INPRO Scenario Analysis and Nuclear Energy System Assessment (NESA)

14th INPRO Dialogue Forum

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INPRO Section
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Nuclear Energy System (NES) Strategic Planning: 3 linked Parts

Sustainability questions

Nuclear Energy System (NES) modelling and the ‘GAINS Framework’: How do we get there from here?

National Energy Planning: How does nuclear energy fit into the national energy mix?

Nuclear Energy System Assessment (NESA): INPRO Methodology of sustainability assessment
What are the gaps?
Modelling NES Development and Progress Toward Sustainability: The GAINS Framework

• The collaborative project GAINS was initiated by MS as a part of INPRO project

• The objective was to develop a common framework for modelling global, regional and national NES to support sustainable development

• The purpose of a GAINS scenario modelling is to facilitate understanding of long-term outcomes in different potential NES architectures – to achieve sustainable NES growth while minimizing financial, environmental, and political risks

• Comparative analysis of key indicators from various scenarios can inform strategic NES planning and decision making
Framework for scenario modelling and analysis (GAINS, MESSAGE-NES) is derived from certain high level INPRO Methodology topics:

- Areas for scenario analysis are evaluated through material stock and flow simulations treating facilities as “lumped capacity” models that communicate materials, equipment and value through system links.

- Major areas of analysis include:
  - resource availability
  - associated power capacity curves for nuclear reactor models involved
  - production, radioactivity and radiotoxicity of waste
  - demand and distribution in fuel cycle services
  - estimates of costs / required investment flows
  - limited non-proliferation and security considerations
  - trade effects

- Important sustainability areas including safety cannot be adequately addressed in scenario analysis since they involve specific design details of facilities and equipment that cannot be treated in a lumped capacity model.
SYNERGIES: Scenario Analysis Applied to Specific Case Studies

• LWR mono-U/Pu recycling
• Multi-recycling Pu-management in LWR+FR
• FR-centred scenarios
• Transition to Th/\(^{233}\)U via U/Pu HWR-LWR-FR Phase
• Alternative Complete U/Pu/Th-cycle
• Scenarios with advanced MA management

SYNERGIES final report is in publication
### SYNERGIES Case Studies

Specific scenario case studies performed by Member State participants:

<table>
<thead>
<tr>
<th>#</th>
<th>Task Title</th>
<th>Responsible</th>
<th>Country</th>
<th>Status/Deadline</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Chapter on SYNERGIES overviews</td>
<td>L. Van den Dauwel</td>
<td>France</td>
<td>Second Draft Submitted, Complete draft to be provided before February 28, 2014</td>
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<tr>
<td>2</td>
<td>Task 1. Comparative assessment of collaborative fuel cycle options for Indonesia</td>
<td>B. Hertzenz</td>
<td>Indonesia</td>
<td>In progress: April-May 2014</td>
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<tr>
<td>3</td>
<td>Task 1. Recycle of REU in PHWRs</td>
<td>D. Worster and C. J. Edwards</td>
<td>Canada</td>
<td>In progress: Draft report in May 2014</td>
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<tr>
<td>4</td>
<td>Task 1. Scenario A.1 EU22 scenario with the extended use of regional fuel cycle center composed of the La Hague and MELOX facilities and including Scenario A.1.1 Pre-cycling and/or TOP-MOX reactor of introducing LWR-MOX as countries before domestically produced Pu can be recycled</td>
<td>L. Van den Dauwel</td>
<td>France</td>
<td>In progress: January 2014</td>
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<tr>
<td>5</td>
<td>Task 1. National Romanian scenario with reliance on domestic and imported fuel supply, by considering regional collaboration in nuclear fuel cycle and including economic analysis</td>
<td>C. Margaran</td>
<td>Romania</td>
<td>In progress: Draft report in May 2014</td>
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<td>6</td>
<td>Task 1 Scenario A.4 – National Argentinian scenario with cooperation options</td>
<td>S. Jansen</td>
<td>Argentina</td>
<td>Submitted</td>
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<td>7</td>
<td>Task 1 Scenario B.1 with introduction of a number of first reactors aimed at supporting the multi-recycling of Pu in LWRs and FRs: EU22 Framework</td>
<td>L. Van den Dauwel</td>
<td>France</td>
<td>In progress: 28 February 2014</td>
</tr>
<tr>
<td>8</td>
<td>Task 1 Scenario B.1 with introduction of a number of first reactors aimed at supporting the multi-recycling of Pu in VVERs and PFRs</td>
<td>G. Foessel and V. Gospodinov</td>
<td>IAEA and Bulgaria</td>
<td>Submitted</td>
</tr>
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<td>9</td>
<td>Task 1 Scenario D.2 – ADRIL study</td>
<td>J. Manzato, M. Corti</td>
<td>Italy</td>
<td>In progress: April 2014</td>
</tr>
<tr>
<td>10</td>
<td>Task 1 Scenario C.1 – Demonstration on Chinese simple case of NES scenario with Pu multi-recycling based on LWRs and FRs and CNF</td>
<td>K. Zhou, Zhou</td>
<td>China</td>
<td>In progress: reported to submit a report needs to be issued from IAEA April-May 2014</td>
</tr>
<tr>
<td>11</td>
<td>Task 1 Scenario C.2 and Task 1 – Long-term Scenario Study for Nuclear Fuel</td>
<td>K. Makatani</td>
<td>Japan</td>
<td>Submitted, additional</td>
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#### Attachment 2: Synergies planned deliverables table

- **Task 3**: Summary of a French study on radioactive waste transportation options. Draft report developed available on SYNERGIES web page.
Ongoing Scenarios Projects: KIND and ROADMAPS

• Key Indicators (KIND) collaborative project further refines concept of key indicators for NES sustainable development analysis and uses standard multicriteria decision theory approaches for aggregate analysis

• ROADMAPS collaborative project formalizes approaches to document storylines of sustainable development and specific actions necessary – what, where, when?
Today

- Reactors
  - Water cooled – modest thermal efficiency
  - Large units
- Fuel resource
  - Natural/enriched U – limited natural resource
  - Limited U/Pu mono recycle – MOX
- Most SNF is stored and accumulating
- HL waste and direct SNF disposal
  - National repository development programmes
- Most trade in reactor and front end services

The Future?

- Reactors
  - Water, gas, metal and salt cooled, double the range of thermal efficiencies
  - Large and small modular units
- Fuel resource
  - Diverse and indefinite supply
  - U, U/Pu, Th/U-233
- SNF inventory in equilibrium with reactor fleet capacity
- HL waste and limited direct SNF disposal
  - National and regional repositories in operation
  - MA incinerated and disposed
- Trade distributed more uniformly across sectors improves economics

Developing system analysis and assessment tools to evaluate cooperative strategic paths to a sustainable future…
Example finding: trade cooperation can dramatically influence important outcomes

Even if only a few countries master innovative technologies of fast reactors and closed fuel cycles within this century, others could benefit from this through trade in fuel services.

E.g., global accumulation of spent fuel could be reversed. The synergistic approach could also secure uranium resource savings of up to 40%, over a heterogeneous non-synergistic case (severely limited back end trade).
Example finding: achieving equilibrium of spent fuel storage

Scenarios with the introduction of a limited number of fast reactors to support multi-recycling of plutonium in LWRs and in fast reactors.
EXAMPLE FINDING: BENEFITS FOR SUSTAINABILITY FROM TRADE COOPERATION ON RD&D ECONOMICS

RD&D investments on innovative technology are large and provide reasonable pay-back times only in the case of large scale deployment of technology. Cooperation among countries that allows large scale deployment, improves the economics of innovation.

![Graph showing the return of RD&D, demonstration, and construction investments for innovative reactor technology (FR). New capacity 1 GW/yr.](image)

**Fig. 1.** Return of RD&D and construction investments for the INS of 10 GW_{e}
Nuclear Energy Systems – 6 Key Sustainability Issues

To measure NES sustainability, metrics covering 6 key issues are assessed:

• Public and occupational safety – radiation protection
• Radioactive waste disposal
• National and international security
• Resource depletion
• Environmental impact
• Affordability and competitiveness

Among energy technologies, the set of unique nuclear energy sustainability issues are radiation protection, radioactive waste disposal and security.
IAEA’s NES Sustainability Metric – INPRO Methodology

• Derived from the UN sustainable development concept (Brundtland Commission, 1987) – concepts of needs, limitations and intergenerational responsibility

• Sustainability measured in a time frame – a century

• Types of INPRO sustainability criteria:
  • Progress toward improved metric within a technology lineage
  • Comparative performance on a metric with respect to technology used for similar purpose (e.g., coal, natural gas)
  • Forward-looking target value of a metric
  • Yes or no answers on certain requirements and good practices

• INPRO Methodology currently being updated/revised
History of INPRO methodology

- **2000**: Launching of the INPRO based on IAEA General Conference resolution (GC(44)/RES/21)

- **2001 – 2006**: Development of the Methodology as a tool for Nuclear Energy System Assessment (NESA):
  - Contribution by 150 experts (29 countries) and 50 IAEA staff
  - Total effort for development: ca. 40 person years
  - Two “prototypical versions” were released in this period

- **2004 – 2008**: Six national and one multinational NESA leading to several collaborative projects

- **2008**: Latest complete version of INPRO methodology (IAEA-TECDOC-1575, 9 volumes) published

- **2009 – 2011**: NESA in Belarus (exemplary study published in 2013)

- **2011 –**: NESAs in Ukraine, Indonesia, Romania

- **2012**: INPRO methodology update project started (four updated volumes were published in 2014-2016)
What is INPRO Methodology?
Holistic NES Sustainability Assessment

6 key issues that influence sustainability of nuclear power:

- Safety
- Affordability
- Security
- Waste
- Environment and Resources

Complete INPRO Methodology (TECDOC 1575) – 9 manuals covering 8 areas:

- Economics
- Safety (Reactor)
- Safety (Fuel Cycle)
- Proliferation Resistance
- Physical protection
- Waste Management
- Environment
- Infrastructure

Cursory if INIR mission process is completed
Experience with NESA – Performed using “prototype” INPRO Methodology

- 6 national assessments:
  - Argentina, Brazil, India, Republic of Korea as technology developer
  - Armenia, and Ukraine as technology user
- Documented in IAEA report TECDOC-1636

- 1 multinational assessment (“Joint Study”):
  - Canada, China, France, India, Japan, Republic of Korea, Russian Federation, and Ukraine
  - Development of NES of sodium cooled fast reactor with closed NFC
- Documented in IAEA report TECDOC-1639
Experience with NESA (2) – Performed using INPRO Methodology

- NESA completed in Belarus:
  - Full scope assessment of all INPRO methodology areas
  - Published as TECDOC 1716

- NESA on-going in Indonesia:
  - Full scope assessment of two types of reactors and certain fuel cycle facilities – Indonesia has completed assessment of large reactor case and produced final country report

- NESA on-going in Ukraine:
  - Limited scope: economics, infrastructure, SNF/waste management – has produced draft country report

- NESA on-going in Romania:
  - Full scope assessment of two types of reactors and certain fuel cycle facilities – has produced draft country report

- New projects: 1) Limited Scope Assessments of SFR Designs of China, India and Russia; 2) Preparatory visit and MS consideration of potential NESA of Malaysia
Main messages in areas of INPRO Methodology

- **Economics:** Nuclear energy products must be competitive against alternative energy sources available in the country – emissions control effects, including GHG are extremely important here.

- **WM:** Waste must be managed so that humans and environment are protected and undue burdens on future generations are avoided.

- **Infrastructure:** Adequate infrastructure and effort to create / maintain it.
  - Legal and institutional framework
  - Industrial and economic infrastructure
  - Socio-political infrastructure (Public acceptance, Human resources)

- **PR:** Future NES must remain unattractive for a nuclear weapon program by a combination of intrinsic features and extrinsic measures.

- **Environment:** Impact of Stressors must stay within performance envelope of current NES. Resources sufficient until end of 21st century.

- **Safety:** Safety of NES installation should be superior compared against safety of reference plant. Large off-site releases should be prevented so that evacuation is avoided.*

* - emergency preparedness and response remain a prudent requirement regardless.
Scope of INPRO area of economics

• **Cost** competitiveness of power production (compared to “similar alternatives”):
  • Dominated by costs of reactor construction, maintenance and operation
  • Involves costs of services from fuel cycle facilities
  • Depends strongly on emission control and subsidy schemes which directly influences other User Requirements below

• **Attractiveness for investment** – internal rate of return, net present value, etc.

• **Risk of investment** – maturity of design and sensitivity analysis

• **Flexibility** of design – increasingly in the future, diversity in fuel resource and cogeneration could improve performance here

• IAEA NEST code has been benchmarked with GIF G4ECONS to ~1%
Updated INPRO manual on environmental impact of stressors (NG-T-3.14) is focused on:

• Screening of every facility within a given NES including NPP;
• Normal operation and anticipated occurrence events (no accidents considered in this area – that topic is covered under safety of reactors);
• Adverse effects of radiological and non-radiological (e.g. water intake, heat, chemicals etc.) stressors;
• Effects of stressors on public and non-human biota.
To recap...

INPRO efforts to support sustainable NES development:

• INPRO tools for NES scenario modelling, Key Indicator evaluation, decision analysis methods and NES economics (NEST)

• Training and use of INPRO Methodology for NES sustainability assessment (NESA) – including update/revision of INPRO Methodology
...Thank you for your attention