INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO)

INPRO activities on Nuclear Fuel Cycle: Scenarios and Innovations

Presented by Zoran Drace
on the behalf of NENP/INPRO Section

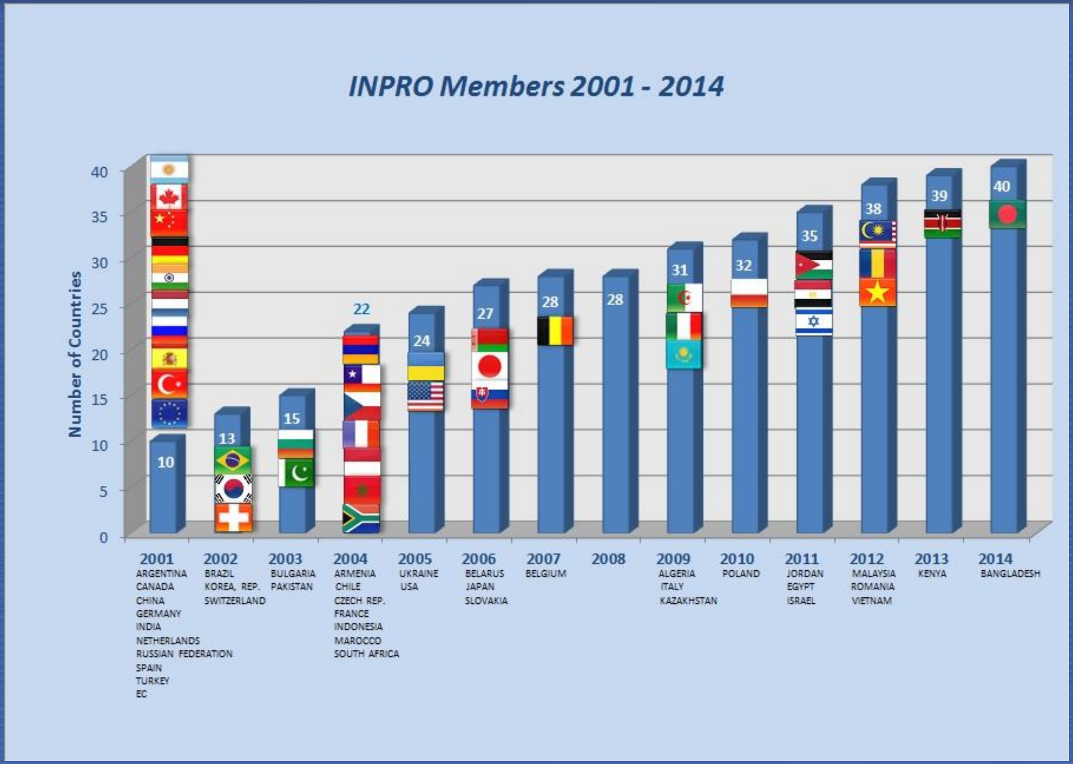
IAEA
International Atomic Energy Agency

INPRO Objectives

- To help to ensure that nuclear energy is available to contribute, in a sustainable manner, to meeting the energy needs of the 21st century
- To bring together technology holders and users to jointly consider the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles

INPRO Membership 2001-2014

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles



In 2014, INPRO has grown from an initial 10 to 40 members, which represent over 65% of the world population and 75% of the world's GDP. Several other countries have observer status as they consider membership or are participating on a project working level.

INPRO Tasks

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

1. INPRO provides long-term scenario evaluation using dynamic simulation of national, regional and global nuclear energy systems

2. INPRO designs and convenes **collaborative projects** on topics crucial to future nuclear sustainability and technological innovations.

3. INPRO **assists** Member States to build sustainable nuclear energy program strategies and plans through Nuclear Energy System Assessments (NESAs), using the INPRO Methodology.

4. INPRO organises **Dialogue Forums** on subjects of immediate interest to INPRO members and to the larger nuclear energy community.

INPRO Task 1: Global Scenarios

Objective:

To develop, on the basis of a scientific-technical analysis, global and regional nuclear energy scenarios that lead to a global vision on sustainable nuclear energy development in the 21st century.

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Collaborative Project SYNERGIES

- Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability (SYNERGIES)
- Duration: 2012–2014
- Objectives:
  - To identify and evaluate mutually beneficial collaborative architectures and the driving forces and impediments for achieving globally sustainable nuclear energy systems
  - To identify short-term and medium-term collaborative actions capable to develop pathways to long-term sustainability.
- Deliverable: IAEA report in 2015

Collaborative project SYNERGIES

Participants:

- Algeria, Armenia, Belarus, Belgium, Bulgaria, Canada, China, France, India, Indonesia, Israel, Italy, Japan, Republic of Korea, Malaysia, OECD-NEA, Pakistan, Poland, Romania, Russian Federation, Spain, Ukraine, USA and Vietnam are involved as participants or observers in different tasks *(UK recently joined as observer at SYNERGIES meetings)*

Collaborative project SYNERGIES

- Participants of the SYNERGIES meetings

Predecessor project “Global Architectures of Innovative Nuclear Energy Systems with Thermal and Fast Reactors and a Closed Nuclear Fuel Cycle”

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International Project on Innovative Nuclear Reactors and Fuel Cycles

http://www-pub.iaea.org/books/IAEABooks/8873/Framework-for-Assessing-Dynamic

Framework for Assessing D...

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Framework for Assessing Dynamic Nuclear Energy Systems for Sustainability - Final Report of the INPRO Collaborative Project GAINS

IAEA Nuclear Energy Series NP-T-1.14

Subject Classification: 0700-Nuclear power

STI/PUB/1598 (ISBN:978-92-0-140410-7) 253 pp.; 233 figures; 40.00 Euro;
Language: English
Date Published: 2013

DESCRIPTION

As an integral part of the international project on innovative nuclear reactors and fuel cycles (INPRO), several collaborative projects were established by its members. The collaborative project on global architectures of innovative nuclear energy systems based on thermal and fast reactors including a closed fuel cycle was one of them. This publication presents the study, its results and the conclusions drawn. A major achievement of the project is the development of a unique heterogeneous world model considering specific nuclear energy strategies of various countries. This model simulates important realities of the global nuclear energy system thus enabling the assessment of resource, financial, and proliferation risks and identification of areas for beneficial multilateral cooperation. It shows that innovative nuclear technologies serve as a driving force for enhancing the sustainability features of nuclear energy supply, while a multilateral approach amplifies the positive effects of the technological innovations.

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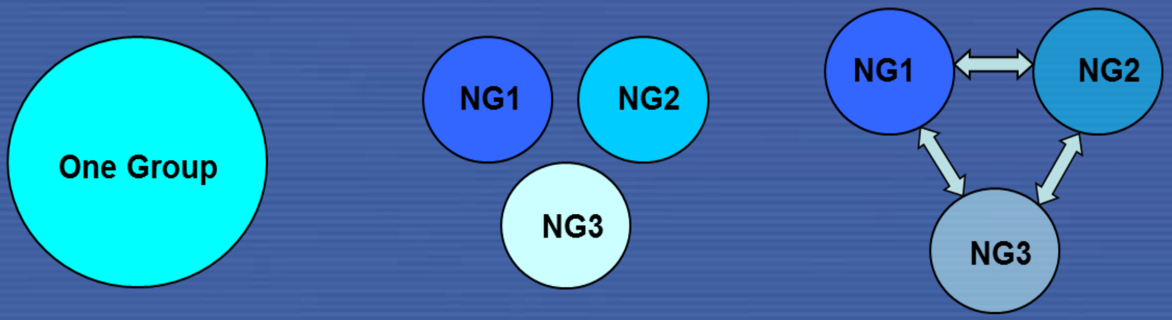
GAINS Framework

WORLD MODELS



(a) Homogeneous | (b1) Heterogeneous Non-Synergistic | (b2) Heterogeneous Synergistic

- Most analyses treat world as single technology group
  - Assumes all follow the same strategy and use the same facilities
- GAINS Framework also supports breaking world into three separate nuclear strategy groups following different fuel cycle strategies
  - NG1 starts with LWRs, transitions to a closed fuel cycle with fast reactors
  - NG2 maintains an open fuel cycle with LWRs and HWRs
  - NG3 starts with no reactors, develops LWRs & minimal fuel cycle infrastructure

NG1:NG2:NG3 = 0.4 : 0.4 : 0.2 with further sensitivity studies

GAINS major findings

WHICH MODEL WOULD THE WORLD FOLLOW? ADDITIONAL ECONOMIC STUDY

Conclusions:

- For small programmes of the fast reactors/closed nuclear fuel cycle deployment the economic benefits from their introduction would be substantially lower than the amount of investments needed for RD&D, licensing and deployment.
- Only a few countries in the world with large nuclear energy programmes (30 GW(e) for fast reactors) can bear the burden of the technology development for fast reactors/closed nuclear fuel cycle.
- Therefore, global nuclear energy system would follow a heterogeneous world model, at least, within the present century.

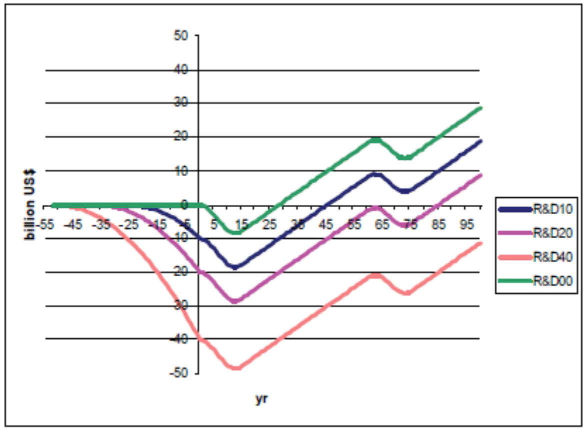
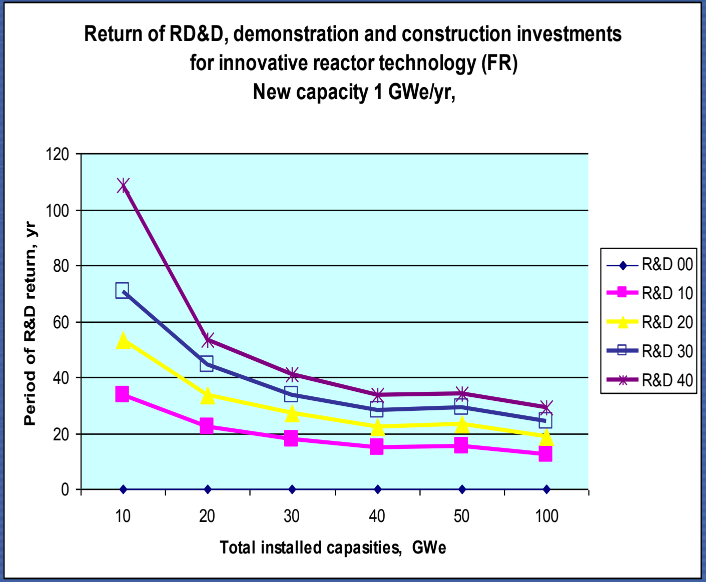


Fig.1. Return of RD&D and construction investments for the INS of 10 GWe



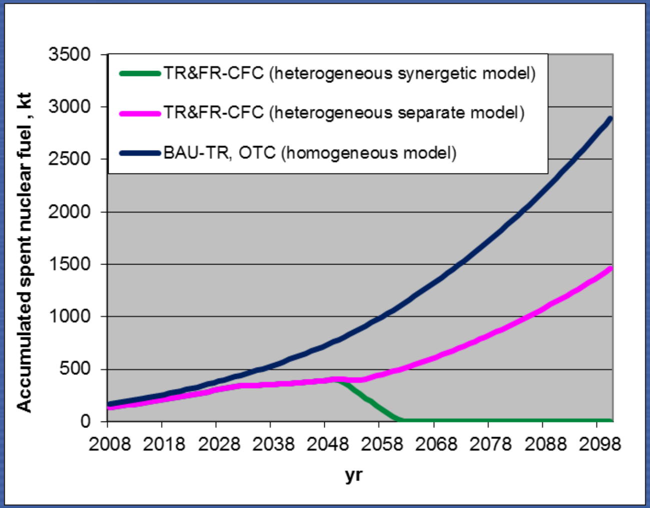
GAINS major findings

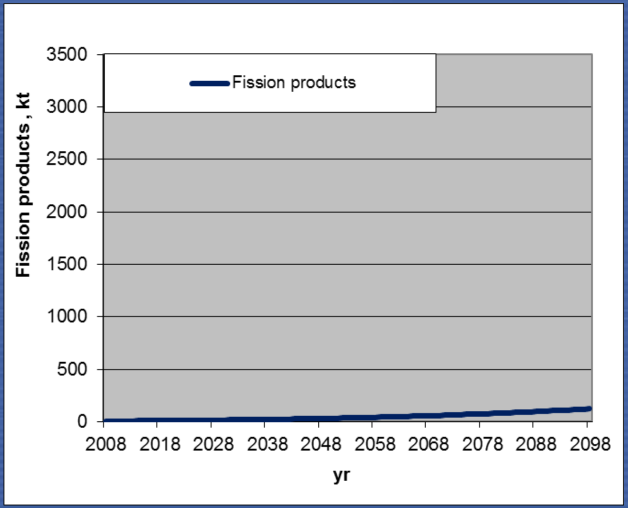
INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

SYNERGISTIC HETEROGENEOUS CASE: MINIMIZED SPENT FUEL ACCUMULATION

- Although few (NG1) countries will master fast reactor/fuel cycle technologies, all other countries (NG3 and NG2) could benefit from this if they follow *synergistic approach* in fuel cycle back-end, by sending their SNF to NG1 for reprocessing and used in fast reactor programmes

- Progressive accumulation of SNF on a regional and global scale could be mitigated or even reversed to limit the inventory of such fuel to MA and FP, or even only FP if MA are further incinerated in FR or dedicated transmutation systems





2100: 2500 GW(e) scenario

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SYNERGIES Structure

Task 1 (Core Task). Evaluation of Synergistic Collaborative Scenarios of Fuel Cycle Infrastructure Development

Task 4 (Cross-cutting Task). Elaboration of key indicators specific for synergistic collaboration, including economic assessment methods

Task 2 (Support Task). Evaluation of Additional Options for NES with Thermal and Fast Reactors

Task 3 (Support Task). Evaluation of Options for Minor Actinide Management (NES Expansion & Legacy Waste)

Task 1: About 30 case studies on-going around selected items of the SYNERGIES Storyline

SYNERGIES Task 1: Storyline

Today — **2025** — **2040** — **2050**

Technology 'off the shelf'

Synergistic Solutions:

- Shared NPP (investment)
- Shared capabilities & resources
- Front-End:
  - Multi-national facilities (URENCO, Angarsk)
  - Fuel Bank
  - MOX / 100% MOX / TOP-MOX/ERU & precycling schemes
- Back-End:
  - Recycling services
  - (Regional) interim storage solutions
- NPPs:
  - LWR / PHWR

Result of today's R&D

Additional Synergistic Solutions:

- Front-End:
  - Additional multi-national facilities
  - New fuels (dense: metal, nitride, Th, TRISO) opening additional options
  - Fuel leasing
- Back-End:
  - Additional regional recycling services (China, India, Japan, Russian Federation)
  - DUPIC
  - Multi-Pu recycling in LWRs
  - Regional interim storage solutions
  - (Regional) geological disposal sites deployment
- NPPs:
  - ALWRs / AHWRs
  - (oxide-fuel) FRs
  - SMRs / HTRs

Fruits of tomorrow's R&D

Additional Synergistic Solutions:

- Front-End:
  - Th/^{233}U cycle deployment
- Back-End:
  - Additional regional Recycling services (Rep. of Korea, Latin America, USA)
  - Advanced reprocessing technologies (P&T, Pyro, …)
- NPPs:
  - Proven F(B)R deployment
  - Maturing symbiotic NPP-parks with integrated fuel cycle schemes

SYNERGIES Scenarios

- 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 Case Studies

Attachment 2. Synergies planned deliverables table

#	Task/ Title	Responsible	Country	Status/Deadline
	Task 1			
1	Chapter on SYNERGIES storylines	L. Van den Durpel	France	Second Draft Submitted Complete draft to be provided by February 28th 2014
2	Task 1. Comparative assessment of collaborative fuel cycle options for Indonesia	B. Herutomo	Indonesia	In progress/ April-May 2014
3	Task 1. Recycle of REPU in PHWRs	D. Wojtaszek and G.W.R. Edwards	Canada	In progress/ Draft report in May 2014
4	Task 1. Scenario A.1 EU27 scenario with the extended use of regional fuel cycle centre composed of the La Hague and MELOX facilities and including Scenario A.1.1: Pre-cycling and /or TOP-MOX variant of introducing LWR-MOX in countries before domestically produced Pu can be recycled	L. Van den Durpel	France	In progress/ 31 January 2014
5	Task 1. National Romanian scenarios with reliance on domestic and imported U /fuel supply, by considering regional collaboration in nuclear fuel cycle and including economic analysis	C. Margeanu	Romania	In progress/ Draft report in May2014
6	Task 1.Scenario A.4 – National Argentinean scenario with cooperation options	S. Jensen	Argentina	Submitted
7	Task 1. Scenario B.1 with introduction of a number of fast reactors aimed at supporting the multi-recycle of Pu in LWRs and FRs: EU27 Framework	L. Van den Durpel	France	In progress/ 28 February 2014
8	Task 1. Scenario B.1 with introduction of a number of fast reactors aimed at supporting the multi-recycle of Pu in VVERs and FRs	G. Fesenko and V. Usanov	IAEA and Russia	Submitted
9	Task 1.Scenario B.2: ADRIA study	J. Manzano, M. Ciotti	Italy	In progress/ April 2014
10	Task 1. Scenario C.1 – Demo study on China simple case of NES scenario with Pu multi-recycling based on LWR and FR and CNFC	Keyan Zhou	China	In progress/ request to submit a report needs to be issued from IAEA/ April-May 2014
11	Task 1 Scenario C.2 and Task 3 - Long-term Scenario Study for Nuclear Fuel Cycle in Japan	K. Mukaida	Japan	Submitted, additional part to be submitted by May 2014
12	Task 1. Scenario C.3: Russia, Ukraine and Armenia study on the VVER-FR collaborative deployment scenarios aimed at solving the problem of accumulating spent fuel inventory to match FR deployment needs	V. Usanov, A. Egorov, O. Godun, V. Sargsyan	Russia,Ukraine, Armenia	Draft prepared/ May 2014
13	Task 1. Scenario C.3 with the VVER-FR collaborative deployment scenarios	O. Godun	Ukraine	Draft report under review/ May 2014
14	Task 1. Study on sensitivity of key indicators to the shares of the GAINS NG1/NG2/NG3 country groups	G. Fesenko and A. Egorov	IAEA and Russia	Submitted
15	Task 1. Study on sensitivity analysis to the shares of NG1/NG2 country groups in GAINS scenarios	A. Egorov	Russia	In progress/ February 2014
16	Task 1. Scenario D.1 - Evaluation of a scenario of transition of Th/233U fuel cycle	U. Malshe	India	In progress/ April 2014
17	Task 1. Scenario D.2 - Where, e.g. India though also considerable in other regions, Th is introduced earlier already in a LWR-phase to slowly breed 233U (despite not optimal) in view of furthering the multi-recycling potential of U and/or Pu in LWRs in complement to FRs	L. Van den Durpel	France	In progress/ 28February 2014
	Task 2			
18	Task 2. Alternative deployment strategy of Fast Reactors - start-up on enriched uranium fuel	A.Egorov	Russia	In progress/ May 2014
19	Task 2. Study on alternative fast reactor start-up deployment strategies	G. Fesenko and A. Egorov	IAEA and Russia	Submitted, economics to be added
20	Task 2.2 – Analysis of ALWR based scenario	K. Mukaida	Japan	In progress/ May 2014 (to be checked)
21	Task 2. Homogeneous and heterogeneous world mode scenarios with VVER-S, SMR and HTR, including non-electrical applications	E. Andrianova	Russia	Draft developed/ February 2014
22	Task 2. Scenarios with (i) replacement heat generation by small nuclear units, (ii) wide deployment of SCWRs	O. Godun	Ukraine	Started/ May 2014
	Task 3			
23	Task 3. Summary of a French study on radioactive waste transmutation options	L. Van den Durpel	France	TBD, once the report is translated into English, expected by March 2014
24	Task 3. Summary of EU scenarios with transmutation option for nuclear phase-out and continued nuclear scenarios	G. Van den Eynde	Belgium	Report in preparation/ Submission of a summary conditioned by a EU permission
25	Task 3. Analysis of Belgium nuclear phase-out scenario with and without ADS	G. Van den Eynde	Belgium	In progress/ May 2014
26	Task 3. Analysis of advanced European scenarios including transmutation and economical estimates	F. Martin-Fuertes	Spain	Partly completed, economic assessments to be added/ March 2014
27	Task 3. Transmutation using fast reactors	Keyan Zhou	China	In progress/ request to submit a report needs to be issued from IAEA/ April-May 2014
28	Task 3. A scenario analysis of re-burning LWR Americium in HWRs	D. Wojtaszek and G.W.R. Edwards	Canada	In Progress/ Draft report in May 2014
New	Task 3. Luc Van den Durpel to provide Task 1 Scenario A.1 full data to Gert Van den Eynde to perform transmutation options analysis	L. Van den Durpel G. Van den Eynde	France Belgium	December 9th 2013
New	Task 3. Contribution on Am use for space applications	D. Mathers	UK	To be checked
	Task 4			
29	Task 4. Economic data on nuclear reactors and fuel cycle facilities/services	G. Fesenko and D. Shropshire	IAEA	In progress/ current version available on SYNERGIES Web page
30	Task 4. Comparative economic analysis of selected synergistic and non-synergistic GAINS scenarios	G. Fesenko	IAEA	Submitted
31	Task 4 – Report on KI down selection	IV. Dulera, C. Johari, Leaders of Tasks 1-3	India and IAEA	Draft report developed/ Available on SYNERGIES web-page

SYNERGIES Final Report Outline

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INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

Attachment 1.

Outline of the Final Report of the INPRO Collaborative Project "
Energy Regional Group Interactions Evaluated for Sustainabilit

TABLE OF CONTENTS

EXECUTIVE SUMMARY

CHAPTER 1. INTRODUCTION *(to be developed by the INPRO Sec*

1.1. Background

- Sustainable nuclear energy systems,
- Levels of sustainability,
- Pathways to sustainability,
- INPRO project "Global scenarios",
- GAINS – SYNERGIES –ROADMAPS activity line

1.2. Definitions

1.3. Objectives

- ToR for the SYNERGIES collaborative project

1.4. Scope and structure of the report

References to Chapter 1

CHAPTER 2. SYNERGIES STORYLINES AND SCENARIO FA *developed by Mr Luc Van den Durpel and Mr Brent Dixon)*

- Major drivers and impediments towards nuclear energy deployn regional and/or global scale
  - nuclear energy's key features and key drivers defining s scenarios for nuclear energy deployment
- Key challenges towards global sustainable deployment of nucle
- Significance of international collaboration and types of synergie sustainable nuclear energy deployment
- Synergies among technologies
- Synergies through collaborations among countries/ entities
- Scenario families
- Drivers and impediments for collaboration among countries, ge specific
- Collaborations among countries/ entities as a mechanism to am technologies
- Key recommendations towards increased synergies for nuclear e

References to Chapter 2

CHAPTER 3. MAJOR FINDINGS OF SYNERGIE

3.1. Introduction to Chapter 3 *(to be developed by t*

Summary table of studies explaining their attributes:

(a) Scenario family: global, regional, national;
(b) Material flow analysis (MFA only)/ (MFA and
(c) Relevance to heterogeneous/homogeneous wo framework); for heterogeneous case: synergist
(d) Reactor and fuel cycle types used in the analys
(e) Category of synergies examined: technology o
(f) Where to read the full material, i.e., number of report;

3.2. Scenarios of regional cooperation based on exis *be developed by Mr V. Usanov, Mr. A. Egorov,Ms G. and Mr O. Godun)*

- Russia, Ukraine and Armenia study on the VV scenarios aimed at solving the problem of accu FR deployment needs (# 12 and 13 in Attachm
- ADRIA study (# 9 in Attachment 2);
- Study on sensitivity of key indicators to the sh country groups (# 14 and 15 in Attachment 2);
- Comparative economic analysis of selected sy scenarios (# 30 in Attachment 2) and others, as
- Recycle of REPU in PHWRs (# 3 in Attachme

3.3. Scenarios illustrating the potential of a variety approaches *(to be developed by Ms E. Andrianova, M den Durpel, Ms K. Mukaida and Ms G. Fesenko)*

- Scenario B.1 with introduction of a number of multi-recycle of Pu in LWRs and FRs (# 7 and
- Alternative deployment strategy of Fast Reacto (# 18 and 19 in Attachment 2);
- Analysis of ALWR based scenario (# 20 in Att
- Homogeneous and heterogeneous world mode HTR, including non-electrical applications (#
- Scenarios with (i) replacement heat generation deployment of SCWRs (# 22 in Attachment 2)

3.4. Medium and long term national scenarios *(to b Jensen, Mr. U. Malshe, Ms C.A. Margeanu)*

- National Argentinean scenario with cooperatio
- Long-term Scenario Study for Nuclear Fuel Cy
-
- Scenario D.1 – Evaluation of a scenario of tran Attachment 2).

National Romanian scenarios with reliance on domestic and imported U /fuel supply, by considering regional collaboration in nuclear fuel cycle and including economic analysis (# 5 in Attachment 2)

3.5. Scenarios with advanced minor actinide management *(to be developed by Mr G. Van den Eynde and Mr L. Van den Durpel)*

- All scenarios related to Task 3 (## 23-28 and the following two new activities in Attachment 2)

References to Chapter 3

CHAPTER 4. ECONOMIC ASSESSMENT METHODS AND KEY INDICATORS *(to be developed by Mr U. Malshe, Ms G. Fesenko, Ms C. Johari and Task leaders for Task 1-3)*

4.1. Introduction to Chapter 4

4.2. Economic assessment methods and data

4.3. Key indicators for transition scenarios to sustainable nuclear energy systems (NES)

References to Chapter 4

CHAPTER 5. NEAR AND MEDIUM TERM ACTIONS TO ENSURE LONG TERM SUSTAINABILITY OF NUCLEAR ENERGY SYSTEMS *(to be developed by Mr Luc Van den Durpel, Mr Brent Dixon, IAEA Secretariat and Task leaders for Tasks 1-4)*

This was part of the original SYNERGIES ToR, and it is recognized that this is in many parts non-technical and policy related. Since that time a proposal for the ROADMAPS collaborative project has been developed and reference is made to this new project to elaborate on non-technical issues. However, some technical issues will be summarized in this chapter, such as FR development, development of advanced technologies for MA transmutation, etc. Additionally, a link between the SYNERGIES project and the remaining questions to be addressed by the ROADMAPS project would be highlighted, pointing to the overall (strategic) decisions that would need to be timely made to ensure a meaningful contribution of nuclear energy to global sustainable development.

References to Chapter 5

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS *(to be developed by the IAEA Secretariat and Task leaders for Tasks 1-4)*

6.1. Possible directions of future activities

References to Chapter 6

ANNEXES – Contributions from Member States (## 1-31 and two new activities in Attachment 2) – *Argentina, Armenia, Belgium, Canada, China, France, India, Indonesia, Italy, Japan, Romania, Russian Federation, Spain, Ukraine, including those developed in cooperation with the IAEA's INPRO Group*

ACRONYMS

3

Task 4. Example: Economic data Report

Table 1.3. Enrichment facilities costs (data sources [6])

Firm/Facility	Capacity	Investment	Overnight cost	O&M cost	Lev. Inv. cost	Tot. Lev. cost
	MSWU/yr	M 2008$	$/kgSWU	$/kgSWU	$/kgSWU	$/kgSWU
Future Centrifuge Capacity						
Urenco NEF	3.0	1650	550	21	41	62
Eurodif Besse II	7.5	4066	542	20	41	60
Areva Idaho	3.0	2000	667	23	50	73
USEC ACP	3.8	3500	921	32	69	101
Brasil Resende	0.2	278	1369	54	103	156
Operating Centrifuge Capacity (Europe and Japan)						
JNFL Rokkasho	1.5	1095	730	33	47	80
Urenco Gronau	1.8	1445	803	32	52	84
Urenco Almelo	2.9	2076	716	27	47	73
Urenco Capenhurst	3.4	2342	689	26	45	70
Existing Centrifuge Capacity (Russia)						
TENEX Angarsk	2.5	1854	742	18	48	66
TENEX Zelenogorsk	7.4	4226	572	16	37	53
TENEX SKhK	3.7	2472	677	19	44	63
TENEX UEKhK,	12.5	6282	505	15	33	47

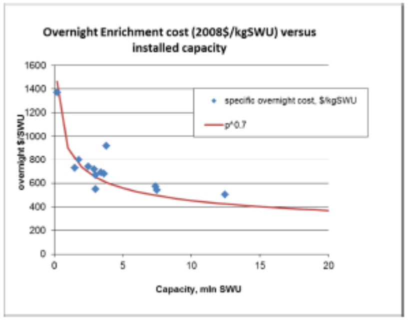


Fig.1.5. Overnight Enrichment cost (2008$/kgSWU) versus installed capacity

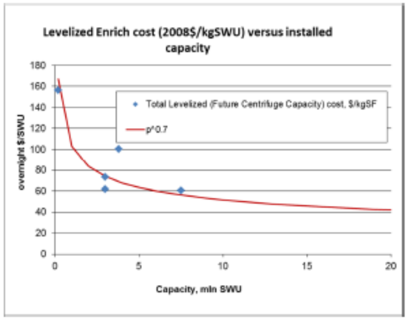
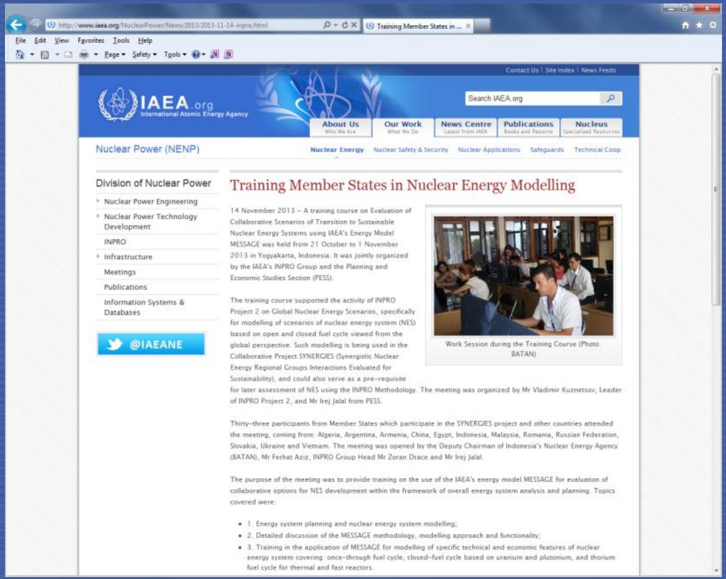


Fig.1.6. Levelized Enrich cost (2008$/kgSWU) versus installed capacity

Training course on evaluation of collaborative scenarios of transition to sustainable nuclear energy systems using IAEA's energy model MESSAGE (jointly with PESS)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Training Member States in Nuclear Energy Modelling

14 November 2013 – A training course on Evaluation of Collaborative Scenarios of Transition to Sustainable Nuclear Energy Systems using IAEA's Energy Model MESSAGE was held from 21 October to 1 November 2013 in Yogyakarta, Indonesia. It was jointly organized by the IAEA's INPRO Group and the Planning and Economic Studies Section (PESS).

Work Session during the Training Course (Photo: BATAN)

The training course supported the activity of INPRO Project 2 on Global Nuclear Energy Scenarios, specifically for modelling of scenarios of nuclear energy system (NES) based on open and closed fuel cycle viewed from the global perspective. Such modelling is being used in the Collaborative Project SYNERGIES (Synergistic Nuclear Energy Regional Groups Interactions Evaluated for Sustainability), and could also serve as a pre-requisite for later assessment of NES using the INPRO Methodology. The meeting was organized by Mr Vladimir Kuznetsov, Leader of INPRO Project 2, and Mr Irej Jalal from PESS.

Thirty-three participants from Member States which participate in the SYNERGIES project and other countries attended the meeting, coming from: Algeria, Argentina, Armenia, China, Egypt, Indonesia, Malaysia, Romania, Russian Federation, Slovakia, Ukraine and Vietnam. The meeting was opened by the Deputy Chairman of Indonesia's Nuclear Energy Agency (BATAN), Mr Ferhat Aziz, INPRO Group Head Mr Zoran Drace and Mr Irej Jalal.

The purpose of the meeting was to provide training on the use of the IAEA's energy model MESSAGE for evaluation of collaborative options for NES development within the framework of overall energy system analysis and planning. Topics covered were:

- 1. Energy system planning and nuclear energy system modelling;
- 2. Detailed discussion of the MESSAGE methodology, modelling approach and functionality;
- 3. Training in the application of MESSAGE for modelling of specific technical and economic features of nuclear energy system covering: once-through fuel cycle, closed-fuel cycle based on uranium and plutonium, and thorium fuel cycle for thermal and fast reactors.

SYNERGIES: Expected Outcomes

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International Project on Innovative Nuclear Reactors and Fuel Cycles

- SYNERGIES is deemed to support development of comprehensive national nuclear energy strategies regarding international collaboration to achieve sustainable regional and global NES.

- In particular, SYNERGIES will help:

➢ define attractive innovative fuel cycle options possible at a regional level and promote an improved understanding of associated front-end and back-end regional interactions

➢ identify technical and institutional gaps that still need to be addressed within the specific future projects

- Next logical step could be to identify *“who could do what, where and when”* to achieve sustainable NES

RUSSIA :

REGIONAL CENTER (HIGH AND LOW FR SHARE)

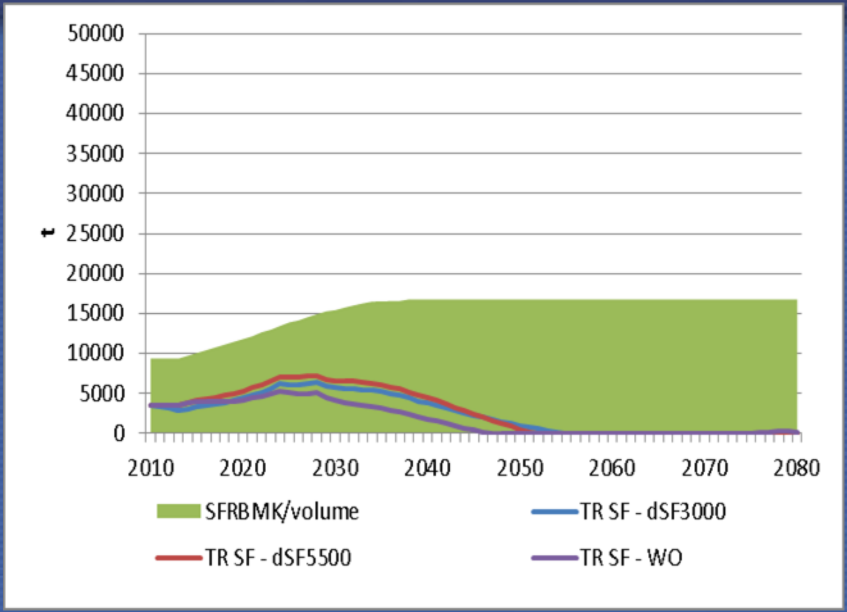
Total NP capacities: 100 GWe by 2050, 160 GWe by 2100;

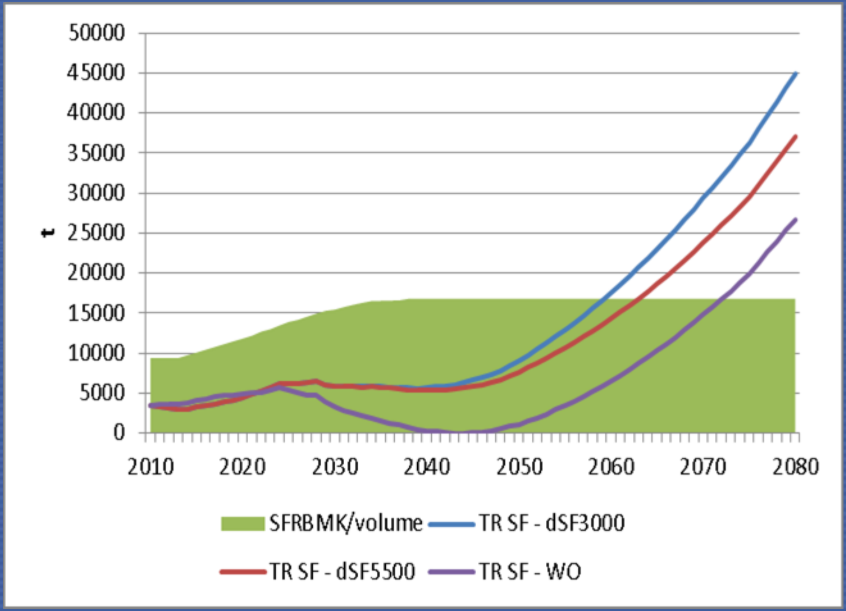
High share of FR (based on Pu availability): ~50% by 2050; ~80% by 2100;

Low FR share: ~25% by 2050; ~40% by 2100.

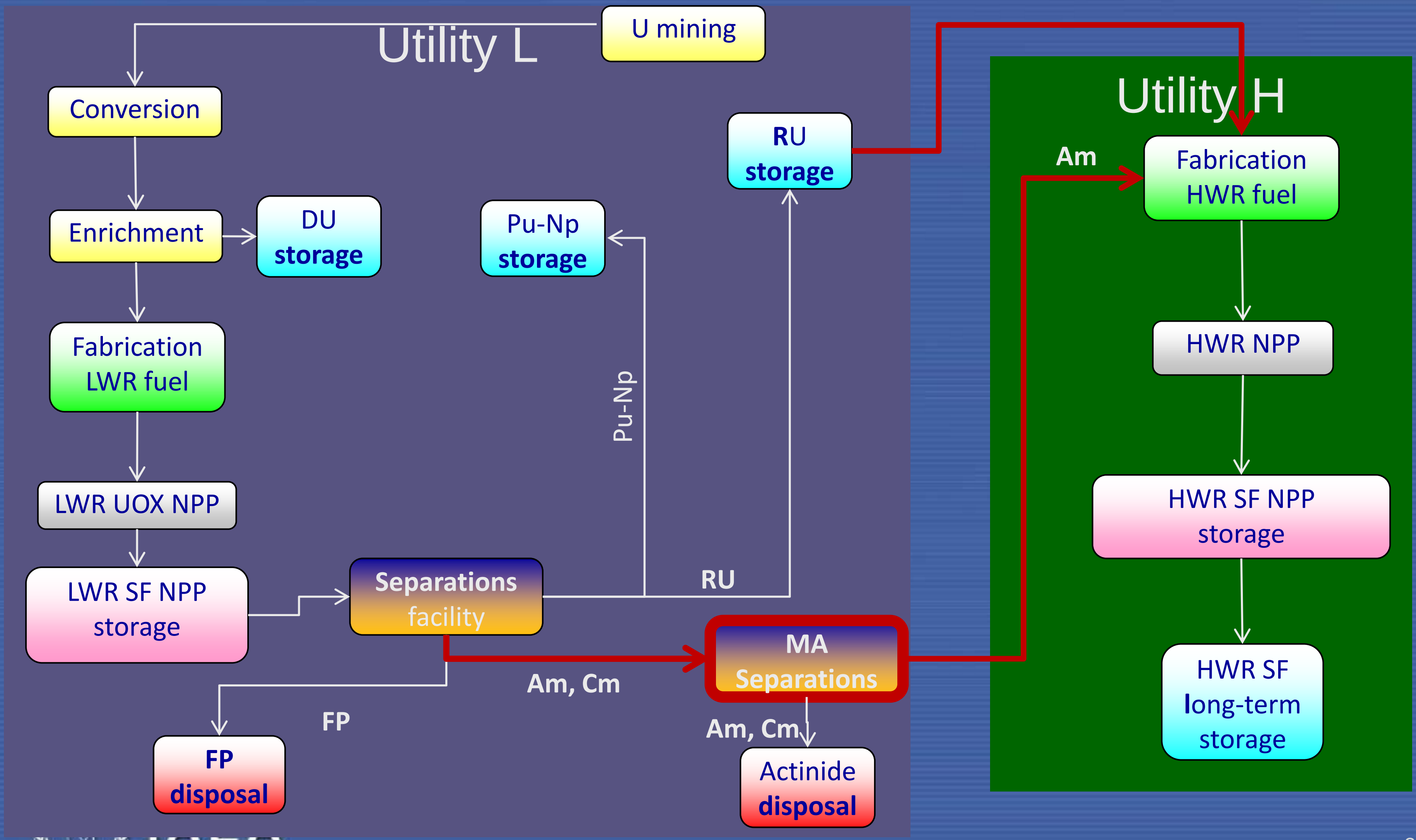
- Slowing down with the FR introduction results in SF accumulation in the storages
- Under high FR share in the NES and without impediments, Pu from SF of Russian and Ukraine VVERs could be reused by 2050

WO – FR share without regional cooperation;
dSF3000 – High scenario of Ukraine NE development
dSF5500 – Moderate scenario of Ukraine NE development





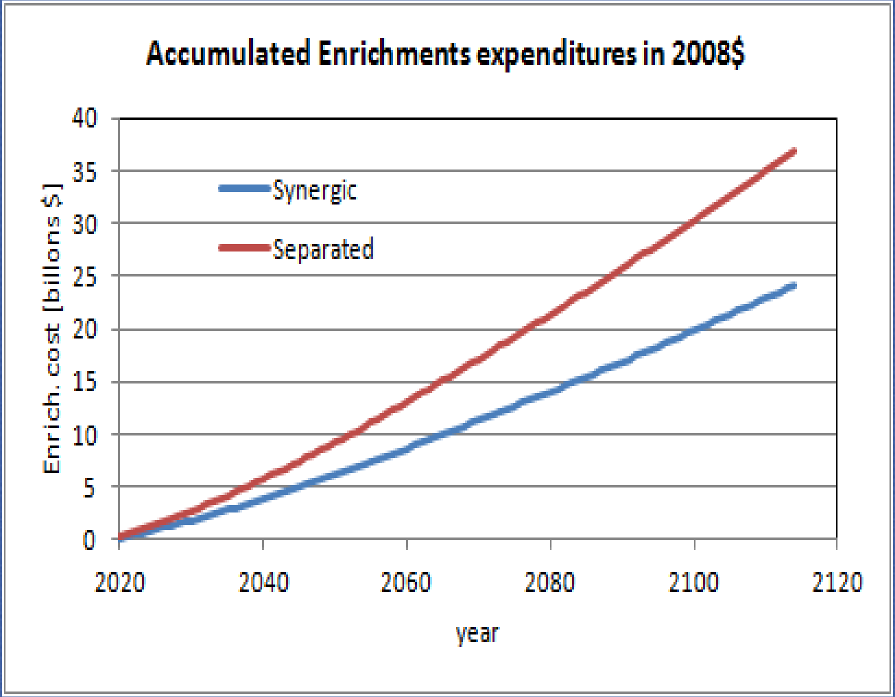
Canada: A Scenario Analysis of Re-burning LWR Americium in HWRs

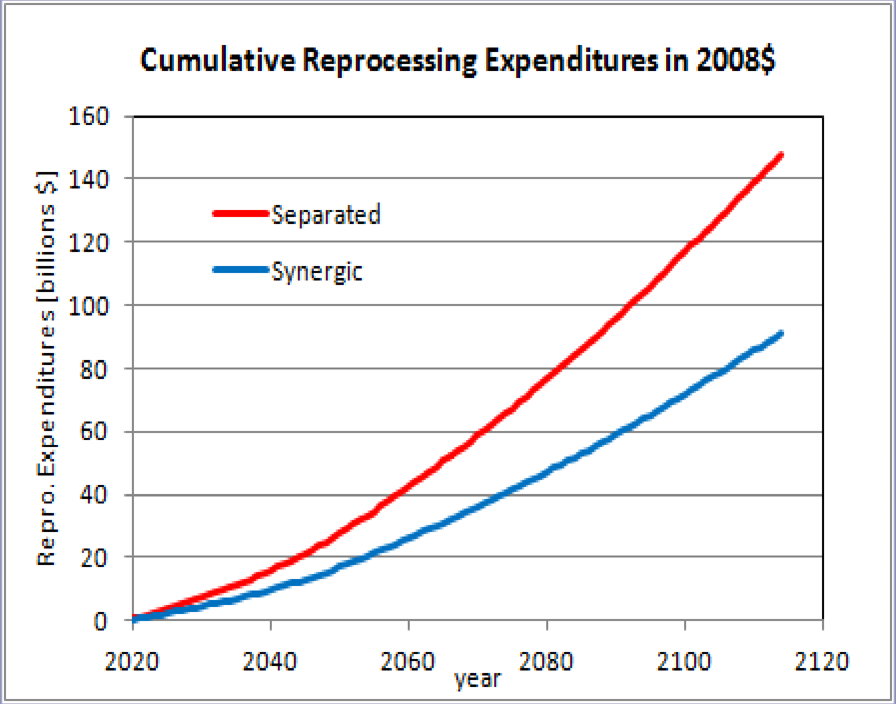


Italy:
ADRIA Regional Scenario

Regions:
- **I. SEE (South East Europe)**
- **II. Slovenia, Czech Republic, Slovakia, Hungary**
- **III. Italy**
- **IV. Ukraine**

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles





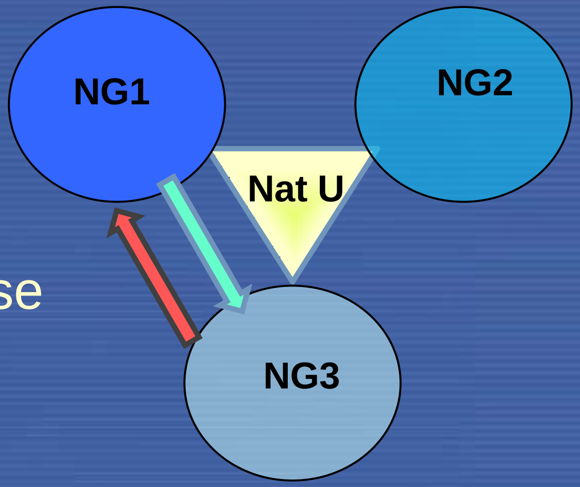
- Sharing the Enrichments facilities bring an accumulated difference of 12.8 billion$
- Synergies allows 35% save on total Enrichment Expenditures.

- Sharing the Reprocessing facilities bring an accumulated difference of 60 billion$.
- Synergies allow 39% save on total Reprocessing Expenditures.

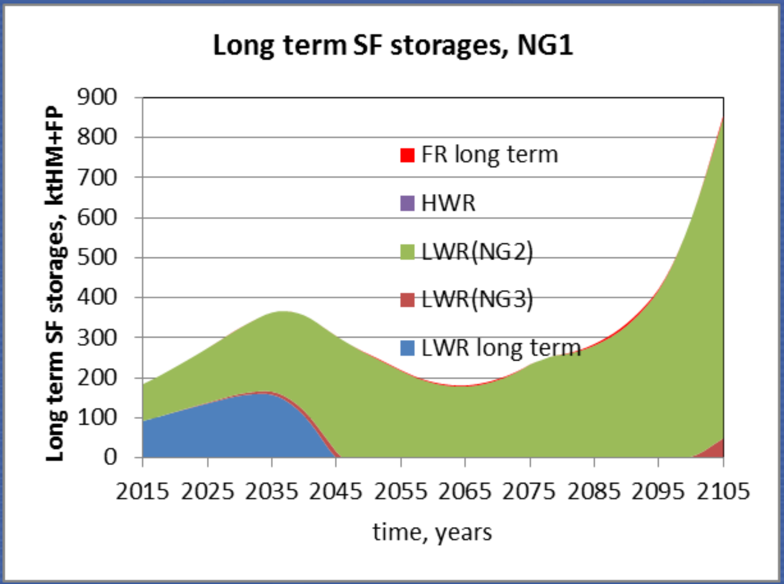
INPRO GROUP:

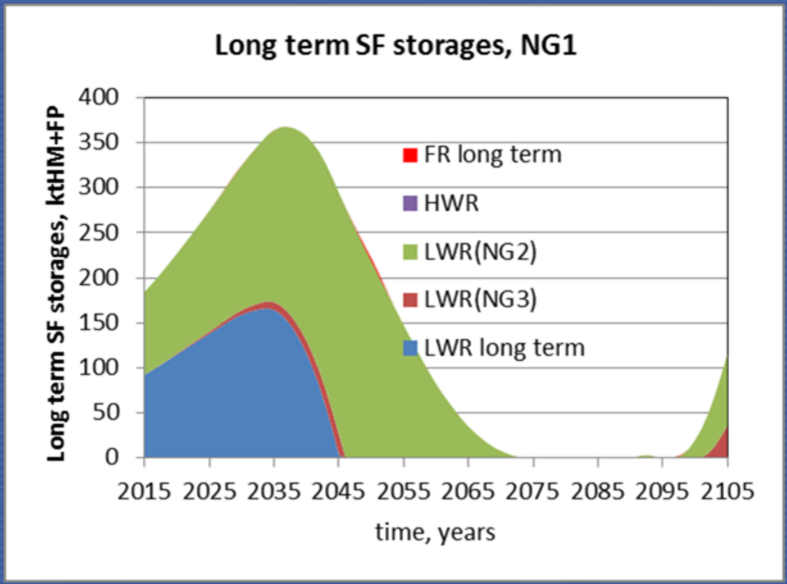
STUDY ON SENSITIVITY OF KEY INDICATORS TO THE SHARES OF THE GAINS NG1/NG2/NG3 COUNTRY GROUPS

- NG1 share always a nominal fraction (40% in 2100)
- NG3 share in 2100 varied as 10%, 20% (nominal), 30%, 40%, 50% of total demand
- Separate (non-synergistic) and synergistic case : NG1 provides 100% of the fresh fuel and taking back 100% of the spent fuel
- Impact of NG3 share on key output parameters for Front end and Back end requirements



Impact of NG3 and NG2 on NG1 (nominal case and high NG1 growth case)

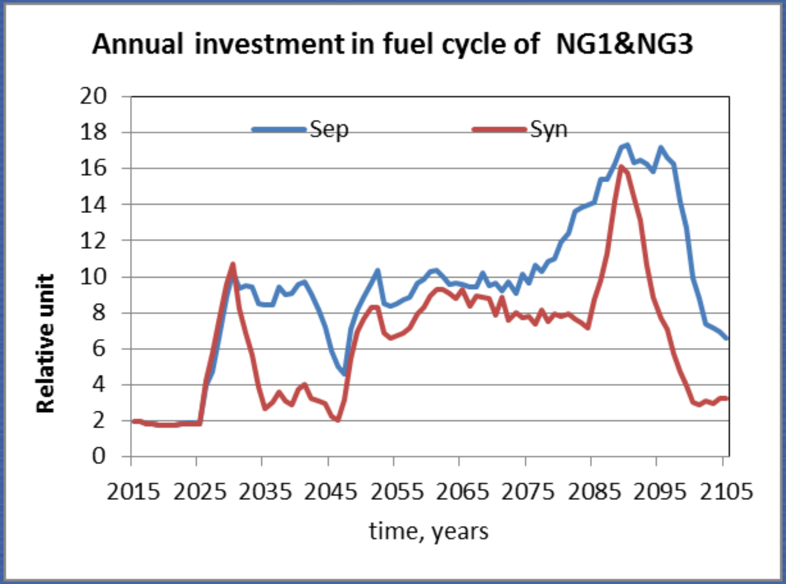


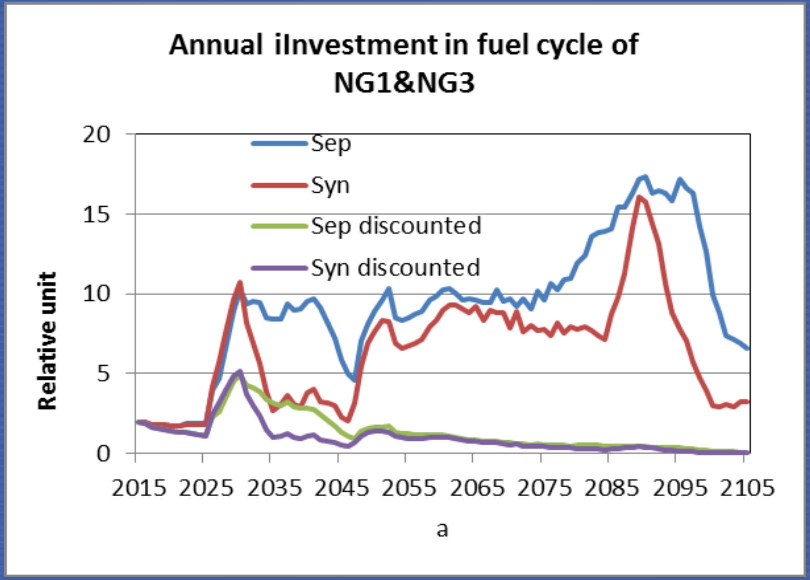


LWR long term storage in NG1 (nominal case, NG3&NG2 impact)

LWR long term storage in NG1 (High NG1 growth case, NG3&NG2 impact)

Relative investments in NFC for separate and synergistic nominal cases





INPRO Task 2 : Innovations

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

Objective:

- **The objective is to investigate innovations in selected nuclear energy technologies, related R&D and innovative institutional arrangements for deployment of innovative NESs in the 21st century.**
- **INPRO wants to focuses on specific innovations, recommended by Member States as well as on subjects that are complementary to activities in the areas of INPRO Methodology and Global Scenarios**
- **Action Plan 14/15 provides new projects on Nuclear Fuel and Fuel Cycle analysis for future NES and Waste from Innovative Types of Reactors and Fuel Cycles**

CP Nuclear Fuel and Fuel Cycle analysis for future NES (FANES), 2014-2015

Objective:

- Carry out feasibility analyses of advanced and innovative fuels and its influences on development of future NES.
- Analyse spent fuel management options for advanced and innovative FC addressing potential technology improvements.

Scope:

- ✓ Provide an overview of advanced and innovative fuels for different NES.
- ✓ Identify influences of advanced and innovative fuels on development of NES.
- ✓ Consider the technical viability of several options for fabrication of advanced fuel and its reprocessing in order to identify key innovations which are necessary for deployment of future NES.

Output: A TECDOC series publication.

CP Waste from Innovative Types of Reactors and Fuel Cycles (WIRAF), 2014-2015

Objective:

- Identify the potential wastes arising from for advanced and innovative reactors and their fuel cycles and eventually the technical needs for managing such wastes.
- Identify if there are any potential or known show-stoppers to for advanced and innovative reactors and their fuel cycles resulting from new or existing waste types.

Scope:

- ✓ Identify the optimal disposition (processing and disposal) pathways for the most common of these wastes (e.g., combustible, ferrous metals, resin, sludge, etc.); and
- ✓ Identify any problematic wastes from particular advanced and innovative reactor design which will require further study as part of a separate project and publication.

Output: A TECDOC series publication.

Back End Study

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- At a number of INPRO meetings such as SYNERGIES Technical Meetings, the 4th INPRO Dialogue Forum on Drivers and impediments for regional cooperation on the way to sustainable Nuclear Energy Systems (NESs) and others, it was noted that particular legal and institutional impediments for collaboration among countries in Fuel Cycle Back End exist.

- Examination of such impediments and outlining the pathways for their resolution might be an important near term step to ensure effective cooperation among countries toward long term sustainable nuclear energy.

- Therefore it could be recommended to initiate a new study on Multilateral Approaches to the Back End of Nuclear Fuel Cycle: drivers and legal, institutional and financial impediments.

Objectives of Study on Multilateral Approaches to the Back End of Nuclear Fuel Cycle

Objective:

- Carry out feasibility analyses of mechanisms for international cooperation in the area of Nuclear Fuel Cycle Back End, such as return of spent fuel to the country of origin, etc.
- Analyse legal aspects of international cooperation in the area of Nuclear Fuel Cycle Back End.
- Analyse institutional impediments of international cooperation in the area of Nuclear Fuel Cycle Back End.
- Study economic aspects of international cooperation in the area of Nuclear Fuel Cycle Back End.
- Analyse spent fuel management options for advanced and innovative fuel cycles addressing potential technology improvements.

THANK YOU !

Zoran DRACE
Z.Drace@iaea.org

IAEA
International Atomic Energy Agency