International Atomic Energy Agency

International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

Study on Opportunities and Challenges of Large-Scale Nuclear Energy Development

M.Khoroshev, IAEA

ANS 2006 Summer Meeting 5-7 June, Reno, NV, USA

Technical Session

"Long-Term Sustainability of Nuclear Fission Energy", 6 June 2006

INPRO

Goals

- **To help ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner;**
- **To bring together both technology holders and technology users to consider jointly the actions required to achieve desired innovations in nuclear reactors and fuel cycles**

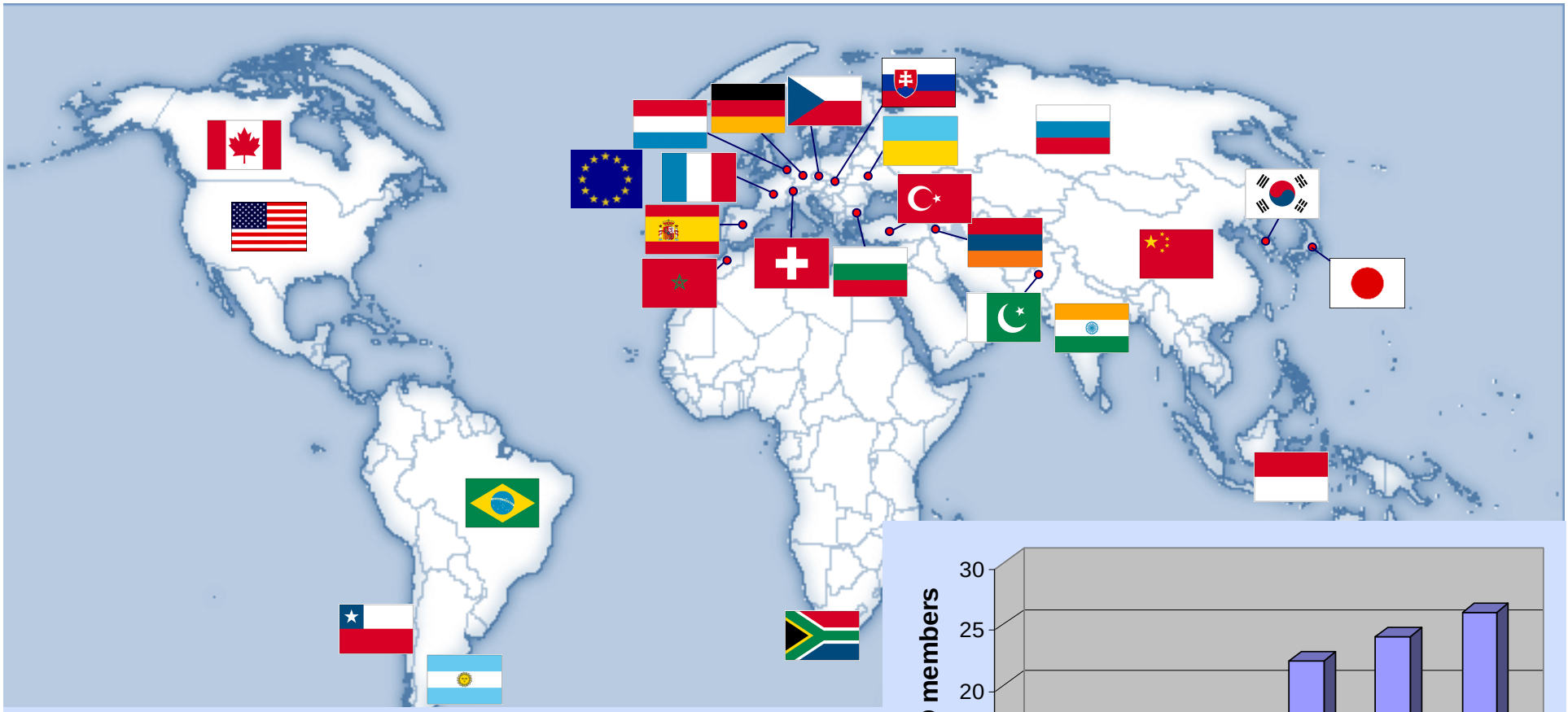
INPRO Time horizon

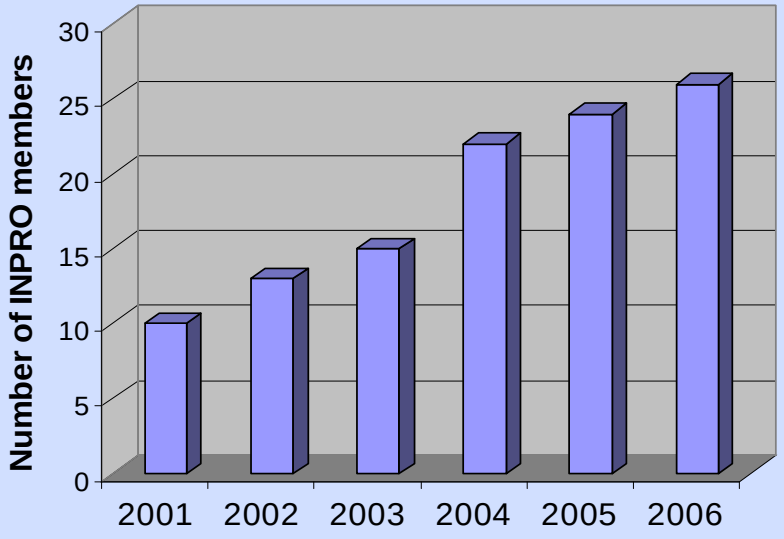
- **From today 50 years into the future**

INPRO Mission

- To provide a forum for discussion of experts and policy makers from industrialized and developing countries on all aspects of nuclear energy planning as well as on the development and deployment of innovative nuclear energy systems (INS) in the 21st century.
- To develop the methodology to analyze INS on a global, regional and national basis and establish it as an Agency's recommendation
- To facilitate coordinating and collaboration among member states for planning of INS development and deployment
- To pay particular attention to the needs of developing countries interested in INS.

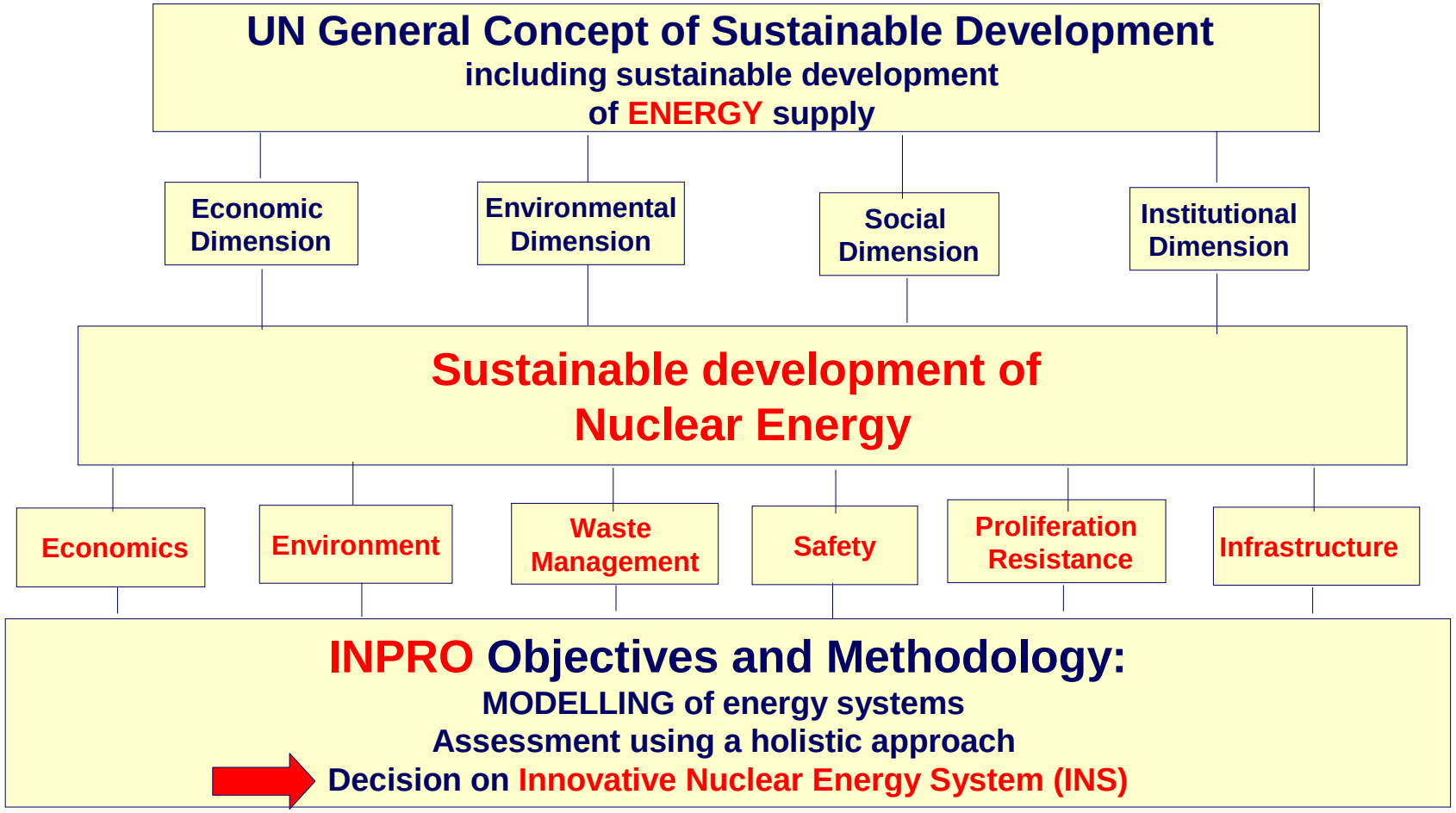
Current Members





26 Members Argentina, Armenia, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Japan, Republic of Korea, Morocco, Pakistan, Russia, Slovakia, South Africa, Spain, Switzerland, The Netherlands, Turkey, Ukraine, USA and the EC
+ Observers

UN Concept of Sustainability and INPRO



- Energy supply is fundamental to sustainable development of the world
- Sustainable energy supply needs significant contribution by NE
- INPRO assures that NE is available in a sustainable manner in the 21st century
- INPRO addresses all dimensions of the concept of Sustainability

Definition of Selected INPRO Terms

- **Innovative Nuclear Energy System (INS):**
  - **INS will position NP to make Major Contribution to Energy Supply in the 21st Century.**
  - **INS includes Innovative and Evolutionary Designs.**
    - Innovative design (= advanced design) incorporating radical conceptual changes in design approaches or system configuration in comparison with existing designs.
    - Evolutionary design (= advanced design) incorporating small to moderate modifications with strong emphasis on maintaining design proveness**.**
  - **INS includes all Components: Mining and Milling, Fuel Production, Enrichment, Fabrication, Production (incl. all types and sizes of reactors), Reprocessing, Materials Management (incl. Transportation and Waste Management), Institutional Measures (e.g. safe guards, etc.).**
  - **INS includes all Phases (e.g. cradle to grave)**

General features of INPRO Methodology (1)

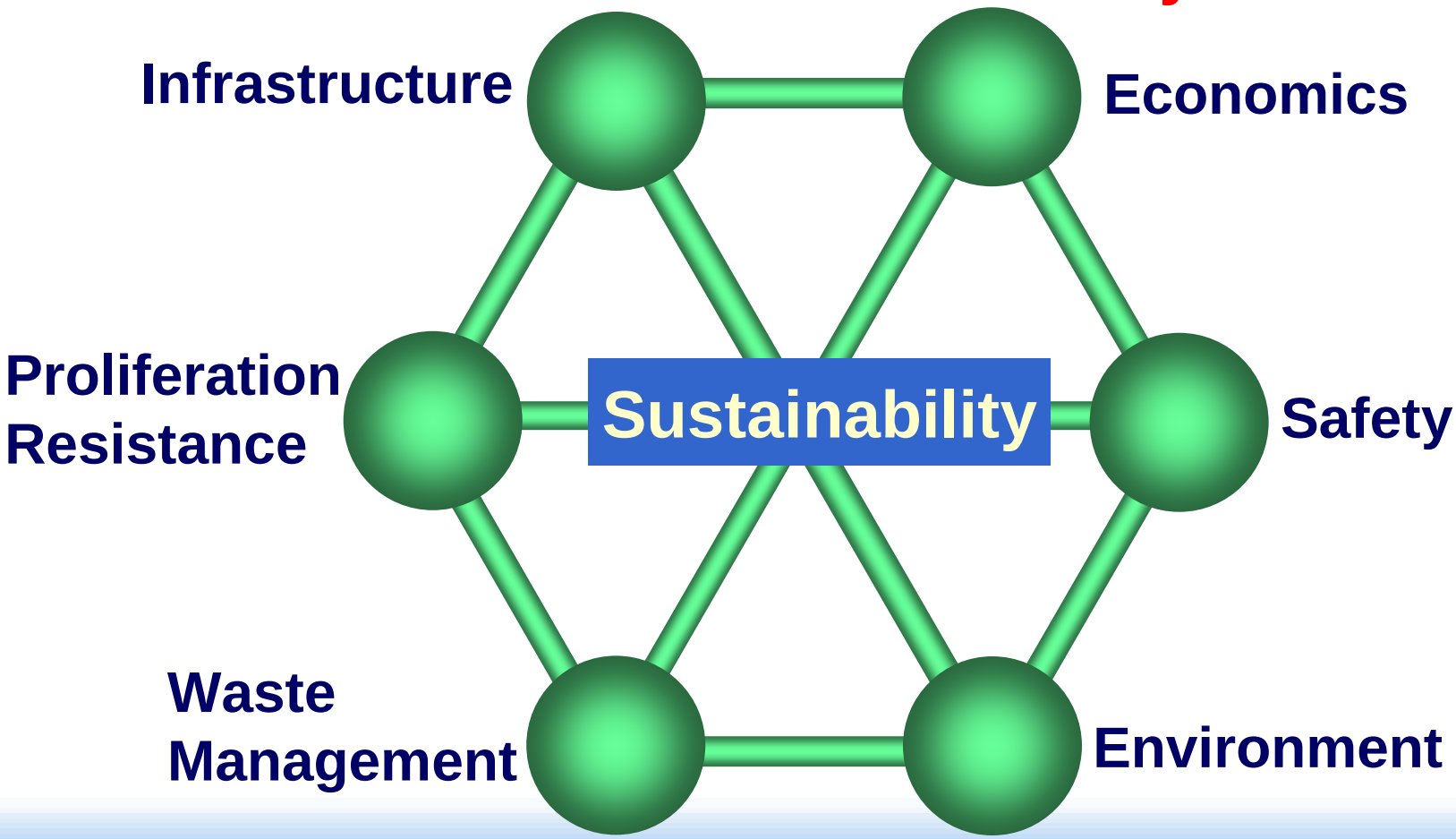
The INPRO method of assessment provides a tool for:

- **Screening of INS* for their compatibility with the INPRO set of Basic Principles and User Requirements;**
- **Comparison of different INS or components thereof to find a preferred or optimum INS consistent with the needs of a given IAEA Member State;**
- **Identification of R&D needed to improve the performance of existing INS components and for the development of new components.**

* Innovative Nuclear Energy System

General features of INPRO Methodology (2)

Holistic approach to assess INS in six areas* to assure its sustainability



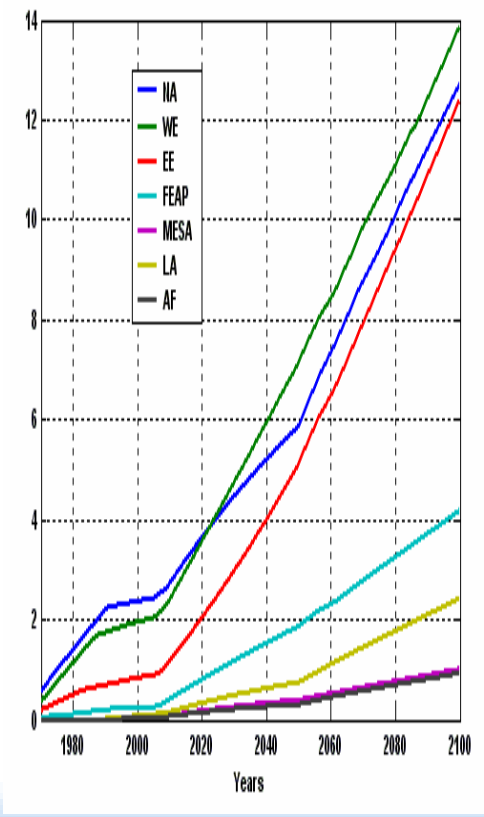
*:Physical Protection will be included

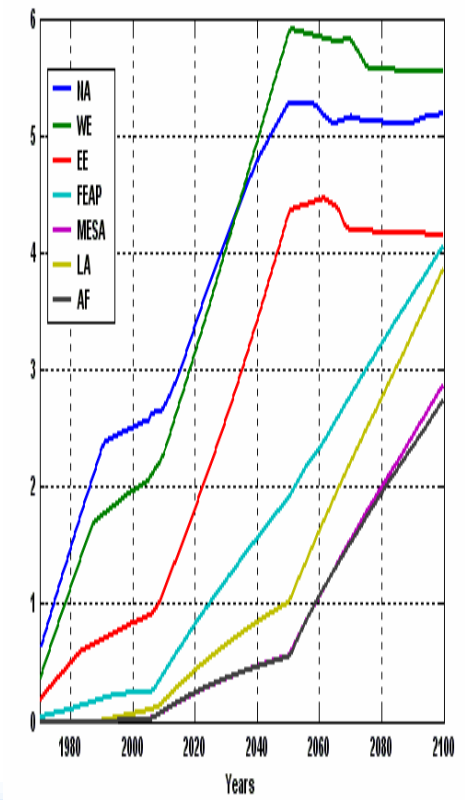
Opportunities and challenges for large-scale global nuclear energy development

presented by the global balance of demands and resources

Global future energy scenario+national power strategies (time frame–100 years)

Electricity generation,
MWh per capita



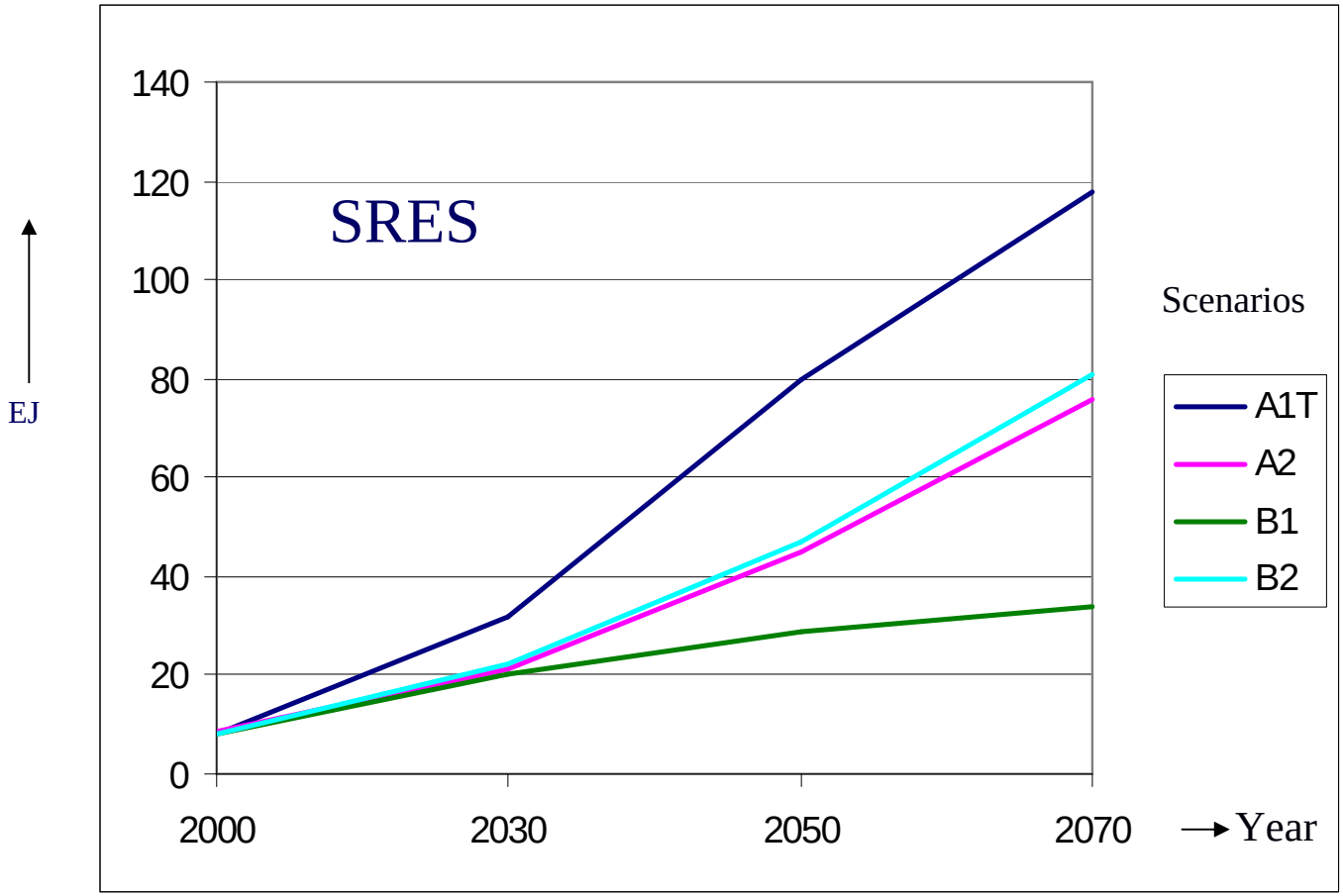


Electricity generation per capita:

NA-North America;
WE-Western Europe;
EE- Eastern Europe;
FEAP-Far East Asia (China, Korea, Japan);
MESA-Middle East & South Asia (Near East, India);
LA-Latin America;
AF- Africa

(DESAE code)

Nuclear electricity production (EJ) for the four selected SRES scenarios



Opportunities for Nuclear Energy

- **Limited amounts of available fossil fuels**
- **Rates of economic growth**
- **Ecological constraints**
- **Extension of the effective use of potential fossil resources**
- **Huge amount of U-238 and Th-232**
- **Experience in Nuclear Power Technology**

INS scenario analysis tool

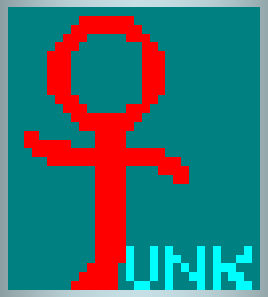
INPUT DATA

Reactor Types

Reactor Power
(as a function of time)

Costs of:
Fuel;
Operating & Maintenance
Capital,
etc.

DESAE



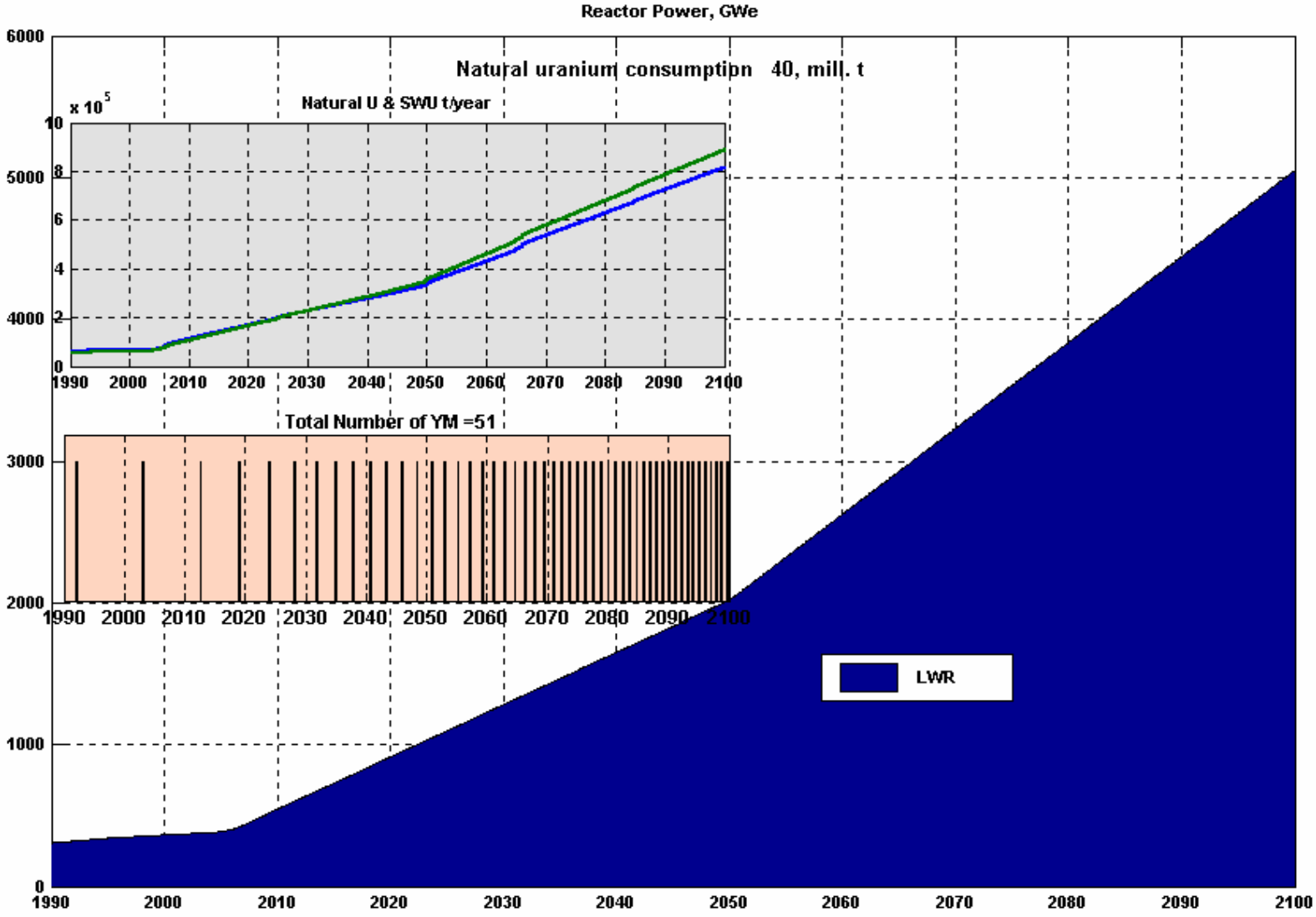
MAIN OUTPUT DATA

Natural parameters:
- **Energy production;**
- **Consumption of natural Uranium;**
- **Spent Fuel;**
- **Quantity of Fissile Isotopes;**
- **Quantity of Recycled Isotopes;**
- **Quantity of Minor actinides;**
- **Activity of Spent Fuel;**
- **Quantity of Critical materials;**
- **Quantity of dangerous materials.**

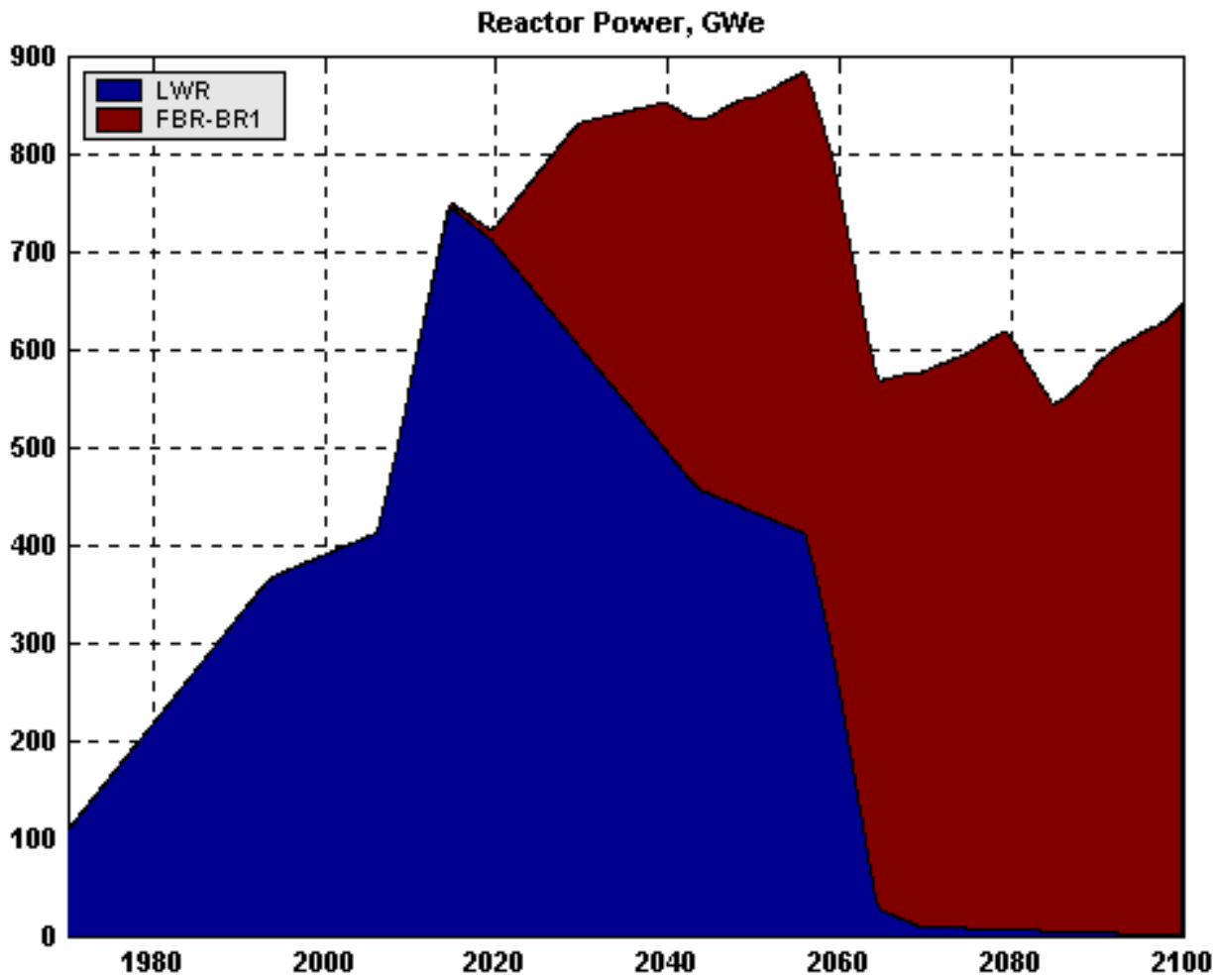
Economics:
- **Required Investments;**
- **Current price of energy;**
- **Net present value of Investment.**

No sustainable NE development with open NFC

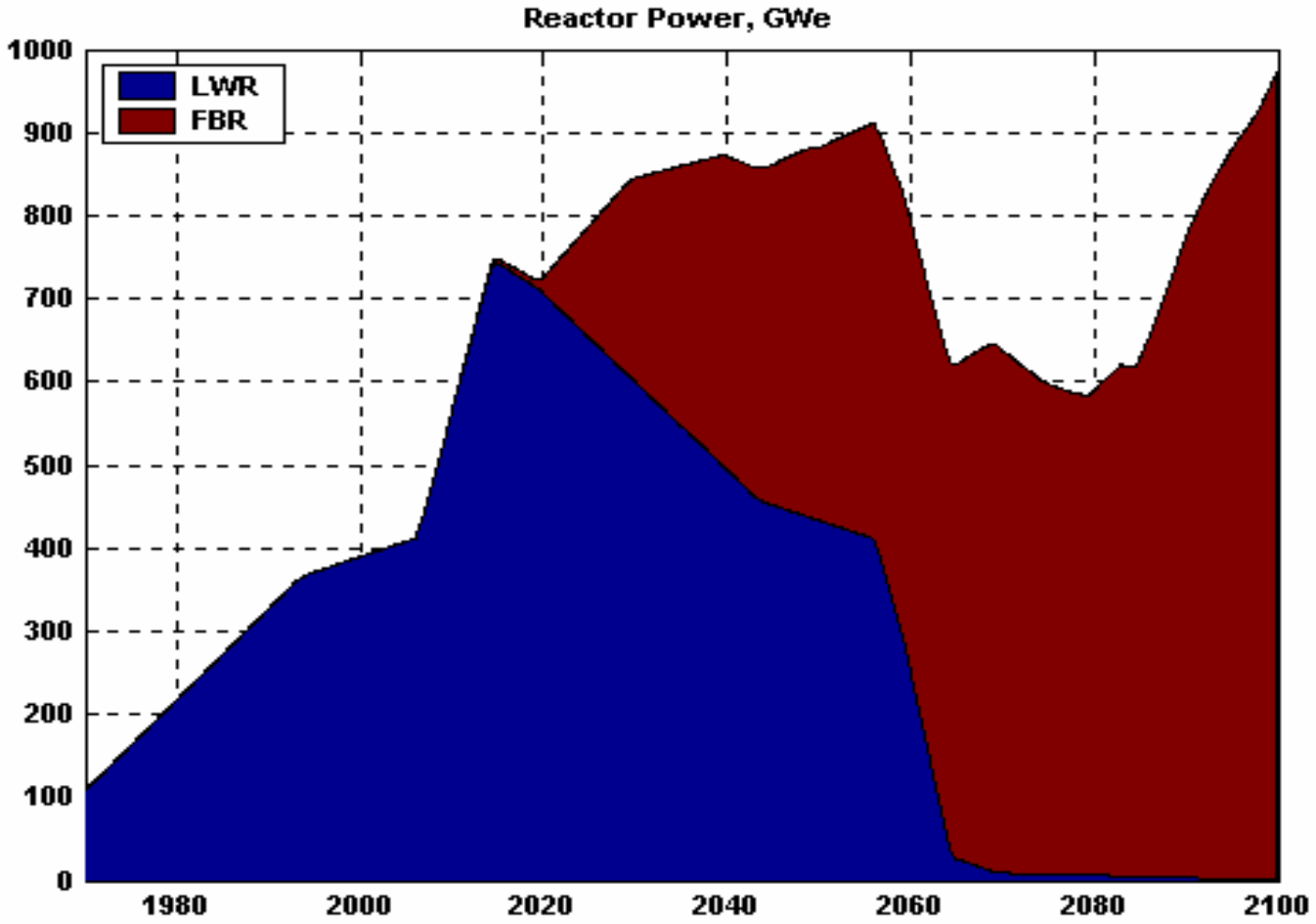
Uranium Consumption and Repositories in Large-Scale Development of NE in Open NFC



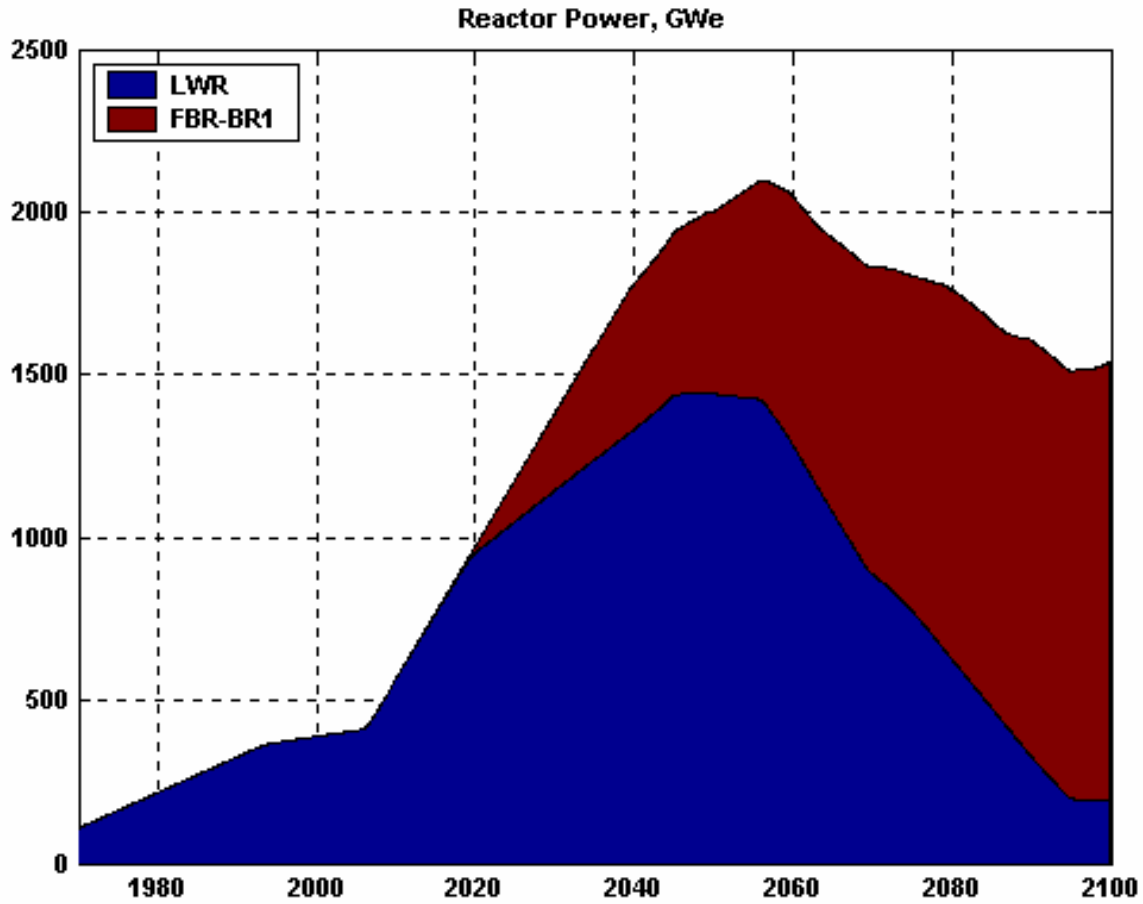
Installed capacities of INS: LWR, FR (2020)
Uranium – 6 mln t, BR=1.05



Installed capacities of INS: LWR, FR (2020)
Uranium – 6 mln t, BR=1.6

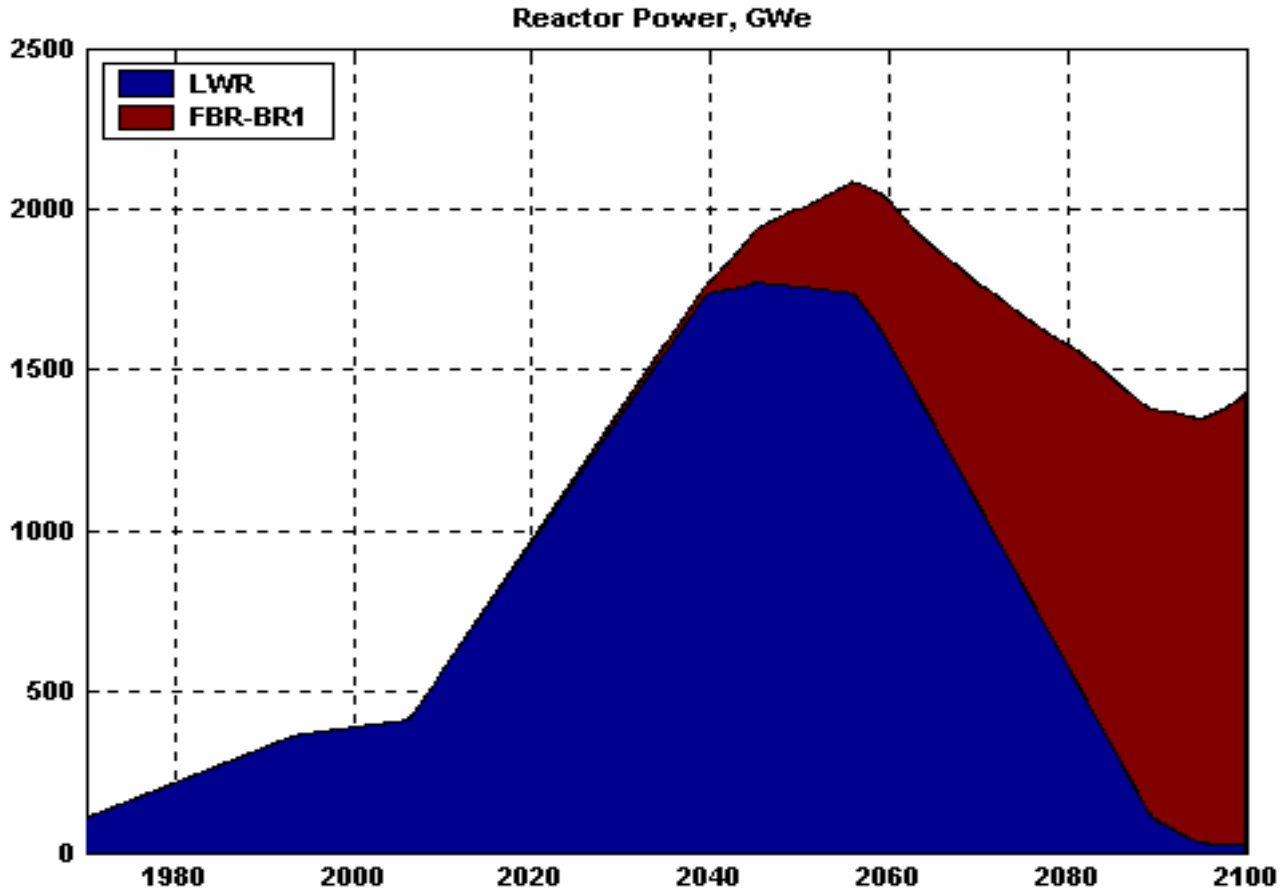


Installed capacities of INS: LWR, FR (2020)
Uranium – 16 mln t, BR=1.05

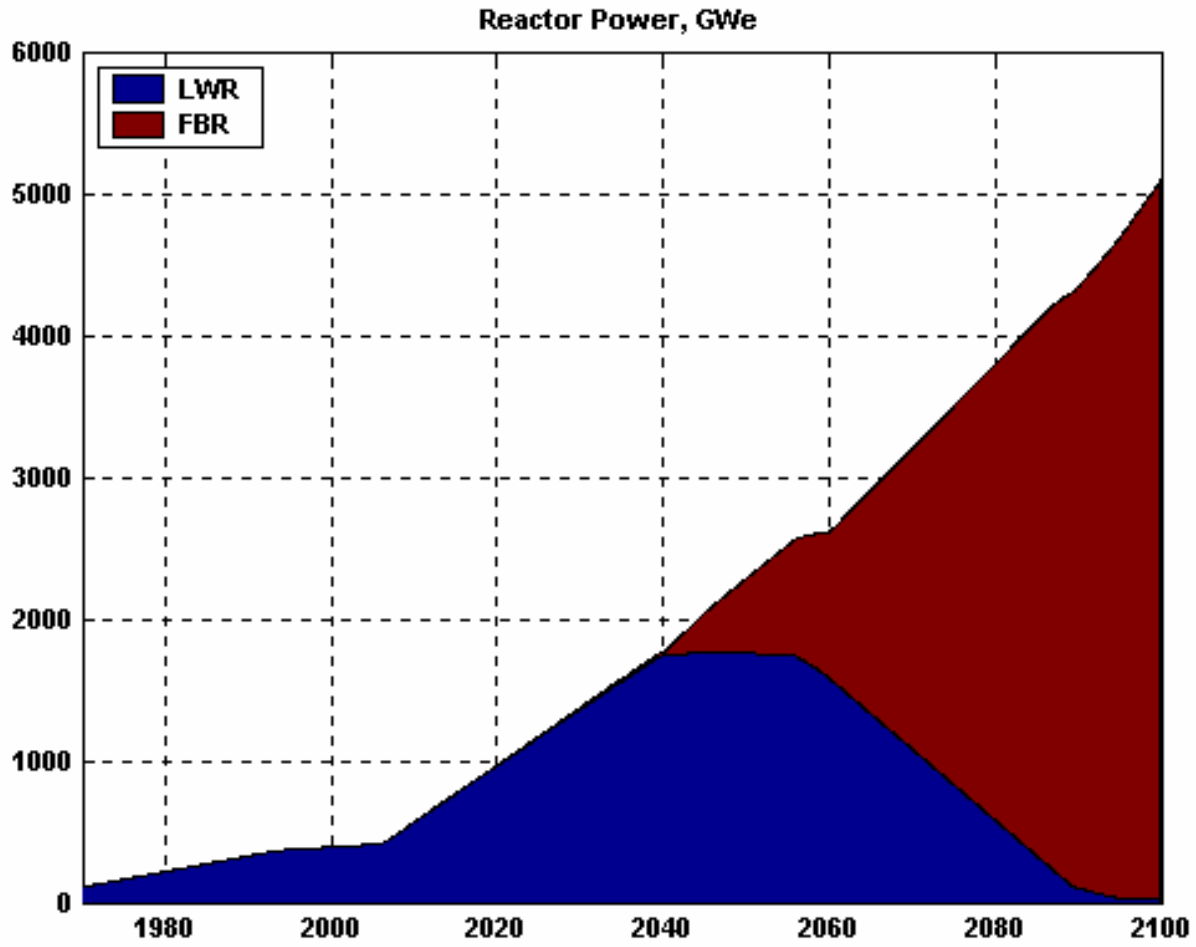


Agency

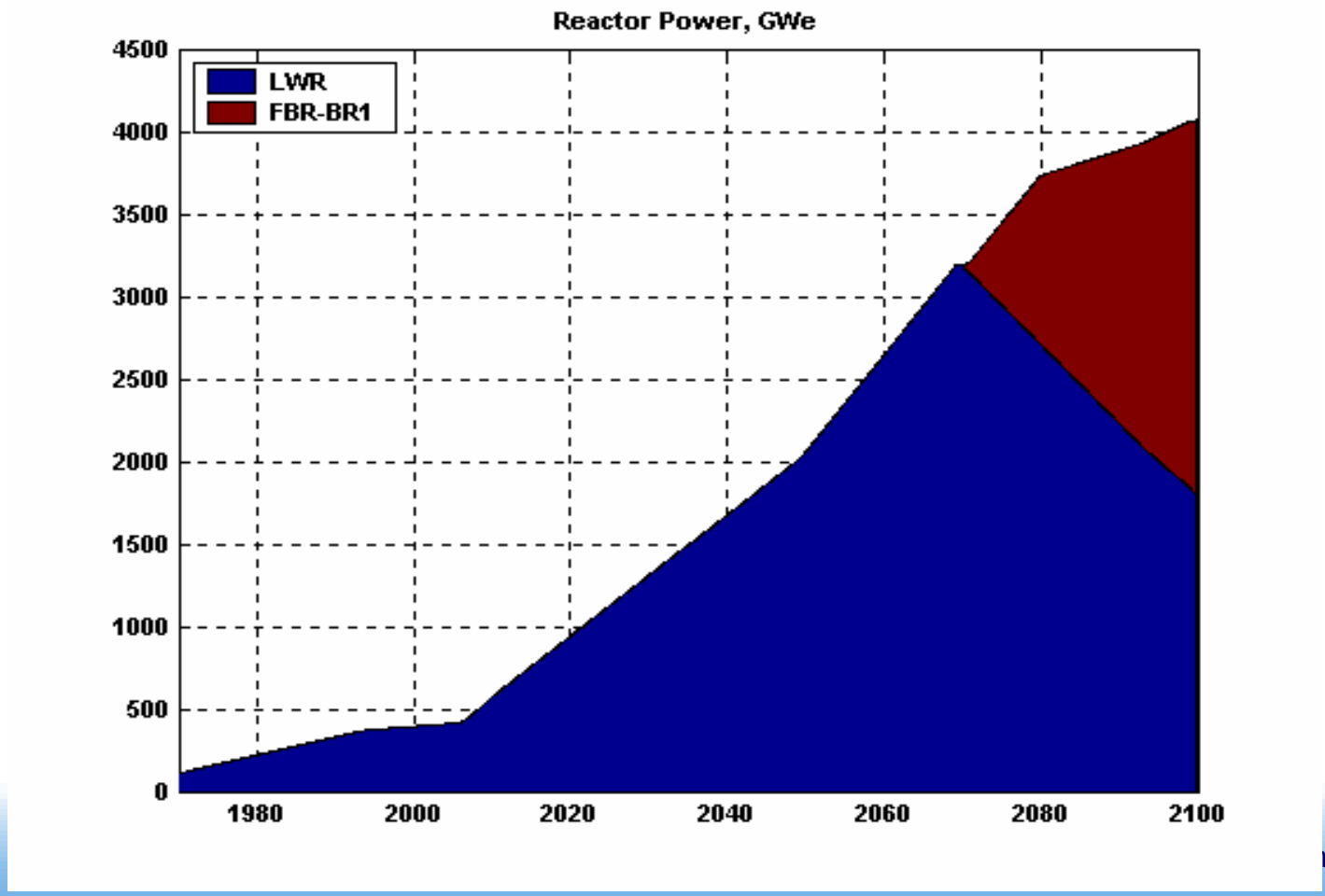
Installed capacities of INS: LWR, FR (2040)
Uranium – 16 mln t, BR=1.05



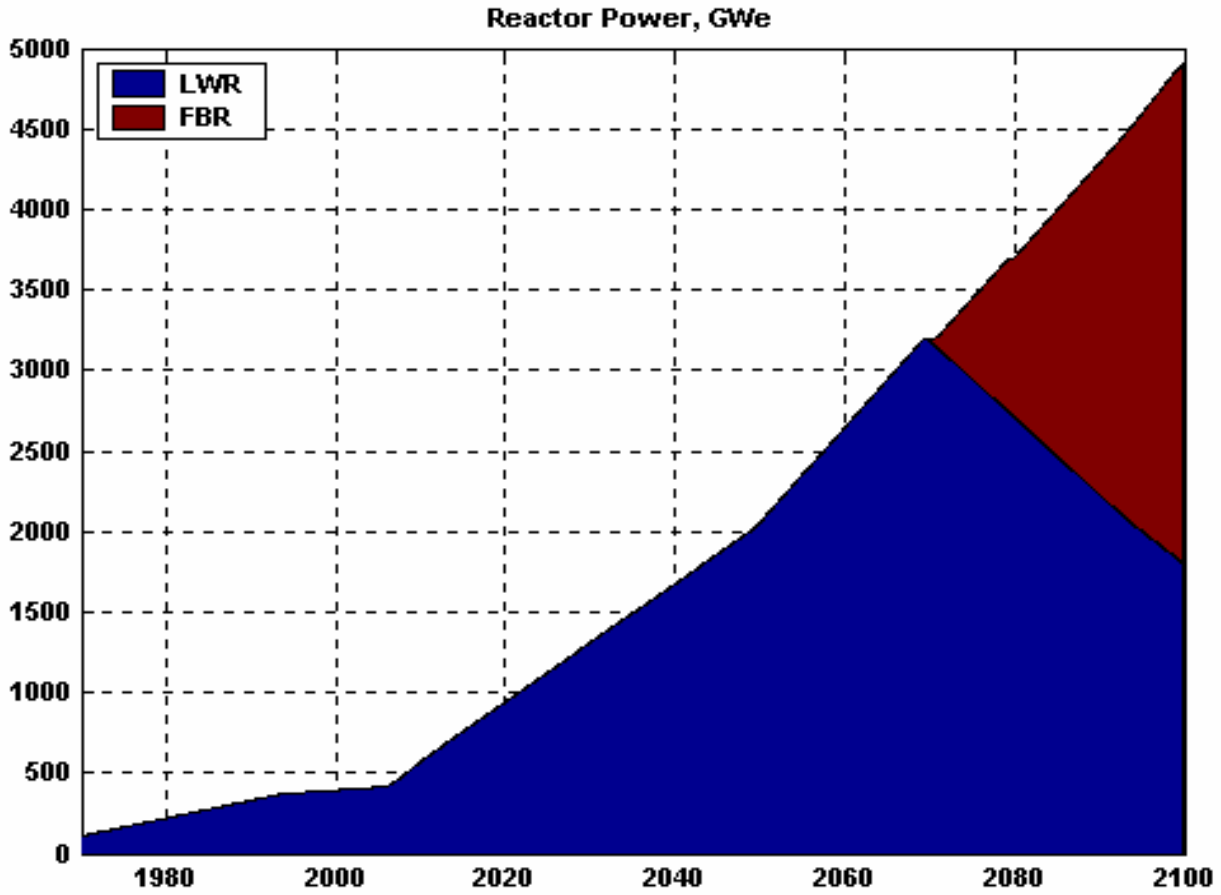
Installed capacities of INS: LWR, FR (2040)
Uranium – 16 mln t, BR=1.6



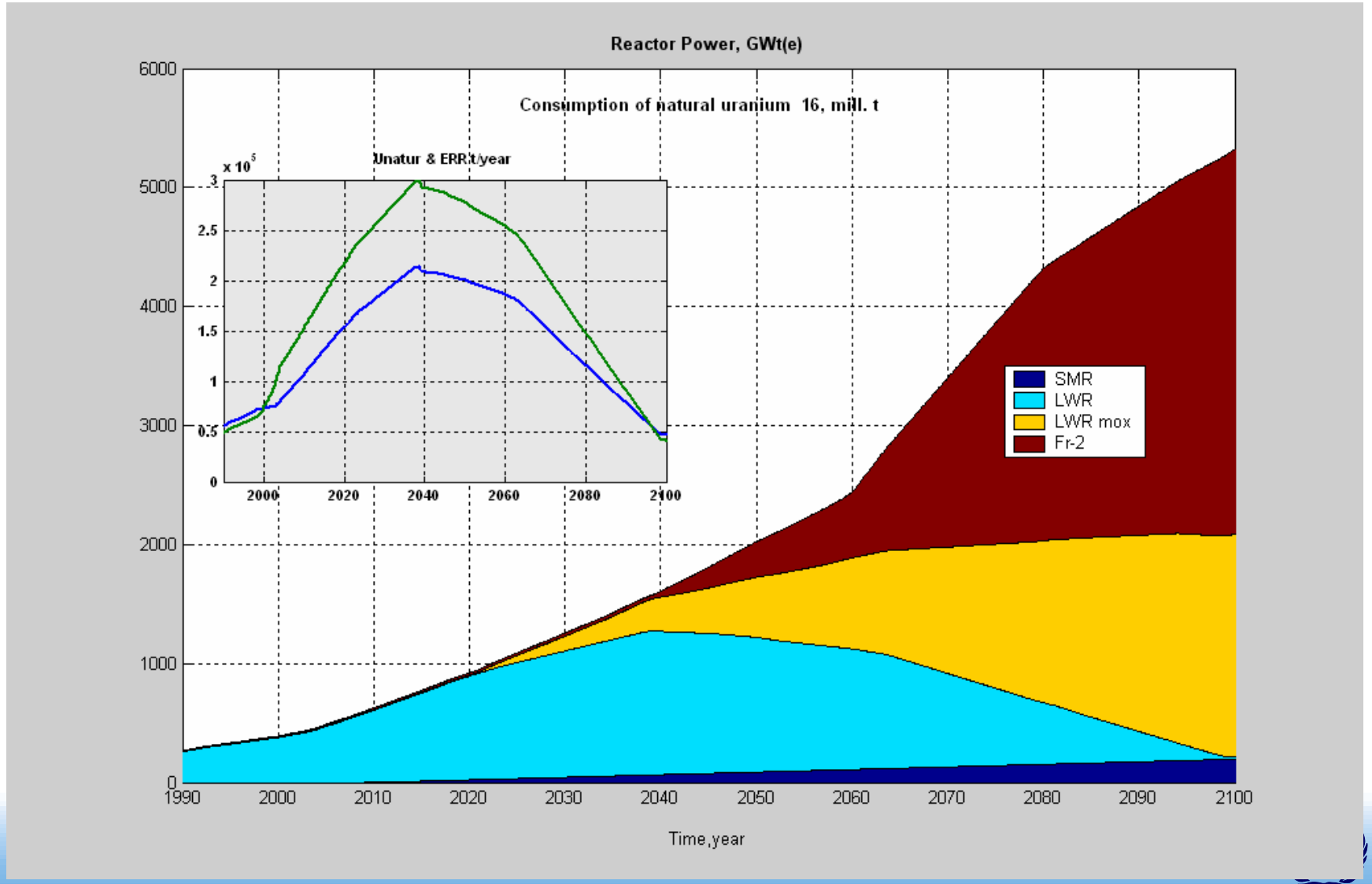
Installed capacities of INS: LWR, FR (2070)
Uranium – 40 mln t, BR=1.05



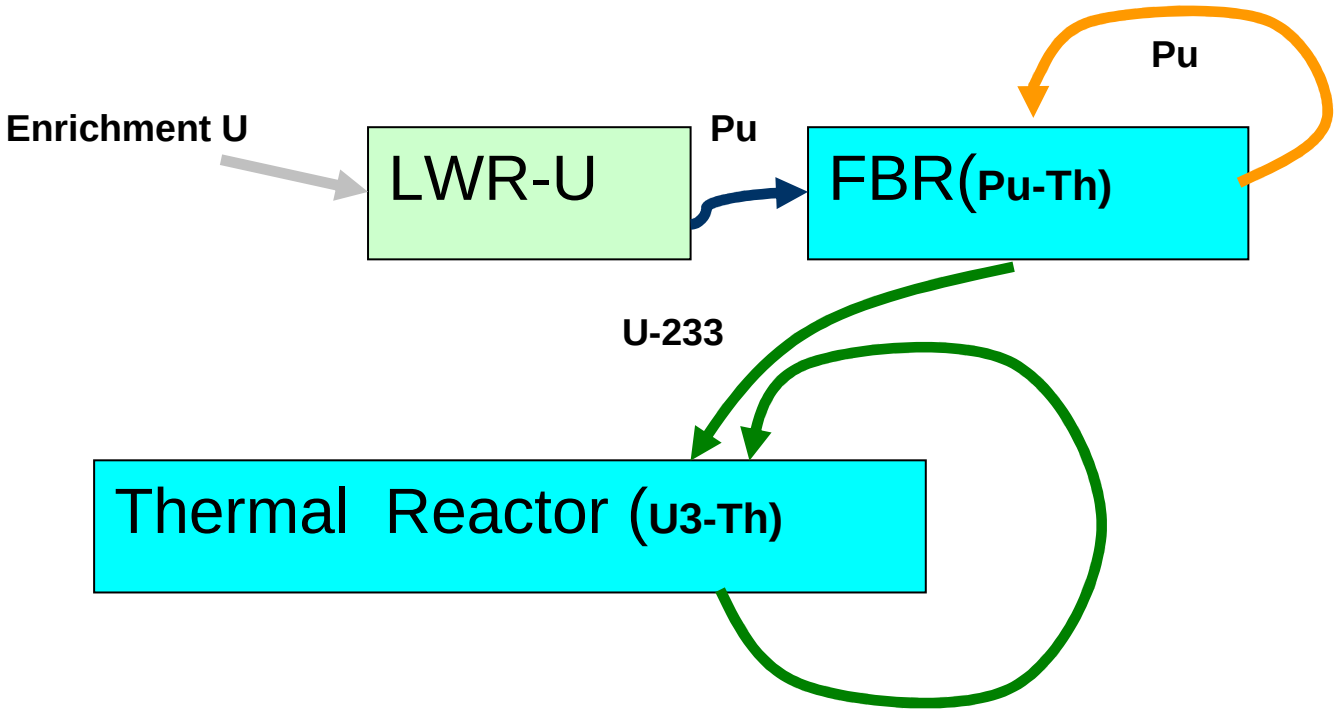
Installed capacities of INS: LWR, FR (2070)
Uranium – 40 mln t, BR=1.6



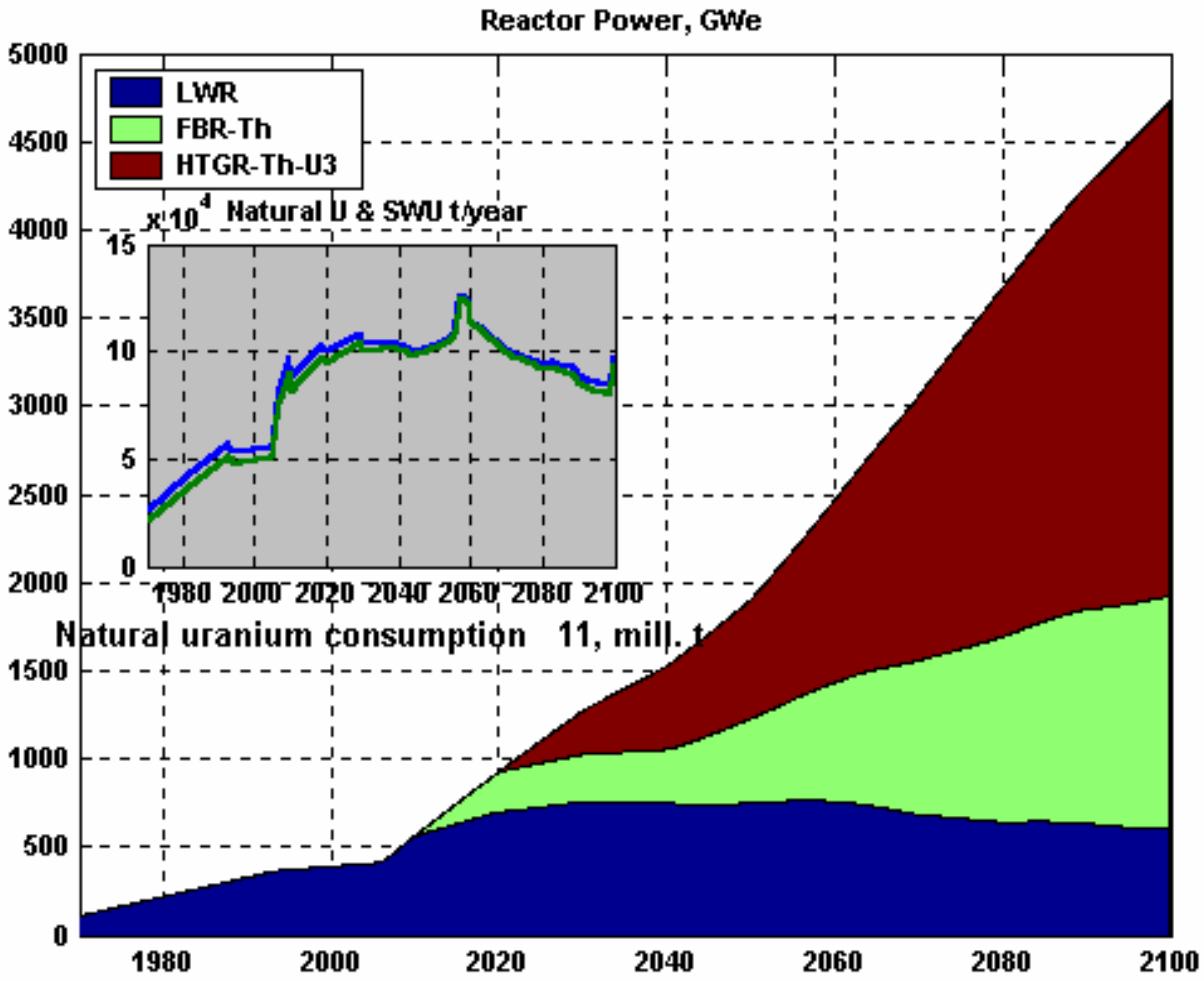
Example of sustainable INS based on LWR, FBR (BR=1.6) +LWRs + small and middle capacity reactors (SMR)



U-Th-Pu closed fuel cycle

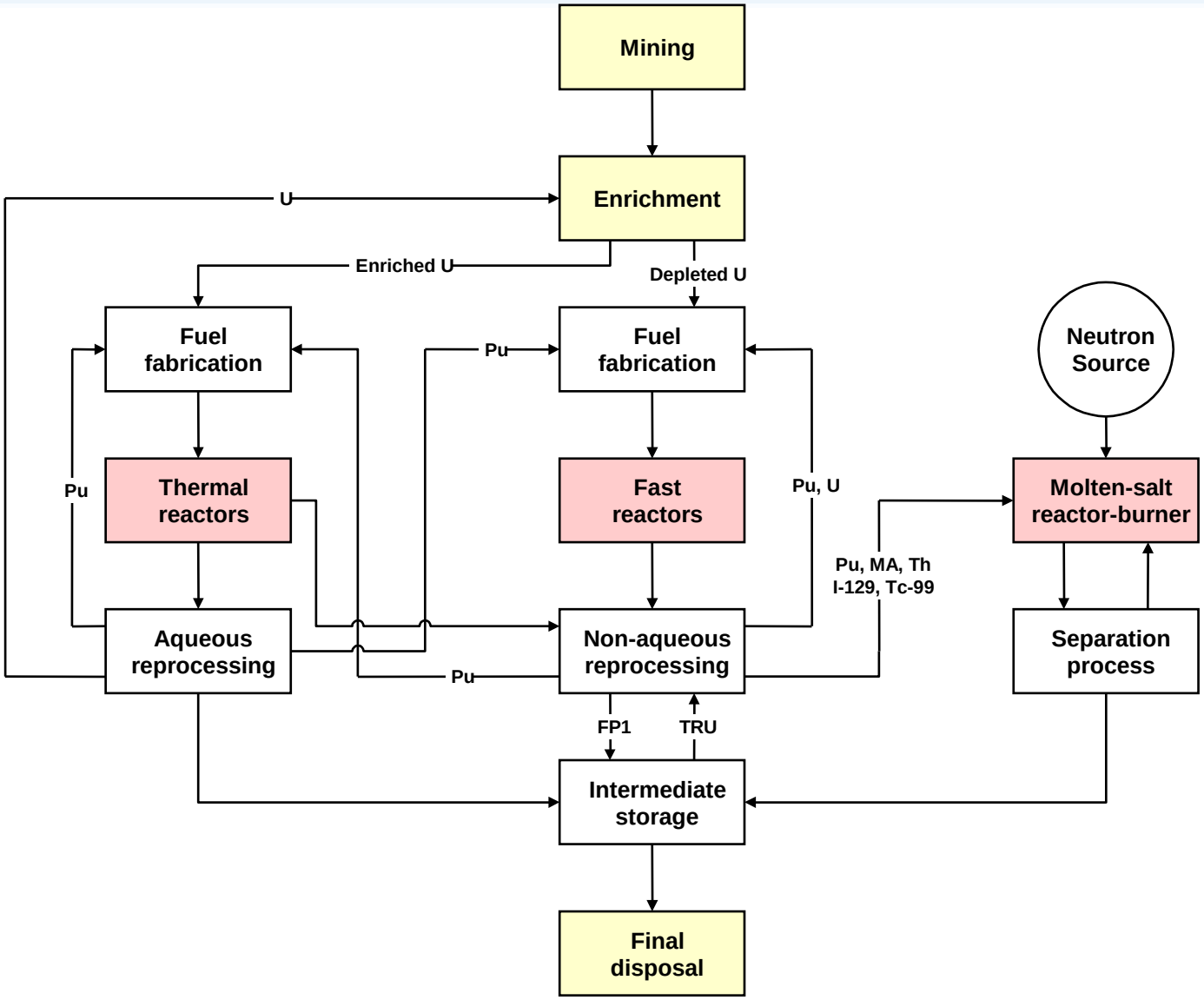


Closed fuel cycle: LWR(U); FR(core-U-Pu, blanket-Th); HTGR(Th-233U)
Total consumption of natural Uranium – 11 mln t



Agency

Example of INS -Multi component nuclear energy system (RRC "Kurchatov institute", Russia)

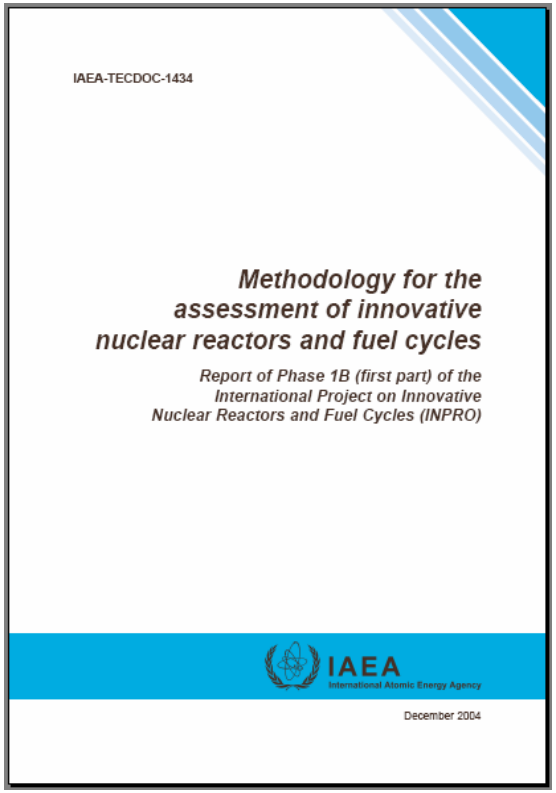


INPRO Methodology
IAEA-TECDOC-1434

Can be used:

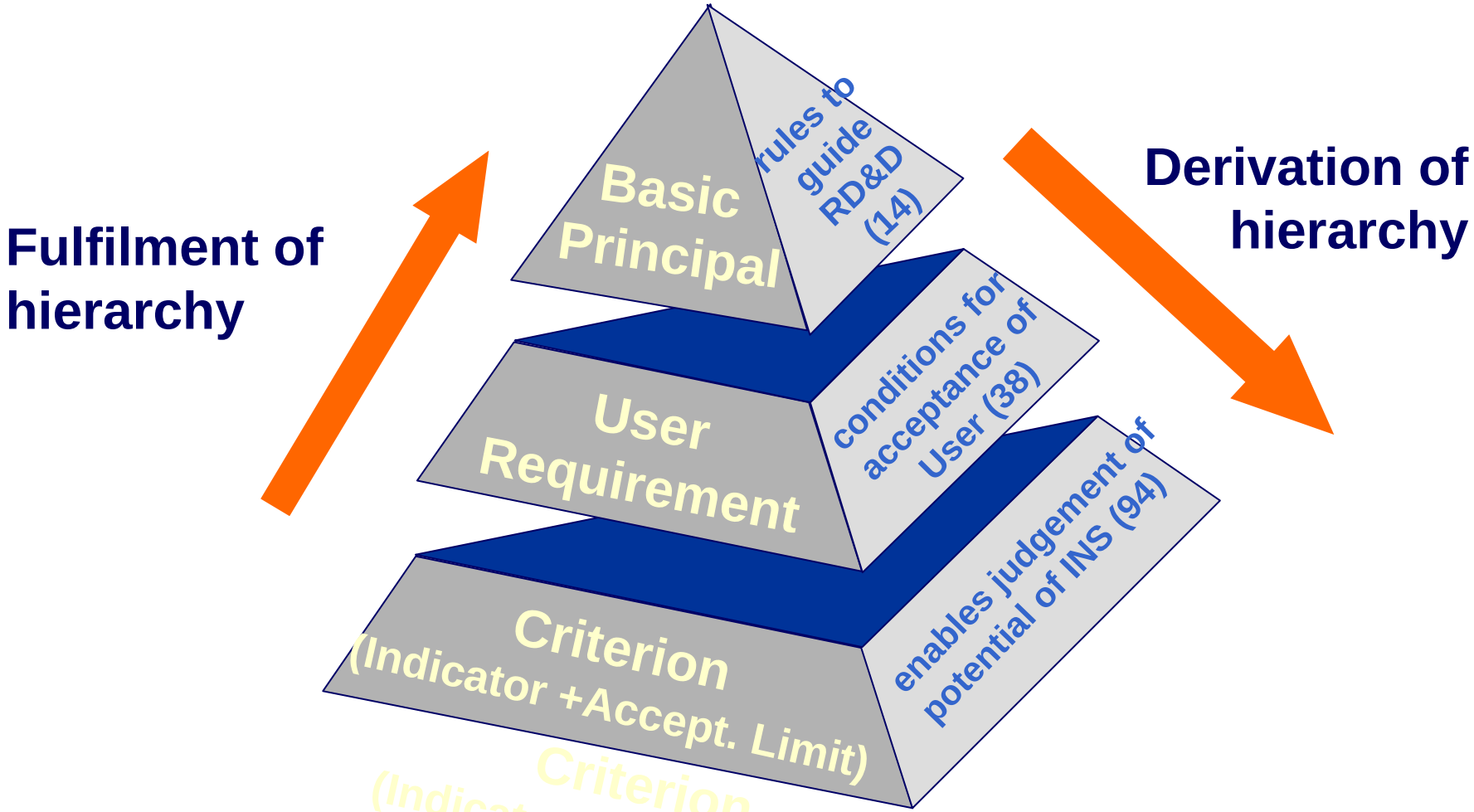
- **to screen an Innovative Nuclear Energy System (INS) for its compatibility with the energy needs of the 21st century and sustainability considerations;**
- **to compare different INSs;**
- **to identify the RD&D required to improve and validate the performance of an INS.**

The assessment must include in the evaluation all components of the INS to achieve a holistic view and ensure that the overall system is sustainable.



General features of INPRO Methodology (1)

INPRO Hierarchy of demands on INS



Set of basic principles, user requirements and criteria is defined in the areas of sustainability, economics, environment, safety, waste management, proliferation resistance, infrastructure

Assessment Studies by INPRO members (1)

- Joint assessment of INS based on closed fuel cycle with fast reactors (China, France, India, Korea and Russia. Japan *as observer*)
- Assessment of hydrogen generating INS (India);
- Study on transition from LWRs to Gen IV fast neutron system (France);
- Assessment of the introduction of a nuclear block of 700 MWe (Argentina);
- Assessment of INS for country with small grid (Armenia); and
- Assessment of whole fuel cycle of DUPIC in the area of Proliferation Resistance (Republic of Korea)

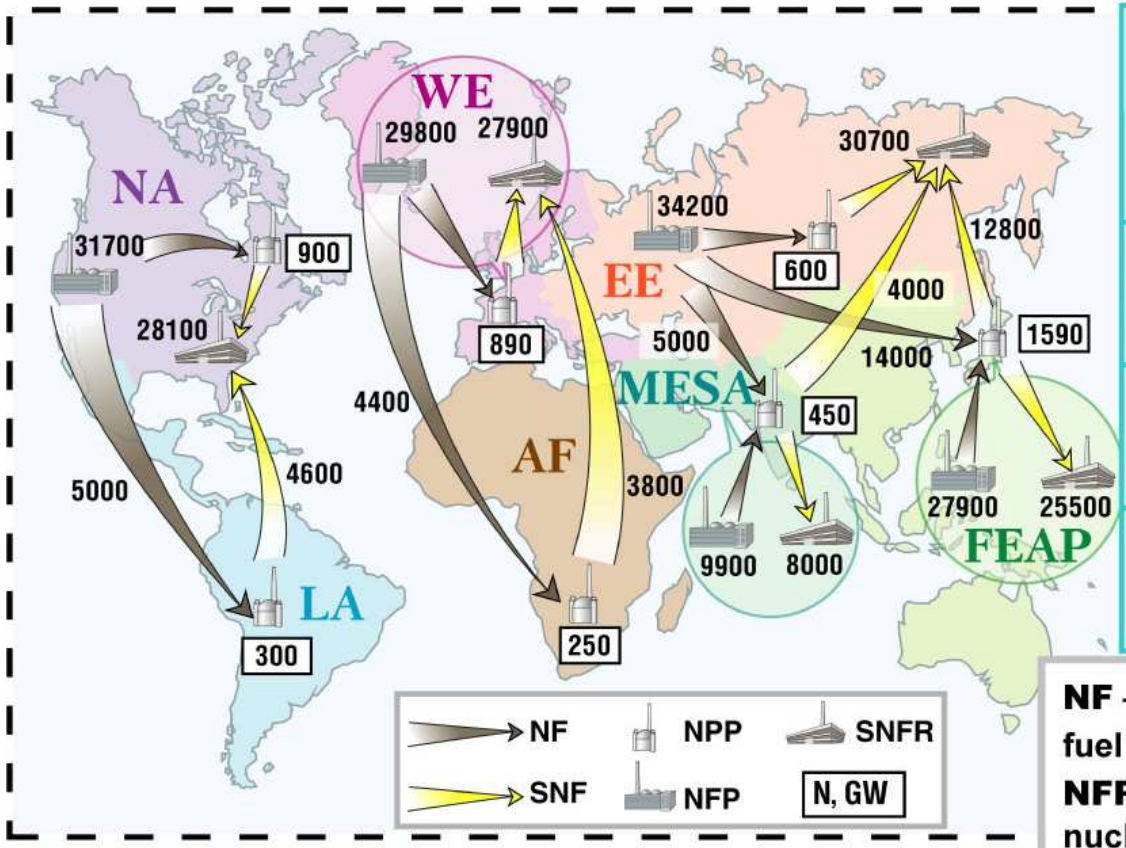
Assessment Studies by INPRO members (2)

- **Two independent assessment studies on IRIS and FBNR (Brazil);**
- **Assessment study of NPP economics (Morocco);**
- **Assessment of advanced high-temperature gas-cooled reactor (China) ;**
- **Assessment of national INS (Ukraine);**
- **Assessment of INS to meet energy demand during periods of raw materials insufficiency (Czech Republic jointly with Bulgaria, Poland, Russia, Slovak Republic).**

* Additional assessments expected

Production and Trans-regional Flows of Fresh and Irradiated Nuclear Fuel in 2100, t/year; N ≅ 5000 GWe

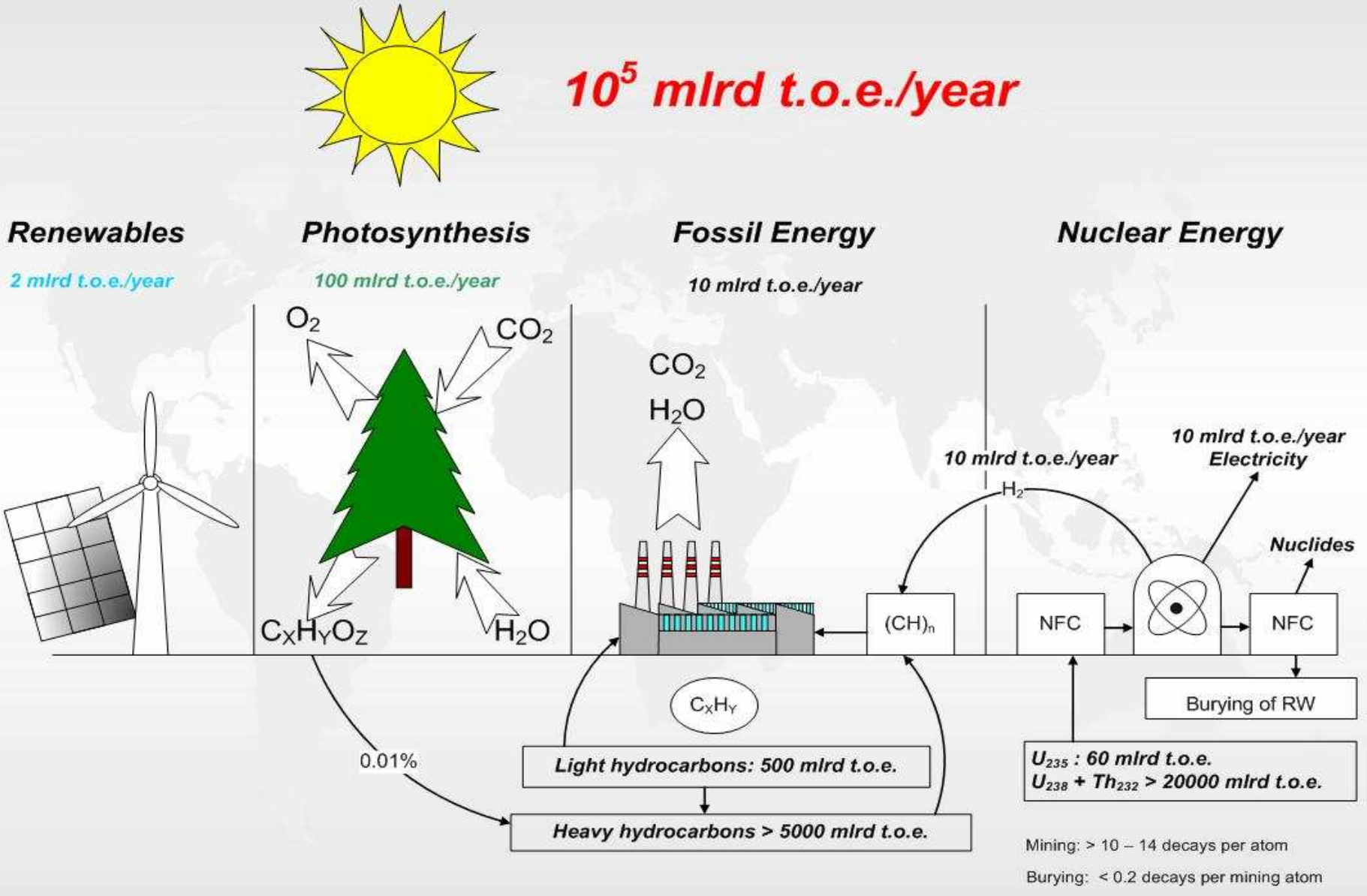
("Traditional" Model)



	NA + WE + EE		LA + AF + MESA + FEAP	
	NF	SNF	NF	SNF
Production 2005	16 000	4 800	5 000	1 100
Production 2010	72 000	64 000	47 000	41 000
Flows 2010	53 000	42 000		

NF – nuclear fuel flow; **SNF** – spent nuclear fuel flow; **NPP** – nuclear power plant; **NFP** – nuclear fuel plant; **SNFR** – spent nuclear fuel reprocessing plant

Asymptotic view of Sustainable Energy Future



NE visions/scenarios analysis for sustainability

- Global/regional/national visions & implementing strategy for decision-makers on the existing & future role of NE for sustainability

- Translate visions of nuclear expansion into technological and policy scenarios that can guide and help coordinate strategies for R&D and NPP deployment.

NE visions/scenarios analysis for sustainability

Visions/scenarios analysis in the framework of INPRO

- Create a vision report
  by selecting representative reference scenarios for NE development in 21st century by identifying nuclear energy growth related sustainability challenges, with associated key indicators and time dependent targets

- Supported by nuclear power development models (MESSAGE etc) as well as by newly developed code
  - DESAE for resources analysis (finance, material)
  - SYRTEX for assessing the economic competitiveness of different INS

INPRO's Three Directions after 2006

- **Infrastructure/**Institutional oriented activities including:
  - **Harmonization of licensing, codes and standards;**
  - **Selection of technological and infrastructure options of INS**
- **Methodology** oriented activities including:
  - **Further development and maintenance of methodology**
- **Collaborative Project** oriented activities (next phase) including: Development and demonstration of INSs by MS (facilitated and coordinated by the Agency);

Ideas for Collaborative Projects

At INPRO Ad-hoc meeting in April to discuss framework of Collaborative Projects, 90 ideas on R&D areas were expressed from 12 INPRO members;

(Examples)

- Fast structural feedbacks in unprotected SFR accidents
- Development of wrapper and cladding materials for FBR
- Joint test of advanced fuel cycle based on vibropacking, pyro-processing
- International assessment on "very long life core" reactors
- Standardized approach for « regional reprocessing centres »
- Analysis of application of Fuel Cycle (Waste management) to a country with small territory

General objective of *INPRO* task 3

Analyse O**pportunities and Challenges for Large-scale Global NE** to define responses that have to be done today in institutional and technology development areas:

- to facilitate global NE use in medium term and
- to prepare basis for NE to play an important role for global sustainable development.

Why INPRO needs global analysis?

- To understand boundary conditions for INS assessments at national level (global energy demand; economic data; resources; environmental issues; non-proliferation; safety)
- To estimate role of NE for sustainable development at global level
- To define effective institutional and technology development responses having global impact

NE Specific Challenges

Large scale global NE development may face some nuclear specific challenges in areas such as:

- **Natural resource availability (Pu–internal resource)**
- **Assurance of proliferation resistance**
- **Assurance of safe nuclear waste management**
- **Nuclear safety assurance**
- **Specific NE environmental issues**

A need for dynamic NE modelling

Understanding NE challenges Modelling needs

- Geographic coverage - regional and global
- Time horizon – 21st century, benchmarks at 2030 and 2050
- Areas of analysis – nuclear energy system
- Type of nuclear energy services - electricity, transport, heating, desalination and other
- Areas of concern (resources, PR, waste management, infrastructure, safety? environment? other?)
- Key Indicators and criteria to measure success in addressing NE specific challenges - TBD.
- Model availability – DESAE or any other NE model with detailed fuel cycle description applicable for analysis of economics, infrastructure, resources, waste and PR challenges.

Modelling Needs
for
Joint Study on Assessment of INS based on Closed Nuclear Fuel Cycle with Fast Reactors using INPRO Methodology

Joint Study on Assessment of Innovative Nuclear Energy Systems based on Closed Nuclear Fuel Cycle with Fast Reactors using INPRO Methodology

Dates for the study:

beginning of 2005 – end of 2006

Participants:

- **China,**
- **France,**
- **India,**
- **Russian Federation,**
- **Republic of Korea,**
- **Japan – as observer**

Joint Study stages:

Stage 1: Suggestions of INSs based on a closed nuclear fuel cycle with fast reactors.

Stage 2: Assessment of the proposed INSs using the INPRO methodology.

Stage 3: Elaboration and preparation of a conclusion on the long-term viability of INSs.

Joint Study on Assessment of Innovative Nuclear Energy Systems based on Closed Nuclear Fuel Cycle with Fast Reactors using INPRO Methodology

1st Scientific and Technical Committee Meeting: 16-17 March 2005, Obninsk, Russia

*** Draft JS Concept presented, discussed and approved in general;**
*** National development/deployment strategies presented:**

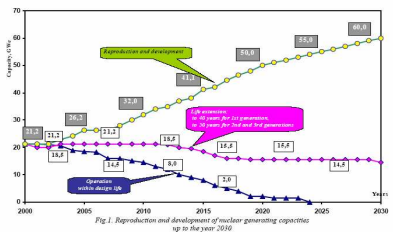
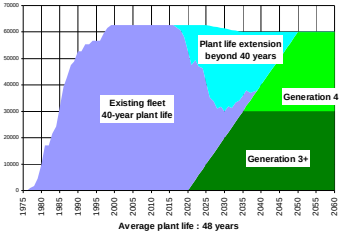
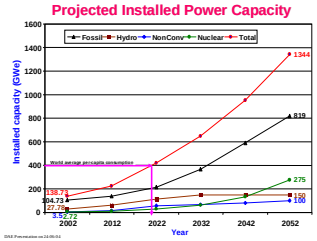
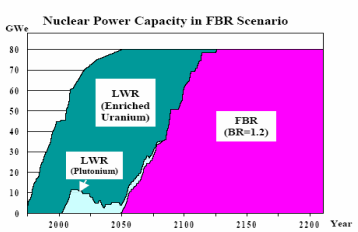


Fig.1. Reproduction and development of nuclear generating capacities up to the year 2030







- **JS MS identified technologies to be considered as INS CNFC-FR components:**

France – Gas and Na cooled reactor technologies with appropriate fuel cycle technologies

India - Na cooled reactor technologies with involvement of Th fuel and appropriate fuel cycle technologies with high breeding

Korea - Na cooled reactor technologies with appropriate fuel cycle technologies

Russia - Na, Pb, Pb-Bi and gas cooled reactor technologies with dry and aqueous reprocessing technologies

Japan - Any promising fast reactor technologies with appropriate fuel cycle technologies

Objectives of GIF and INPRO

GIF

To develop one or more nuclear energy systems which :

- **are deployable by 2030;**
- **offer significant advances in sustainability, safety and reliability, proliferation and physical protection, economics;**
- **can compete in various markets;**
- **offer various energy applications electricity, hydrogen, clean water, and heat energy.**

INPRO

-To help to ensure that nuclear energy is available to contribute towards fulfilling, in a sustainable manner, the energy needs of the 21st century.

-To bring together all interested MS, both technology holders and users, to consider jointly those actions required to achieve desired innovations in nuclear technologies.

-To create a process that involves all relevant stakeholders.

Time horizon is 50 years into the future

Interface with GIF

- Interface meeting of IAEA/INPRO with GIF (20Sept2004, 20-21Sept2005)
  - 20-21Sept2005 interface meeting by11 GIF members and 30 IAEA/INPRO staff members to confirm complementary nature between two parties
  - Recommendations on activities for information exchange and synergy in the area of Economics, Risk and Safety etc.
- IAEA/INPRO staff participating in GIF WG (Economic Model, Risk and Safety, Proliferation Resistance and Physical Protection), GIF participating in INPRO meeting (Proliferation Resistance)

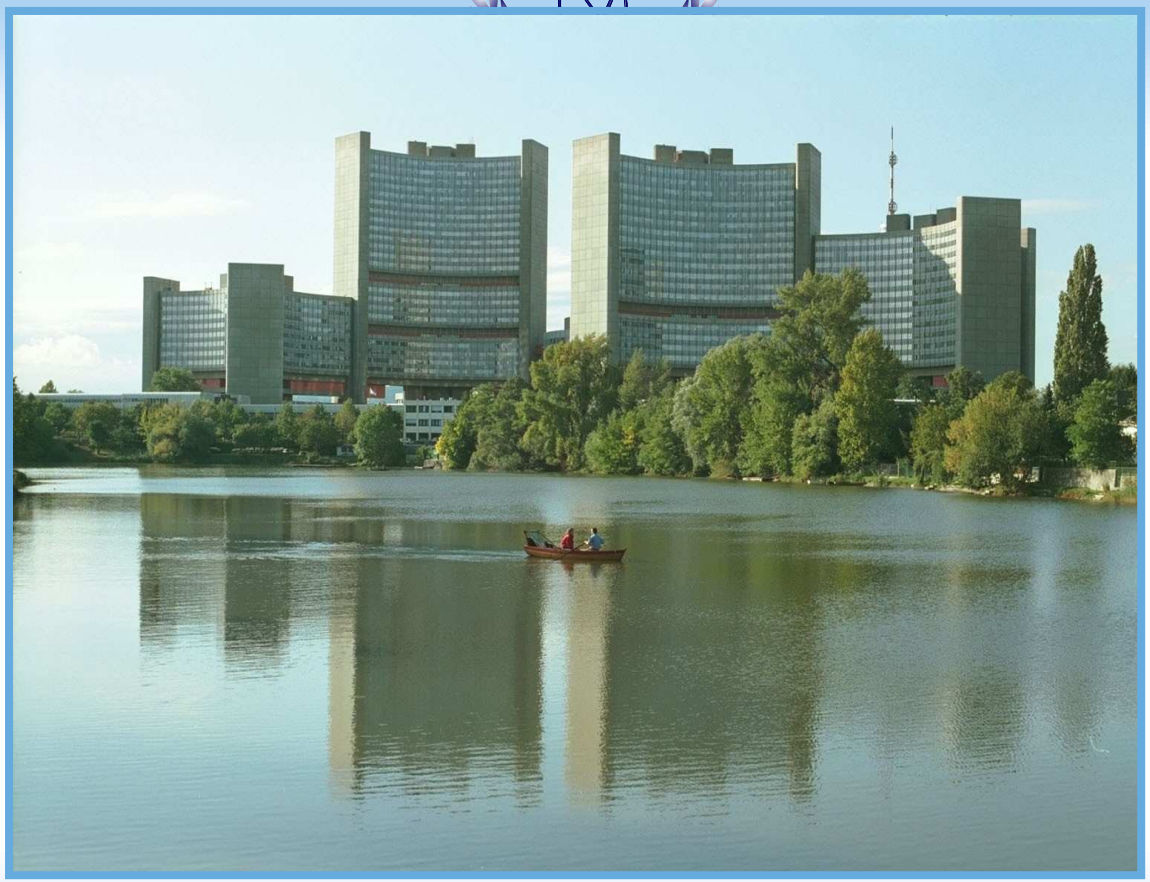
GIF/IAEA/INPRO Interface Meeting
20-21 Sep 2005 Vienna International Center, Austria

Kupitz, Cirimello, Facer, McDonald, Gasparini, Gunguly, Depisch, Kim, Haas, Fiorini, Omoto, Bursurin, Kuznetsov, Leahy, Usanov, Rasin, Matsui, Bennett, Bari, Allan, Moriwaki, Ranguelova, Cojazzi, Reig, ?, Khalil, El-Shanawany

In Conclusion: INPRO Today

- is an international project, with growing membership and recognition, jointly implemented by the IAEA and INPRO Member States (MS);
- has produced, and is producing, tangible results and achievements;
- is of clear interest to many MS, including both developed and developing countries;
- is important to the Agency;
- is becoming an international center for analysing the role of Innovative Nuclear energy Systems (INS) in nuclear power's future;
- has developed methodology to assess INSs and will identify strategic R&D improvements;
- Methodology is based on a holistic approach.
- creates an important opportunity for collaborative international R&D on INSs.

Thank you for your attention



WWW.iaea.org/INPRO

www.iaea.org/INPRO

Thank you!