Status of Partitioning &Transmutation R&D, and research needs for ATW from JAERI perspective

ATW Meeting, USDOE/OCRWM

Washington DC, 17-18 Feb. 1999

T. Mukaiyama
Center for Neutron Science
Japan Atomic Energy Research Institute

Difference of Transmutation Concept between Japan and USA

Japan

- Pu is fuel : MOX-LWR then FBR
- Transmutation is for long-lived nuclides in reprocessed HLW (MA, LLFP)

USA

- Pu is evil material, costly for management
- Pu is the major part of waste

TOPICS

- **ADS development under Neutron Science Project and OMEGA Program of JAERI**
- **Highlights from OECD/NEA Workshop (Mito, Japan, Oct. 1998) "On Utilization & Reliability of High Power Proton Accelerator"**
- **World status of P&T study**
- **Research needs and collaboration for ADS development**

Nuclear Waste Disposal and OMEGA Program

- **Japanese policy: Pu is fuel material, MOX-LWR, then FBR**
- Present HLW Management Policy;
  - stabilize HLW in solid form (vitrification),
  - and store the stabilized HLW for 30 - 50 years for cooling,
  - then, final disposal into deep geological formation
    - ***Public Acceptance ?***
- Advanced Option for HLW management
  - P & T of HLW: as the technology for the future

    (AEC directives in 1994 Long-term R&D, and Utilization Nuclear Energy)
  - still needed some kind of geological disposal even after P&T

➡ R&D Activities : OMEGA Program

Options Making Extra Gains for Actinides & FPs

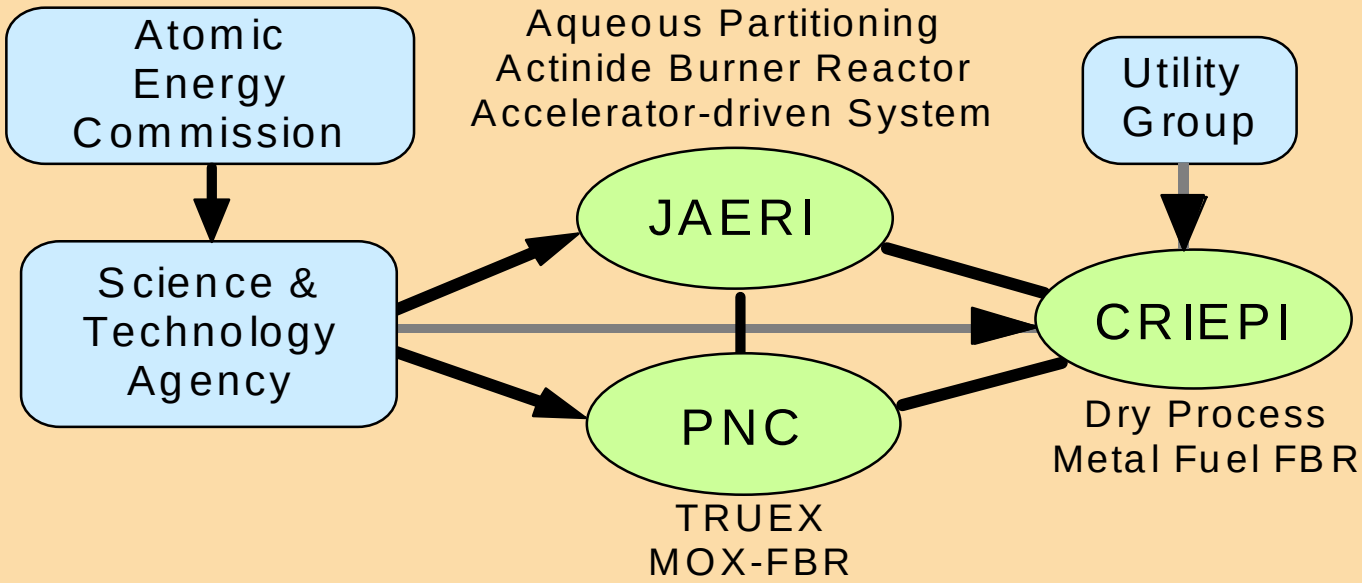
One Method Expecting General Acceptance of Nuclear Energy

OMEGA Program

AEC initiated the Phase-1 in 1988.

Main purposes; to explore possibilities of ;

reduction of the burden due to HLW, and utilization of HLW as useful resources.

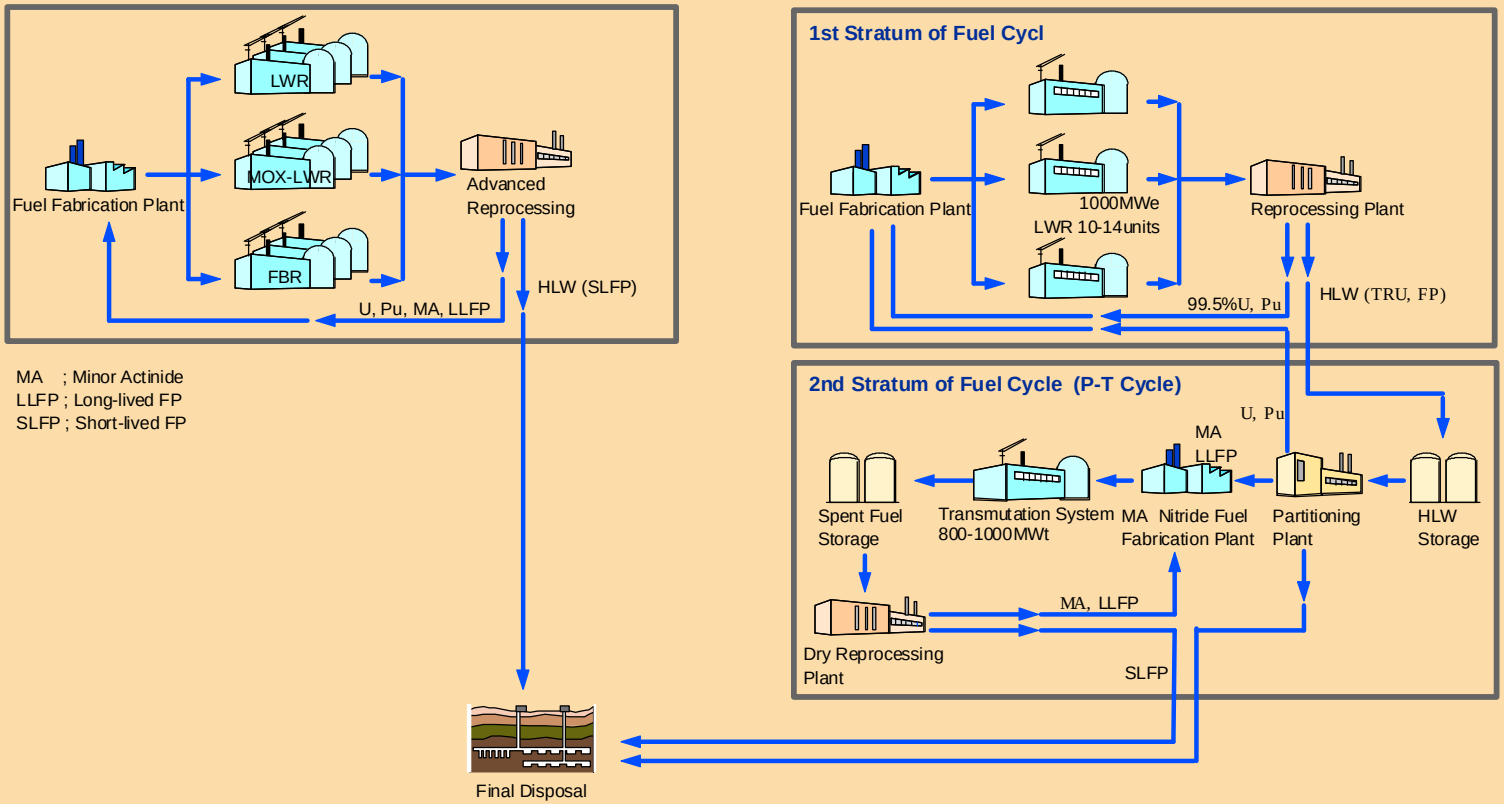


Phase-1 : Basic studies and testing

Check and Review by AEC has started in February 1999.

Phase-2 : Engineering tests and demonstration of technology

Fuel Cycle Concepts with P-T implimented



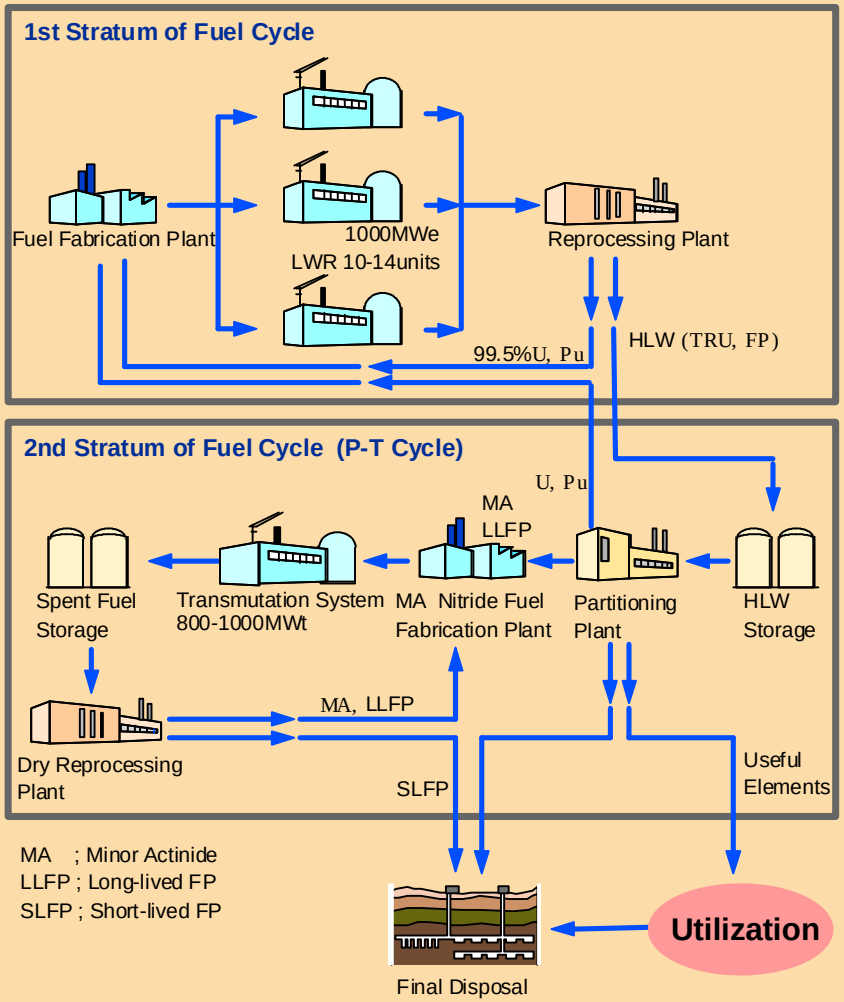
- **Advanced fuel cycle**
  - ❒ Commercial FBR for transmutation
  - ❒ Oxide fuel, Metal fuel
  - ❒ Limited MA content to avoid reactor physics parameters worsening

- **Double-strata fuel cycle concept**
  - ❒ Combination of a power reactor fuel cycle & an independent P-T cycle
  - ❒ Dedicated systems for P-T

"Double Strata Fuel Cycle" Option

CENS/JAERI

JAERI proposal



■ Advantages of Double Strata Fuel Cycle

- ❒ Independence from commercial fuel cycle
  - P-T : burden for commercial fuel cycle
    - because of higher radiation dose, larger decay heat, & reduced safety margin due to MA
  - P-T with double-strata : no impact on commercial cycle
  - Easier Implementation of future technology development
- ❒ Smaller throughput in the P-T cycle
  - Partitioning HLW(MA & FP) is 1/30 of Spent Fuel
  - Transmutation MA and Tc-99 & I-129 is 1/50 of Spent Fuel
  - Small throughput offers favorable P-T design & economy
- ❒ MA confinement in one small P-T cycle site
- ❒ Simple Scenario & System Design for Low Cost aiming at Effective & Efficient Reduction of Long-lived nucleids in HLW

■ Goal of P-T with double strata

More than 99.5 % reduction of MA and LLFP in HLW
In UP-3, U & Pu recovery higher than 99.88%
Dedicated P-T System to accomplish this goal

◆ long-lived Nuclides:
- ➨Minor Actinides
- ➨LLFP: FPs with half-live . 30 years ^{99}Tc, ^{129}I

OMEGA Program Activities at JAERI

- A. "***Double Strata Fuel Cycle***"

  New Fuel Cycle Concept Proposed by JAERI

  - Dedicated P & T
  - Partitioning For HLLW from Reprocessing
  - Transmutation Systems with Fast Neutron

    1) Accelerator-Driven System (ADS)

    2) Actinide Burner Fast Reactor (ABR)

- B. Development of Technologies

  1. Four Group Aqueous Partitioning Process
  2. High Power Proton Accelerator
  3. Nitride Fuel Cycle Technology

     Fuel fabrication & Dry process for MA & LLFP recovery

R&D Activities at JAERI -continued-

C. Basic Research to support these developments

1. Nuclear Data evaluation and Data File compilation

   JENDL-Actinide File for ABR, ADS

   JENDL-High Energy File for ADS

2. Integral experiments

   1) at FCA for evaluation of MA File

   2) at KEK for evaluation of High Energy File of spallation reaction

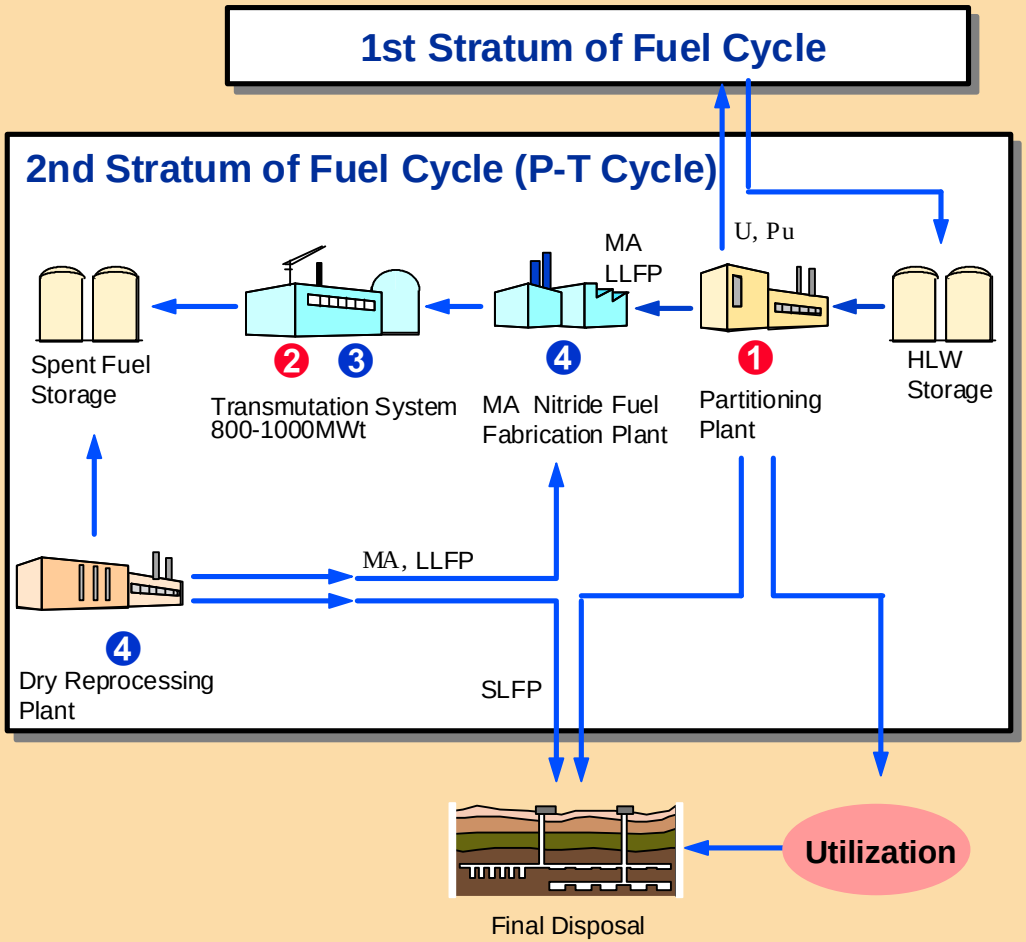
3. Nuclear data measurements of MA

   Collaboration with ORNL, ISTC

4. Fuel property data measurements

   Collaboration with ORNL

JAERI 's Activities for OMEGA Program



Double Strata Fuel Cycle

A. *"Double Strata Fuel Cycle"*

New Fuel Cycle Concept Proposed by JAERI

Dedicated P & T

- ❑ Partitioning of HLLW
- ❑ Dedicated transmutation Systems with Fast Neutron

B. Development of Technologies

❶ Four Group Aqueous Partitioning Process

❷ Dedicated transmutation Systems

1) Accelerator-Driven System (ADS)

2) Actinide Burner Fast Reactor (ABR)

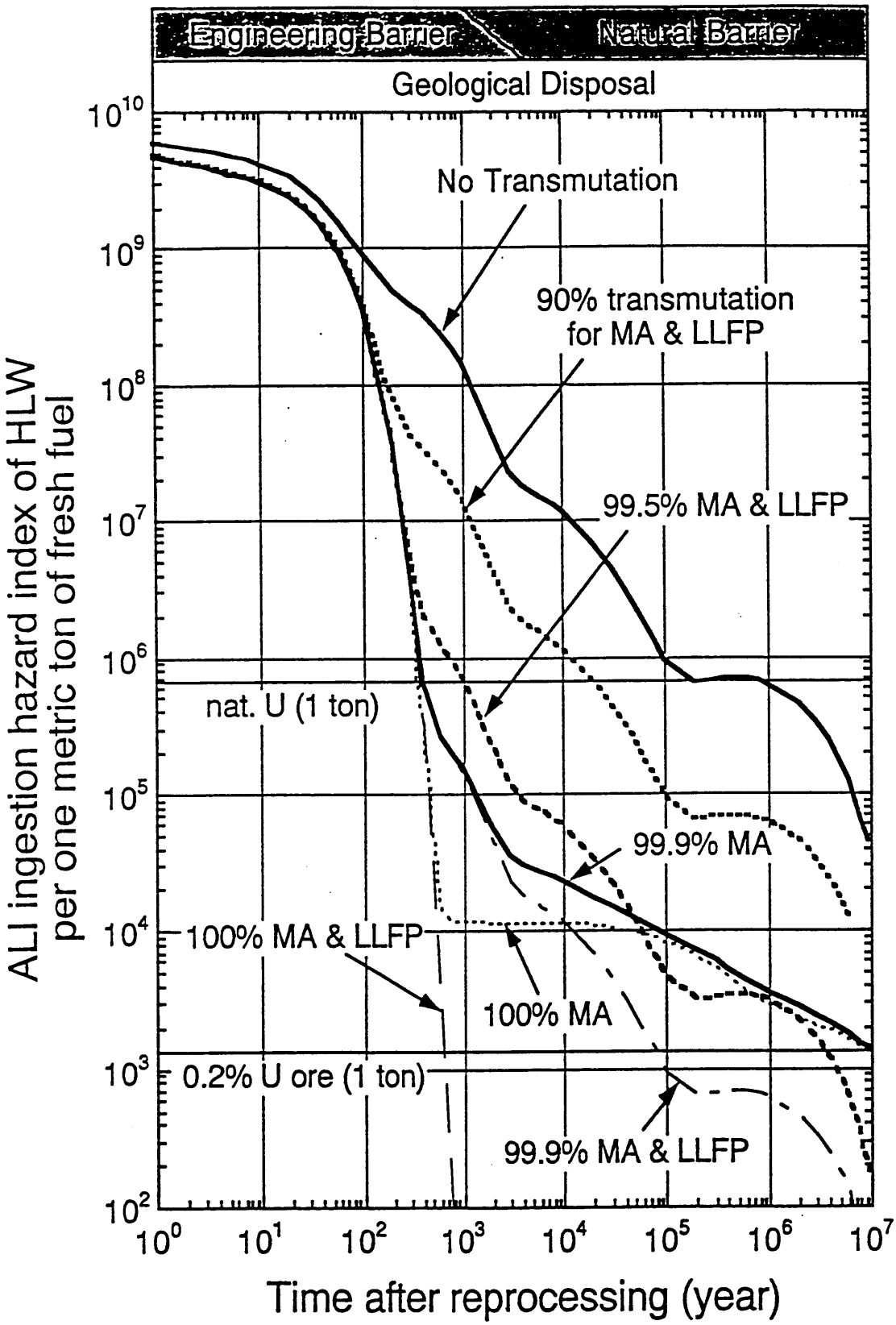
❸ High Power Proton Accelerator

❹ Nitride Fuel Cycle Technology

Fuel fabrication & Dry process for MA & LLFP recovery

C. Basic Research to support these developments

1. JENDL file: for ABR, ADS, for proton accelerator
2. Integral experiments for data validation
   MA File, High Energy File of spallation reaction
3. Nuclear and fuel property data measurements
   Collaboration with ORNL, ISTC



Reduction of Potential Radiological Toxicity of Long-lived Nuclides by Transmutation

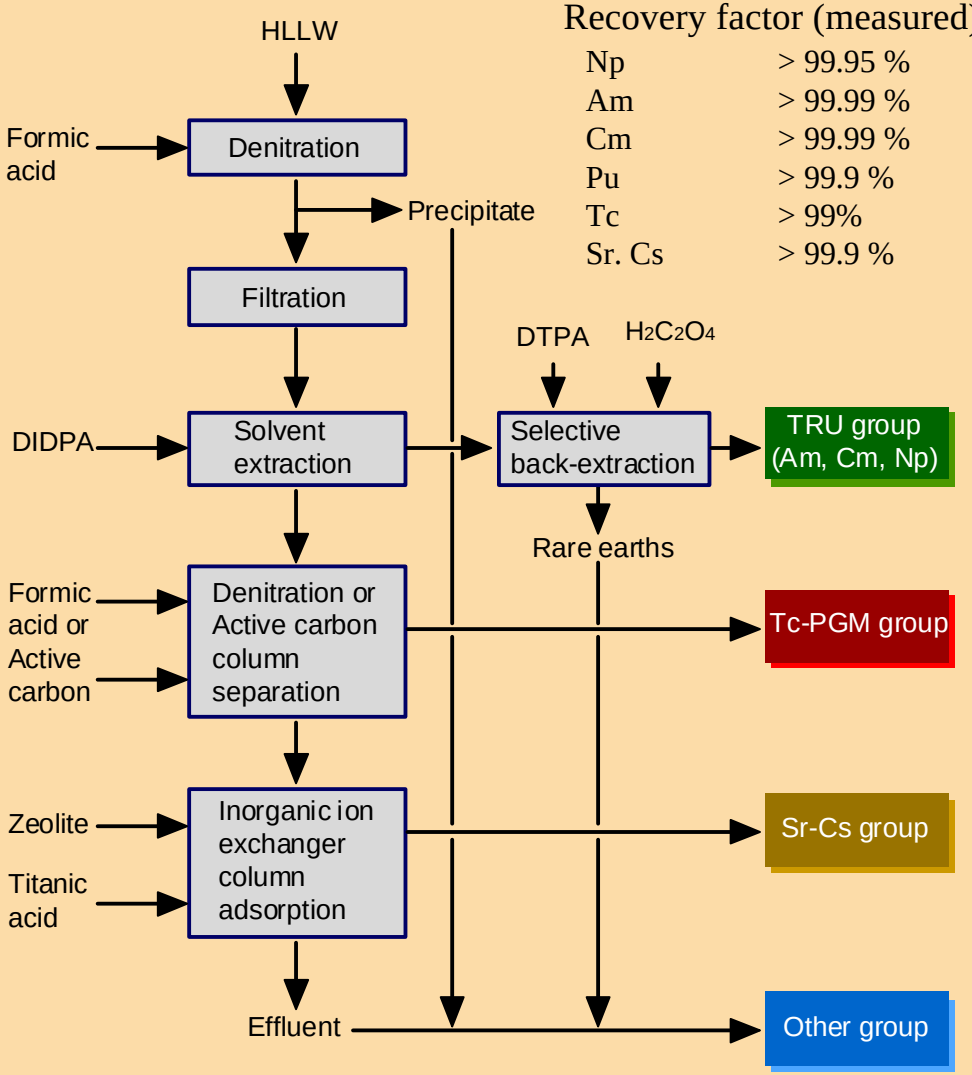
LLFP : FPs with $T_{1/2} \geq 30$ years

Development of 4-group Partitioning Process

CENS/JAERI

Recovery factor (measured)

Np	> 99.95 %
Am	> 99.99 %
Cm	> 99.99 %
Pu	> 99.9 %
Tc	> 99%
Sr. Cs	> 99.9 %



Four-Group Partitioning Process

Test Facility at NUCEF

Transmutation Systems

- Dedicated transmutation systems for MA transmutation
  - Hardest possible Fast Neutron System for direct fission of MA
  - Homogeneous MA fuel: no separation amongst MAs
  - Support Factor. 10 Units of Large LWR
  - Nitride fuel with enriched N-15
    - good thermal properties
    - pyrochemical reprocessing for compactness and easier recovery of N-15
- Design study of transmutation systems

1. Accelerator-driven subcritical system : “ADS”

   Proton Accelerator: 1 - 1.5 GeV, Several 10s mA

   Nitride Fuel Core/ Tungsten Target, Na Cooling, Pb-Bi Target-Cooling

2. Actinide Burner Reactor: “ABR”

   Pin bundle fuel with Pb-cooling L-ABR

   Particle fuel with He-cooling P-ABR

Design Study of ADS

- Fast Neutron System
- Support Factor. 10 Units of Large LWR
- Proton Accelerator: 1 - 1.5 GeV, Several 10s mA

❒ Solid System

Nitride Fuel Core/ Solid Tungsten Target, Sodium Cooling

Nitride Fuel Core/ Lead-Bismuth Target-Cooling

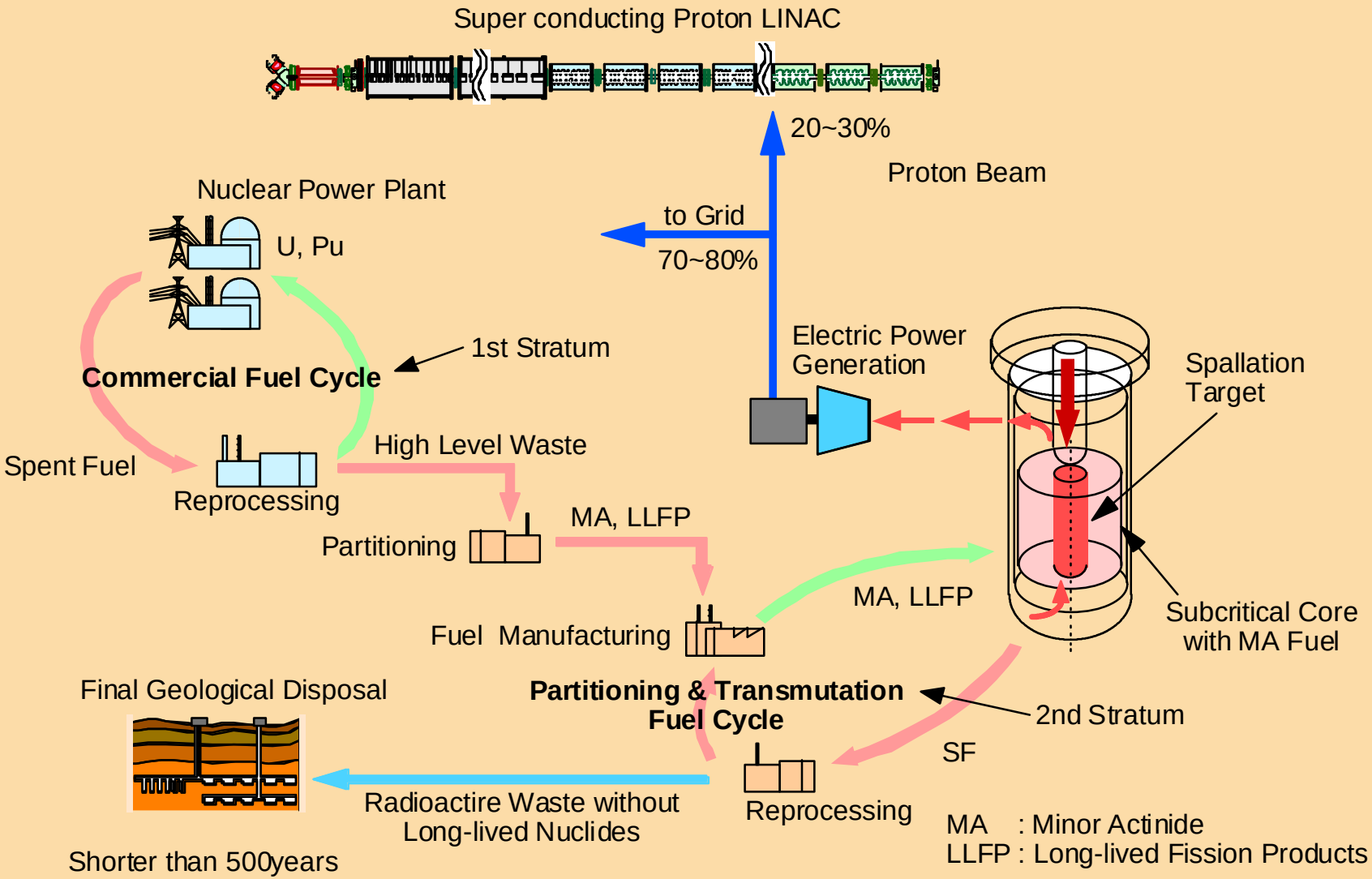
❒ Molten- Salt System

Chloride salt as target, fuel and coolant

on-line Processing

Material Compatibility Problem

Double-strata Fuel Cycle and ADS



ADS is the first choice for MA Transmutation

- Dedicated system is preferable for MA transmutation

- In a dedicated system;
  - ❒ Fuel material: mostly MA and no U-238 to avoid generation of MA
  - ❒ Hard neutron spectrum
  - ↪ small βeff, small Doppler Coeff.

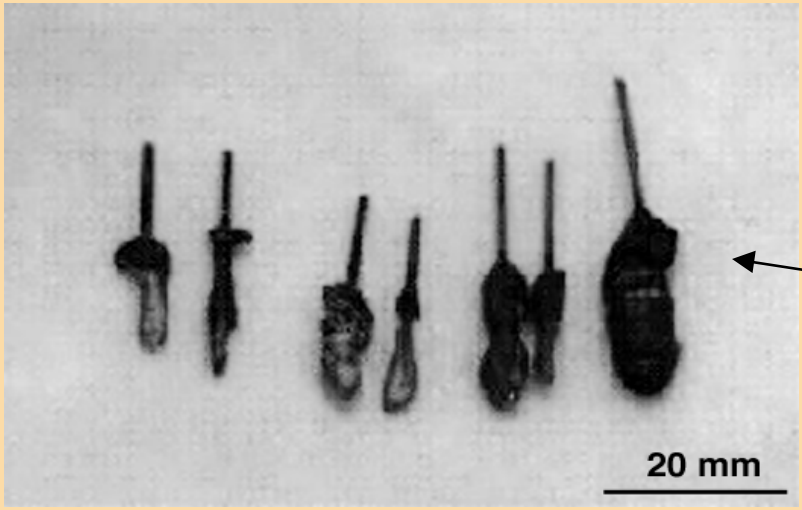
- in ABR, therefore, HEU is needed to increase b eff
  - ❒ NPT problem

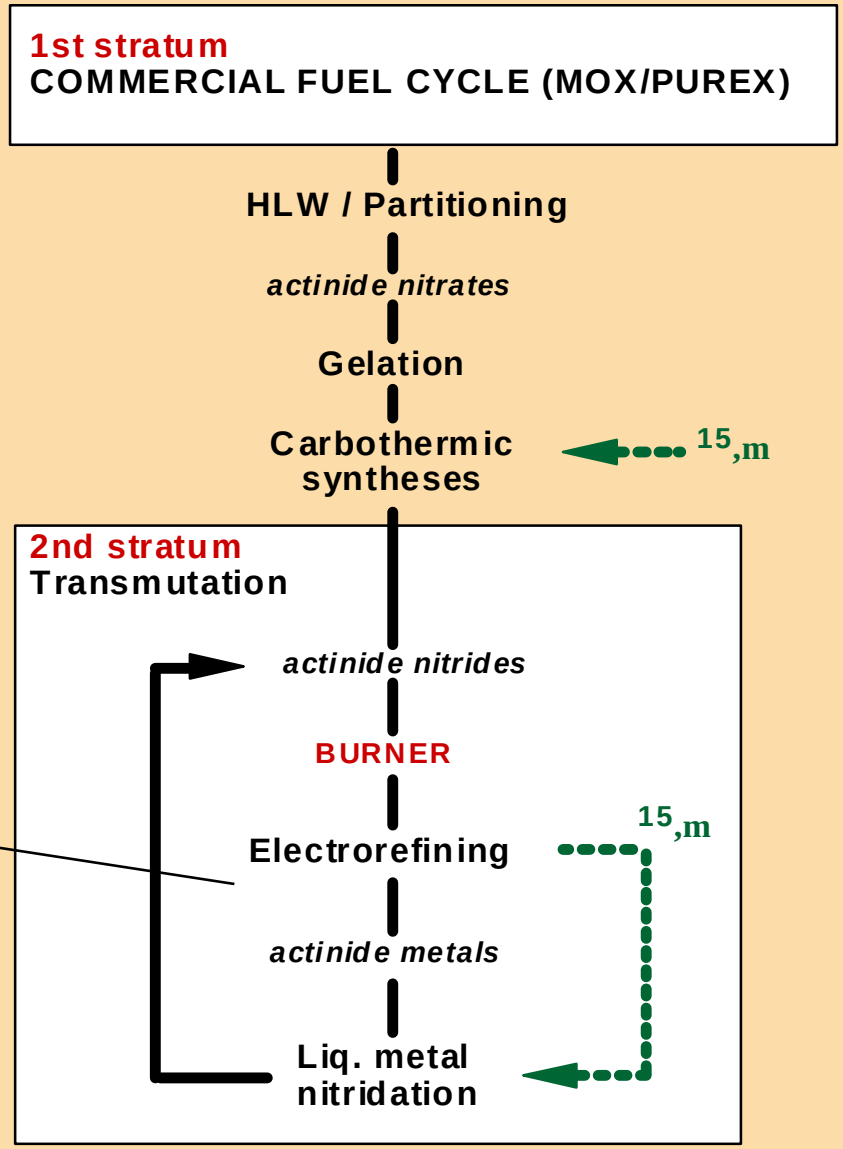
➡ ADS is the first choice, ABR is the backup.

Transmutation Fuel/Target-JAERI Approach

CENS/JAERI

- **Nitride fuel**
  - Thermochemical stability
  - Good thermal property
  - High heavy-metal density
- **Pyroprocess**
  - Compact facility with minimum envelope
  - Easy recovery of **N-15**
    (to avoid C-14 from N-14)





Highlights of OECD/NEA Workshop on Utilization and Reliability of High Power Proton Accelerators

Mito, Japan, 13-15 October 1998, Hosted by JAERI

Workshop Outline

- 93 participants
  - 11 Countries, CERN, and OECD/NEA
  - from abroad: 32 participants

    Italy 6, USA 5, Russia 5, France 3, Korea 3, China 2, Swiss 2,

    Germany 1, Spain 1, Sweden 1, Czech 1, CERN 1, OECD/NEA 1
  - Domestic: 61 participants

- Presentations

  Keynote talks : Neutron Structural Biology, Status of HPPA

  Projects 11, Reliability of HPPA 8, New Accelerator Concepts: 6

  Beam Trips/Fluctuations: 4, Interface Technology: 4

- **Objectives of the workshop**

  To explore more efficient utilization of high power proton accelerators (HPPAs) in various fields and to ensure the future possibility of Accelerator-driven Subcritical System (ADS).

- **Motivation:**

  Many projects related to HPPAs in various countries to promote basic and applied sciences, including ADS

- **Reality:**
  - Very frequent proton beam trips of existing HPPAs
  - To understand the effects of beam trips on sub-systems especially on ADS.
  - Additional R&D to accomplish a highly reliable HPPA and sub-systems resistant to thermal shocks
  - ADS is Ractor, or not

HPPAs Projects (presented)

Project	Country	Specification	Utilization
SNS	USA	1GeV, 1MW(4MW)	NS
ESS	EU	1.3GeV, 5MW	NS
JAERI-NSP	Japan	1.5GeV, 8MW	NS, ADS
KEK-JHF	Japan	3GeV, 0.6MW	NS, Muon, Kon
KOMAC	Korea	1GeV, 20MW	ADS, Therapy RI production
RCNPS	China	0.15GeV, 0.45MW	ADS, Therapy RI production,
TRASCO	Italy	1GeV, 30MW	ADS
GEDEON	France	not yet specified	ADS
ATW	USA	1GeV, 140MW (for APT)	ADS
?	Czech	35MeV deuteron	ADS

(NS: Neutron Scattering)

Major Conclusions

1. First occasion to get together for Reactor Physicists, Accelerator Specialists, Nuclear Physicists, to discuss the common topic"ADS".
2. ADS may be comparable to Critical reactor.
3. Requirement for accelerator reliability
   - ❒ Beam trips are very frequent : . 8000trips/y
   - ❒ MTBF **has not been** an important issue of current use of HPPAs. Severe requirement from ADS is completely new for the accelerator community.
   - ❒ MTBF can be improved to about 80 trips/y using recent technology.
   - ❒ Significant reduction of beam trips inevitable (two order of magnitude)
   - ❒ Beam trip which will cause the ADS restart would be less than once per year.
4. Linear or Circular Accelerators for ADS
   - ❒ A linac is for several ten mA and a cyclotron is for less than 10 mA.
   - ❒ Beam profile and halo are also to be considered.

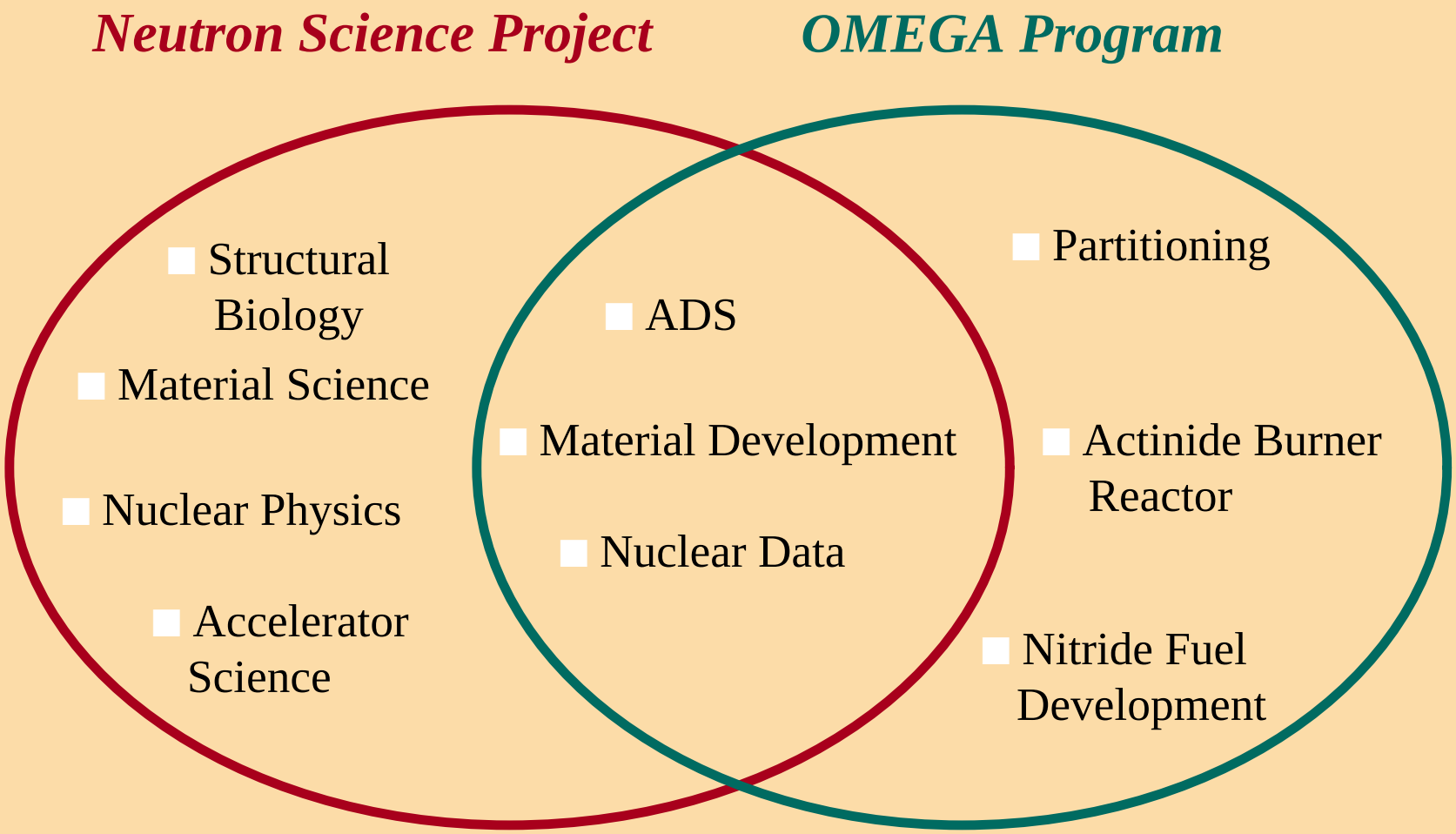
Major Conclusions -2

5. R&D needs in ADS
   - A reference subcritical system should be developed for benchmark analysis for common understanding of possible problems.
   - How to control ADS power level must be studied.
   - Stable k_{eff} or changeable k_{eff} shall be discussed.
   - R&D on structural materials for frequent thermal shocks.
6. Single or Multiple Accelerators for ADS
   - ADS test facility may be with one accelerator and ADS Plant has options.
   - The key question is economy and reliability.
7. Dedicated or Multi-purpose Facility
   - A multi-purpose facility, such as JAERI-NSP, aims at multi-disciplinary or cross-disciplinary for development phase.
   - A dedicated ADS facility to demonstrate ADS as a promising system to a society.

Research needs for ADS Development

- ***Highly Reliable High Power Accelerator***
  - Significant reduction of beam trips
- ***Target, Subcritical Reactor Technology***
  - long-lived window concept
  - selection of coolant Pb-Bi, Pb, Na, He
  - high heat flux, power flattening, thermo-fluid-dynamics
  - optimization of neutron spectrum
  - hybrid system control, transient property
- ***Materials***
  - MA fuel, structural material compatible with coolant
  - irradiation damage by energetic proton &neutron
  - thermal cycle by beam trips
- ***Demonstration of ADS***
  - 30 MWt -100 MWt Engineering Test Facility
  - MA Burn-up

Neutron Science Project and OMEGA Program



Neutron Science Project

Since 1996

Objectives

Development of High Power Spallation Neutron Source
& Research Facility Complex

for

1. Basic Science

Neutron Scattering for: Structural Biology, Material Science
Materials Irradiation
High Energy Neutron Physics
Creation of Transactinides with Spallation RIs, muon science, etc.

2. Accelerator Driven Transmutation

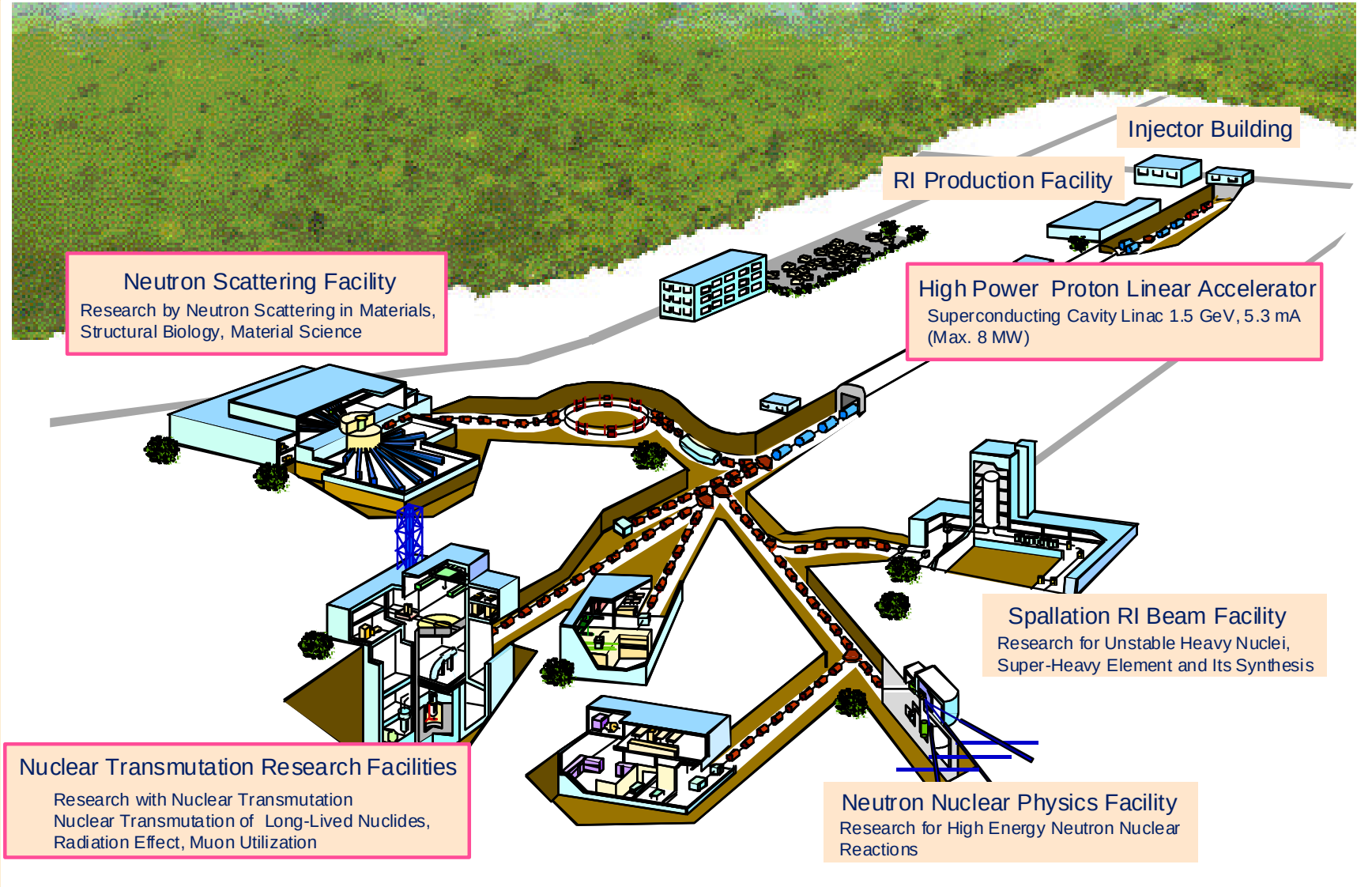
High-level radioactive waste management

3. Accelerator Development for Industry Application

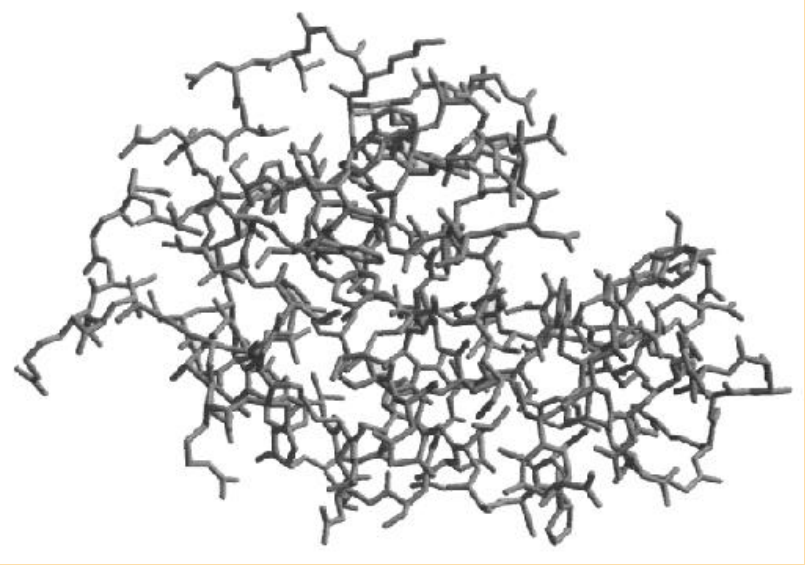
High Reliability & Stable Operation

Neutron Science Project - Conceptual Layout

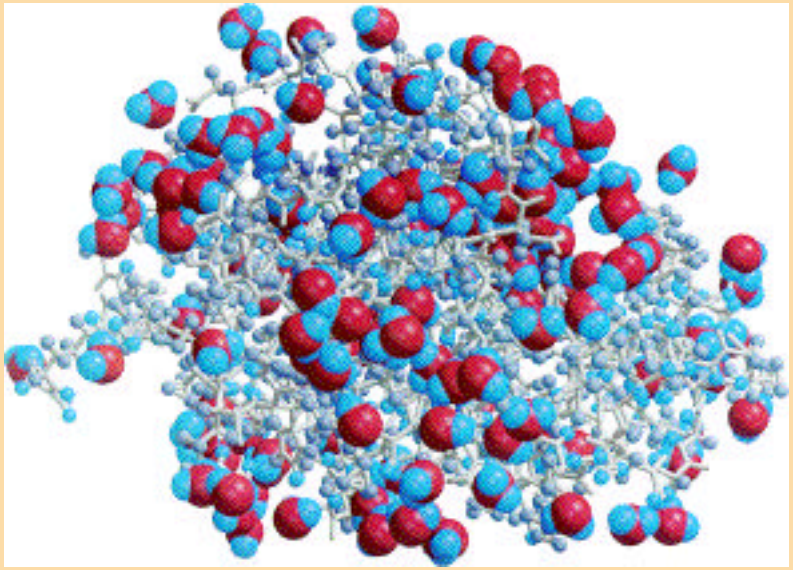
CENS/JAERI



Observation of protein structure by neutron scattering



Molecular backbone structure (C, N, O, S) determined by ***X-ray analysis***

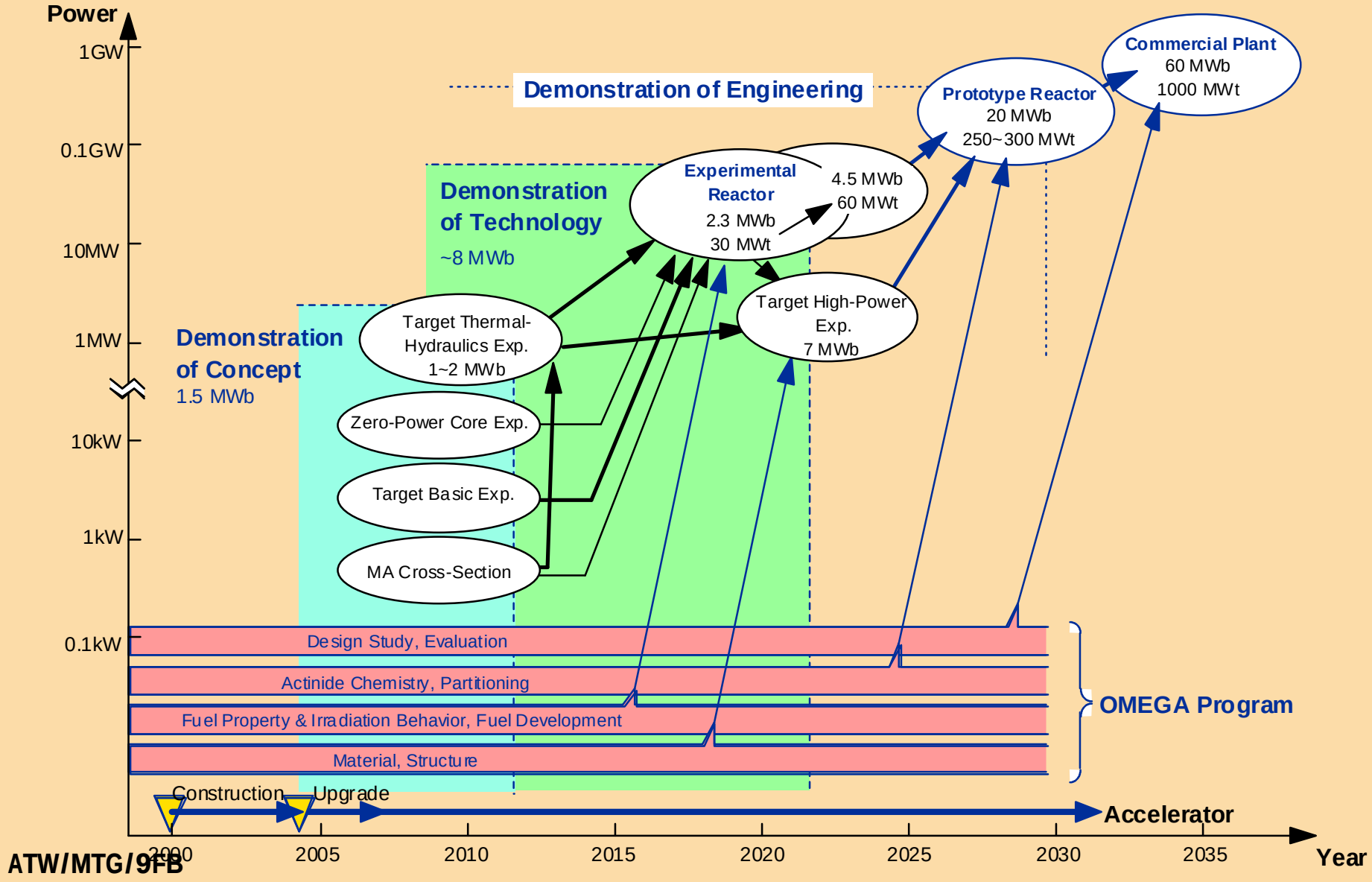


Total 3-D arrangement including 157 solvent H_2O molecules and 948 hydrogen atoms determined ***by neutron analysis***, Niimura, JAERI

Hen Egg-White Lysozyme

Development Scenario of Accelerator-driven Transmutation System

CENS/JAERI



OMEGA Program and Neutron Science Project

OMEGA Program
for P - T

- Partitioning
- Transmutation
  - System Development
    - ABR
    - ADS
  - Fuel Development
  - Material Development

Neutron Science Project
for Basic Science & ADS

- High Power Proton Accelerator
- 5MW Spallation Target
- Experimental Facility Complex
  - ADS Target , System
  - Spallation RI Beam Science
  - Nuclear Physics
  - Material Irradiation
  - Muon Science

Possible collaboration for ADS development

- Development of ADS
  - Target, coolant material: Pb, Pb-Bi, Na, He, W
  - Design code system,. system design study
  - Nuclear data & design code
- Accelerator Development

  High power proton linac, superconducting (SC) cavities, high power RF source
  - Optimization of accelerator parameters
  - Comparison of design codes
  - Control system, beam diagnostics
  - Evaluation of reliability, availability and maintainability
- Development of Spallation Target
  - Target neutronics: nuclear data & design code
  - Thermal-Hydraulics
  - Material irradiation

Preliminary Cost Estimation of Double- Strata Fuel Cycle

- Not direct cost calculation, but relative cost analysis to the cost of LWR electricity generation using cost factor and scale factor:
  - Cost factor
    Ratio of each process cost in Double Strata(DS) to that of LWR Cycle(LC) per material throughput
  - Scale factor
    Ratio of material throughput, of thermal output of DS to that of LC
- Electricity cost breakdown of LWR Cycle(LC) in Japan
  - Electricity cost
    Fuel: 28%, Capital: 42%, Operation: 30%
  - Fuel cost

    Uranium mining: 10%, Conversion: 2%, Enrichment: 18%

    Fabrication: 24%, Transportation of spent fuel: 10%,

    Reprocessing: 31%, Waste Disposal 6%

Assumption for Cost Analysis

- Expected performance of ADS/ABR
  - MA Transmutaion efficiency: 10%/y
- Fuel cost factors relative to LC
  - 3 x fuel fabrication, transportation of spent fuel, dry processing waste disposal
  - 5 x wet partitioning
- Costruction cost relative to LWR
  - 3 x ADS/ABR construction cost per thermal output
    LWR: 340 kyen/kWe (3.4k$/kWe, 1$=100)
  - 1.5 x Operation cost of ADS/ABR per one plant
  - Accelerator construction for 1000MWt-ADS: 50Byen (500M$)

Cost Increase by P&T

- Cost increase by P&T

  for ADS 9.95%

  for ABR 9.45%

- Cost decrease by electricity generation of ADS/ABR
  - ADS (330MWe x 0.7)/(1000MWe/unit x 12 units) = 0.019

    (0.7 = 1.0 - 0.3 0.3 for accelerator operation)
  - ABR 330MWe /(1000MWe/unit x 12 units) = 0.028

- Net cost increase

  for ADS 8.1%

  for ABR 6.7%

  - In this cost evaluation, cost decrement of geological repository by reduction of HLW volume is not considered.

Summary

- Dedicated Transmutation Systems for Double Strata Fuel Cycle
  - ADS, and ABR
- Technology Development for dedicated transmutation
  - DIDPA Partitioning
  - Nitride Fuel Technology: fabrication, dry-processing
  - High-intensity Proton Linac and Spallation Target

    Successful Development of Injector & SC Cavity
- ADS can play a significant role as “Transmuter” in back-end of fuel cycle
- P&T with Double Strata Scheme is not costly
  - Electricity cost increment is only about 3 to 5%.
  - In this cost evaluation, cost decrement of geological repository by reduction of HLW volume is not considered.
- Construction of Neutron Science Facility will start within 2years!

Summary

- P-T can reduce the volume of HLW
  - Reduction of radiotoxicity of HLW after about 1000 years Reduction factor: about 200
- After P-T, some kind of geological disposal still needed
- With P-T, current scheme of geological disposal may be modified

  or at least significant size reduction of geological disposal site can be expected
- Active R&Ds in Japan, France, Russia, EC and Korea

  probably in the near future in USA, China for Accelerator-Driven System
- ADS becoming a major topic in the community of Nuclear Energy & Nuclear Physics
- P-T can offer an option for advanced HLW management

Concluding Remarks

1. ADS can play a significant role as “Transmuter” in the back-end of fuel cycle with the double strata fuel cycle

2. R&D of P-T: 15-20 years

   (One cycle of fuel irradiation : 7 Years, two cycles are needed)

   Demonstration of P-T Plant : 10 Years

3. Start of vitrification of HLW upon start of Rokkasho Reprocessing Plant of JNFL.

   30-50 years storage for cooling

   Start of retrievable technology of radioactive nuclides from vitrified waste

Concluding Remarks (Cont.)

4. R&D for conditioning of transmutation waste, which has minimal content of long-lived nuclides
5. After 30 years, decision making:
   - P-T (Yes/No)
   - If yes, radionuclides to be retrieved from solidified waste (Yes/No)
6. Nuclear Technology needs breakthrough for the second nuclear era!
7. P-T is a good subject for breakthrough!