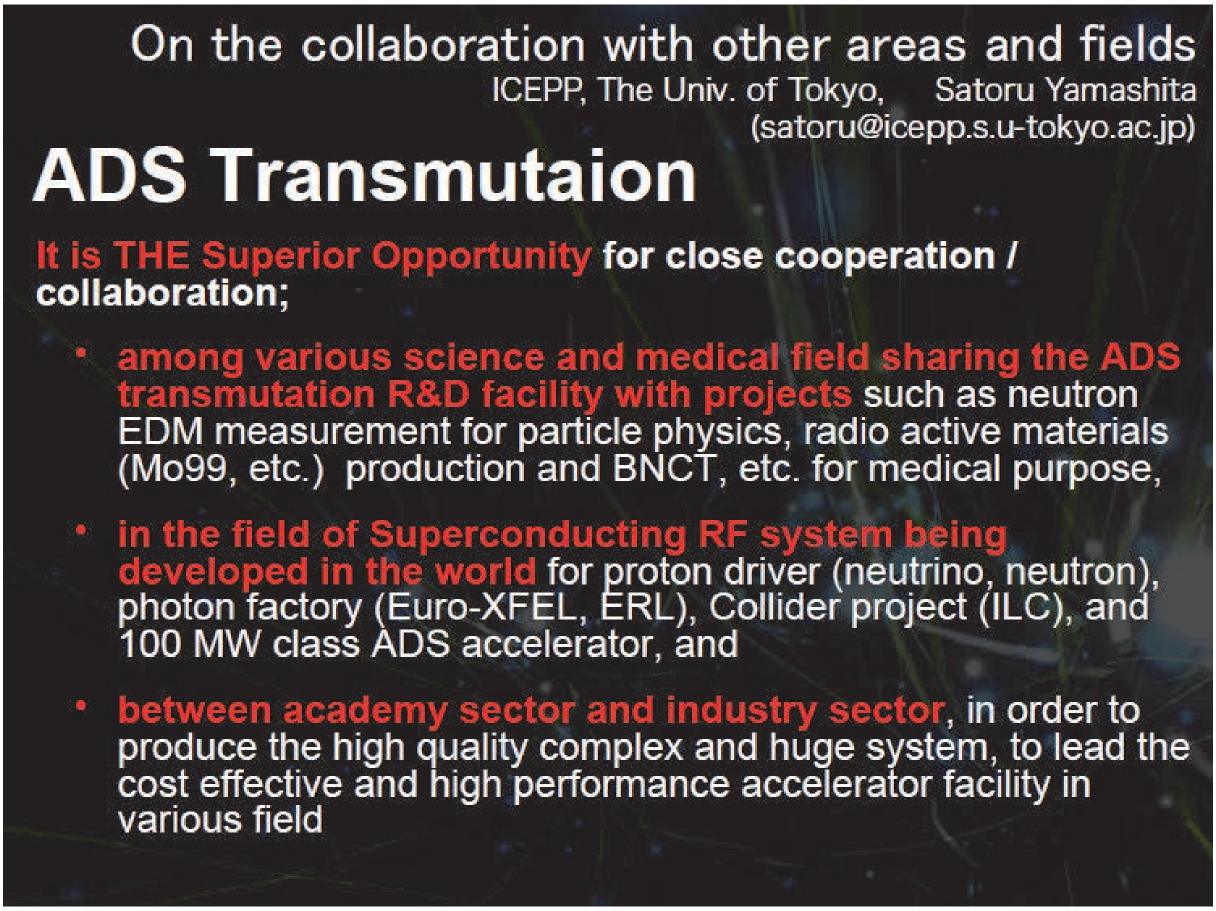
STATE NUCLEAR POWER TECHNOLOGY CORP. 10

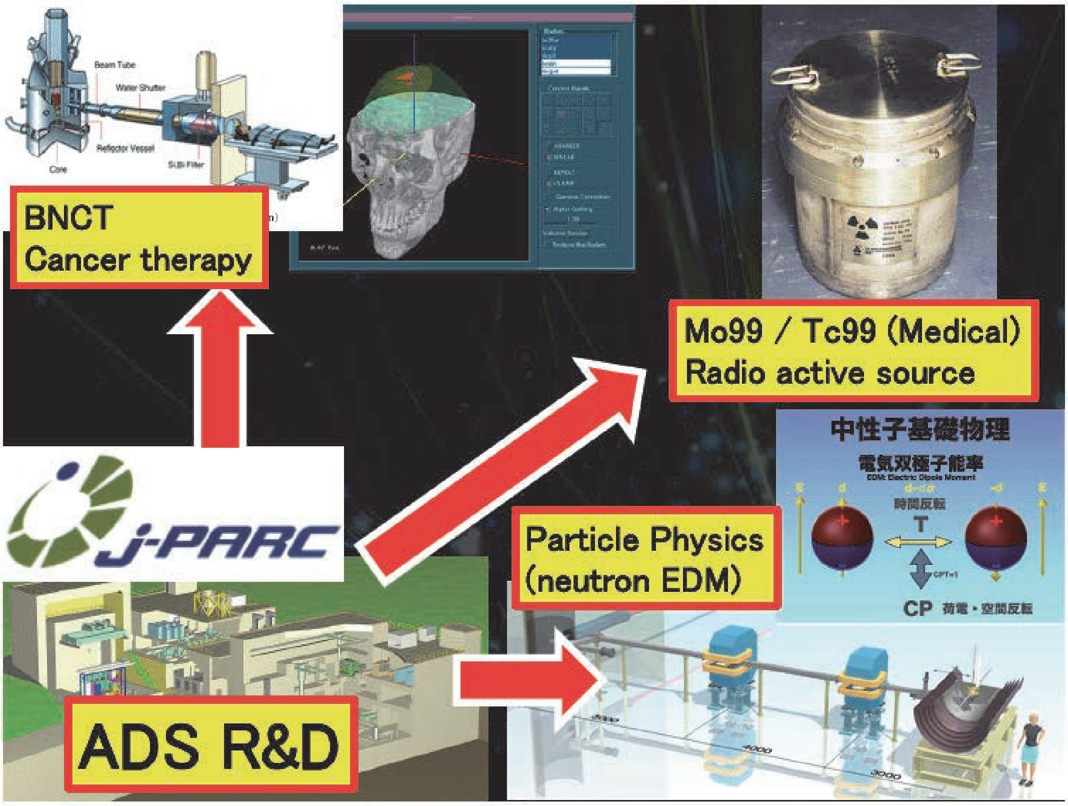
国家核电 SNPTC

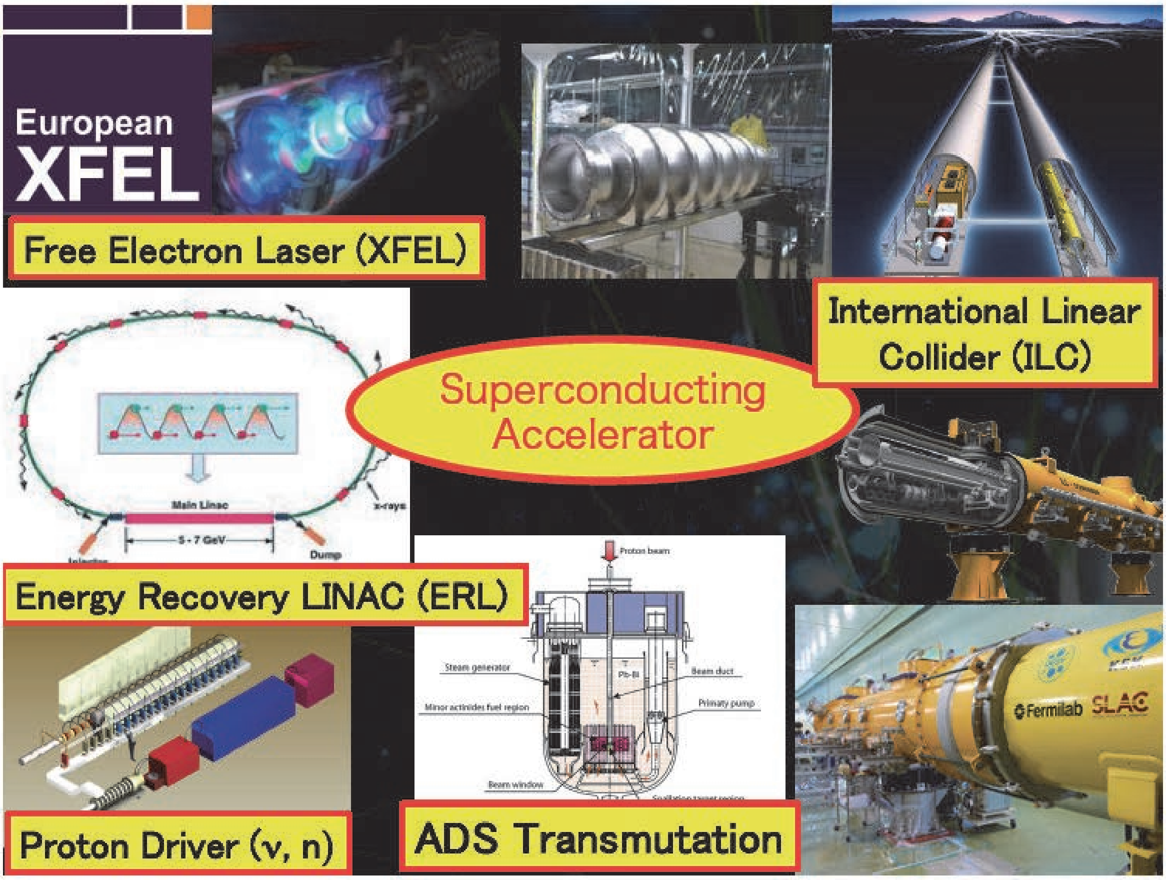
谢谢
Thank you

3.11 ADS Transmutation

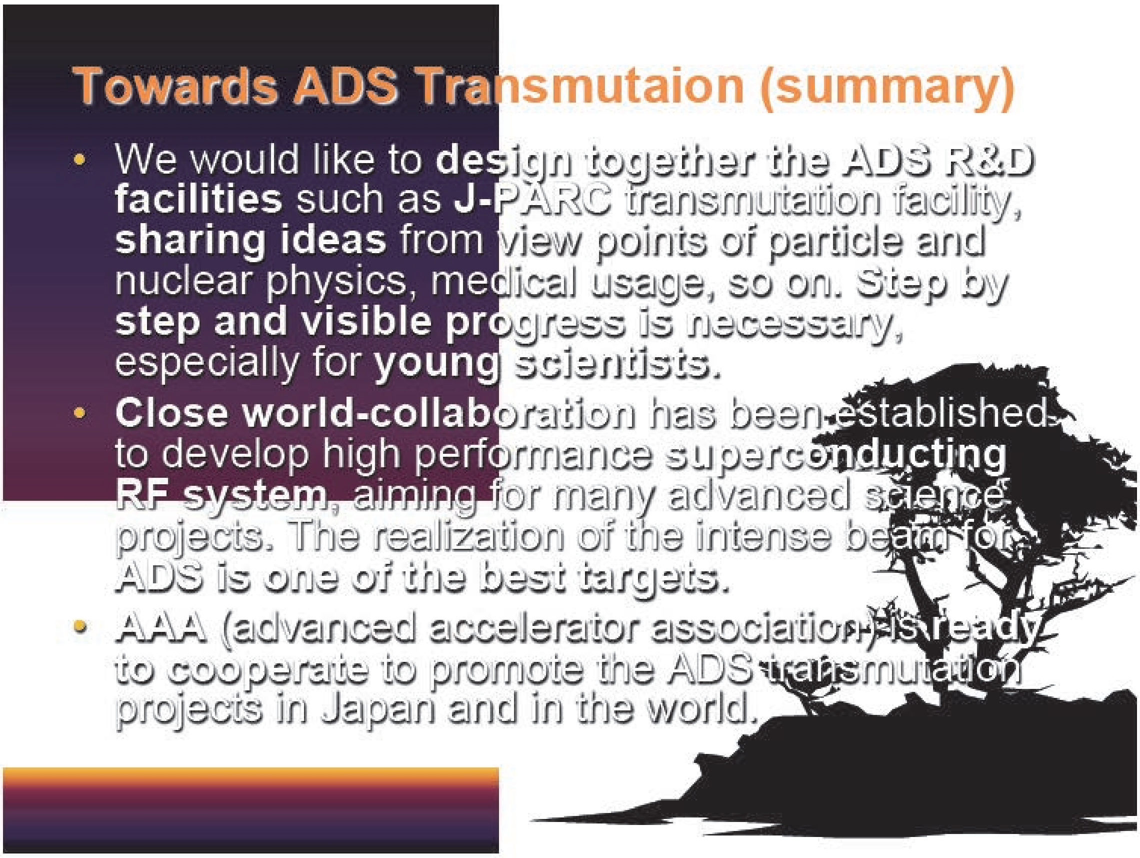
S. Yamashita (University of Tokyo)




BNCT
Cancer therapy
Beam Tube
Water Shutter
Reflector Vessel
Core
Si,Bi-Filter
Mo99 / Tc99 (Medical)
Radio active source
中性子基礎物理
電気双極子能率
EDM: Electric Dipole Moment
時間反転
T
CP 荷電・空間反転
J-PARC
Particle Physics
(neutron EDM)
ADS R&D


European
XFEL
Free Electron Laser (XFEL)
International Linear
Collider (ILC)
Superconducting
Accelerator
Main Linac
x-rays
5 - 7 GeV
Dump
Energy Recovery LINAC (ERL)
Proton beam
Steam generator
Pb-Bi
Beam duct
Primary pump
Minor actinides fuel region
Beam window
Proton Driver (ν, n)
ADS Transmutation
Fermilab
SLAC


Close Cooperation between Academy sector and Industrial sector (Advanced Accelerator Association)
AAA (Advanced Accelerator Association Promoting Science and Technology) consisting of 84 private companies and more than 30 public research institutions and Universities in Japan (since 2008)
先端加速器科学技術推進協議会 設立総会
Promoting the wide area of Accelerator Science and Technology
~ core target model is ILC project ~
ADS would be one of the best targets !
http://www.aaa-sentan.org


Towards ADS Transmutaion (summary)
We would like to design together the ADS R&D facilities such as J-PARC transmutation facility, sharing ideas from view points of particle and nuclear physics, medical usage, so on. Step by step and visible progress is necessary, especially for young scientists.
Close world-collaboration has been established to develop high performance superconducting RF system, aiming for many advanced science projects. The realization of the intense beam for ADS is one of the best targets.
AAA (advanced accelerator association) is ready to cooperate to promote the ADS transmutation projects in Japan and in the world.

Appendix A: Program

International Symposium on "Future of Accelerator Driven System"

Date: 29th February, 2012

Place : Gakushi-kaikan 202, Tokyo, Japan

Program :

1. Opening remarks 10:00～10:10
   H. Yokomizo (Executive Director, JAEA)

2. Special session 10:10～10:40
   Expectation for Transmutation Technology
   A. Arima (President of Musashi Gakuen, Former Minister of Education)

3. Current R&D Status of ADS in Japan 10:40～12:00
   Chaired by H. Oigawa (JAEA)
   3.1 Back-End Issue of the Japanese Nuclear Utilization being Discussed
   H. Yamana (Kyoto University)
   3.2 Present Status of R&D on Accelerator Driven System in JAEA
   K.Tsujimoto (Nuclear Transmutation Technology Group, JAEA)
   3.3 Reactor Physics Experiments on ADS using KUCA Reactor and Future Plan for ADS Neutron Source at Kyoto University Research Reactor Institute
   T. Misawa (Kyoto University)

Lunch （80） 12:00～13:20

4. Current R&D Status of ADS in Asian Countries 13:20～14:40
   Chaired by K. Hasegawa (JAEA)
   4.1 Present R&D status in China
   L. Yang (CAS, China)
   4.2 Present R&D status in Korea
   S. W. Hong (Sungkyunkwan University, Korea)
   4.3 Accelerator Driven System: Plans & Present Status in India
   P. K. Nema (BARC, India)

5. Current R&D Status of ADS in Europe 14:40～15:40
   Chaired by H. Yamana (Kyoto University)
   5.1 The MYRRHA-Project: Status and R&D Plan
   P. Baeten (SCK-CEN, Belgium)
   5.2 Nuclear Power Utilization in Future at EU

B. Frois (Scientific adviser, CEA, France)

Coffee break（20） 15:40～16:00

6. Discussion: Future of ADS and International collaboration 16:00～17:30

Chaired by Y. Ikeda (Deputy Director, J-PARC Center, JAEA)

Panelist：

P. Baeten (SCK-CEN, Belgium)
H. Xia (Vice President, SNPRI, China)
S. W. Hong (Sungkyunkwan University, Korea)
P. K. Nema (BARC, India)
T. Misawa (Kyoto University)
S. Yamashita (University of Tokyo)
H. Oigawa (JAEA)

7. Closing speech（10） 17:30～17:40

S. Nagamiya (Director, J-PARC center)

Reception（Josui-kaikan） 18:00～19:30

Appendix B: Photos

http://j-parc.jp/Transmutation/en/ADS-symposium-2012/photo/album.html

Dr. H. Yokomizo

Dr. A. Arima

Dr. H. Yamana

Dr. K. Tsujimoto

Dr. T. Misawa

Dr. L. Yang

Dr. S.W. Hong

Dr. P.K. Nema

Dr. P. Baeten


A Brief Overview
in France a
Berna
Direction of Tech
ADS Symposium

Dr. B. Frois


International Symposium on Future of Accelerator Driven System
国際シンポジウム「加速器駆動核変換システム(ADS)の未来」

Dr. H. Xia

Dr. S. Yamashita

Dr. S. Nagamiya

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度 (a)，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率 (b)	（数字の） 1	1
比透磁率 (b)	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(b)	rad	1 (b)	m/m
立体角	ステラジアン(b)	sr(c)	1 (b)	m^{2}/m^2
周波数	ヘルツ (d)	Hz		s^{-1}
力	ニュートン	N		$m\ kg\ s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N m	$m^2\ kg\ s^{-2}$
仕事率，工率，放射束	ワット	W	J/s	$m^2\ kg\ s^{-3}$
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
電気抵抗	オーム	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
磁束	ウエーバ	Wb	Vs	$m^2\ kg\ s^{-2}\ A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
セルシウス温度	セルシウス度(e)	℃		K
光束	ルーメン	lm	cd sr(c)	cd
照度	ルクス	lx	lm/m^2	$m^{-2}\ cd$
放射性核種の放射能 (f)	ベクレル (d)	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	$m^2\ s^{-2}$
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト (g)	Sv	J/kg	$m^2\ s^{-2}$
酸素活性	カタール	kat		$s^{-1}\ mol$

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	$m^{-1}\ kg\ s^{-1}$
力のモーメント	ニュートンメートル	N m	$m^2\ kg\ s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\ s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\ m^{-1}\ s^{-1}=s^{-1}$
角加速度	ラジアン毎秒毎秒	rad/s^2	$m\ m^{-1}\ s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\ s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\ kg\ s^{-2}\ K^{-1}$
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	$m^2\ s^{-2}\ K^{-1}$
比エネルギー	ジュール毎キログラム	J/kg	$m^2\ s^{-2}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	$m\ kg\ s^{-3}\ K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\ kg\ s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\ kg\ s^{-3}\ A^{-1}$
電荷密度	クーロン毎立方メートル	C/m^3	$m^{-3}\ sA$
表面電荷	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
電束密度，電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\ sA$
誘電率	ファラド毎メートル	F/m	$m^{-3}\ kg^{-1}\ s^4\ A^2$
透磁率	ヘンリー毎メートル	H/m	$m\ kg\ s^{-2}\ A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\ kg\ s^{-2}\ mol^{-1}$
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	$m^2\ kg\ s^{-2}\ K^{-1}\ mol^{-1}$
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\ sA$
吸収線量率	グレイ毎秒	Gy/s	$m^2\ s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\ m^{-2}\ kg\ s^{-3}=m^2\ kg\ s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\ sr)$	$m^2\ m^{-2}\ kg\ s^{-3}=kg\ s^{-3}$
酵素活性濃度	カタール毎立方メートル	kat/m^3	$m^{-3}\ s^{-1}\ mol$

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	µ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$1ha=1hm^2=10^4m^2$
リットル	L，l	$1L=1l=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3\ kg$

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	$1\ bar=0.1MPa=100kPa=10^5Pa$
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	$1\ Å=0.1nm=100pm=10^{-10}m$
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\ s\ cm^{-2}=0.1Pa\ s$
ストークス	St	$1\ St\ =1cm^2\ s^{-1}=10^{-4}m^2\ s^{-1}$
スチルブ	sb	$1\ sb\ =1cd\ cm^{-2}=10^4cd\ m^{-2}$
フォト	ph	$1\ ph=1cd\ sr\ cm^{-2}\ 10^4lx$
ガル	Gal	$1\ Gal\ =1cm\ s^{-2}=10^{-2}ms^{-2}$
マクスウェル	Mx	$1\ Mx = 1G\ cm^2=10^{-8}Wb$
ガウス	G	$1\ G\ =1Mx\ cm^{-2}\ =10^{-4}T$
エルステッド (c)	Oe	$1\ Oe \triangleq (10^3/4\pi)A\ m^{-1}$

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R = 2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1 γ =1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	µ	$1\ \mu =1\mu m=10^{-6}m$

（第8版，2006年改訂）