Challenges and Opportunities of Accelerator Driven Systems (ADS) as Sustainable Energy Solutions

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Outline

- Korea's Nuclear Energy Success
- Global Nuclear Energy Outlook
- Challenges
  - Nuclear Safety
  - Spent Nuclear Fuels
  - Nuclear Safeguards and Security
- Advanced Partitioning & Transmutation
- ADS+PyroGreen : PEACE Solution
- Multi-National Alliance for PEACE

Korea’ s Nuclear Energy Success

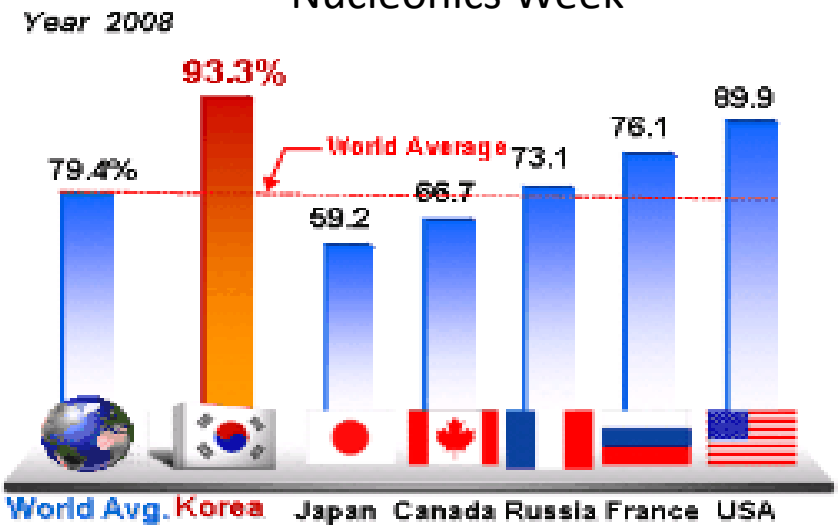
Korea’ s Nuclear Energy Success

All Korean Presidents Strongly Supported Nuclear Energy Program During Past 60 Years.

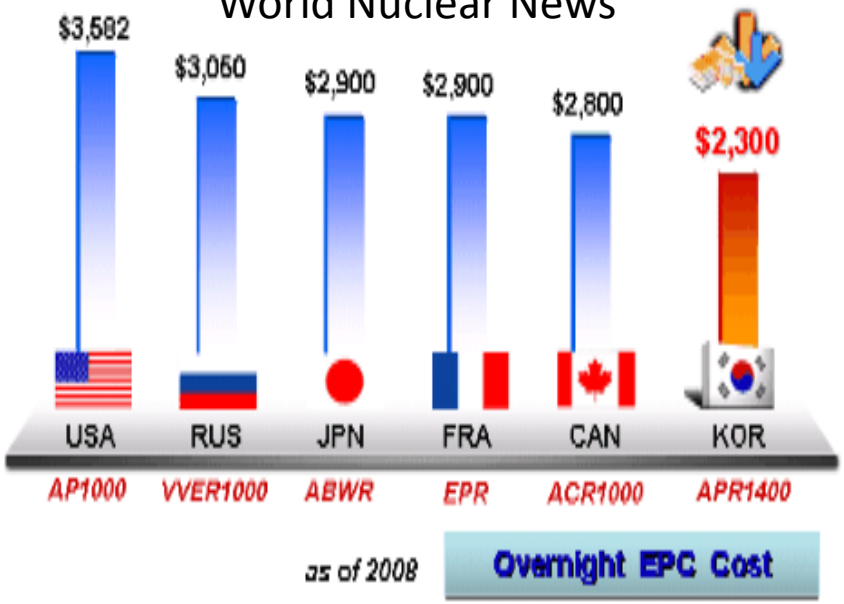
New President PARK Geun Hye

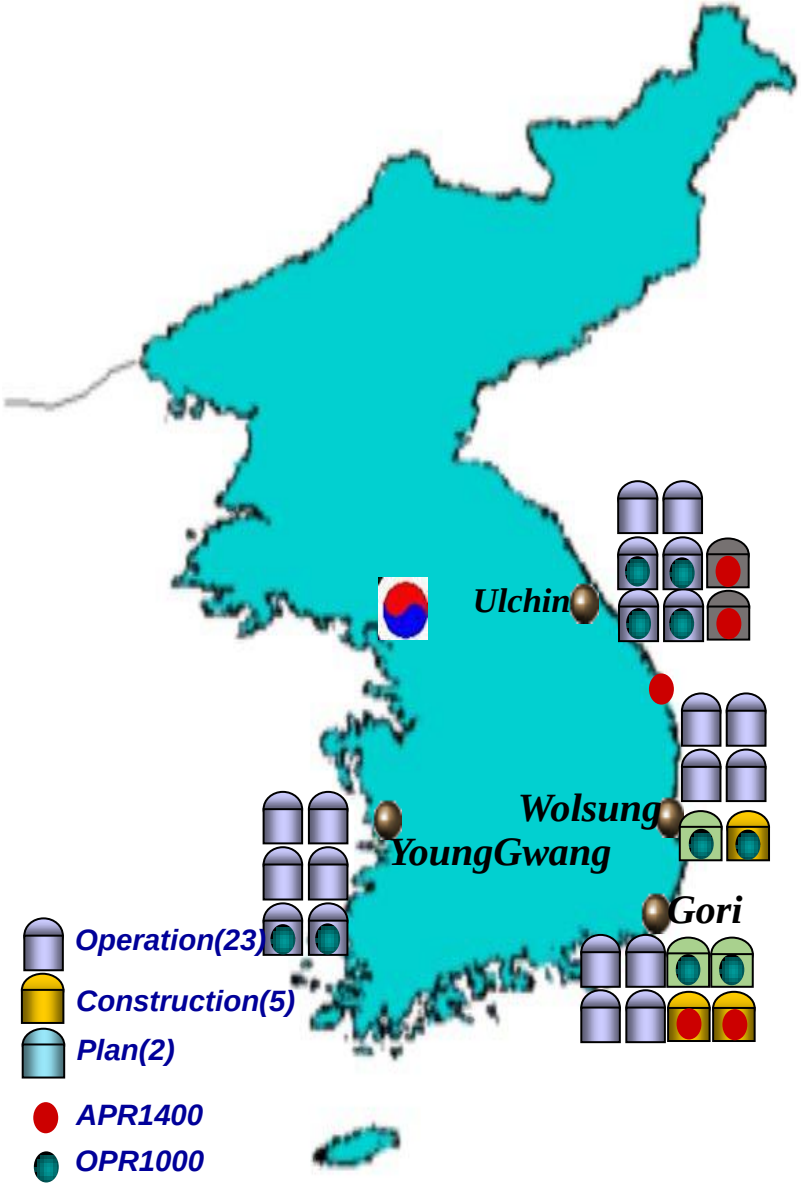
Korea's Nuclear Energy Success

Nucleonics Week

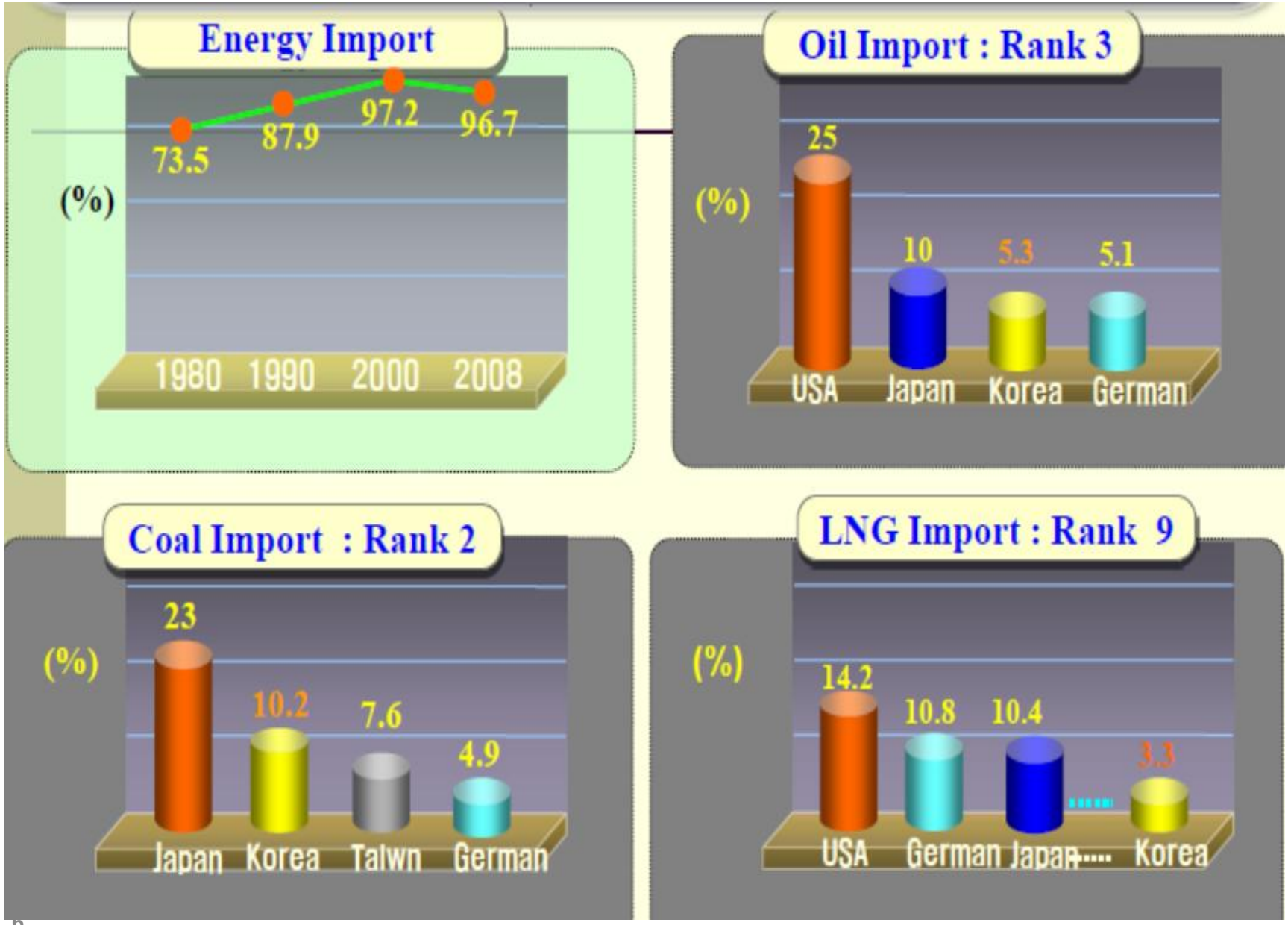


World Nuclear News

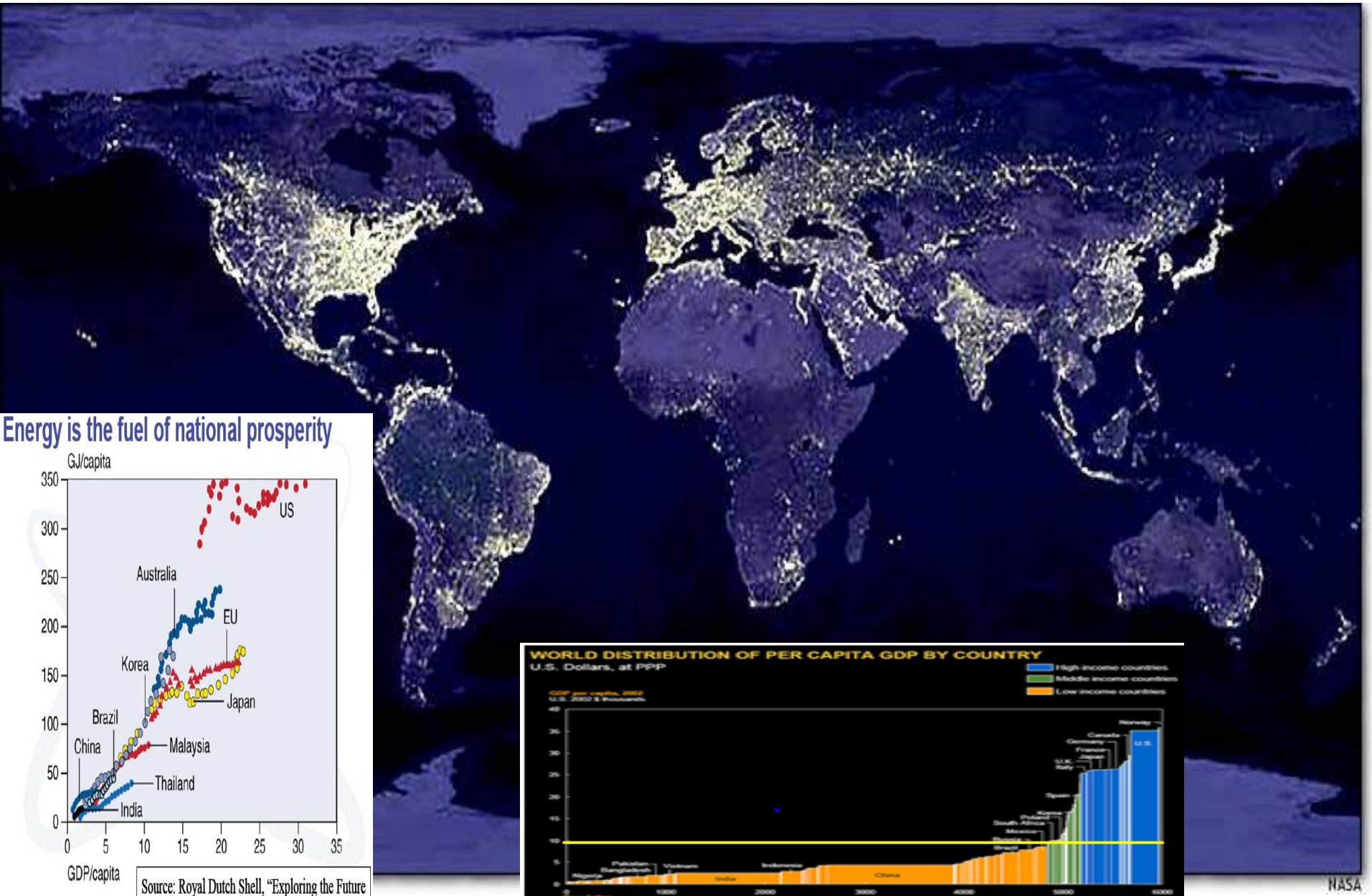




Global Nuclear Energy Outlook

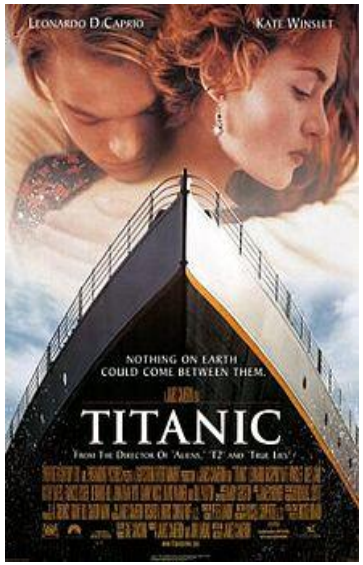


Global Nuclear Energy Outlook



NASA

Challenge : Nuclear Safety

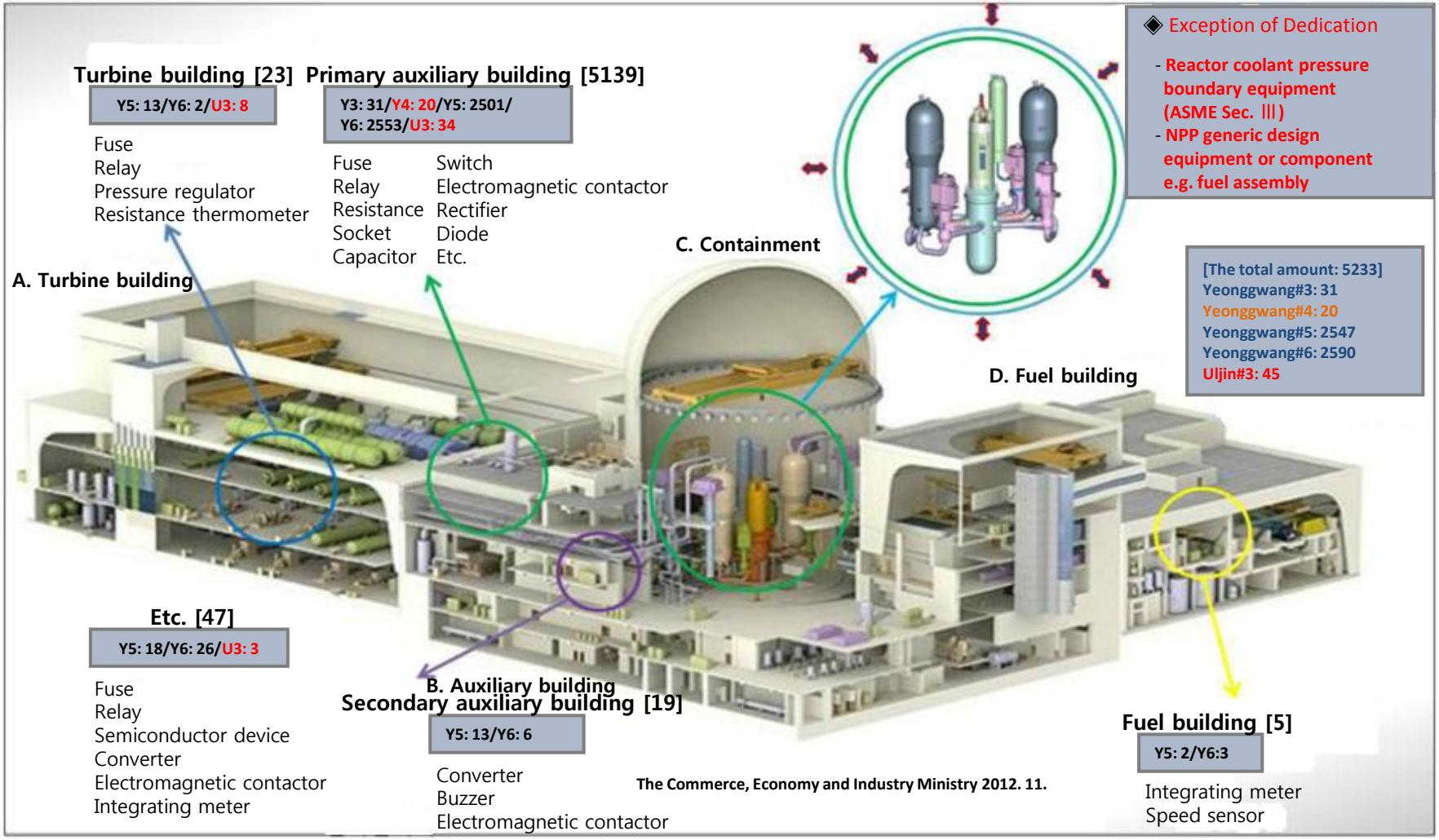


Today's Nuclear Power

- "Safety-critical"
  - Meltdown Accident
  - Chemical Explosion
  - Criticality Accident
- Mandates Safety Culture
- Public Distrust

Challenge: Safety

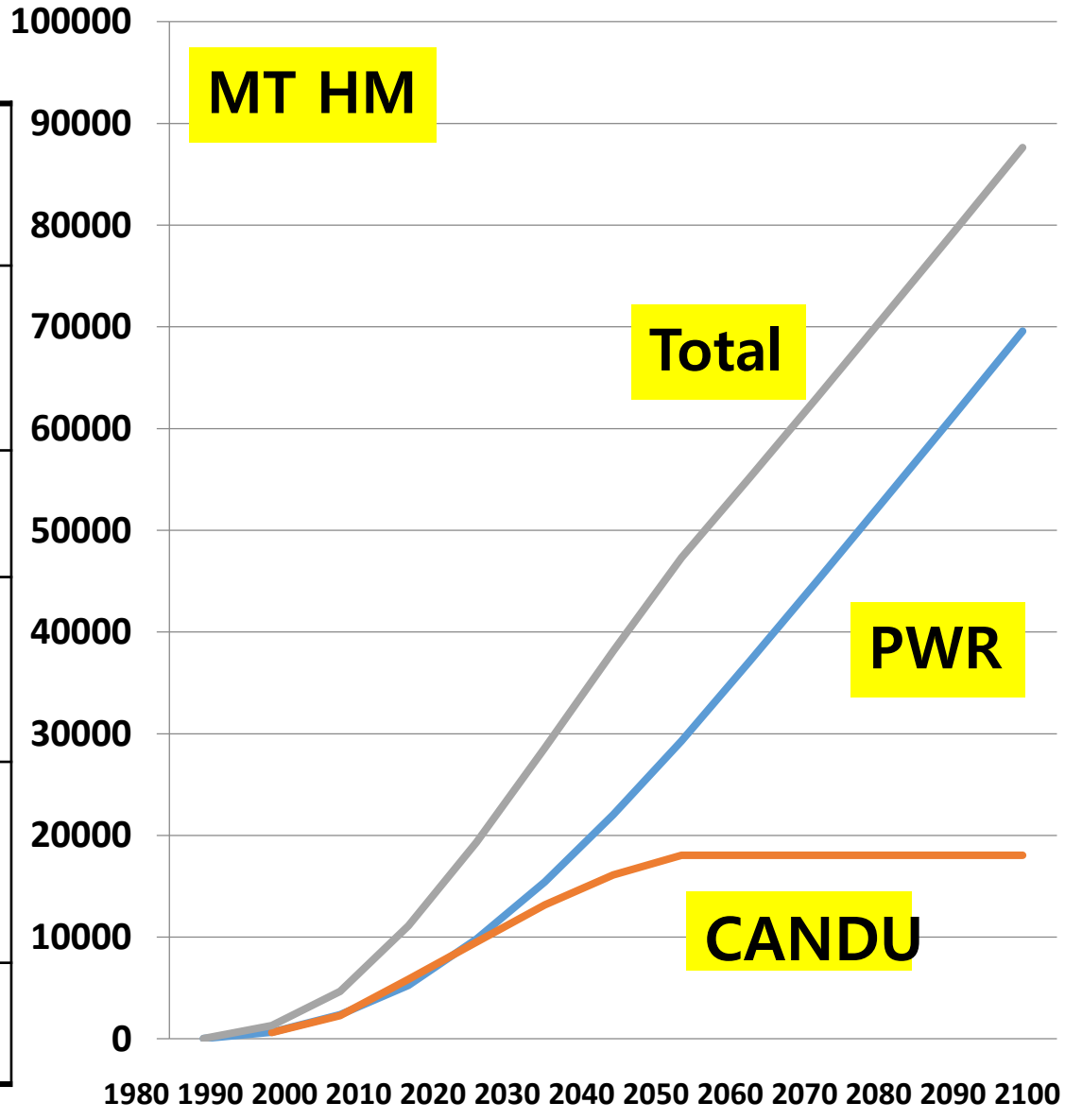
2012 whistle-blow of unqualified parts in NPP



Challenge : Spent Nuclear Fuels and HLW

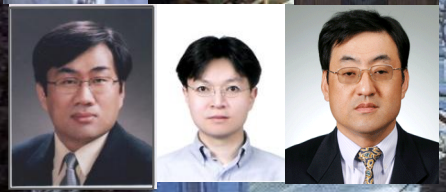
Korean Challenge

NPP sites (no. units)	Sat. Year	Re-racking Pool-sharing
Gori (4) Shin-Gori(4)	2016	Done (1990+) In Progress
Yonggwang (6)	2024	In progress
Ulchin (6) Shin-Ulchin(2)	2018	In Progress Planned
Wolsong (4) Shin-Wolsung(2)	2017	Expansion + MACSTOR
Total 28 Units	2016	2024



SNU-Nuclear Transmutation Research

SNUMAT (1993~) & NUTRECK(2002~)
SNU, KAIST, KHU, UNIST, CNU



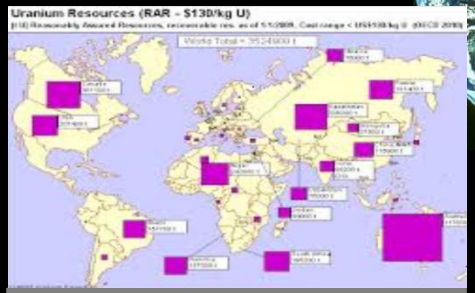
LFR Test Loop
HELIOS 2005. 5

SNU-Nuclear Transmutation Research

Proliferation

Economy

Environment



Continuity

Accident

Proliferation-resistance

Environment-friendliness

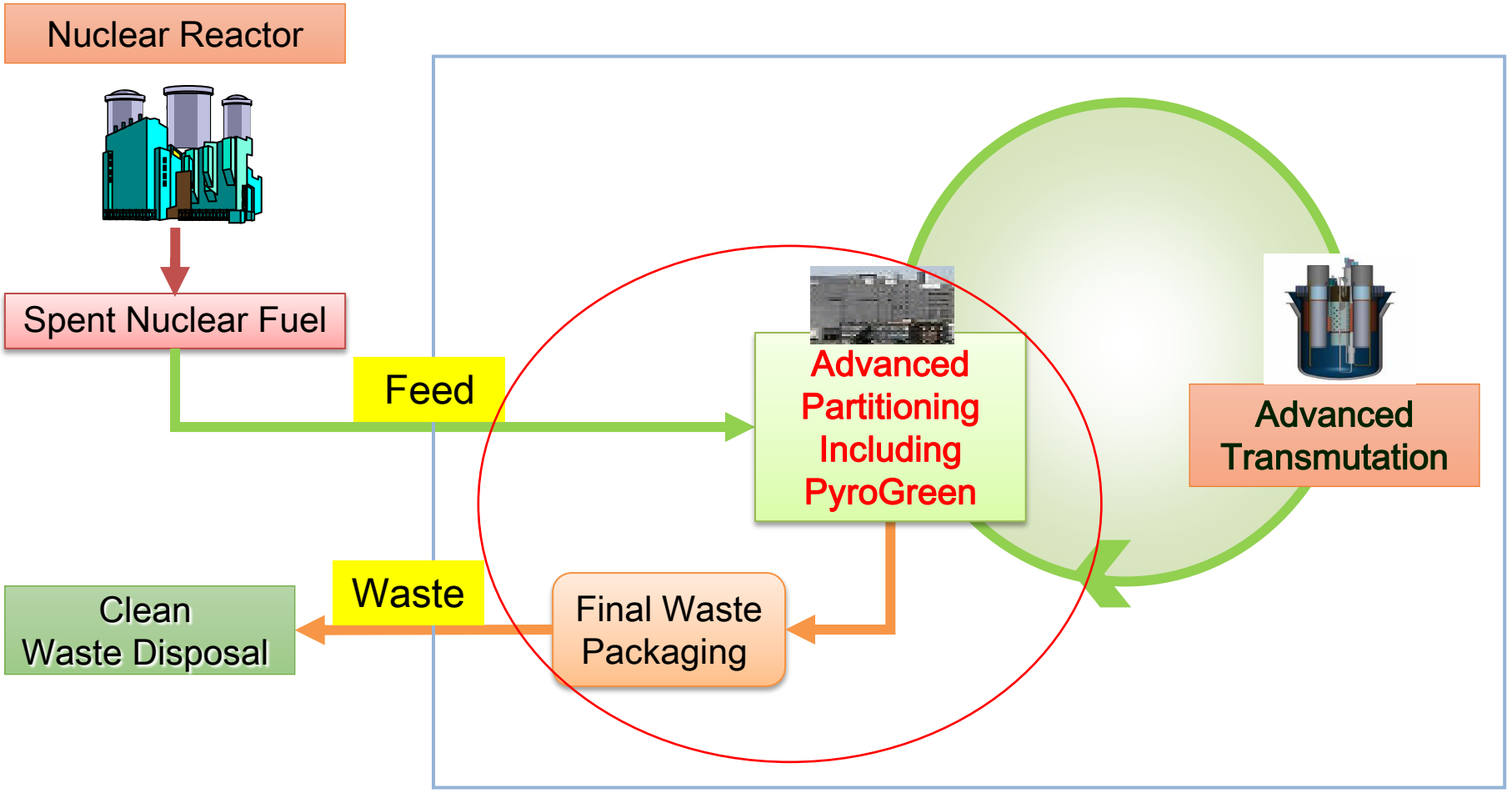
Accident-tolerance

Continuity

Economy

"PEACE"

ADS : Safety and Environment Solution



- Accident: Criticality, Melt-down and Chemical Explosion
- Radio-isotopic Decontamination Factor = $\frac{\text{Feed to P\&T}}{\text{Waste from P\&T}}$

ADS : Safety Solution

Report from the DOE ADS White Paper Working Group

Eric Pitcher
Los Alamos National Laboratory

Stuart Henderson
Fermilab

U.S. DEPARTMENT OF ENERGY

Fermilab

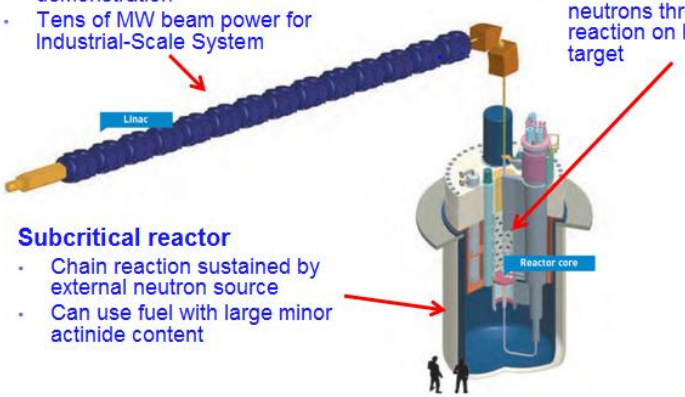
Accelerator Driven Systems

High-power, highly reliable proton accelerator

- ~1 GeV beam energy
- ~1 MW of beam power for demonstration
- Tens of MW beam power for Industrial-Scale System

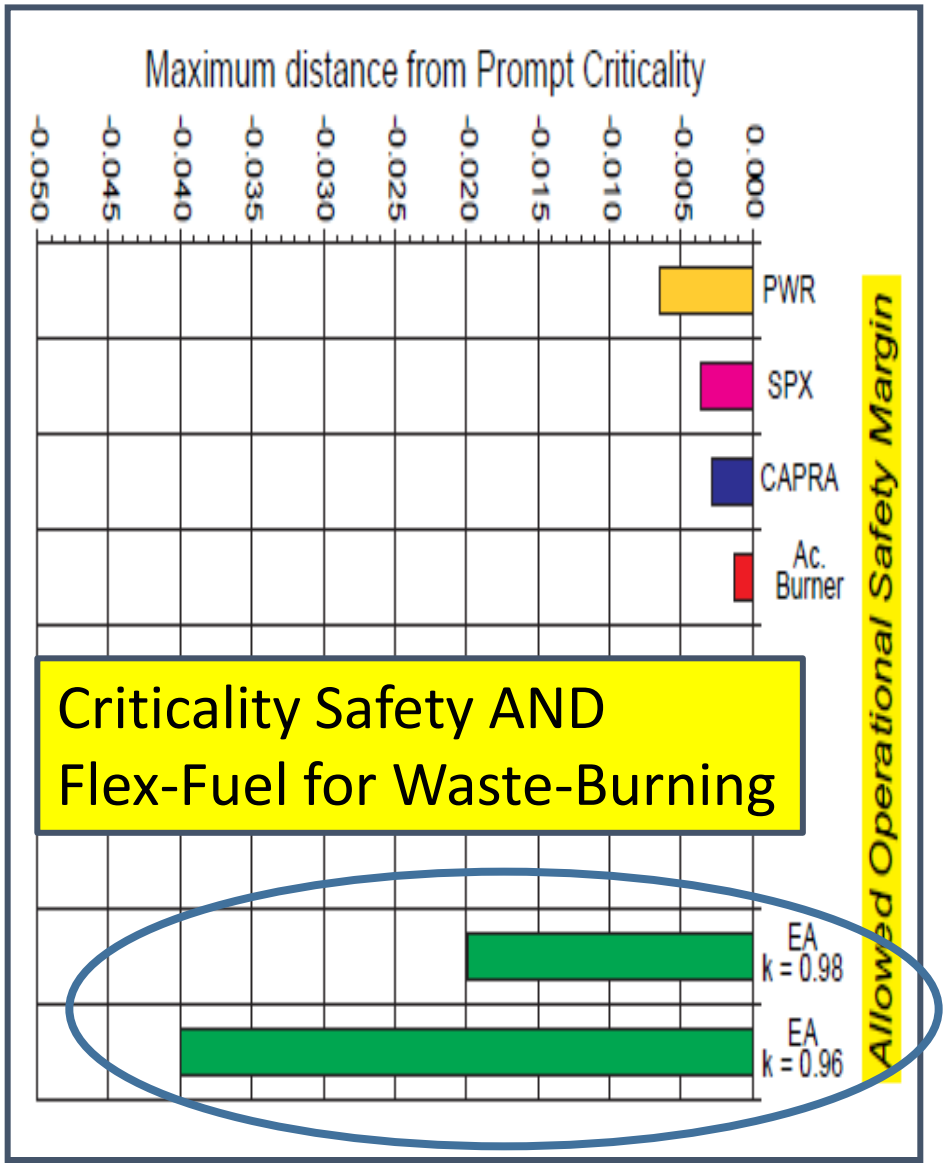
Spallation neutron target system

- Provides external source of neutrons through spallation reaction on heavy metal target



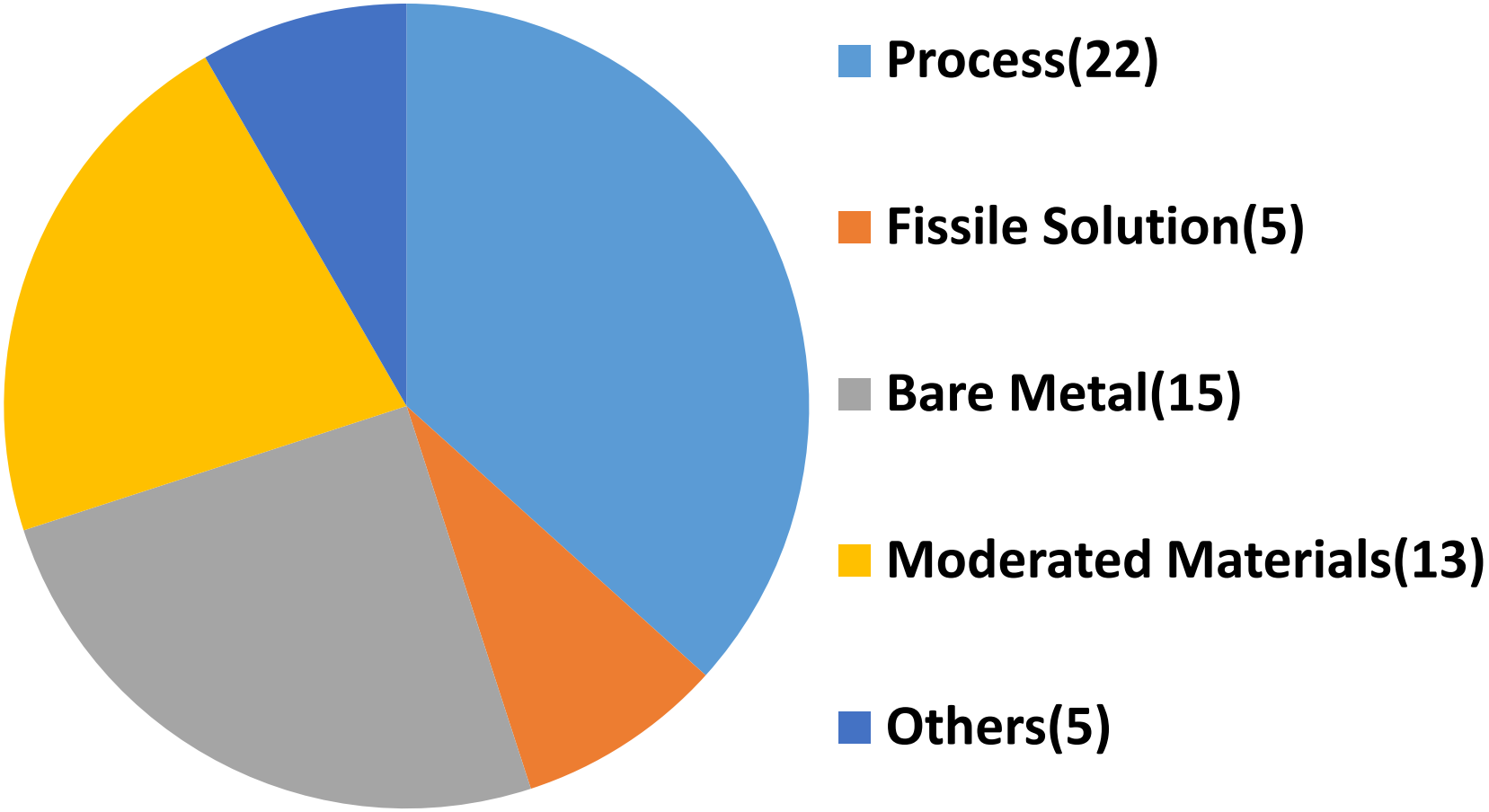
Subcritical reactor

- Chain reaction sustained by external neutron source
- Can use fuel with large minor actinide content



Criticality Safety AND
Flex-Fuel for Waste-Burning

ADS : Nuclear Criticality Accidents

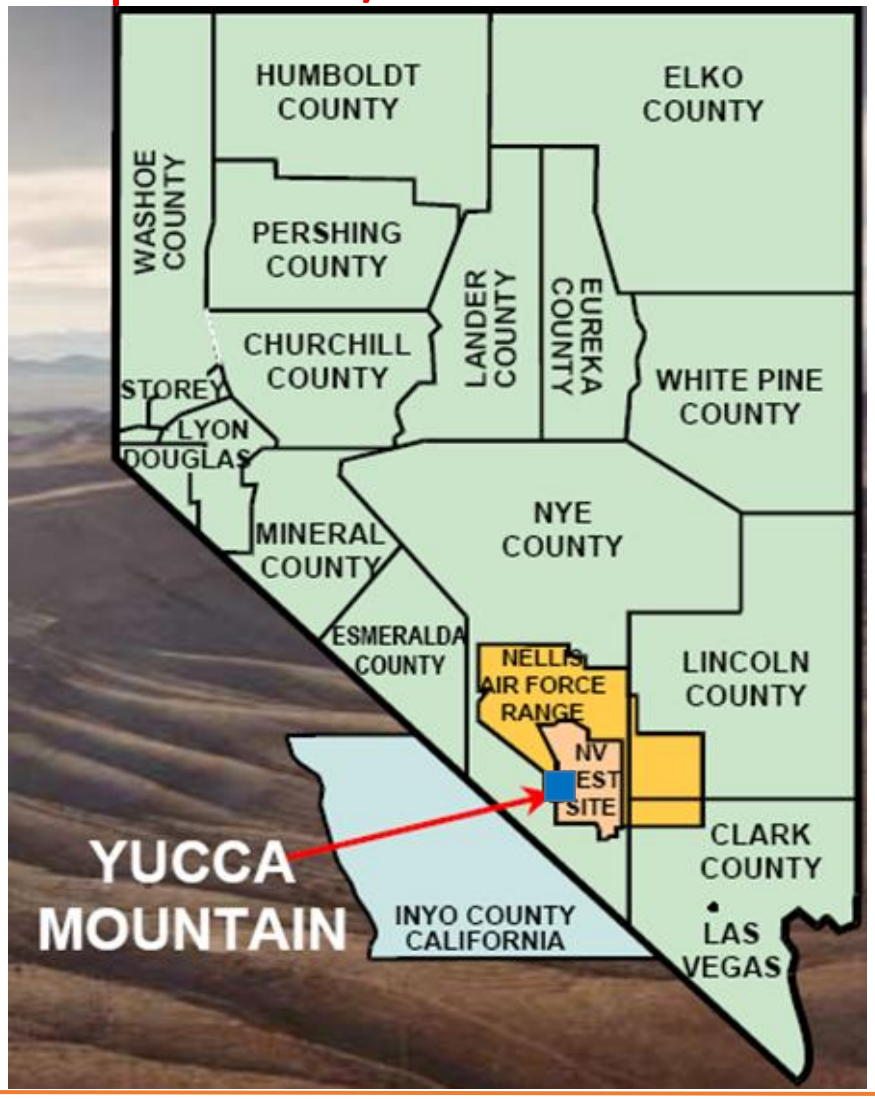


ADS : Safety Solution

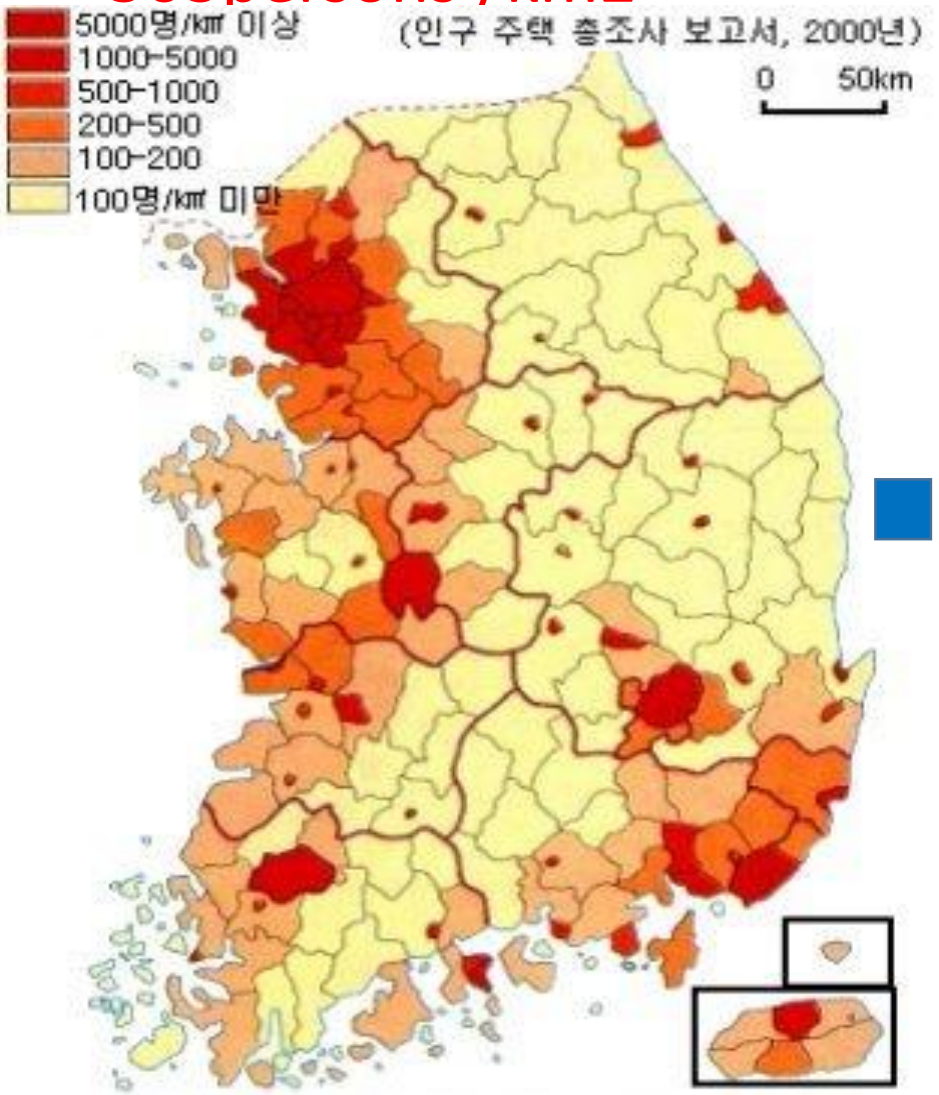
Challenge : Spent Nuclear Fuels and HLW

High Population Density

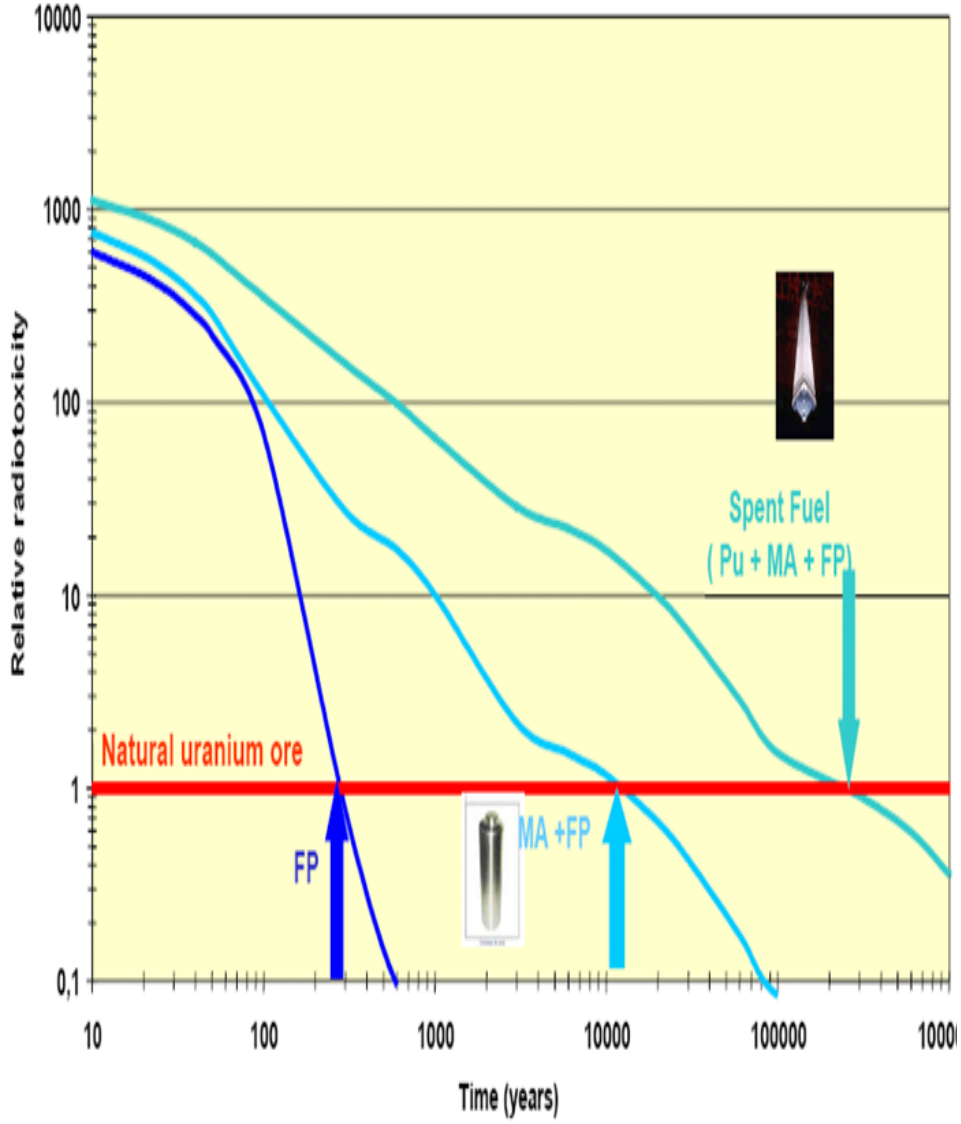
25persons /km2

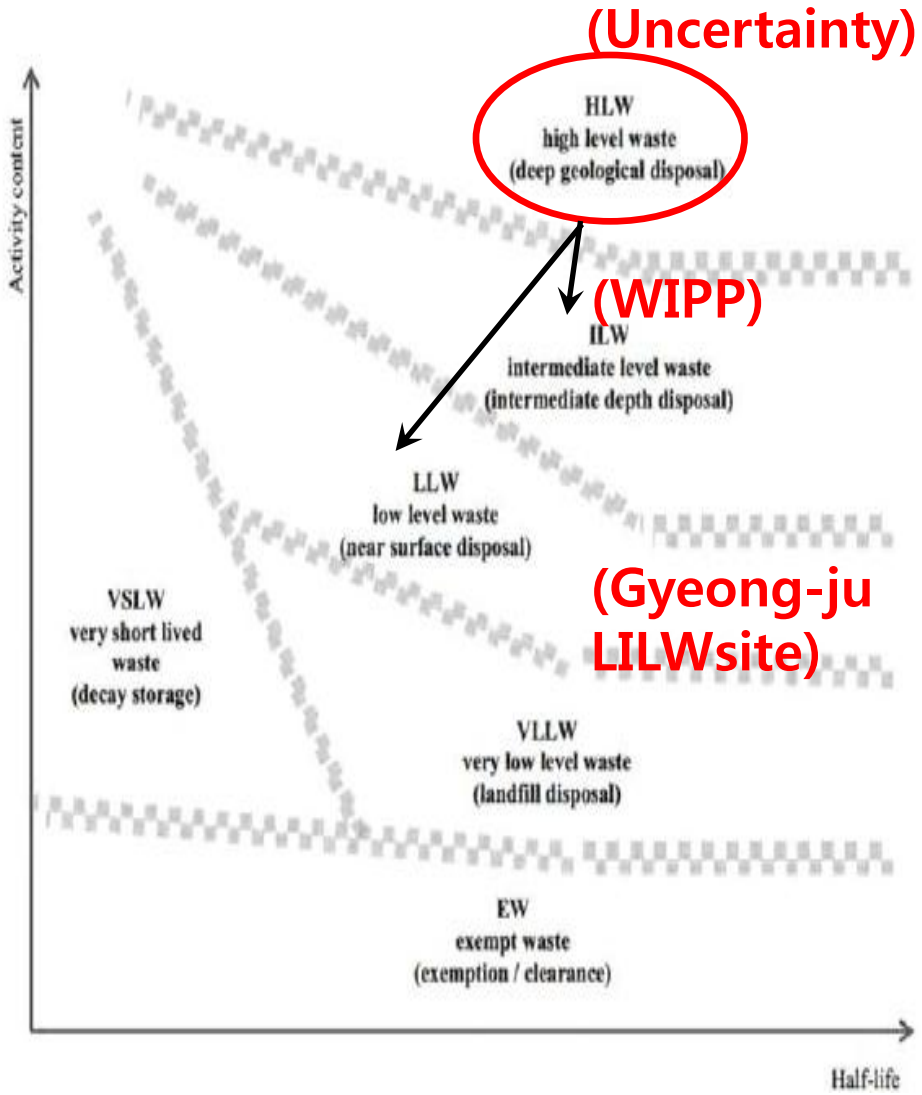


503persons /km2



ADS+PyroGreen: Turning HLW into ILW Cleanliness





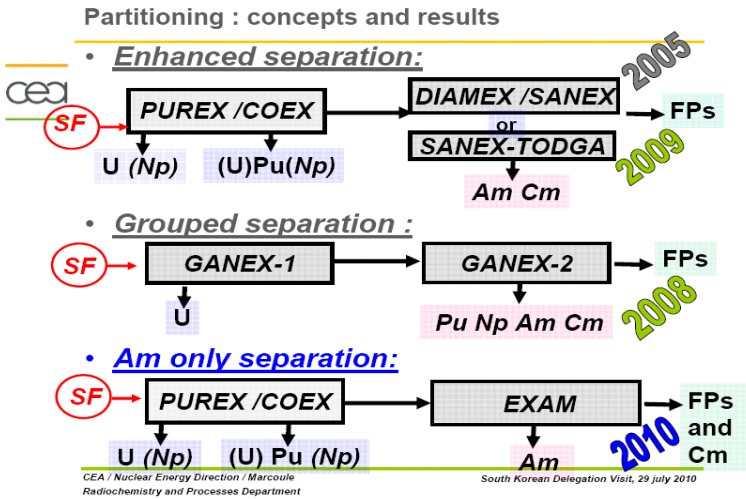
PyroGreen Innovation to Eliminate HLW

- **US Academy of Science (J. Shapira, 1999) : "No, we cannot."**
- **SNU –NUTRECK (I.S. Hwang, 2006~)**
  - **"PyroGreen " to Eliminate HLW**
- **ANL (J. Laidler, 2008)**
  - **Developed UREX+ for SNF Decontar**
  - **High DF has been achieved ~ 30,000**
  - **Meet Class C LLW Cleanliness**
  - **Cs, Sr, ,**
    - **TRU < 100 nCi/gm**
    - **Class C LLW after 150 yr cooling**
- **SCK-CEN (H.A. Abderrahim, 2010)**
  - **MYRRHA for "burning HLW"**
  - **CEA Advanced Hydroprocess**
- **US DOE WIPP : Success of ILW Disposal**

Aqueous Processing Technologies for the Treatment of Spent Nuclear Fuel

International Congress on Advances in Nuclear Power Plants – ICAPP 2008
Anaheim, California
June 9, 2008

James J. Laidler
Distinguished Fellow
Energy Science and Engineering
Argonne National Laboratory

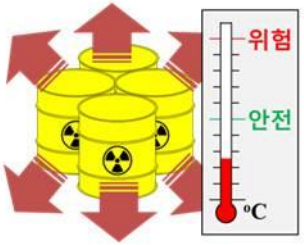


PyroGreen Solution to Eliminate HLW

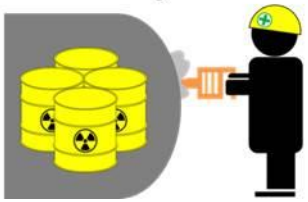
➢ WIPP site vs. YMP

- ~20,000 times lower α concentration
- ~1,000 times lower heat
- 650m underground rock salt
- Repository only 2.5°C up
- Prevention rock fracture
- Slow waste dissolution
- Prevention back-fill materials degradation
- Long-term uncertainty removal
- Human intrusion risk
- Successful operation in NM, USA since 1999

- Low heat density
  - ➢ Rock stability



- Low α concentration
  - ➢ Human intrusion security



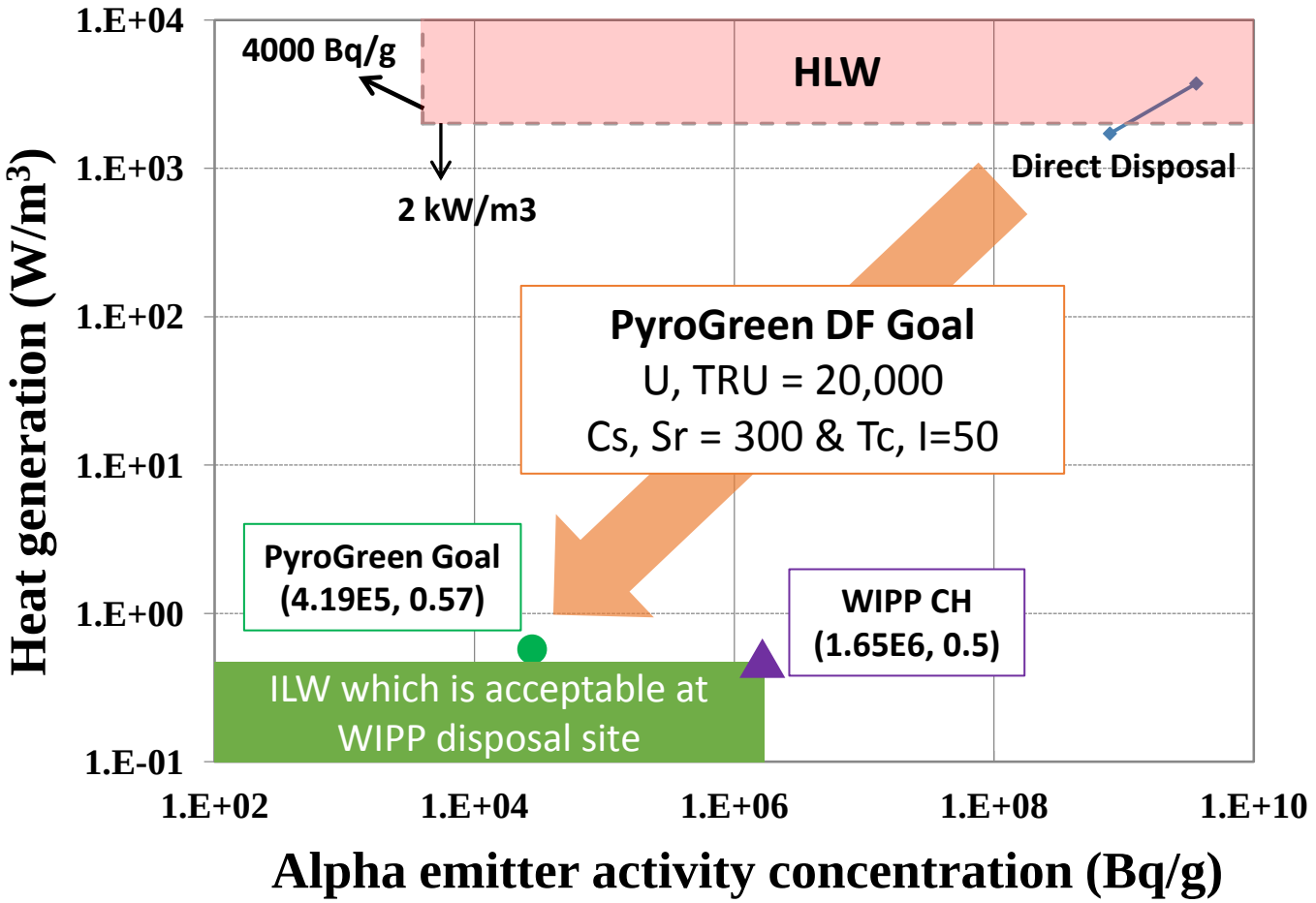
US Waste Isolation Pilot Plant
GTCC-Like (TRU) Low Level Waste

➢Japan demonstrated advanced decontamination process
- CRIEPI(Pyro) and JAEA(aqueous) achieved WIPP Goal

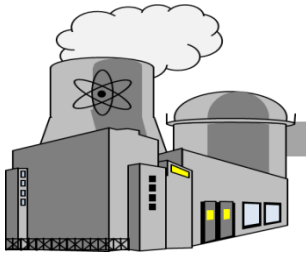
➢U.S. BRC recommends a game- changing Innovation
- All reprocessing wastes are classified into HLW by U.S. law
- U.S. NRC began public hearing for risk-based waste classification
- ANL achieved WIPP goal by UREX+ at lab scale

PyroGreen Solution to Eliminate HLW

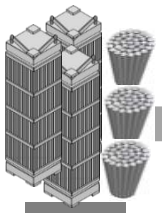
- **PyroGreen DF Goal set-up (Criteria : α-radioactive & heat density)**
  - **Analysis on 8 scenarios by the function of DF**
  - Set-up of DF Goal which satisfies **WIPP disposal site α-radioactivity and heat density**



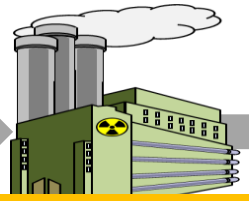
PyroGreen Solution to Eliminate HLW



NPP



SNF



Aqueous or Pyroprocess

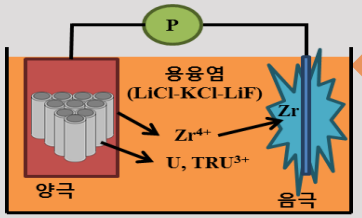
99.9% TRU
99% Tc, I

Transmutation Fast Reactor

0.095% TRU
98% Tc, I

Residual
0.1% TRU
Cs, Sr, Tc, I

Zr Cladding



Computational Model Development

TRU recovery

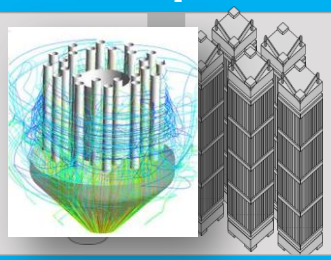
0.01% TRU

PyroRedSox Verification

Preventing hide out in ceramic

0.005% TRU
2% Tc, I

99.7%
Cs, Sr
Utilization

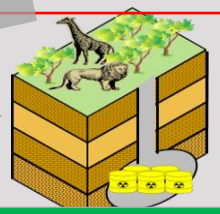


Benchmark and Validation

99.9% Nb, Ni

Small amount of ILW

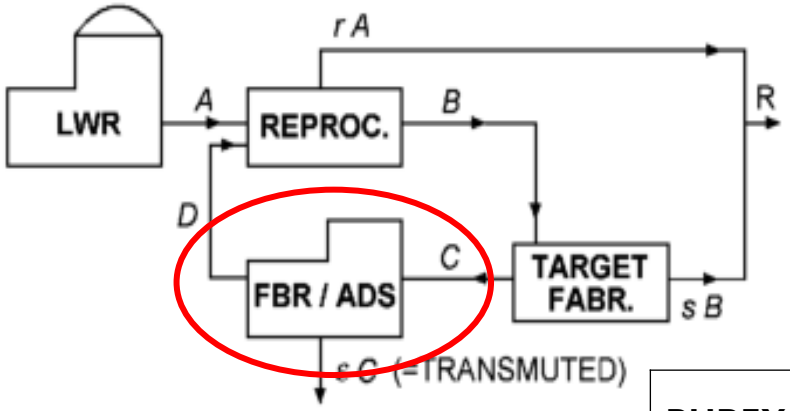
Vitrification



WIPP-type Disposal Site Verification

PyroGreen Process Loss & Waste Volume

Figure 3: A possible batch-wise P&T cycle for Np from LWR fuel



After the first separation process of SNF, materials quanty in the flow is reduced by the factor of 20 (TRU fraction in Target) to that in SNF

R/A = Overall Process Loss/Feed

R/A= (r+s-sr)/(r+s+e-ts-re-se+rse)

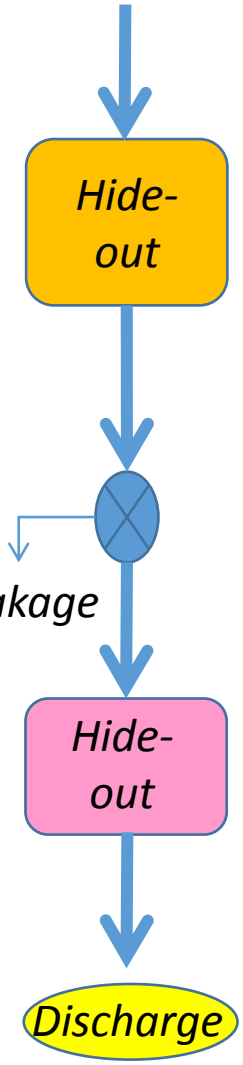
Decontamination Factor(A/R) =

b= (1-r)(1-s)(1-e)

R/A= r+(rab+as-ras)/(1-b)

DF(A/R)=

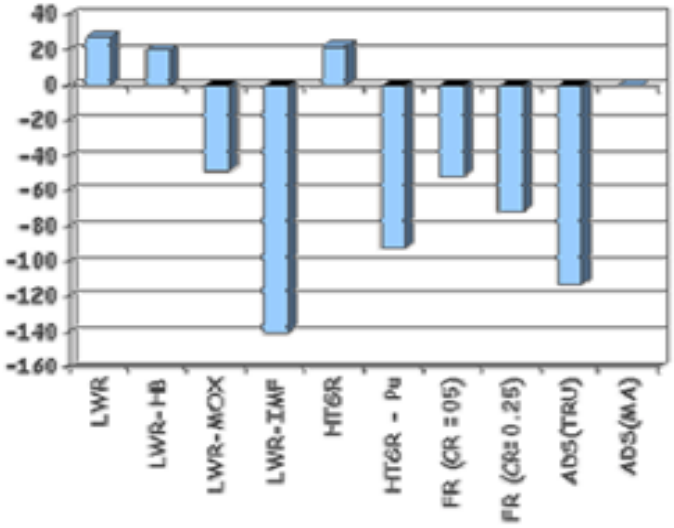
	PUREX-MOX	4-G Part.-MOX	Pyro-KAERI	PyroGreen
R/A = Overall Process Loss/Feed	9.30E-02	2.00E-03	7.29E-03	2.80E-04
R/A= (r+s-sr)/(r+s+e-ts-re-se+rse)	1.08E+01	5.01E+02	1.37E+02	3.57E+03
Decontamination Factor(A/R) =	9.45E-01	8.50E-01	8.49E-01	5.00E-01
b= (1-r)(1-s)(1-e)	1.38E-02	2.90E-04	1.31E-03	5.20E-05
R/A= r+(rab+as-ras)/(1-b)	7.25E+01	3.45E+03	7.61E+02	1.92E+04
DF(A/R)=	1.38E+03	2.90E+01	1.31E+02	5.20E+00
Ac-lost(MT) per 100,000 MTHM=	1.34E+08	2.82E+06	1.28E+07	5.06E+05
Total Ac-lost(Ci) per 10,000MT(to 2100)=	7.30E+06	1.53E+05	6.95E+05	2.75E+04
ILW Vol(m3) (@18.4Ci/m3 WIPP Conc.)=				



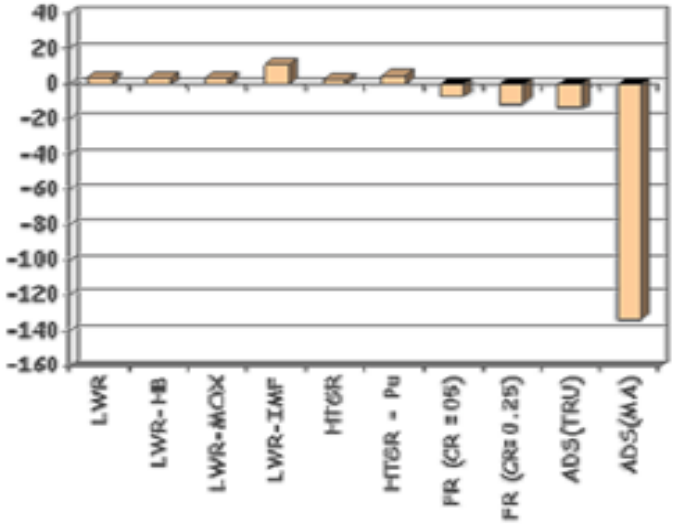
ADS : 10X Lower Process Loss & Waste Volume

M. Cappiello, "The Potential Role of ADS in the U.S."

The ADS is most efficient at Minor Actinide Transmutation



Pu Production Rate (grams / GWh)



MA Production Rate (grams / GWh)

E. Pitcher, S. Henderson

Fermilab

ADS : Price and Delivery

Energy	Food & Agriculture	Information Technology	Construction & Engineering	Automotive
11.8 tril. USD	4.8 tril. USD	2.8 tril. USD	2.1 tril. USD	1.6 tril. USD

Energy Market by Key Sector* (Billion USD)

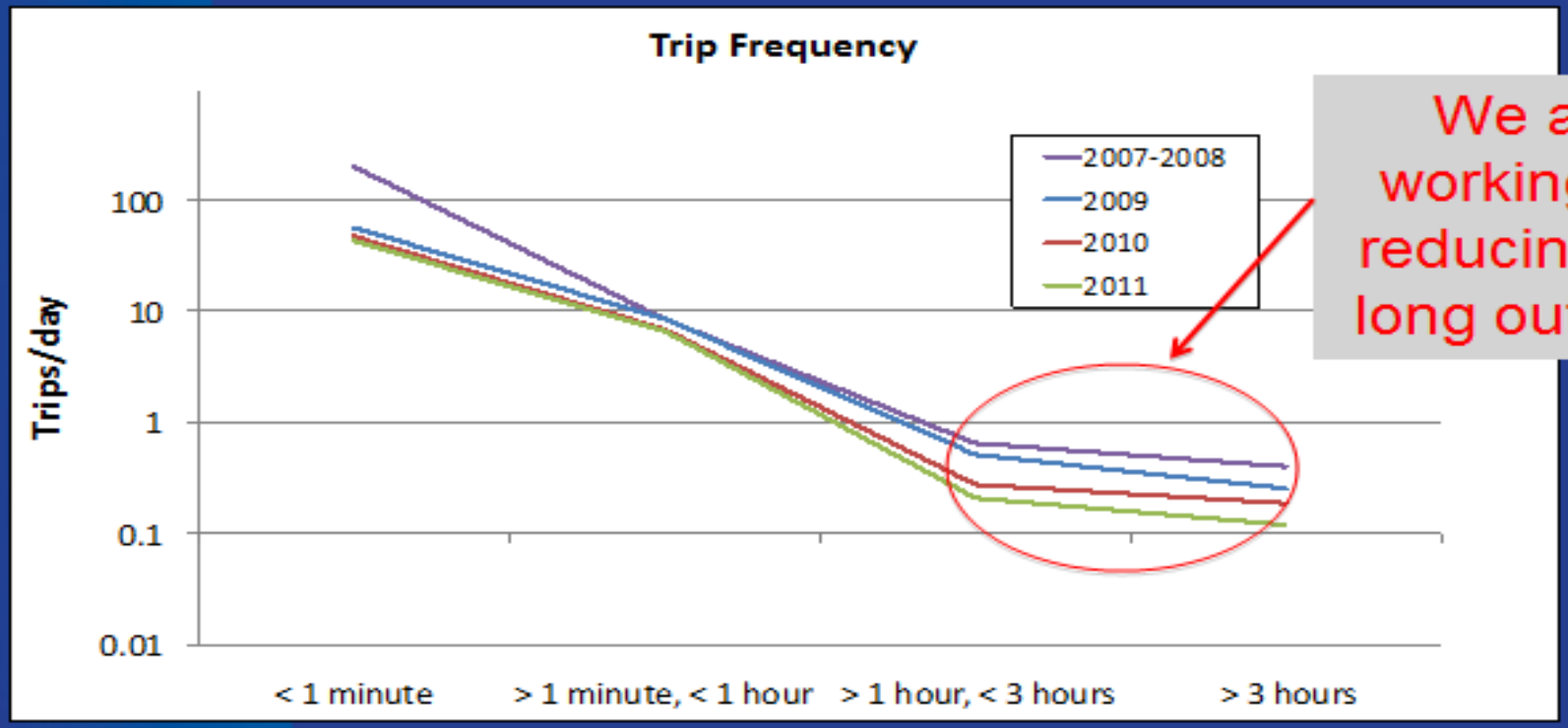
	Global	Korea (1.6% GDP share)
 Oil	6,845	54.8 (0.8%)
 Gas	2,955	12.3 (0.4%)
 Coal	432	0.3 (0.07%)
 Electricity	1,448	32.5 (2.2%)

*Source: DataMonitor Research, 2009 Korea National Statistical Office

ADS : Price and Delivery

Trip Rates at SNS

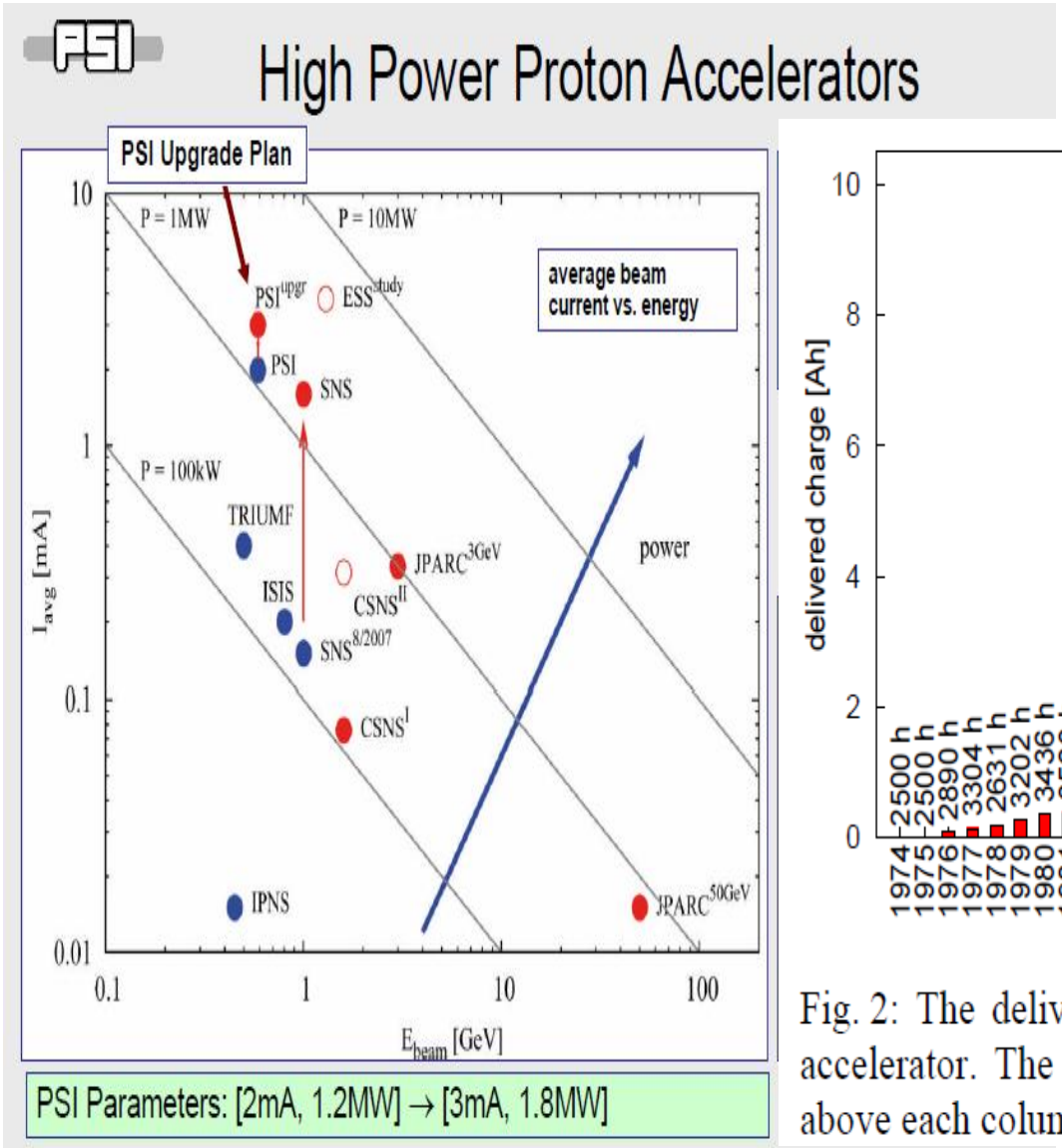
Courtesy J. Galambos



- SNS focuses on reducing long outages – which affect the user program
  - Short trips are not a driver of downtime, and have received relatively little attention
- SNS was not designed for very low trip rates

Fermilab

ADS : Price and Delivery



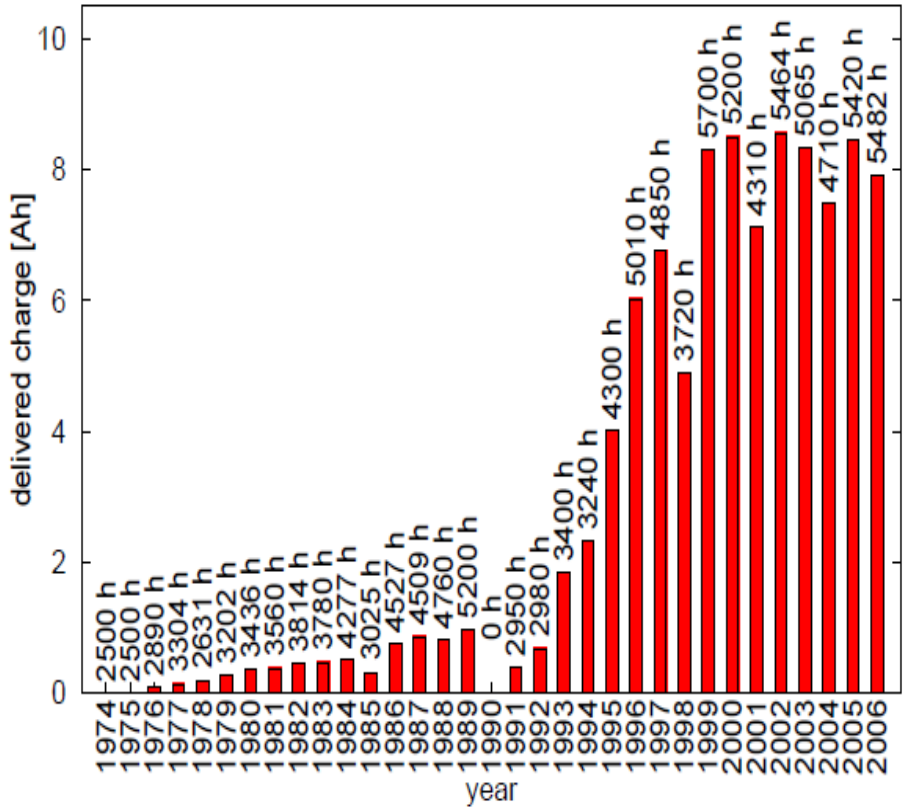
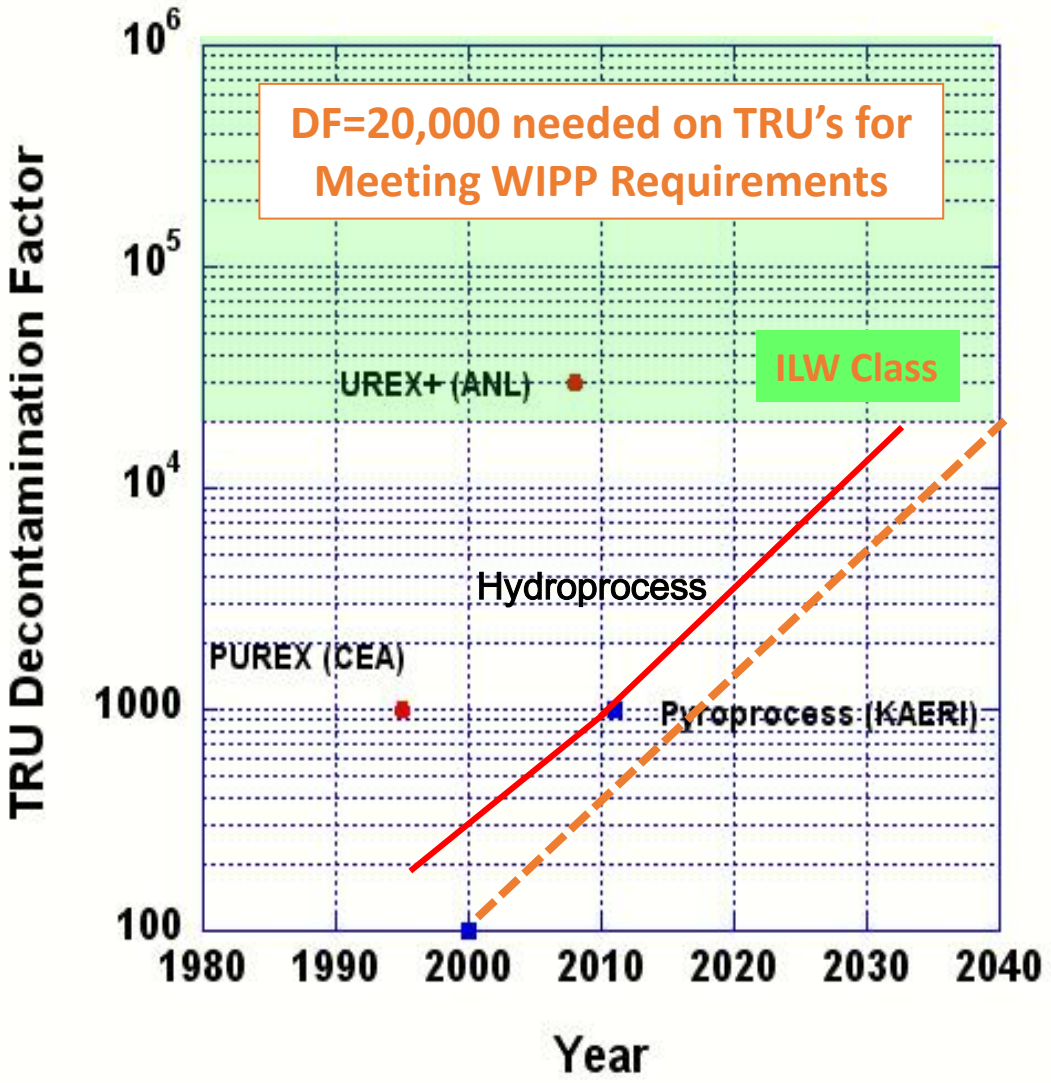


Fig. 2: The delivered charge per year in the PSI proton accelerator. The number of operating hours is indicated above each column for the corresponding year.

ADS : Price and Delivery



PyroGreen

Decontamination Tech

Key Demonstration

International Cooperation

Pyroprocess | Hydroprocess

0.1% TRU

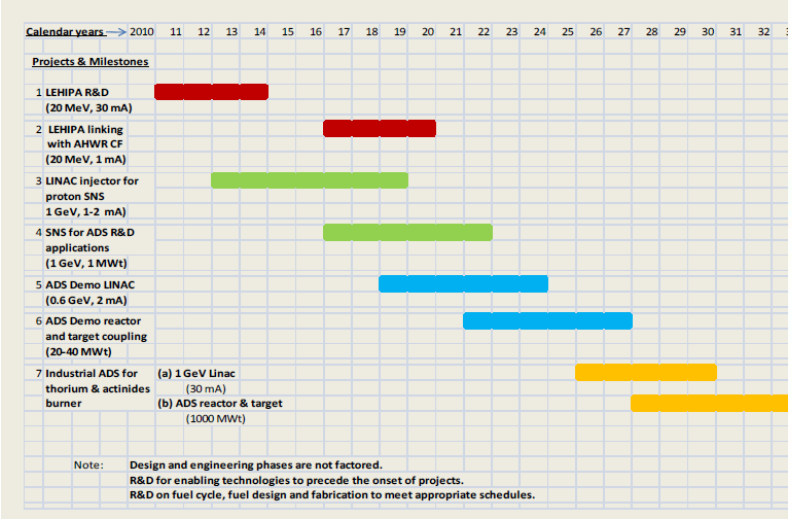
Advanced Partitioning

0.005% TRU

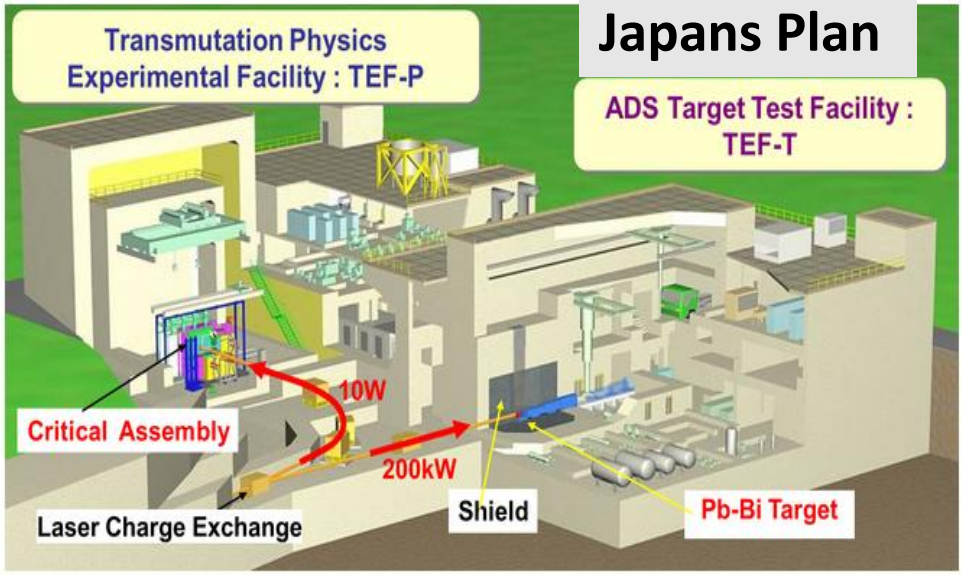
ILW Repository

ADS : Price and Delivery before U-depletion

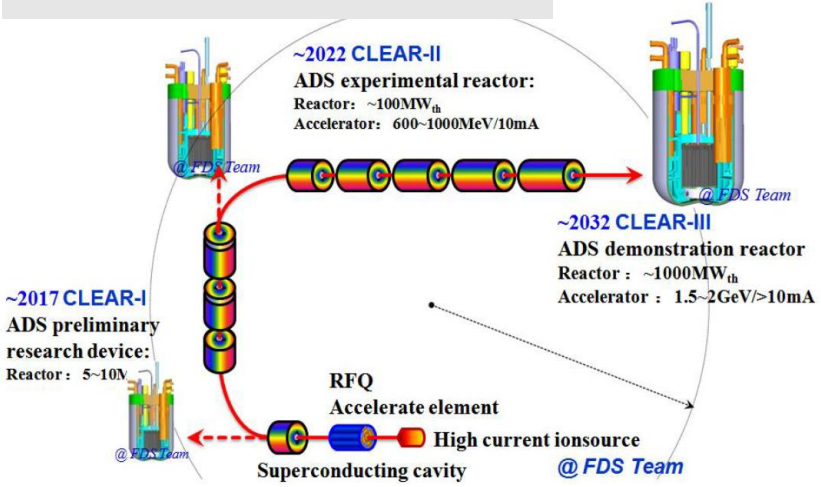
India's Plan for ADS Developments



Japans Plan



China's Plan for 2020



Multi-National Alliance for Peace

Comparison of Proliferation Resistance Measure in Recycle and Once-through (US BRP 2004)

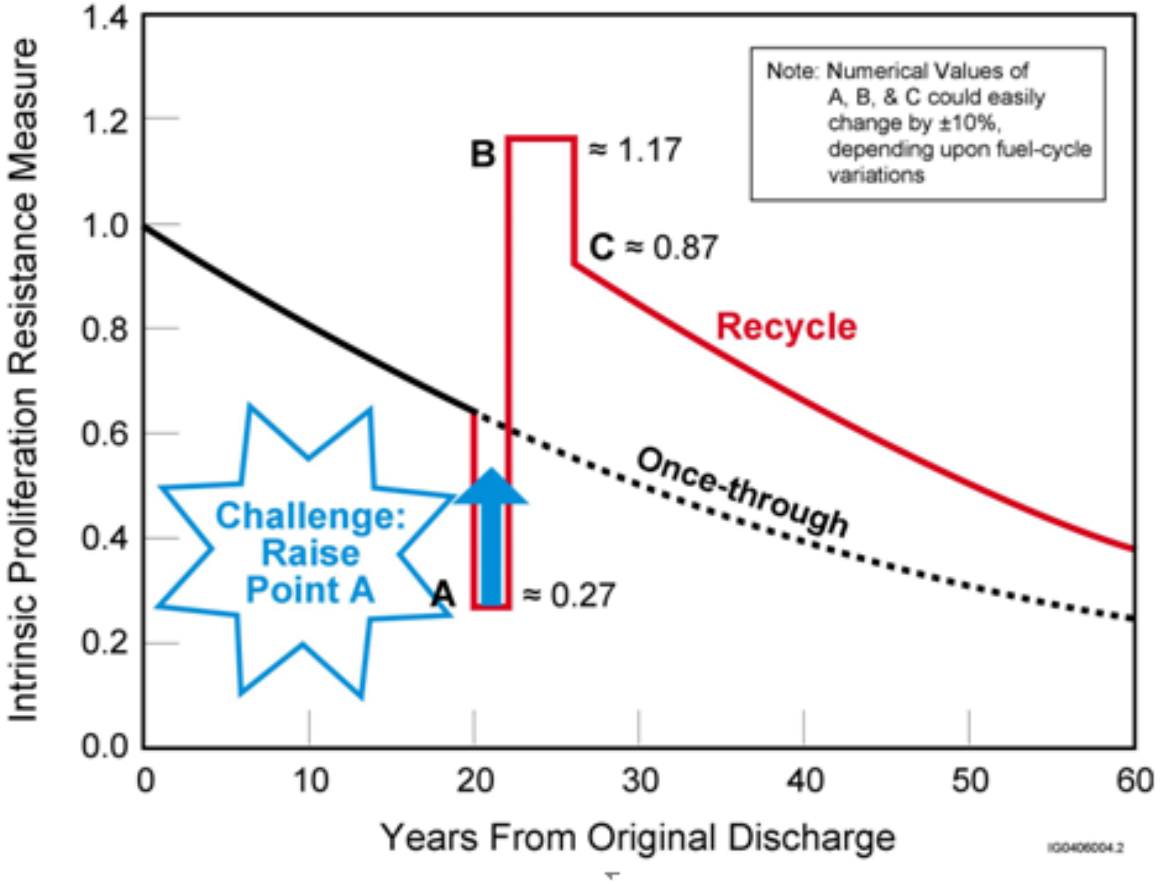


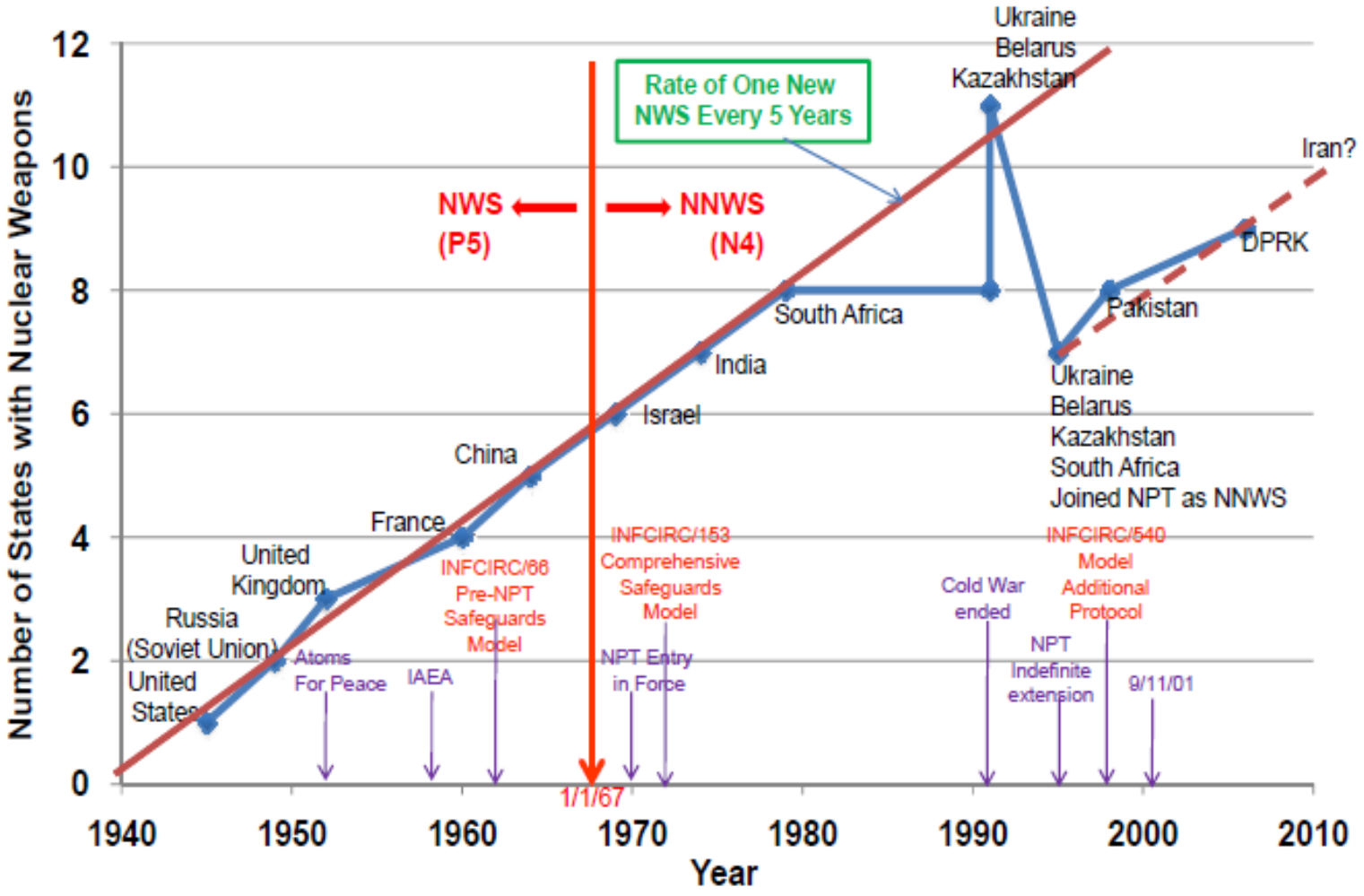
Figure 2 – Potential Impact of Improved Safeguards

Recommendations

1. Np for Pu-238 & Pa-233
2. Inert Matrix Fuels
3. Higher Actinides
4. System Approach

Multi-National Alliance for Peace

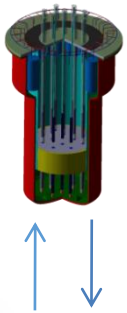
Nuclear Weapons Proliferation To-Date



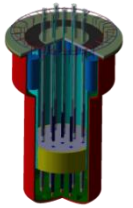
Multi-National Alliance for Peace

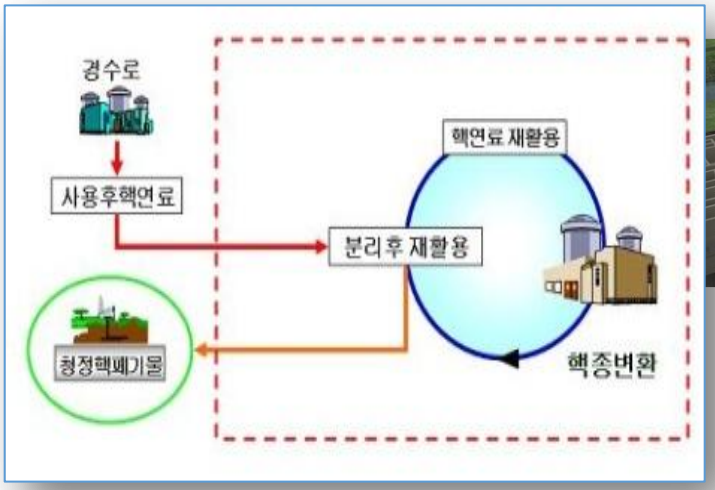
- URANUS (SMR) : Ubiquitous, Rugged, Accident-forging, Non-proliferating, and Ultra-lasting Sustainer

URANUS
- **Small modular reactor (SMR)**
- **Proliferation-resistance**
- **Safe, Secure, Long-burn**



URANUS
- **Fuel supply**
- **Operation supervisor**





Spent fuel take-back

"CRADLE-TO-GRAVE"

Multi-National Fuel Cycle Park (PEACER) with PyroGreen

Multi-National Alliance for Peace: SHAPE

Nuclear Weapons Free World
US President Obama (2009)

The existence of thousands of nuclear weapons is the most dangerous legacy of the Cold War. Today the Cold War has disappeared but thousands of those weapons have not.

Multi-National Approach (MNA)
IAEA DG ElBaradei (2003)

disposal or processing. Not all countries have appropriate geological conditions, and a cost of such operation for many states with small nuclear programs is excessively high. In this respect, I have started to support multi-national proposals as to

Multi-National Alliance for Peace

Korea Nuclear Policy Society

13th Information Exchange Meeting on Partitioning and Transmutation (IEMPT)

Date: 23-26 September 2014
Venue: Hotel Seoul Palace, Seoul, Republic of Korea

UK & ROK Cooperation for PEACE