Joint Stock Company (JSC) State Scientific Centre
"Institute for Physics and Power Engineering" after
A.I. Leypunsky

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ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

The Roadmap Template and Examples of Its Application

(an approach to development of a country level roadmap)

V. Usanov, S. Kvyatkovskiy, P. Moseev

INPRO Dialogue Forum on Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems, 20-23 October 2015, IAEA, Austria, Vienna

PUBLIC REQUEST AND POLITICAL SUPPORT FOR NUCLEAR POWER RENOVATION

- At the turn of the millennium much of the public, experts and professionals came to the conclusion that current nuclear power has faced majour challenges
- The need to update nuclear power was recognized and supported at the political level
- Two major projects were launched up in 2000: the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and the Generation IV International Forum
- 2006: Summit on Global Energy Security, St. Petersburg

  "We acknowledge the efforts made in the complementary frameworks of the INPRO project and the Generation IV International Forum"

OBJECTIVES OF THE ROADMAPS PROJECT AND INTERPRETATION OF SUSTAINABILITY FOR A NUCLEAR ENERGY SYSTEM (NES)

- **Contribution to enhancing NP sustainability** is a mission of IAEA/INPRO project
- The overall **objective of the ROADMAPS project is to develop a structured approach for making transition to a globally sustainable NES**, including the roadmap template to document actions, scope of work, and timeframes for specific collaborative efforts by particular stakeholders
- The principles and requirements of INPRO Methodology on a **sustainable nuclear energy system (NES)** were developed on a basis of the **UN general concept of sustainability**
- Under development of a country roadmap we were guided by these **principles and requirements**

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MAJOUR OBJECTIVES OF THE NES SUSTAINABILITY IN THE IAEA/INPRO PROJECT

POCATOM

Infrastructure
A country shall be able to adopt, maintain or enlarge an NES for the supply of energy and related products without making an excessive investment in national infrastructure

Economics
Energy and related products and services from nuclear energy systems shall be affordable and available

Safety
Future NES facilities should be so safe that they can be located on the same site as non nuclear industrial installations

Sustainable NES

Waste Management
Nuclear waste must be managed so that human health and environment are protected and undue burdens on future generations are avoided

Environment
Impact of stressors from future NES must be within performance envelope of current NES. Resources must be available to run NES until end of 21st century

Physical protection
Efficient and effective regime to be implemented for whole life cycle of NES

Proliferation Resistance
Future NES must remain unattractive for a NW program by a combination of intrinsic features and extrinsic measures

GLOBAL AND LOCAL SUSTAINABILITY OF NUCLEAR ENERGY SYSTEMS

- **A full-scale sustainable NES can be built only at a global level:**
  - directions of the technology development are very diverse, it is unlikely that a single country could manage all of them;
  - even if a country met requirements of sustainability, severe accident or violation of the nonproliferation regime in other part of the world would impact the country, region and the whole NE community;
  - cooperation and complementarity of technology holders and technology users are critical points in the global sustainability
- Therefore **local sustainability** is considered only as **an integral part of the global one**
- The Russian Federation makes considerable efforts to enhance national (local) sustainability and to contribute to the sustainability at the global level
- This presentation summarizes some issues which Russian participants met with when participating in the development of a ROADMAPS Template and displays some findings of the work

IMPLEMENTATION OF RD&D AND STRENTHENING INTERNATIONAL COOPERATION

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POCATOM

Two majour directions are currently being implementing in Russia for enhancing sustainability:

- **nuclear technology innovations;**
- **broad international collaboration;**

both are supported in RF at the political level

"There is no doubt that innovative technologies will be required to develop a new generation of reactors and their fuel cycles. These issues can be resolved only with broad international cooperation."
V. Putin

RD&D:

- **Conceptual NES development:**
  - FR with heavy metal coolants, new nitride fuel, on-site NFC, etc.
- **Evolutionary NES development:**
  - New PWR, sodium FR, MOX fuel, demo-industrial NFC installations on PWR reprocessing, MOX fuel fabrication, waste management

International collaboration:

- **Market activities:**
  - NPPs abroad, NFC services
- **International projects & forums:**
  - Participation in & support of IAEA/INRO;
  - GIF, OECD, etc.
- **Sharing R&D infrastructure**
  - experimental facilities, research reactors (MBIR), power reactors BN-600/800
- **Development of human resource**

ENHANCING SUSTAINABILITY

- An approach to development of **a roadmap template** for an illustrative technology holder was addressed in a Russian study within ROADMAP project

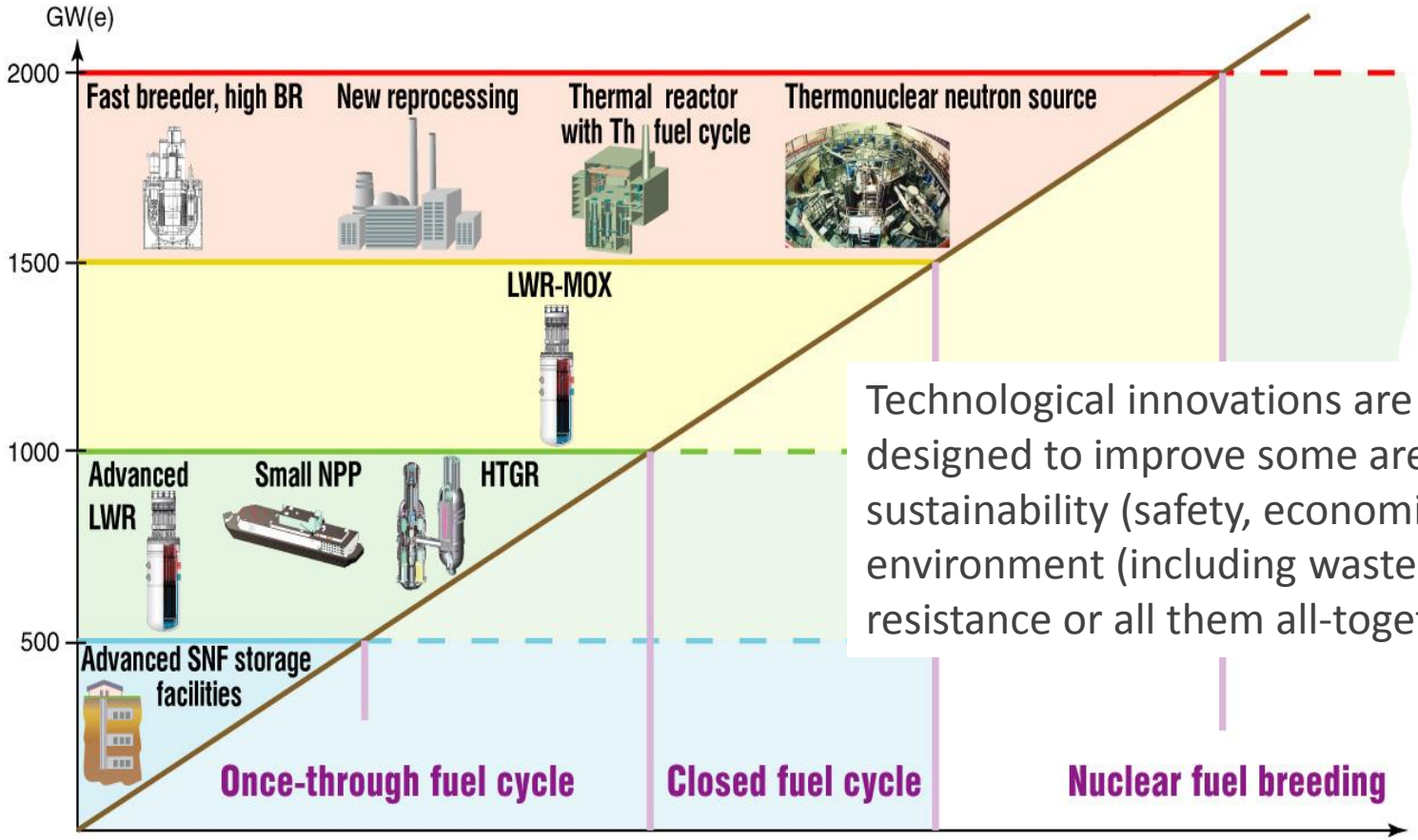
- Nuclear technology **innovations and international collaboration** was assumed to be majour leverages for enhancing NES sustainability for a technology holder

- Current NP is a ***starting point*** for further technological development. It is considered as a socially acceptable option which provides contribution to the security of energy supply and meets current requirements for safety, economy, environmental protection and non-proliferation

- However, **sustainability of NP can be enhanced** in order to provide:

  - ***Solution of the problem of accumulation of SNF*** *by its safe disposal or reprocessing;*
  - ***Complete use of fissile materials from SNF*** *by their recycling and thus* ***strengthening non-proliferation regime;***
  - ***Saving of natural uranium resources*** *via complete recycle of FM;*
  - ***Reduction radiotoxicity of all wastes*** *by the level of natural uranium, etc.*

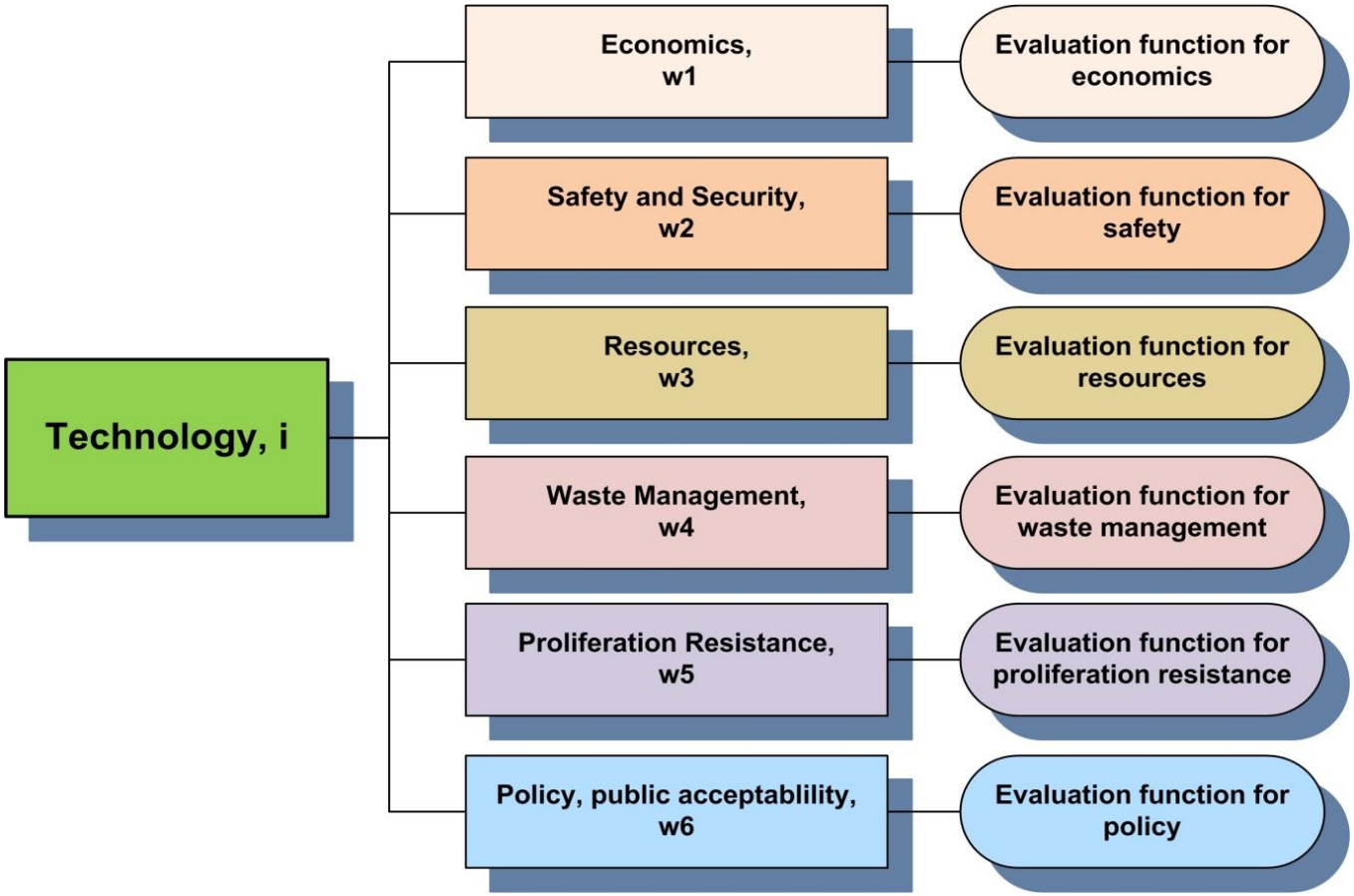
EXAMPLE OF TECHNOLOGICAL INNVATIONS FOR ENHANCING SUSTAINABILITY



Technological innovations are eventually designed to improve some areas of sustainability (safety, economics, environment (including waste), proliferation resistance or all them all-together

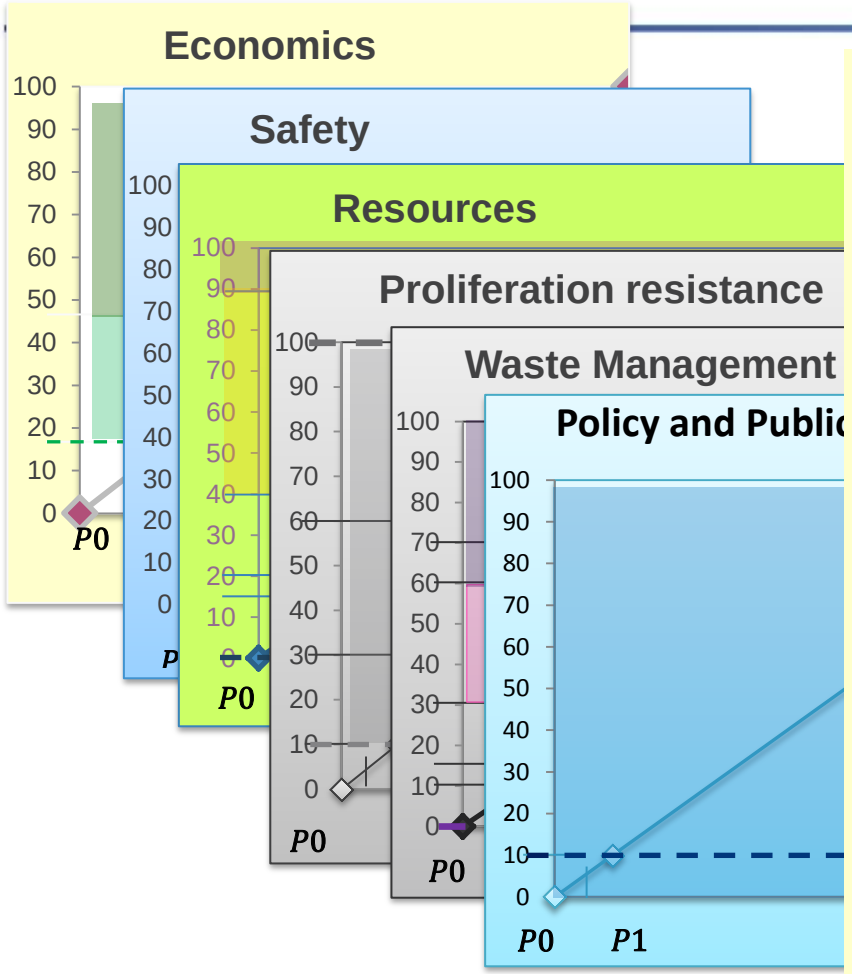
Ref.: IAEA, Nuclear Energy Development in the 21st Century: Global Scenarios and Regional Trends. IAEA NE Series, No. NP-T-1.8, VIENNA, 2010.

COULD STEPS IN ENHANCING NES SUSTAINABILITY BE QUANTIFIED IN DIFFERENT SUBJECT AREAS?



*To provide quantitative assessment of the effectiveness of technological innovations **evaluation functions** should be developed*

OBJECTIVE FUNCTIONS TO BE BUILT IN ALL SUBJECT AREAS FOR NES ASSESSING IN ALL OF THEM



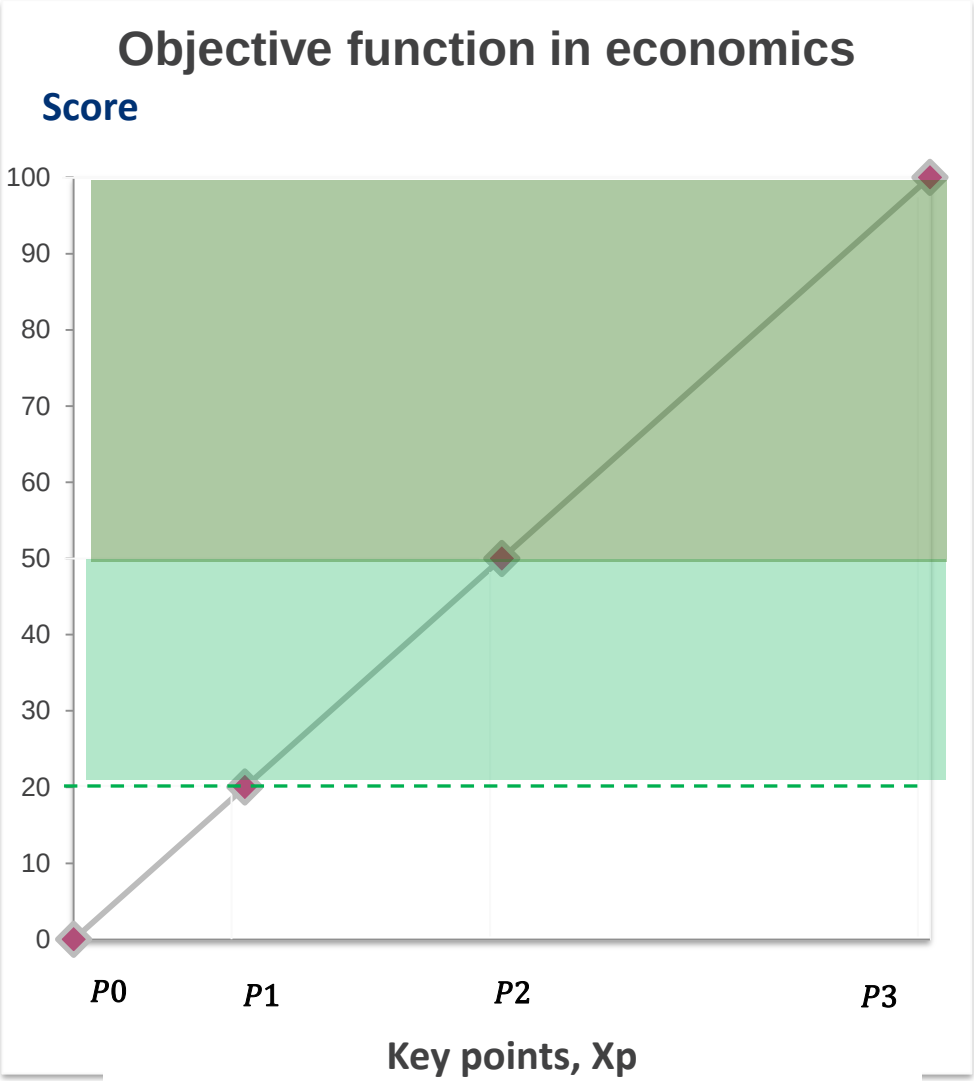
Possible desired targets:

- **Economics:** best economic indicators in energy sector
- **Safety:** exclusion of public evacuation or relocation
- **Resources:** radical reduction of U consumption
- **Proliferation Resistance:** balancing of FM generation and consumption
- **Waste Management:** geological repository without Pu, MA in waste, radiotoxicity of waste in 2-3 hundred years - by the level of natural uranium

For common application of the approach, desired targets and intermediate key points (key events) should be agreed

A NES should be assessed in dynamics from now to the end of projected period

PRELIMINARY VIEW OF AN OBJECTIVE FUNCTION FOR ECONOMICS



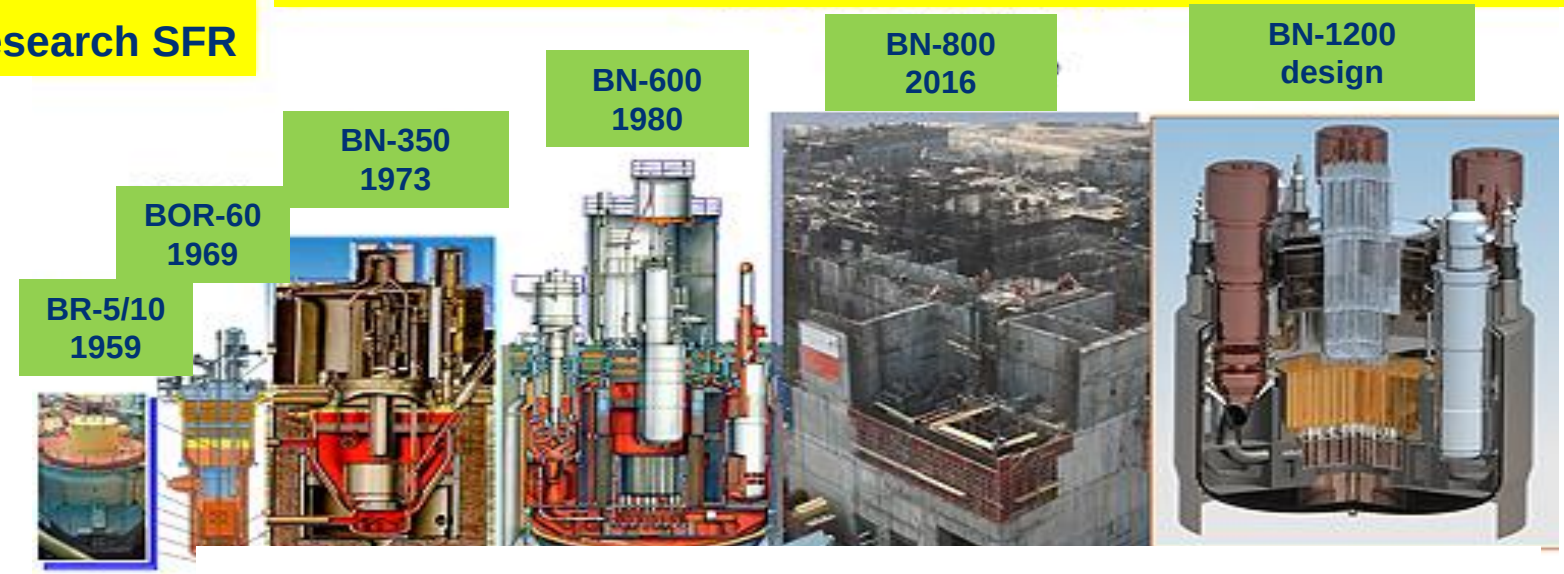
List of key points, Xp	Description of key points, Xp	Value of the evaluation function
P_0	Not competitive	0
P_1	An acceptable economic indicators within state energy policy (FOAK or reasons of energy security or diversification, etc.)	20
P_2	Economic indicators are at the level of competitiveness in the energy sector	50
P_3	Best economic indicators in the energy sector	100

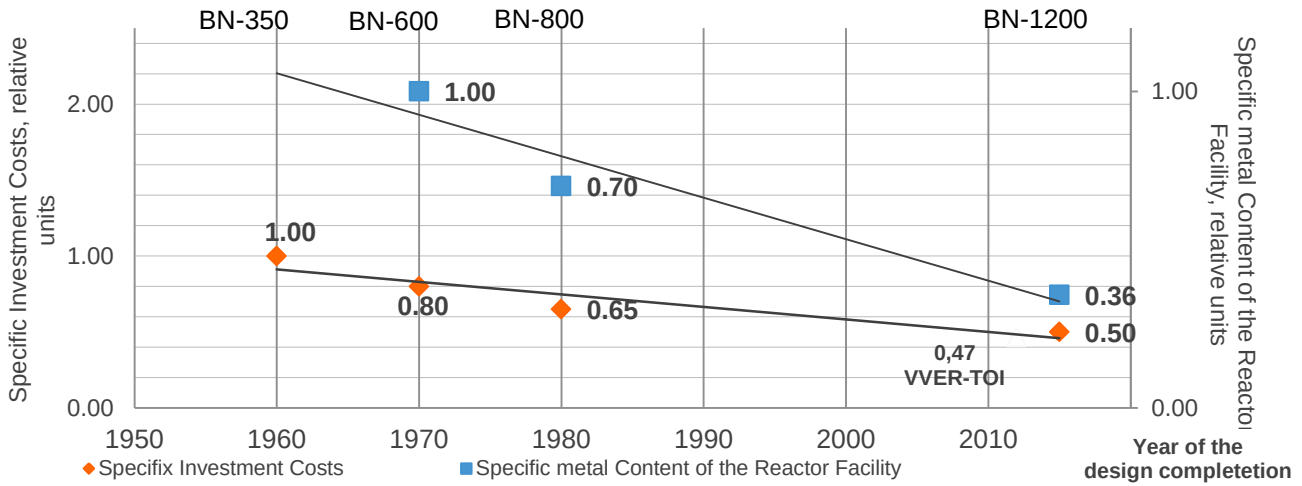
HOW OBJECTIVE FUNCTIONS WORK: IMPROVING ECONOMICS OF SFR AS A PART OF ENHACING NES SUSTAINABILITY

POCATOM

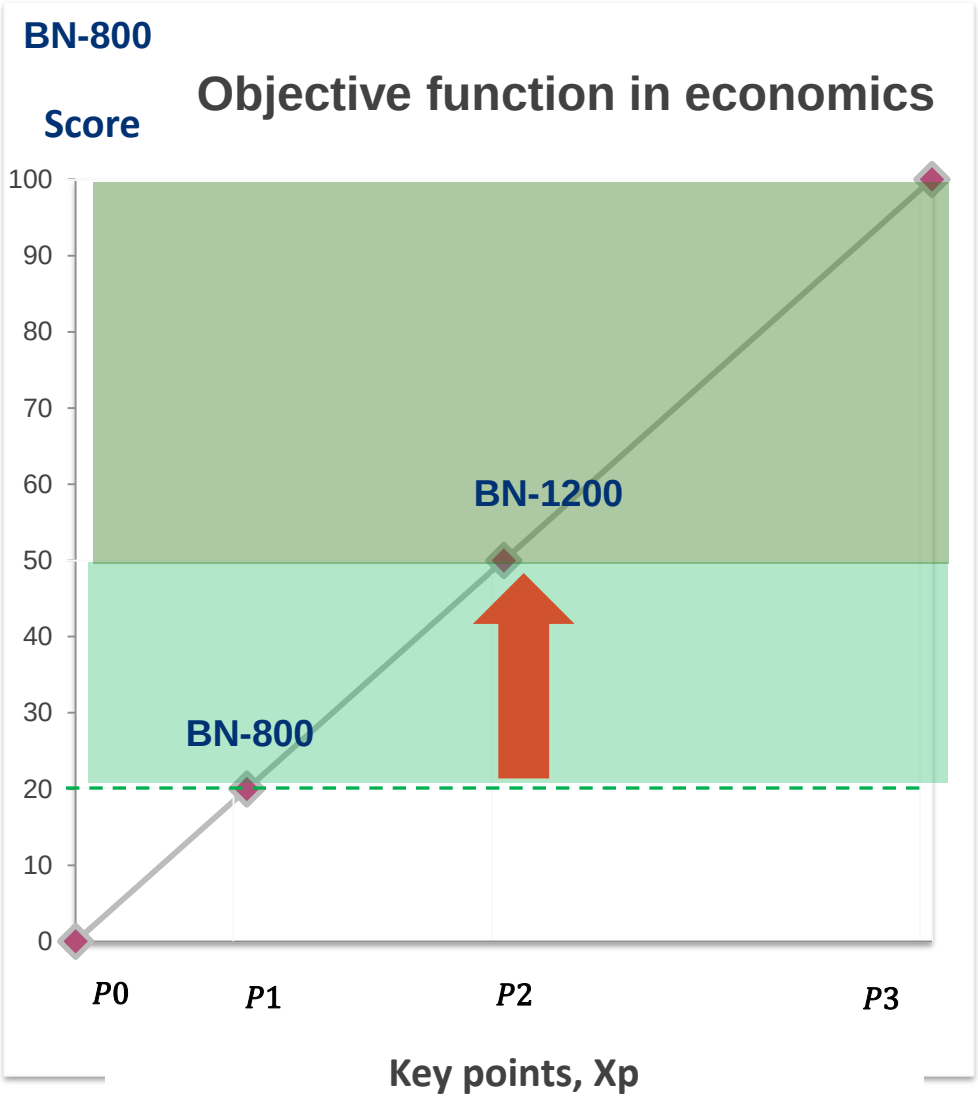
Experimental & research SFR

Power SFR (BN) reactors



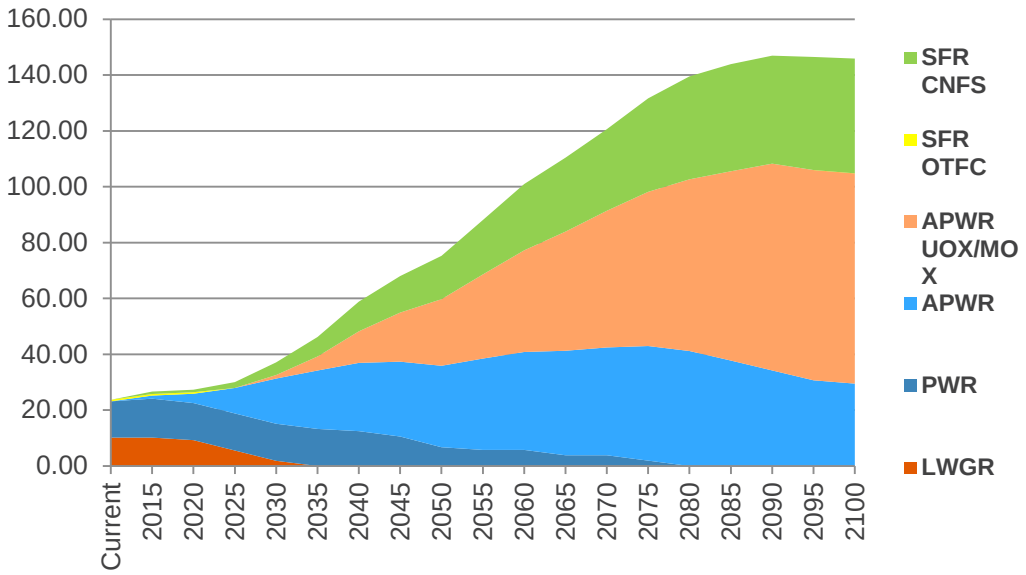


A STEP IN APPROACHING A DESIRED TARGET IN ECONOMIC DUE TO INNOVATION IN SFR (BN)

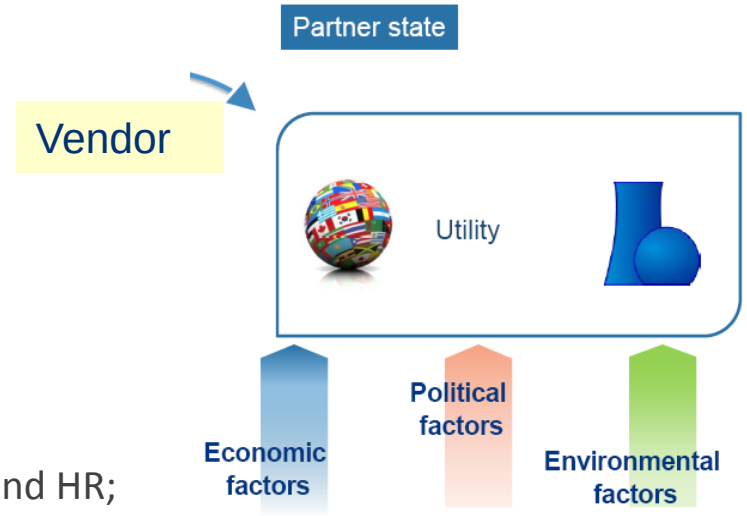


List of key points, Xp	Description of key points, Xp	Value of the evaluation function
P_0	Not competitive	0
P_1	BN-800: acceptable economics for an innovative SFR	20
P_2	BN-1200: economics comparable with new PWR and coal PP	50
P_3	Best economic indicators in the energy sector	100

EXAMPLE OF A SUPPLIER



A scenario of development & deployment of innovative NES (advanced PWR, SFR, MOX fuel, CNFC installations) for a conditional supplier was elaborated as an example



Integrated package of services

Activities taken into account:

-NPP construction and SNF & RW management.

Activities to be taken in the future:

- assistance in industrial solutions including NFC facilities construction;
- support in development of knowledge, industrial skills, and HR;
- assistance in financial solutions, etc.

ELEMENTS OF ROADMAP TEMPLATE RELATED TO DEVELOPMENT OF TECNOLOGIES AND COOPERATION

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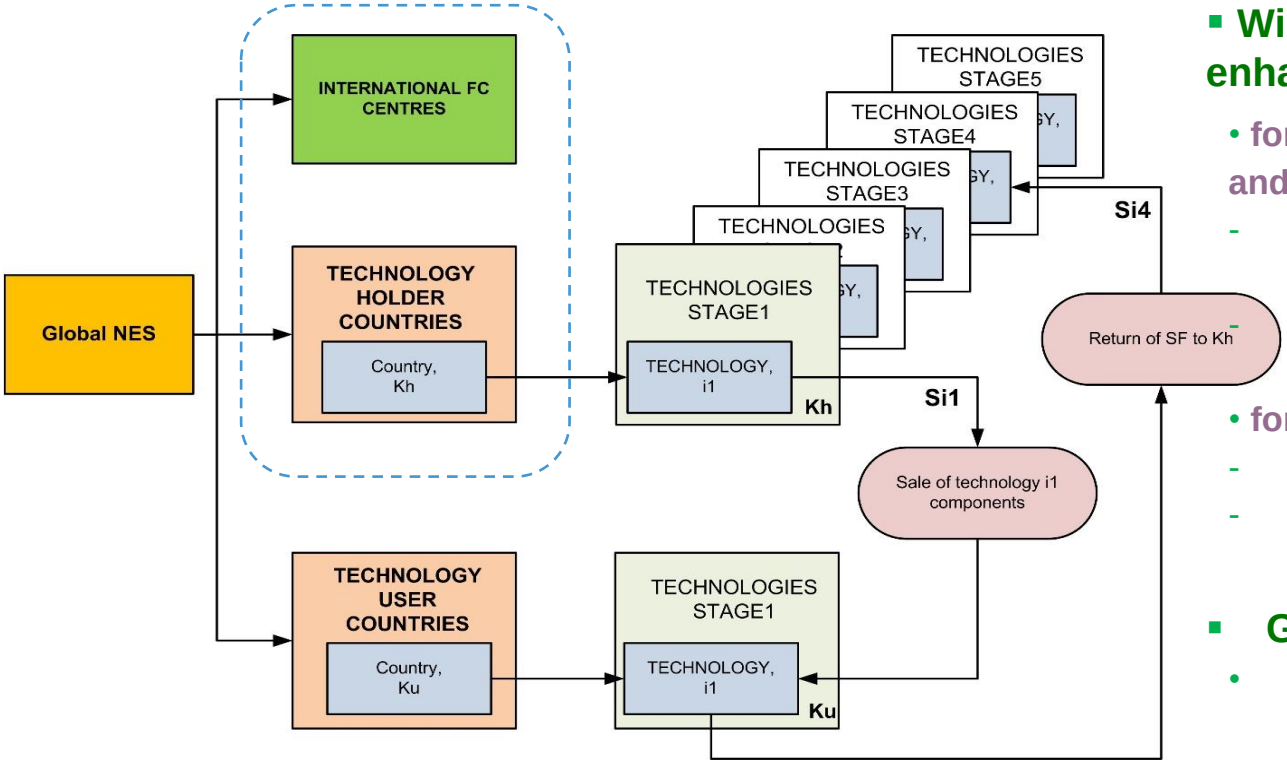
POCATOM

Type of NES			Timeframes			
			Current	2015-2034	2035-2054	2054-2100
Current & advanced NESs, proven technology	Reactor	Domestic	PWR, UOX	PWR+ APWR, UOX	PWR+APWR, UOX	PWR+APWR, UOX
		Services	PWR, UOX	PWR+ APWR, UOX	PWR+APWR, UOX	PWR+ APWR, UOX
	NFC	Domestic	OTFC + U reuse, glass w MA,FP	OTFC + U, Pu reuse	OTFC + U, Pu recycle + Lab for waste repository	OTFC + U, Pu recycle + Retrievable repository
		Services	NFC front-end	NFC front-end + SNF intermediate storage	NFC front-end + SNF intermediate storage	NFC front-end + SNF intermediate storage
Evolving NESs	Reactor	Domestic		SFR MOX, small ser.	SFR MOX, commercial	SFR MOX, commercial
		Services			APWR-MOX, SFR?	APWR-MOX, SFR
	NFC	Domestic			+ Glass or mineral matrix (w MA, FP)	+ Glass or mineral matrix (w MA, FP)
		Services			NFC front-end + SNF take back?	NFC front-end & SNF take back
Conceptual NES	Reactor	Domestic				LFR, nitride fuel
		Services				SFR, LFR?
	NFC	Domestic				Glass or mineral matrix w/o MA, FP
		Services				All set of NFC services

ENHANCING SUSTAINABILITY VIA COOPERATION

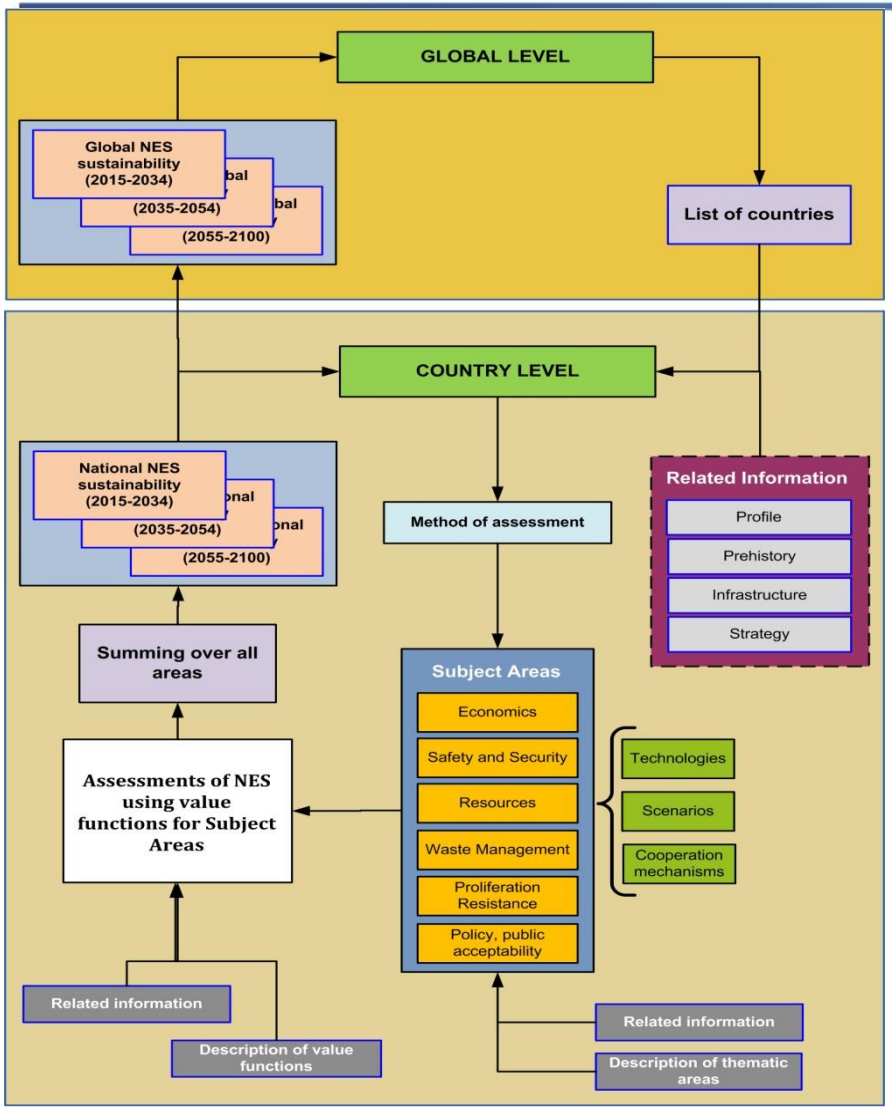


- **Win-win collaboration for enhancing local sustainability:**
  - **for technology user (take back and forget option)**:
    - reduction of investments in a national NES deployment; mitigating NFC problems, first of all, waste disposal, etc.
  - **for technology holder/vendor:**
    - expanding business,
    - reduction of product & service costs due to scale effect, etc.

- **Global effects:**
  - **improved safety and economics** of NES to be performed on reference technologies and high standards;
  - **expanded resource base** by wider use of fissile materials from reprocessed SF;
  - **reduced proliferation risks**, etc.

- **To implement these opportunities a set of problems to be solved, including:**
  - converting SF and fissile materials therein from waste to product by wider using of recycled FM in thermal and fast reactors;
  - providing safe and secure transportation of nuclear fuels;
  - further development of collaborative models and necessary legislation.

FLOWCHART OF THE TRIAL ROADMAPS TEMPLATE



The flowchart of the ROADMAPS Template

- The approach discussed was formalized in a trial version of **a roadmap template for an illustrative technology holder**
- Excel sheets were used for the template
- The flowchart of the template is shown in the Figure
- It includes following elements:

-information block on the country and its NES including the nuclear energy profiles developed in the IAEA for the MSs;
- block on evolution of NES for the projected period trough objective functions in each subject area;
- block on assessment of a NES over subject areas;
- block on the overall assessment of NES sustainability in time.

MENU AND INFORMATION ON SUBJECT AREAS IN THE TRIAL ROADMAPS TEMPLATE

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POCATOM

COUNTRY TECHNOLOGY HOLDER

Prepared data for further calculations. Proposed evaluation functions on the main sustainability areas. The metric of these evaluation functions and the possibility of the integrated assessment of NES require further discussion.

Menu:

TECHNOLOGY HOLDER					
Domestic		Current	2015-2034	2035-2054	2055-2100
	Current NES	+	+	+	+
	Advanced NES	-	+	+	+
	Evolving Startup NES	-	+	+	+
	Evolving NES	-	-	+	+
	Conceptual NES	-	-	-	+
Cooperation					
	Current NES	+	+	+	+
	Advanced NES	-	+	+	+
	Evolving Startup NES	-	-	+	+
	Evolving NES	-	-	+	+
	Conceptual NES	-	-	-	+

Sustanabiliti Index of National NES with Cooperation			
Current	2015-2034	2035-2054	2055-2100
?	?	?	?

COUNTRY PROFILE IN THE TRIAL ROADMAPS TEMPLATE

Back to Summary

COUNTRY PROFILE

* Information about Country (for example - the Russian Federation)

1.1. Country overview *(more information on the links "IAEA Russia Profile")*

1.1.1. Governmental System

The Russian Federation (RF) is a Presidential republic. The President is the head of state and is elected directly by the people. He controls all the three branches of power. The President can even dissolve the Duma, if he doesn't agree with its suggestions three times running. The President has his administration, but it is not part of the Federal Government. The President is involved in the work of the legislative and executive branches.

The Federal Assembly represents the legislative branch of power. It is comprised of the two houses, the Federation Council and the State Duma, which make laws. The Federal Assembly is also called the Parliament, but that is not its official name.

1.1.2. Geography and Climate

Russia is a large country occupying the eastern part of Europe and the northern part of Asia.

The total area of Russia is about 17,075,000 km^2. The country consists of a large number of administrative units: regions (provinces) and republics. The regions of the country differ widely in territory, natural conditions, structure and national composition of the population, and economic development. The climate of the country is marked by very wide regional variations. A significant part of northeastern Russia falls within the Frigid Zone, while the Black Sea region has semitropical conditions.

1.1.3. Population

According to the latest statistics, the population of Russia amounts to about 143 million (Table 1). The average population density is approximately 8.3 inhabitants/km^2. This number greatly varies throughout the country, from more than 100 inhabitants/km^2, for some regions in the European part of Russia, to less than one, for large territories in Siberia and the far northeast.

1.1.4. Economic Data

Russia has undergone significant changes since the collapse of the Soviet Union, moving from a globally-isolated, centrally-planned economy to a more market-based and globally-integrated economy. Economic reforms in the 1990's privatized most industry, with notable exceptions in the energy and defense-related sectors.

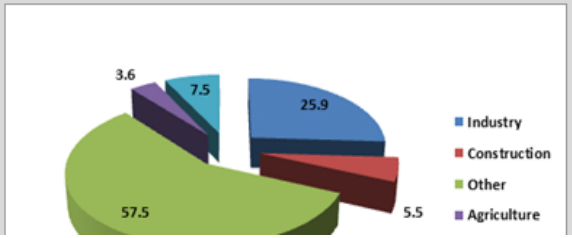
In 2012, Russia became the world's leading oil producer, surpassing Saudi Arabia. Russia is the second-largest producer of natural gas, and holds the world's largest natural gas reserves, the second-largest coal reserves and the eighth-largest crude oil reserves. Russia is the third-largest exporter of both steel and primary aluminum.

The historical data of GDP values are presented in Table 1. Figure 1 shows the GDP structure in 2012.

TABLE 1. GROSS DOMESTIC PRODUCT (GDP)

				Average annual growth rate (%)
	2000	2005	2011	2000 to 2011
GDP (billions of current US$)	973	1371	1858	8,3
GDP (billions of constant 2000 US$)	259,6	349,7	433,6	5,59
GDP per capita (thousands PPP* US$/capita)	8,807	12,123	16,62	7,39
GDP per capita (thousands of current US$/capita)	6,849	9,65	12,956	7,43

* PPP: Purchasing Power Parity



THE FRAGMENT OF THE DATA ON TECHNOLOGIES DEVELOPMENT

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SCENARIO

Reactor and Fuel Services Temp

Domestic																	
Technology, GW(e)	Current	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
PWR UOX	24,64	25,64	23,88	19,88	15,88	13,88	13,00	11,00	7,00	6,00	6,00	4,00	4,00	2,00	0,00	0,00	0,00	0,00
APWR UOX	0,00	1,26	3,77	9,88	17,08	21,88	25,48	27,88	30,28	33,88	36,28	38,68	39,88	42,22	42,11	38,40	34,80	31,20
APWR UOX/MOX	0,00	0,00	0,00	0,00	1,26	5,02	11,30	17,57	23,85	30,12	36,40	42,67	48,95	55,22	61,50	67,77	74,05	75,30
FR-CNFC	0,00	0,80	0,80	2,00	4,40	6,80	10,40	12,80	15,20	19,10	23,30	26,00	28,70	32,90	36,30	37,80	38,10	39,90
Front-end activities																		
Convertion for PWR, th.t	4,14	4,29	3,70	3,11	2,52	2,22	1,92	1,63	1,04	0,89	0,89	0,59	0,59	0,30	0,00	0,00	0,00	0,00
Convertion for APWR, th.t	0,00	0,15	0,44	1,18	2,07	2,66	3,11	3,40	3,70	4,14	4,44	4,74	4,88	5,18	5,18	4,74	4,29	3,85
Convertion for APWR UOX/MOX, th.t	0,00	0,00	0,00	0,00	0,09	0,35	0,79	1,23	1,68	2,12	2,56	3,00	3,44	3,88	4,32	4,76	5,20	5,29
Separation for PWR mil. SWU	3,53	3,65	3,15	2,64	2,14	1,89	1,64	1,39	0,88	0,76	0,76	0,50	0,50	0,25	0,00	0,00	0,00	0,00
Separation for APWR mil. SWU	0,00	0,13	0,38	1,01	1,76	2,27	2,64	2,90	3,15	3,53	3,78	4,03	4,16	4,41	4,41	4,03	3,65	3,27
Separation for APWR UOX/MOX mil. SWU	0,00	0,00	0,00	0,00	0,08	0,30	0,68	1,05	1,43	1,80	2,18	2,55	2,93	3,30	3,68	4,05	4,43	4,50
Fuel Fabrication for PWR th.t HM	0,62	0,64	0,55	0,46	0,38	0,33	0,29	0,24	0,15	0,13	0,13	0,09	0,09	0,04	0,00	0,00	0,00	0,00
Fuel Fabrication for APWR th.t HM	0,00	0,02	0,07	0,18	0,31	0,40	0,46	0,51	0,55	0,62	0,66	0,71	0,73	0,77	0,77	0,71	0,64	0,57
Fuel Fabrication for APWR UOX/MOX th.t HM	0,00	0,00	0,00	0,00	0,02	0,09	0,20	0,31	0,42	0,53	0,64	0,75	0,86	0,97	1,08	1,19	1,30	1,33
Fuel Fabrication for FR th.t HM	0,00	0,00	0,00	0,01	0,02	0,04	0,06	0,08	0,10	0,13	0,17	0,19	0,22	0,26	0,30	0,31	0,32	0,34
Back-end activities																		
Fuel Reprocessing PWR, th.t. HM	0,62	0,64	0,55	0,46	0,38	0,33	0,29	0,24	0,15	0,13	0,13	0,09	0,09	0,04	0,00	0,00	0,00	0,00
Fuel Reprocessing APWR, th.t. HM	0,00	0,02	0,07	0,18	0,31	0,40	0,46	0,51	0,55	0,62	0,66	0,71	0,73	0,77	0,77	0,71	0,64	0,57
Fuel Reprocessing APWR UOX, th.t. HM	0,00	0,00	0,00	0,00	0,02	0,09	0,20	0,31	0,42	0,53	0,64	0,75	0,86	0,97	1,08	1,19	1,30	1,33
Fuel Reprocessing FR, th.t. HM	0,00	0,00	0,00	0,01	0,02	0,04	0,06	0,08	0,10	0,13	0,17	0,19	0,22	0,26	0,30	0,31	0,32	0,34
Wate Management PWR, th.t HM	0,62	0,64	0,55	0,46	0,38	0,33	0,29	0,24	0,15	0,13	0,13	0,09	0,09	0,04	0,00	0,00	0,00	0,00
Wate Management APWR, th.t HM	0,00	0,02	0,07	0,18	0,31	0,40	0,46	0,51	0,55	0,62	0,66	0,71	0,73	0,77	0,77	0,71	0,64	0,57
Wate Management APWR UOX/MOX, th.t HM	0,00	0,00	0,00	0,00	0,02	0,09	0,20	0,31	0,42	0,53	0,64	0,75	0,86	0,97	1,08	1,19	1,30	1,33
Wate Management FR, th.t HM	0,00	0,00	0,00	0,01	0,02	0,04	0,06	0,08	0,10	0,13	0,17	0,19	0,22	0,26	0,30	0,31	0,32	0,34
Cooperation activities, GW(e)																		
PWR UOX	20,00	20,00	20,00	20,00	15,00	10,00	5,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
APWR UOX	0,00	3,60	8,40	14,40	25,20	36,00	48,00	57,60	62,40	68,40	75,60	82,80	91,20	99,60	105,60	112,80	112,80	114,00
APWR UOX/MOX	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,26	3,77	7,53	12,55	16,32	21,34	23,85	27,61	33,89	38,91	45,18
Front-end activities																		
Convertion for PWR UOX, th.t	2,96	2,96	2,96	2,96	2,22	1,48	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Convertion for APWR UOX, th.t	0,00	0,44	1,04	1,78	3,11	4,44	5,92	7,10	7,70	8,44	9,32	10,21	11,25	12,28	13,02	13,91	13,91	14,06

SCENARIOS ON THE DEPLOYMENT OF REACTOR FLEET

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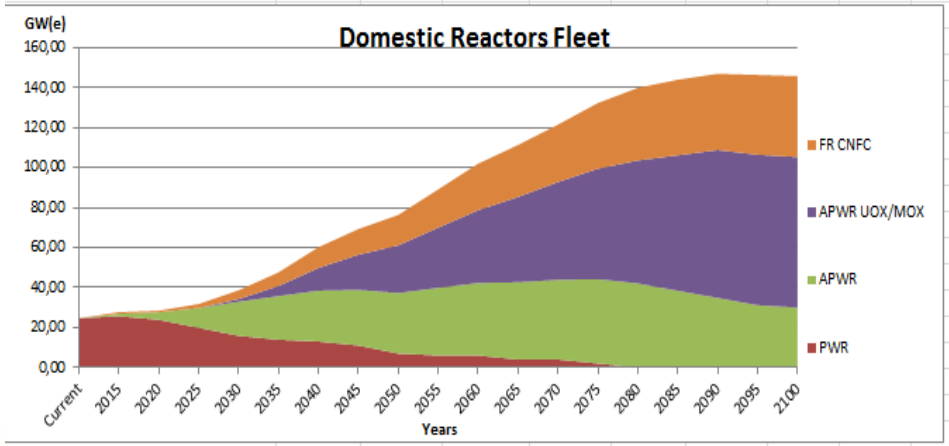
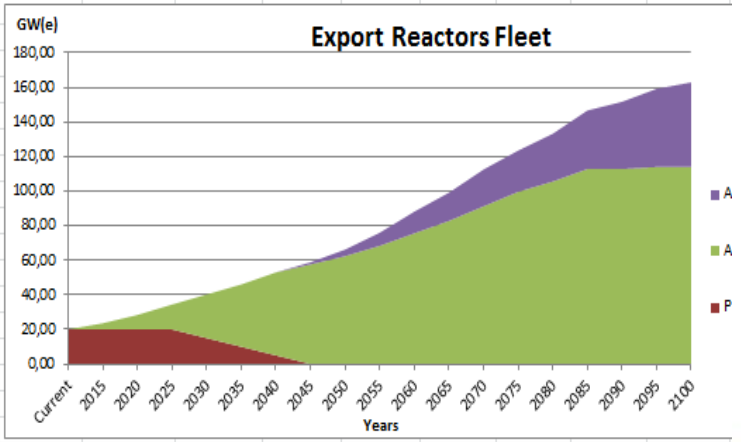
POCATOM

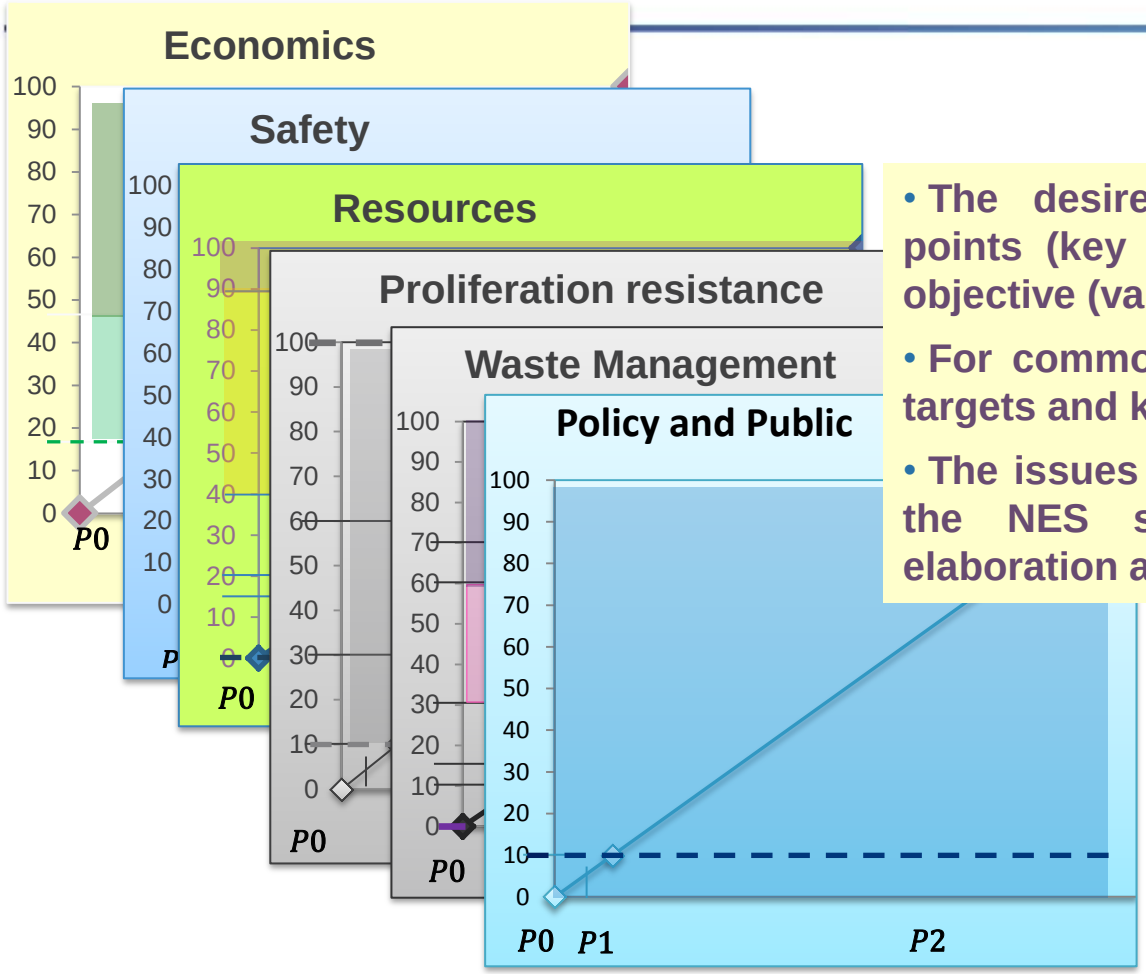
Fuel Cycle Facility	Current	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Intermediate Storage																		
Facility for reprocessing UOX fuel from part of PWR and UOX FR																		
Intenational front-end center																		
Experimental Lab of Nuclear Waste Repository																		
Facility for reprocessing UOX fuel from all LWGR, PWR and APWR																		
Facility for reprocessing fuel from APWR MOX and FR																		
Geological Repository for LWR fuel																		
Geological Repository for FR fuel																		

Reactors details									
Reactor type	PWR 1	PWR 2	APWR 1	APWR 2		FR demo.	FR 1	FR 2	
Neutron spectrum	Thermal	Thermal	Thermal	Thermal		Fast	Fast	Fast	
Electric Power	1000	440	1200	1255		800	1200	300	
Thermal Power	3200	1375	3200	3312		2100	2800		
Fuel	UOX	UOX	UOX	UOX	UOX/MOX	MOX	MOX	UN	
Reprocessing SNF	yes	yes	yes	yes	yes	yes	yes	yes	
Recycle in this reactor core (U or Pu)	none	none	yes	yes	yes	yes	yes	yes	





OBJECTIVE FUNCTIONS FOR SUBJECT AREAS AND DIRECTIONS FOR FURTHER DEVELOPMENT



- The desired targets and intermediate key points (key events) were proposed in related objective (value) functions for each subject area
- For common application of the template, the targets and key points should be jointly agreed
- The issues related to the overall evaluation of the NES sustainability also need further elaboration and agreement

CONCLUSIONS

- CP ROADMAPS advanced in developing **a structured approach and a roadmap template** aimed to document actions, scope of work, & timeframes **to assist in enhancing NES sustainability**
- Approach to development of **a roadmap template** for an illustrative technology holder was addressed in a Russian study within the project
- **Main benefits** from using the template can be:
  - coordination between MS targets of a NES sustainability enhancing in all subject areas and cooperative actions;
  - identification 'gaps' of a national long-term strategy at early stage of its elaboration and development follow up actions;
  - identification reserves of national NES infrastructure for enhancing cooperation with interested partners
- Preliminary approach to summarizing results of the NES evaluations over objection functions has demonstrated a key role of **innovations and cooperation in enhancing NES sustainability**
- **Development of the template for a NES roadmap to enhanced sustainability is inspiring but challenging task that requires further discussions, common efforts and contributions**

THANK YOU FOR YOUR ATTENTION!

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