Summary of session 2: national ADS programs

Jean-Pierre Revol
Thursday February 9, 2017
<table>
<thead>
<tr>
<th>Topic</th>
<th>Presenter</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA and ADS</td>
<td>Stefano Monti</td>
<td>14:00 - 14:25</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe ADS project MYRRHA</td>
<td>Peter Baeten</td>
<td>14:25 - 14:50</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China ADS project</td>
<td>Wenlong Zhan</td>
<td>14:50 - 15:15</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coffee break</td>
<td></td>
<td>15:15 - 15:45</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India ADS programme</td>
<td>Pitamber Singh</td>
<td>15:45 - 16:10</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan ADS project</td>
<td>Takanori Sugawara</td>
<td>16:10 - 16:35</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ukraine NSC KIPT ADS project</td>
<td>Yousry Gohar</td>
<td>16:35 - 17:00</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA Progress on SRF Linacs Driving Subcritical GEM*STAR Reactors</td>
<td>Rolland Johnson</td>
<td>17:00 - 17:25</td>
</tr>
<tr>
<td>6-2-024 - BE Auditorium Meyrin, CERN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
IAEA – Stefano Monti

• **Technical Working Groups** related to ADS
  - **TWG-NFCO**: nuclear fuel cycle options: innovative fuel cycles and nuclear materials management
  - **TWG-FR**: fast spectrum systems, both critical and subcritical, for energy production and transmutation of long-lived radionuclides

• **Coordinated Research Project** (CRP) on “Accelerator Driven Sub-critical Systems (ADS) and Use of Low Enriched Uranium (LEU) in ADS”
  ... Continue Development of Analytical Techniques?

![ADS Nuclear Data Library v2.0](Image)

- IAEA Emerging Technologies Workshops: Trends and Implications for Safeguards, Vienna, 13-16 February 2017
- 3rd International Conference on Fast Reactors and Related Fuel Cycles (FR17) Yekaterinburg, RF, 26-29 June 2017
- Explained how to make use of IAEA through IAEA member States
MYRRHA – Peter Baeten

- Most advanced ADS project. – Should be the flagship of ADS projects
- Strong support from the Belgium Government, where are the others?
15 years to wait for the start of operation!
Proton target facility on the way by 2024

• Impressive amount of technical design work, with many innovative ideas in the design of components, a very broad R&D program, and also breaking new ground in the field of licencing!
ADANES – Wenlong Zhan

• ADANES (Accelerator Driven Advanced Nuclear Energy System) after intensive R&D last 5 years in the Chinese Academy of Science.

• They changed their strategy: Optimizing resources & radiotoxicity
  • Simplify Fuel Recycling: Remove part of FPs (~50%) from spent fuel, Convert Residuals as recycle fuel
  • Power Burner: Transmuting, Breeding & Energy production by fast neutron
Ambitious project, to reach 1 GWe
A lot of resources
2000 people involved!

– Phase II approved by the Central Government
– Get to 10 MWt by 2022?
– 600 MWt by 2030
– Full system, on similar time scale as MYRRHA
Two injectors developed in competition between Lanzhou and Beijing
Components to be combined to reach 25 MeV, 10 mA in new site at HuiZhou in South China
Innovative approaches to the target design

Innovative approach to the subcritical core:
Subcritical Fast Core (Gas+Grain → new, simplify)
LBE, Steam, Gas + Grain coolant cores R&D, Gas+Grain is more optimizing

Systematic innovative approach for the Chinese ADS programme
India ADS – Pitamber Singh

• The clear goal in India is the exploitation of their very large thorium resources
• R&D concentrates at this time on the accelerator, with an ambitious program to reach 1 GeV, 30 mA linac, in collaboration with the USA
• First stage: Low Energy High Intensity Proton Accelerator (LEHIPA) 20 MeV, 30 mA linac
Accelerator Development for ADS

LEHIPA

Phase I
- Proton IS 50 keV
- RFQ 3 MeV
- DTL 20 MeV

High current injector 20 MeV, 30 mA

Phase II
- SC Linac HWR/SSR
- 200 MeV

Phase III
- SC Linac 1 GeV

ECR Ion Source
RFQ
DTL

400 keV RFQ
LEBT
Elliptical SC Cavity
High Yield Neutron Facility

![Diagram of High Yield Neutron Facility]

- **LEBT**
- **MEBT**
- **IS**
- **RFQ**
- **DTL**

**Proton Beam (20 MeV, 30 mA)**

**Moderator**

**Beryllium target**

**Reflector (Pb)**

**Neutron Yield for Beryllium target**

\[ S_0(E_p) = 4.476 \times 10^{11} \times E_p^{1.886} \times I \text{ n/sec} \]
ADS programme in INDIA
- Current Scenario

- BRAHMA – Thermal ADS
  Nat. U fuel
  Deep subcritical (Keff = 0.890)

Next stages proposed

- Thermal ADS with higher Keff - Proposed
  Similar configuration as BRAHMA with SEU/LEU fuel
  Keff ~ 0.95

- Fast ADS - Proposed
  Th-Pu fuel
  Keff ~ 0.97-0.98

Spallation target R&D at BARC

One way Coupled System for ADS

20 MeV Proton beam for ADS experiments in HWR critical facility

Studies have confirmed feasibility of extending 20 MeV proton beam to a target in the core of nearby HWR critical facility (commissioned)

Japan ADS – Takanori Sugawara

• National Policy for Nuclear Energy
  • “Nuclear power is an important base-load power source”
  • Dependency on nuclear energy will be decreased, but Japan will continue to rely on nuclear energy in the future
  • “GOJ will promote development of technologies for reducing the volume and harmfulness of radioactive waste”
  • The basic policy of Japan is to promote a nuclear fuel cycle based on reprocessing, Pu used as fuel, MA to be transmuted
ADS is part of the plan to eliminate Minor Actinides

**Homogeneous cycle**

- MA is homogeneously mixed to FBR fuel with small amount up to 5 wt.%.
- MA transmutation is performed in all electricity generating FBR plant.

**Double-Strata (ADS)**

- 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.
ADS R&D in JAEA and J-PARC

Conceptual Design of ADS in JAEA

**Purpose:** MA transmutation

- Proton beam: 1.5GeV ~30MW
- Spallation target: LBE
- Coolant: LBE
- Subcriticality: $k_{\text{eff}} = 0.97$
- Thermal output: 800MWe
- Core height: 1000mm
- Core diameter: 2440 mm
- Fuel inventory: 4.2t (MA:2.5t)
- Fuel composition:
  - (MA + Pu)N+ZnN (Mono-nitride)
  - Inner: 70%MA+30%Pu
  - Outer: 54%MA+42%Pu
- Transmutation rate:
  - 250kg(MA) / 300EFPD

ADS R&D in Japan

- Work on beam trips, $k_{\text{eff}}$ adjustment by $B_4C$ Subcriticality Adjustment Rod. Reflecting the Fukushima Accident, conceptual design of DRACS (Direct Reactor Auxiliary Cooling System) is investigated, and on Subcritical core layout.
Research Plan at J-PARC

**Transmutation Physics Experimental Facility: TEF-P**
- **Purpose**: To investigate physics properties of subcritical reactor with low power, and to accumulate operation experiences of ADS.
- **Licensing**: Nuclear reactor: (Critical assembly)
- **Proton beam**: 400MeV-10W
- **Thermal power**: <500W

**ADS Target Test Facility: TEF-T**
- **Purpose**: To research and develop a spallation target and related materials with high-power proton beam.
- **Licensing**: Particle accelerator
- **Proton beam**: 400MeV-250kW
- **Target**: Lead-Bismuth Eutectic (LBE, Pb-Bi)
UKRAINE KIPT ADS Facility – Yousri Gohar

• Real ADS, being commissioned!!

• 100kW, 100 MeV electron beam with a thermal neutron subcritical core – Uranium fuel – energy amplification factor 2 to 3 depending on target

• Objectives:
  • Demonstrate ADS
  • Provide neutron facility for research
  • Physics and material experiment inside the subcritical core
  • Production of medical radio-isotopes and neutron therapy
  • Training young specialist for nuclear industry

• The KIPT ADS Facility (KIPT Neutron Source Facility) is open for international cooperation as soon as it is in operation. The current schedule calls for startup in 2017.
KIPT Electron Accelerator Configuration

1 - klystron gallery, 2 - Accelerator tunnel, 3 - Power supply, 4 - Electron gun, 5 - First accelerating section, 6 - Energy filter, 7 - Accelerating section, 8 - Klystron amplifier, 9 - Waveguide, 10 - Quadruple triplet magnet, 11 - Electron Transportation channel, 12 - Subcritical Assembly tank
Tackling real practical problems

Optimum Neutron Flux Detector Positions
USA ADS: GEM*STAR – Rolland Johnson

- **Molten-salt fuel ADS**, to reduce sensitivity to beam trips (fuel pin fatigue no longer an issue)
- **Multipurpose reactor design**
  - internal spallation neutron target
  - high temperature molten-salt fuel
  - feed-bleed innovation
  - continuous purging of volatile radioactive fission products
  - burns SNF, natural uranium, thorium, or surplus weapons material
  - burns its own spent fuel
- **Subcriticality, versatility, and intrinsic safety features imply**
  - *less expensive to build, license, and operate than conventional reactors.*
  - especially effective to dispose of nuclear weapons materials & SNF
- **SRF Linacs - powerful, reliable, affordable, and efficient**
  - steep learning curve with new developments
  - e.g. magnetron power sources and cavity construction techniques
- **Goal - pilot plant demo of a GEM*STAR subcritical molten-salt fueled nuclear reactor** driven by a superconducting RF proton linac
  - Burn SNF and W-Pu
Some GEM*STAR Advantages

- Tested technology put together in a new way.
- The reactor operates at atmospheric pressure.
  - No pressure vessel.
  - Major design simplification, and eliminates many accident scenarios.
- Volatile fission products are continuously removed.
  - Reactor contains almost a million times less than in a LWR.
- No fuel rods.
  - No Zircaloy that can instigate a hydrogen explosion (Fukishima).
  - No mechanical fatigue of UO₂ fuel rods from accelerator trips
- No critical mass is ever present, and cannot form.
- No reprocessing or isotopic enrichment is needed.
  - More proliferation resistant than other technologies.
- Burns SNF, W-Pu, U233, natural uranium, thorium, without redesign
- Passive response to most accident scenarios: turn off the accelerator – passive air cooling is then sufficient.
CONCLUSION

• Numerous important ADS contributions possible thanks to the development of accelerator technology
  • Nuclear waste and nuclear weapon material elimination
  • Energy production, including the use of thorium fuel – make nuclear energy sustainable!
  • Neutron spallation sources
  • Production of radioisotopes, as an alternative to nuclear critical reactor production
  • High intensity beams for fundamental research
    (not mentioning low energy low intensity accelerator applications)

• Impressive effort worldwide on ADS: Europe, China, India, Japan, USA, Ukraine, [Russia/Troitsk],
  (South Korea?, Africa?, Australia?, South America?)

• However, the time scales are depressing: > 2030s

• ADS needs global cooperation – if Fusion could do it why not ADS? One problem is that goals are
  quite different. For instance between China (energy) and the USA (waste elimination)

• The issue of nuclear waste management is not yet resolved – The reasons why the Yucca
  mountain project was cancelled will apply elsewhere. Why should it be different in Europe? The
  requirement of retrievability is orthogonal to the idea of geological storage, and makes it
  problematic

• The ADS community must pursue their efforts, so that the technology is ready when the time
  comes