Progress Report on Nuclear Transmutation

Hiroyuki OIGAWA

Contents

- Situation of P&T technology in Japan and the world
- Outline of previous IAC
- R&D activities in this year
- Perspectives toward the establishment of Transmutation Experimental Facility (TEF)

R&D of P&T Technology in Japan

- In Japan, Partitioning and Transmutation (P&T) is mainly studied at 3 institutes:
  - JAERI (Japan Atomic Energy Research Institute)
  - JNC (Japan Nuclear Cycle Development Institute)
  - CRIEPI (Central Research Institute of Electric Power Industry)

- JAERI is studying P&T technology using Accelerator Driven Subcritical System (ADS) and dedicated transmutation fuel cycle.

- JNC and CRIEPI are studying P&T technology using critical fast reactor cycle. Their activities are now organized as the “Feasibility Studies on Commercialized FR Cycle System”.

- JAERI and JNC will be unified in 2005. Various synergy effects are expected for R&D in P&T technology. High potential of JNC to build and operate large-scale experimental facilities will be useful for JAERI to proceed to the next step from laboratory-scale study.

R&D of P&T Technology in the World

- Europe :
  - ADS is considered as powerful measures to manage long-lived radioactive waste in many countries.
  - Various projects are under way in those countries :

    MEGAPIE , n-TOF , MUSE , TRADE , MYRRHA, ….

- USA :
  - Advanced Accelerator Application (AAA) Project was transformed to Advanced Fuel Cycle Initiative (AFCI).
  - This new program aims at the reduction of radioactive waste to be disposed in deep geological repository and is similar to Japanese strategy to make use of plutonium in power reactors.
  - ADS is considered as a candidate of "Series Two" transmuter.

- Asia :
  - Korea researches ADS for the transmutation of both plutonium and minor actinide (MA).
  - China is performing basic researches on ADS as an option in fuel circulation and energy generation.

International Symposium on Accelerator Driven Transmutation System and Asia ADS Network Initiative

- In Europe, collaboration among various countries and activities in the nuclear physics field are significant.

- On the other hand in Asia, Japan, Korea and China are performing the R&D independently.

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- To review the current status of R&D and future plan in the world, and to initiate the collaboration among Asian countries, we have planned an International Symposium on "Accelerator Driven Transmutation System and Asia ADS Network Initiative" on March 24-25, 2003, in Tokyo.

International Symposium on Accelerator Driven Transmutation System and Asia ADS Network
Program

March 24 (13:00 - 18:00)

1. Opening Remarks (10)
   S. Saito (President, JAERI)
2. Activities in USA (40+10)
   B. Richter (Former President, SLAC)
3. Activities in Europe -1 (40+10)
   C. Rubbia (President, ENEA)

Coffee Break (20)

4. Activities in Europe -2 (40+10)
   B. Frois (Ministry of Research)
5. Activities in Japan (30+10)
   H. Oigawa (JAERI)
6. Activities in Korea (30+10)
   H. S. Park (Vice President, KAERI)
7. Activities in China (30+10)
   Z. Zhao (President, CIAE)

Welcome Party (JOSUI-KAIKAN) 18:00 - 20:00

March 25 (9:30 - 16:00)

8. High-Intensity Proton Accelerator Project: J-PARC (25+5)
   S. Nagamiya (KEK／JAERI)
9. Experimental Program at Kyoto University (20+5)
   S. Shiroya (Kyoto University)
10. Accelerator for ADS (35+10)
   Y. Yamazaki (JAERI), **Y. Mori** (KEK)

Coffee Break (15)

11. ADS Design Study in Korea (15+5)
   T. Y. Song (KAERI)
12. Contribution from Nuclear Physics in China (15+5)
   H. Xia （CIAE）
13. Nuclear Data in Japan (15+5)
   M. Igashira (Tokyo Institute of Technology)

Lunch (70) 12:20 - 13:30

14. Discussion : Future Plan and International Collaboration for ADS (150)

14.1 Keynote Talk -1 : Nuclear Physics and Transmutation Technology (15+15)
   A. Mengoni (CERN)

14.2 Keynote Talk -2 : Technical Issues for ADS (15+15)
   H. Oigawa (JAERI)

14.3 Keynote Talk -3 : Asia ADS Network Initiative (15+35)
   Y. Nagai (Osaka University)

Coffee Break (20)

14.4 Free Discussion (20)

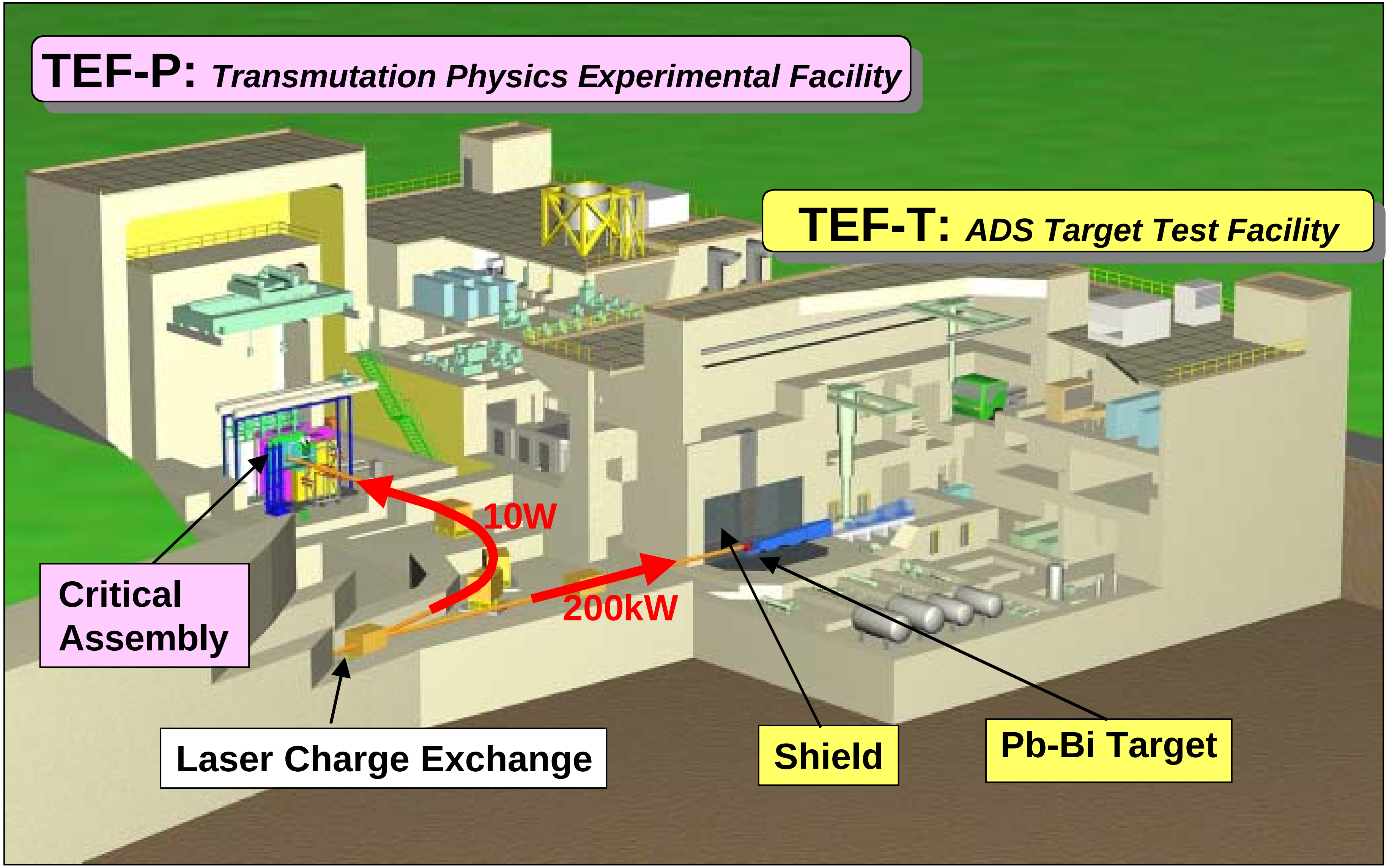
Outline of Previous IAC

☆ We proposed "Transmutation Experimental Facility (TEF)".

- TEF-P (Transmutation Physics Experimental Facility)
  - Critical Assembly based on FCA is proposed.
  - High energy proton beam is available with convenient power level and flexible pulse width.

- TEF-T (ADS Target Test Facility)
  - Material irradiation in flowing liquid metal is proposed.
  - Wide range of parameter survey can be performed as dedicated facility.
  - Experience of Pb-Bi target handling can be accumulated.

Transmutation Experimental Facilities



Items Pointed Out at Previous IAC

- To obtain the participation of foreign countries:
  - The symposium should be an opportunity to initiate the collaboration.
  - JAERI-CEA collaboration agreement was renewed. (up to Sep. 2007).

    Regarding ADS, 7 items are included:

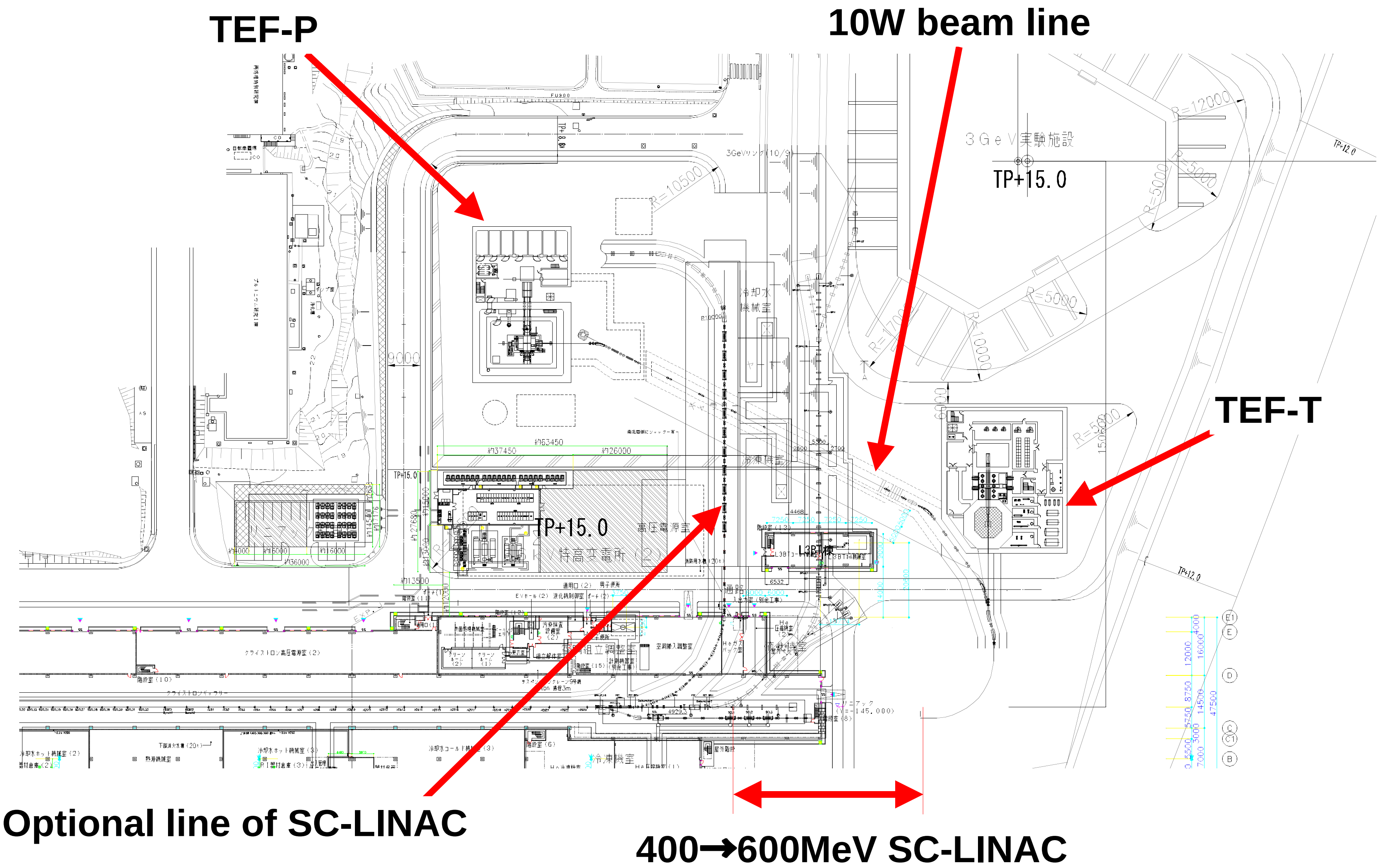
    (1) Design study, (2) Scenario study, (3) Transmutation calculation ,

    (4) Reactor physics experiment, (5) Spallation target and material,

    (6) Proton accelerator, (7) Planning of a new experimental facility

- To promote an Initial design and safety analysis on TEF.
  - Influenced by design change of the accelerator, the arrangement of TEF is investigated. (an example is shown in the next slide.)
  - Main part of Safety Report for TEF-P was drafted. Its validity was reviewed by an external committee.
    - Description of principal device, equipment and system.
    - Strategy to guarantee safety.
    - Evaluation of influences of transient and accident.
    - Analysis for "Beyond Design-Basis Accident" (co-operated by JNC).

Example of "Separated Arrangement"



R&D Activities in this year

- 3-year program for development of ADS technology was approved.
  - FY2002-2004, Total 10M$
  - 3 main areas:
    - Superconducting LINAC (cryomodule test)
    - Pb-Bi technology (material, thermal-hydraulics, Po behavior)
    - Subcritical reactor (structural design and physics)
  - Many institutes, universities and companies are involved.
    - KEK, JNC, Hokkaido-U, Tohoku-U, Kyoto-U, Mitsubishi-HI, Mitsui-ES, ... (total 13)

- R&D for TEF-P:
  - Pulse Neuron Generator is now manufactured for FCA experiment.
  - Laser Charge Exchange Test Device was installed. The test will be carried out next fiscal year.

- R&D for TEF-T:
  - Pb-Bi test loop finished second 3000-hour operation successfully.
  - PIE for SINQ sample was performed.
  - Target design was under way

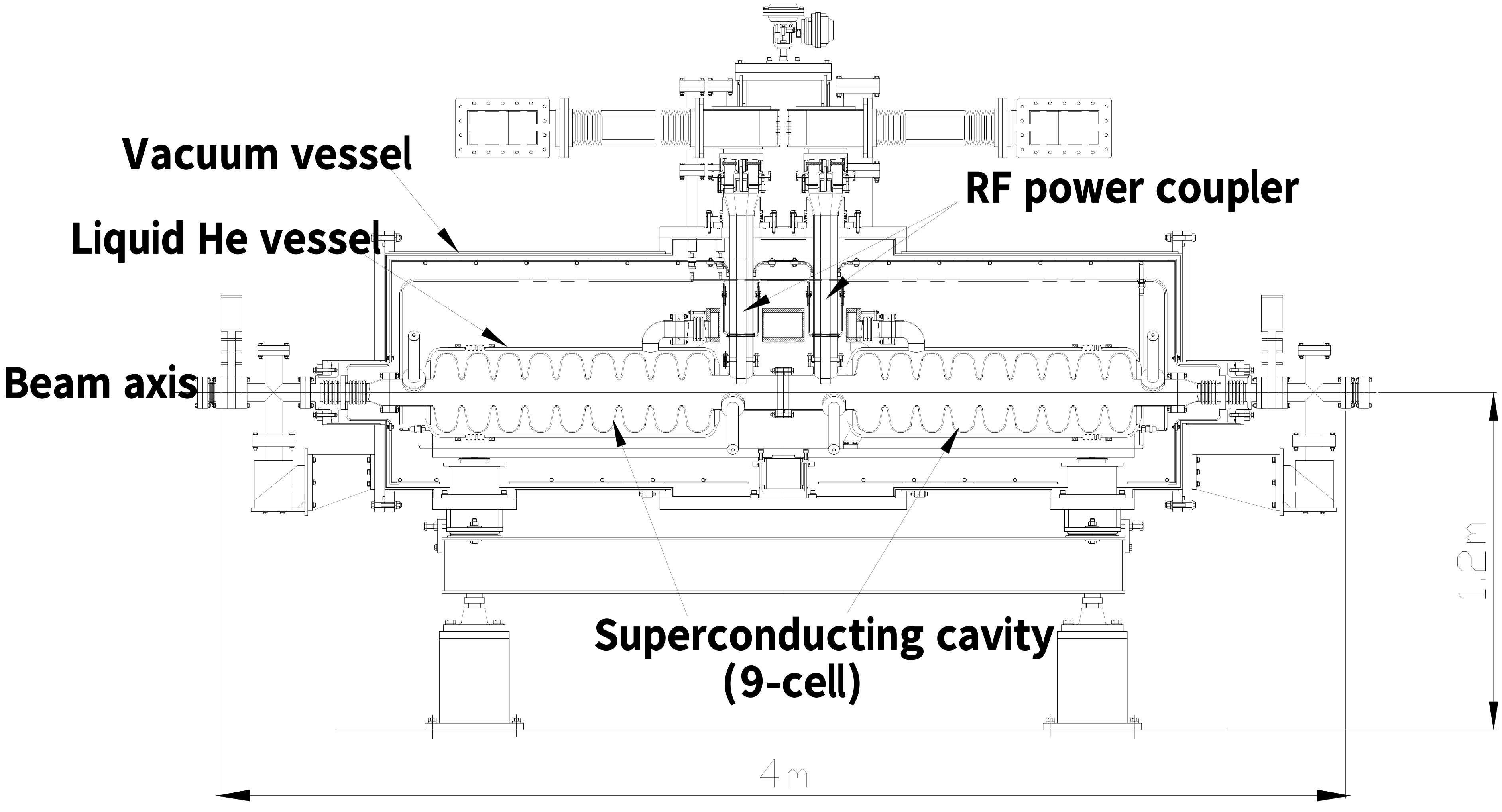
3-year program for ADS (1) Superconducting LINAC

a. **Manufacturing and test of cryomodule (JAERI,KEK,MHI)**
☆Demonstration of high performance for acceleration electric field and cooling

b. **System design of SC-LINAC （JAERI, KEK, MELCO）**
☆Optimization of whole accelerator system

To demonstrate feasibility of accelerator system which is applicable to ADS , where high acceleration performance, high efficiency and low cost are required.

9-cell cryomodule



3-year program for ADS (2)
Pb-Bi Spallation Target / Core Coolant

a. **Material corrosion and purity control （JAERI, MES, Tohoku-U）**

☆Establishment of corrosion database by changing oxygen concentration, flow velocity, etc.

☆Development of purity control system and oxygen sensor

b. **Thermal hydraulics （JAERI, MES, Hokkaido-U）**

☆Loop test of beam window cooled by Pb-Bi

☆Development of ultrasonic velocity probe

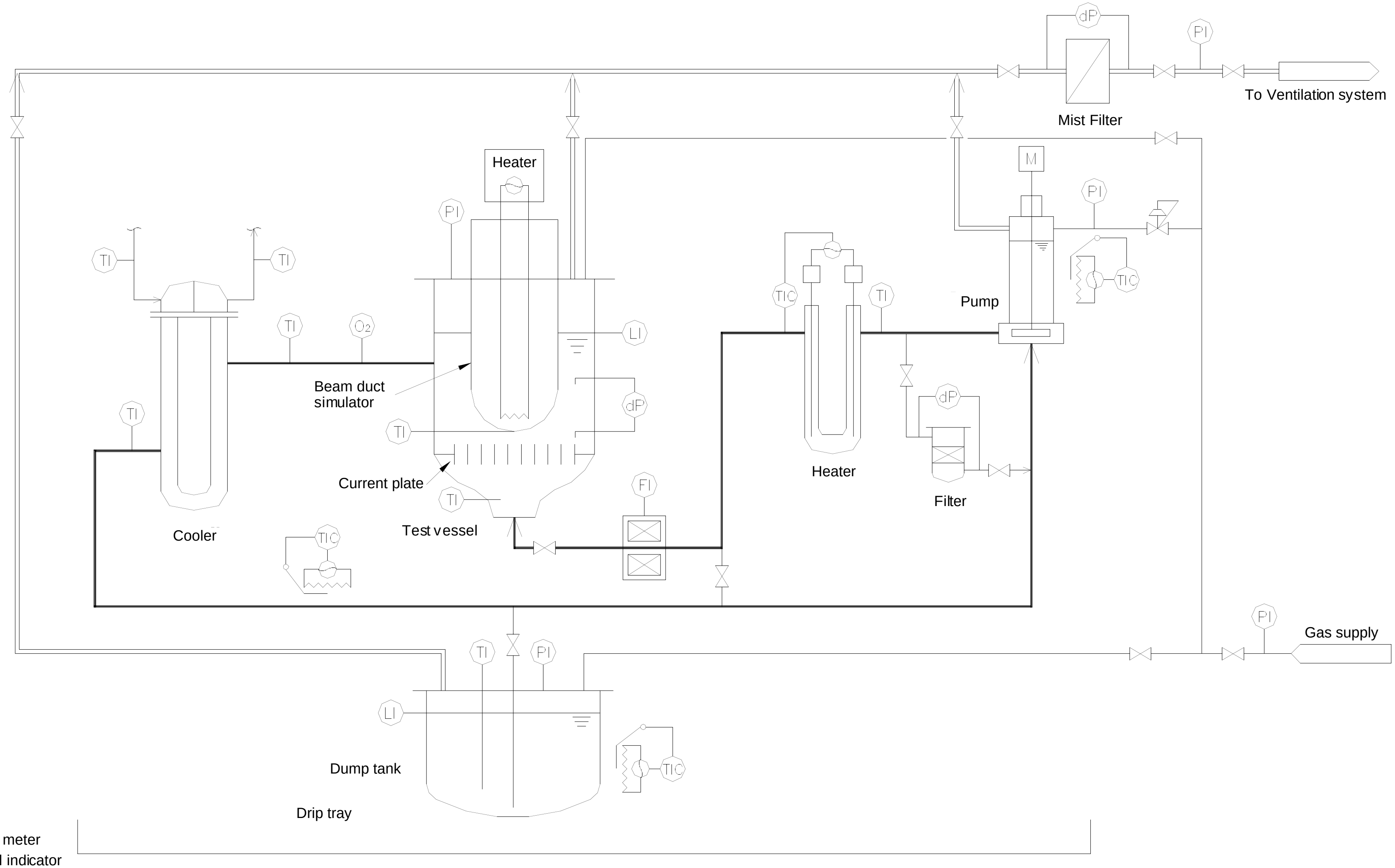
c. **Behavior of radioactive material （JAERI, JNC, TIT,…）**

☆Evaporation test for irradiated Pb-Bi (especially for Po)

☆Improvement of analytical prediction for SP amount

To accumulate database and experience for Pb-Bi as spallation target and coolant

Pb-Bi test loop in MES



FI : Flow meter
LI : Level indicator
TI : Thermometer
PI : Pressure indicator
dP : Pressure difference
O_2 : Oxygen sensor
TIC : Temperature controller

Test loop for beam window cooling

3-year program for ADS (3)
Subcritical core

a. **Feasibility study from engineering aspects （JAERI, MHI）**

☆Proposal of technologically realistic design for core structure

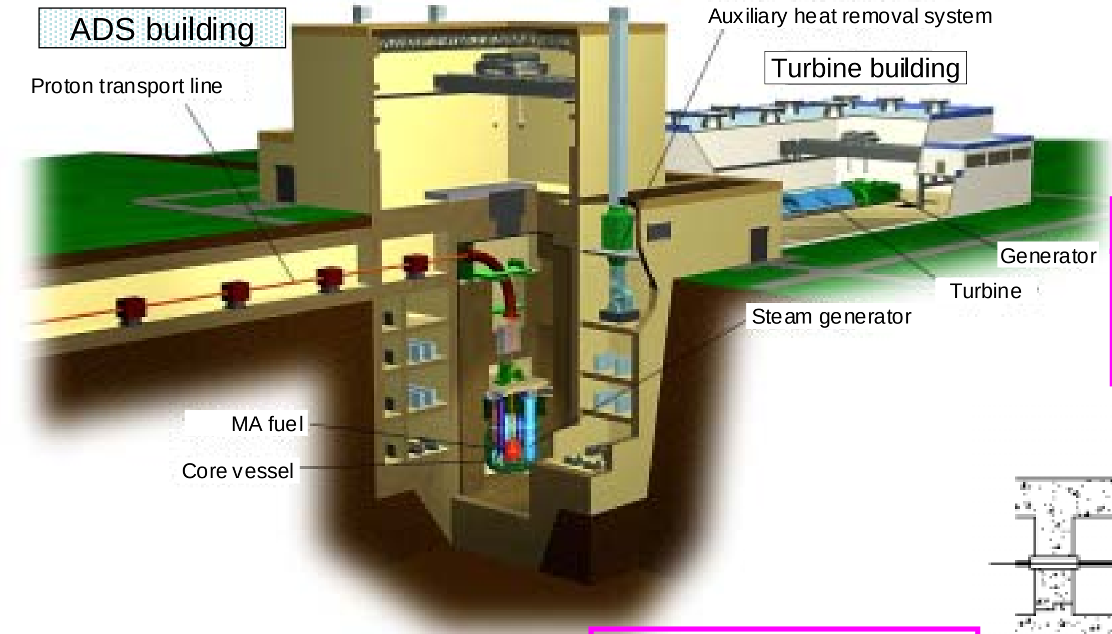
b. **Development of subcriticality monitoring method and evaluation of neutronics design accuracy**

（JAERI, Kyoto-U, Nagoya-U）

☆Experimental study using KUCA and FCA

☆Sensitivity analysis on reactor physics parameters

To establish realistic concept of ADS and reliable design method



Plant arrangement

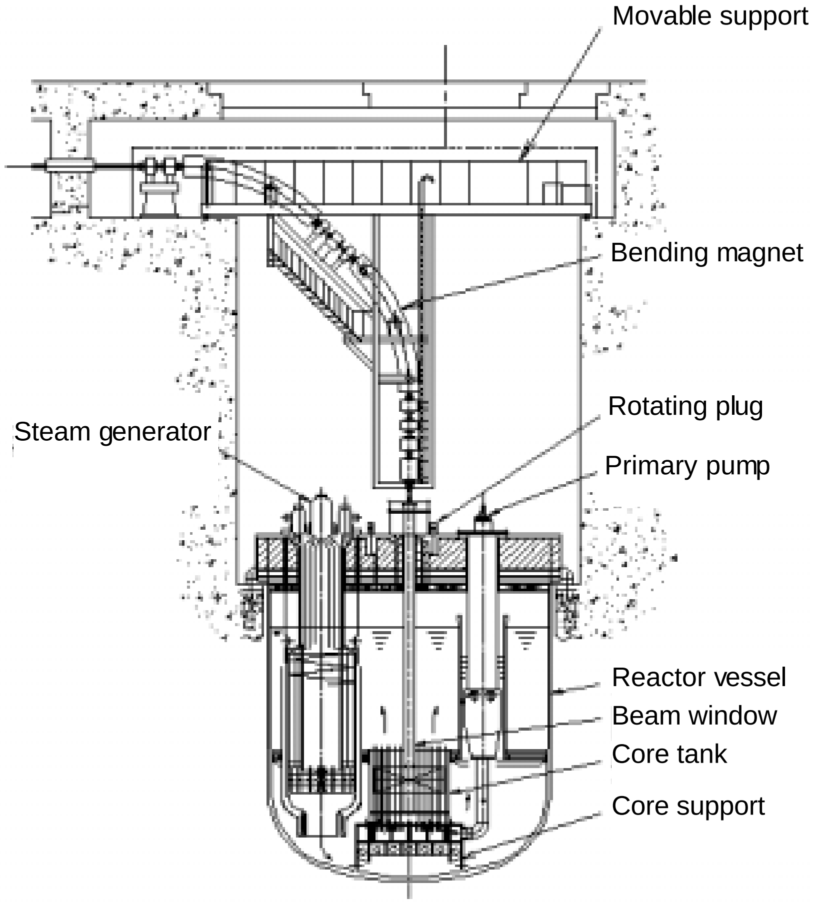
_Building arrangement
_Building specification

Beam window and fuel exchange method

- Beam window, beam line device exchange
- MA fuel exchange
- In-core device (SG, pump,) exchange

Beam introduction

- Beam specification
- Beam transport
- Beam stopper



Core structure

- Structural strength
- In-core flow distribution
- whole core arrangement

Beam window structure

- Optimization of Beam window shape
- Thermal-hydraulics and structural design

Shielding

- Above-core structure
- Sky shine
- Shielding for maintenance

Target flow structure

- Flow path optimization
- Vibration, fatigue of duct
- Seismic design

Cooling system

- Basic design of principal equipment
- Treatment SP and Po

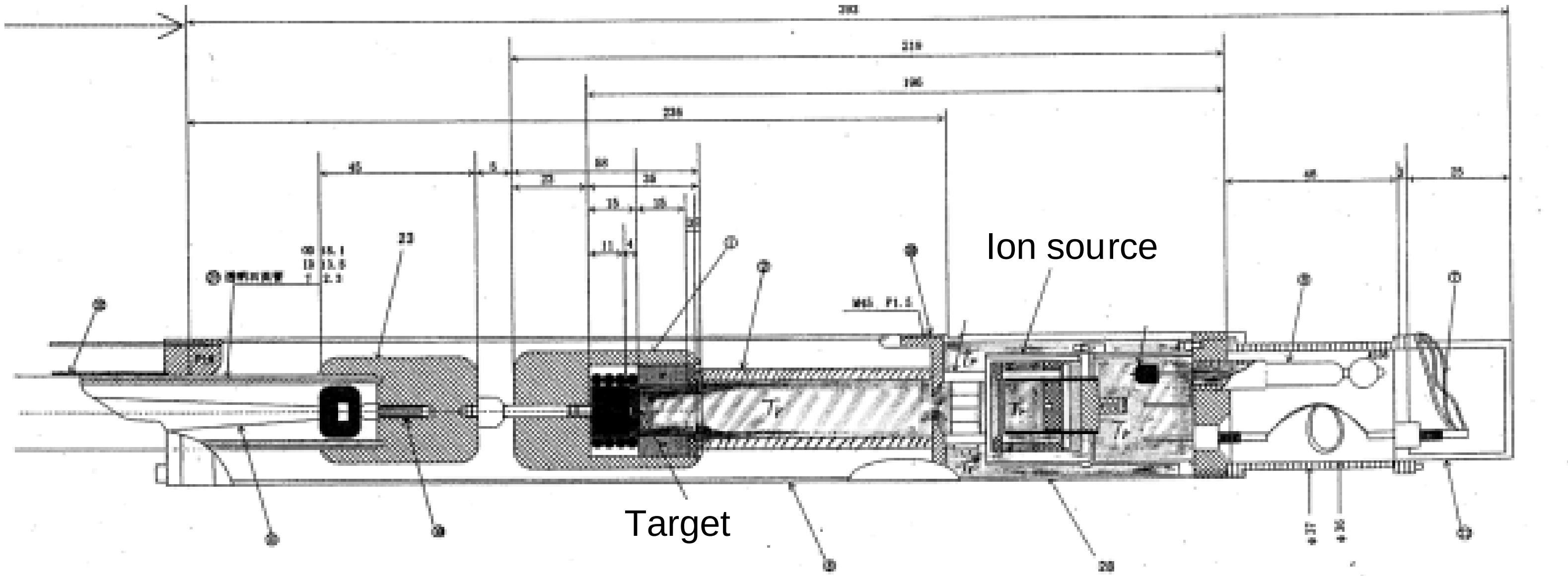
Core basic design

- Fuel performance
- Neutronics

Feasibility study from engineering aspects for subcritical core

R&D Activities for TEF-P (1)

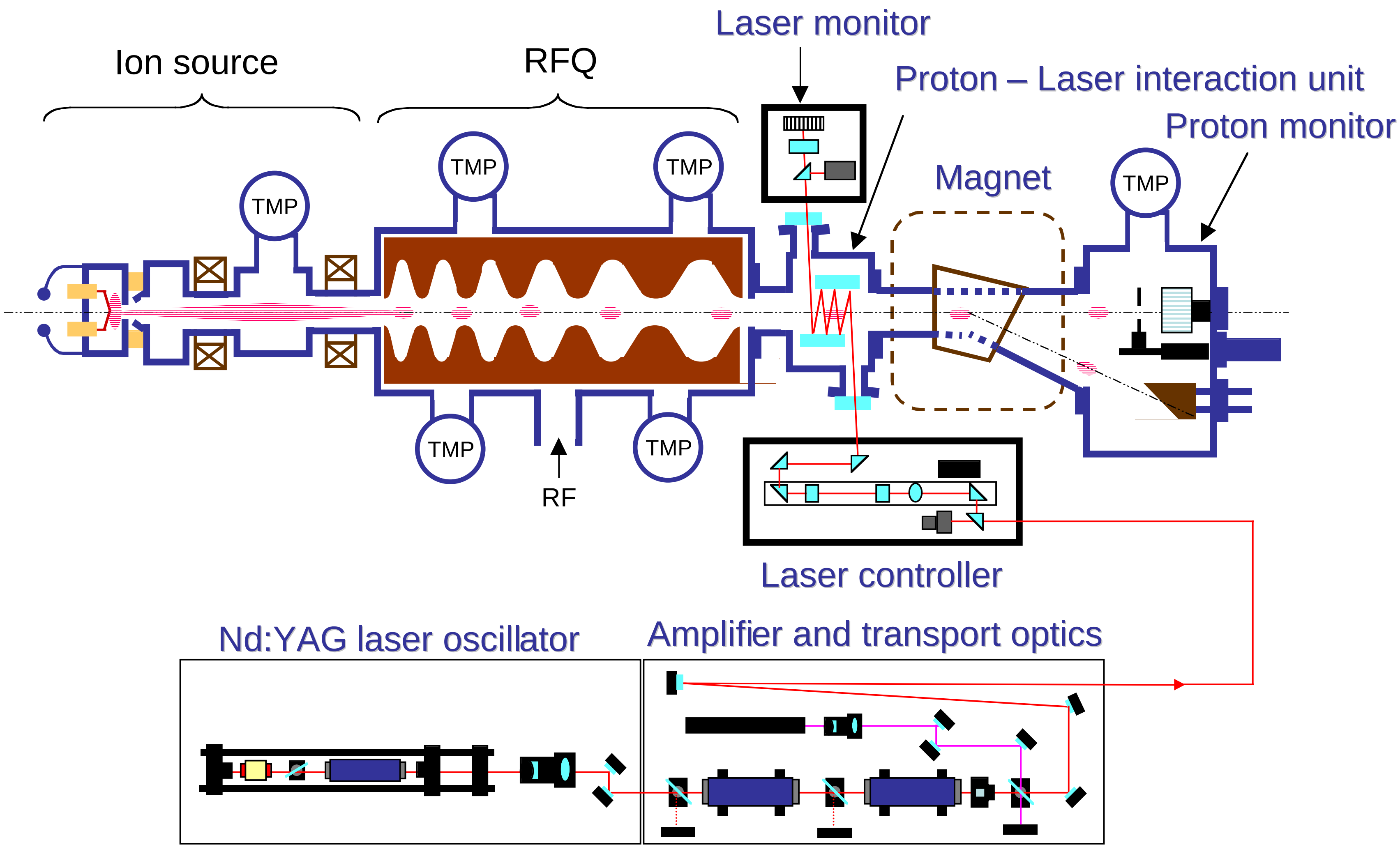
Manufacturing Pulse Neuron Generator for FCA experiment



- **Specification**
  - **Reaction : D-T (14MeV)**
  - **Neutron source strength : 1×10^{8} n/s**
  - **Pulse width : < 5μs**
  - **Repetition : 10 kHz – continuous**
  - **Diameter : < 5cm$^{\Phi}$ (to be inserted in FCA matrix structure)**
- **Purpose**
  - **To verify reactor instrumentation for TEF-P**
  - **To develop subcriticality monitoring method**

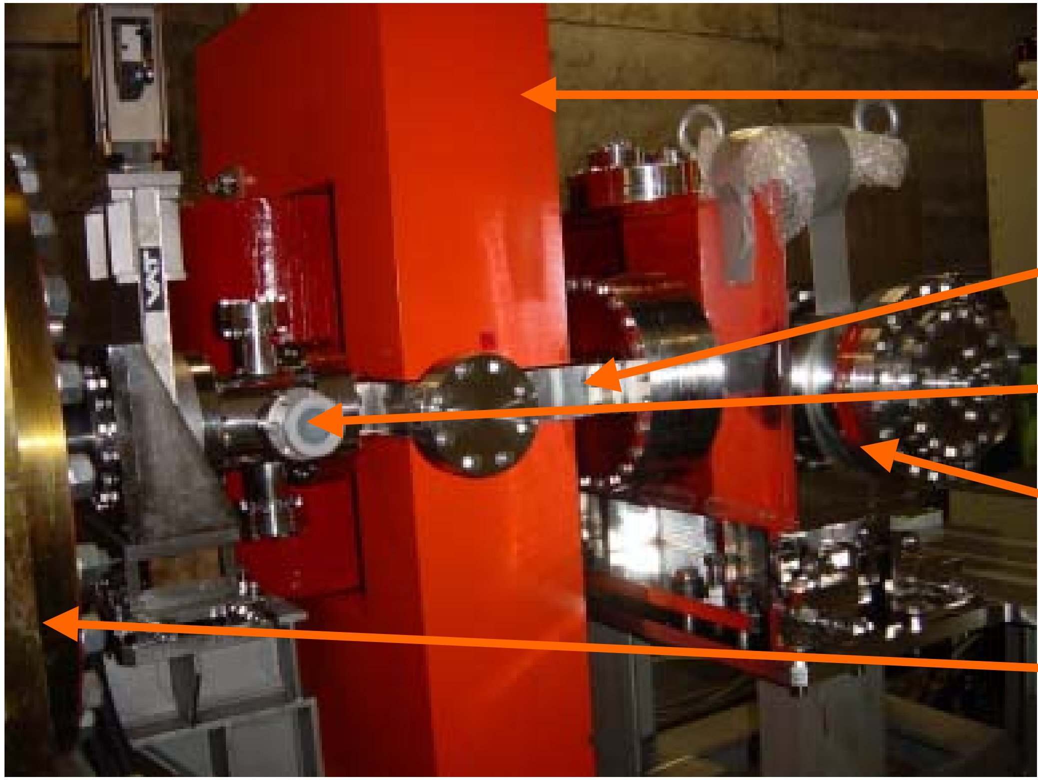
R&D Activities for TEF-P (2)

Installation of Laser Charge Exchange Test Device



R&D Activities for TEF-P (2)

Installation of Laser Charge Exchange Test Device



Magnet

Beam duct

Proton - Laser interaction unit

Proton monitor

Exit of accelerator

R&D Activities for TEF-T (1)

3000-hour test by Pb-Bi loop

Test temperature : 450℃ (High temperature part)

Temperature gradient : 50 -100℃

EMP power : 5 ℓ/min

Velocity at test section : 1m/sec

Flow meter : Electromagnetic type

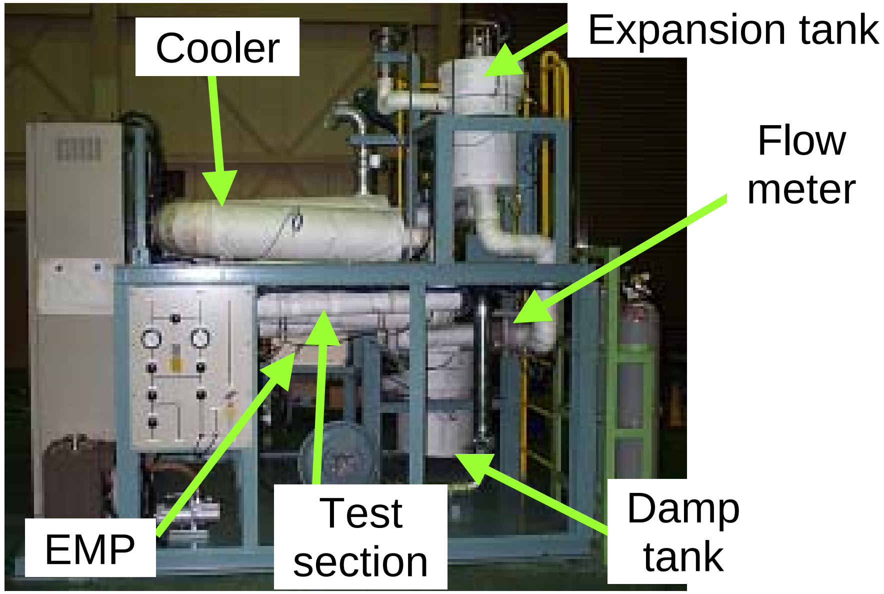
Pb-Bi inventory : 0.018m^3

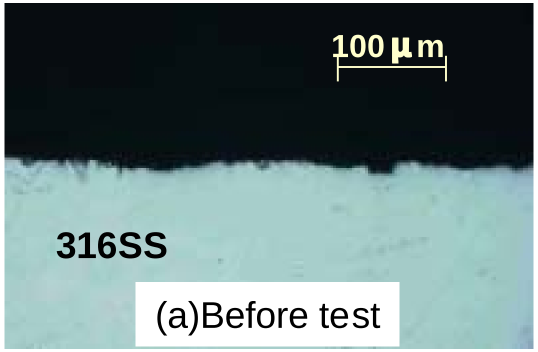
Material of components and specimen : type 316ss

Cover gas : 99.995% Ar

Testing time: ～3000h

- Specimen for 1st operation is under investigation.
- 2nd operation was successfully completed.





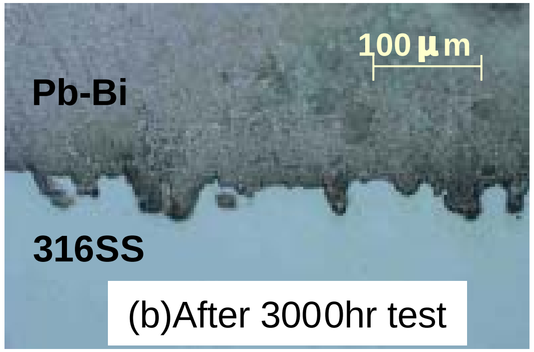


Fig. Result of Pb-Bi loop test for 316SS

R&D Activities for TEF-T (2)

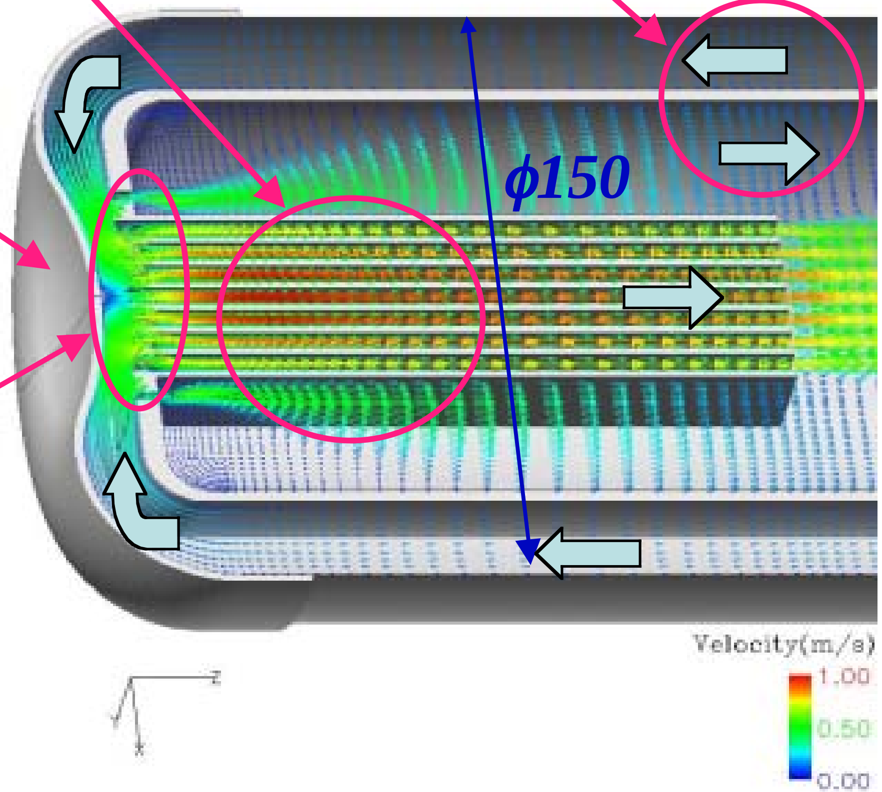
Conceptual Design of TEF-T Pb-Bi Target

Irradiation sample holder:
To install plate specimens

Annular channel :
To flow Pb-Bi

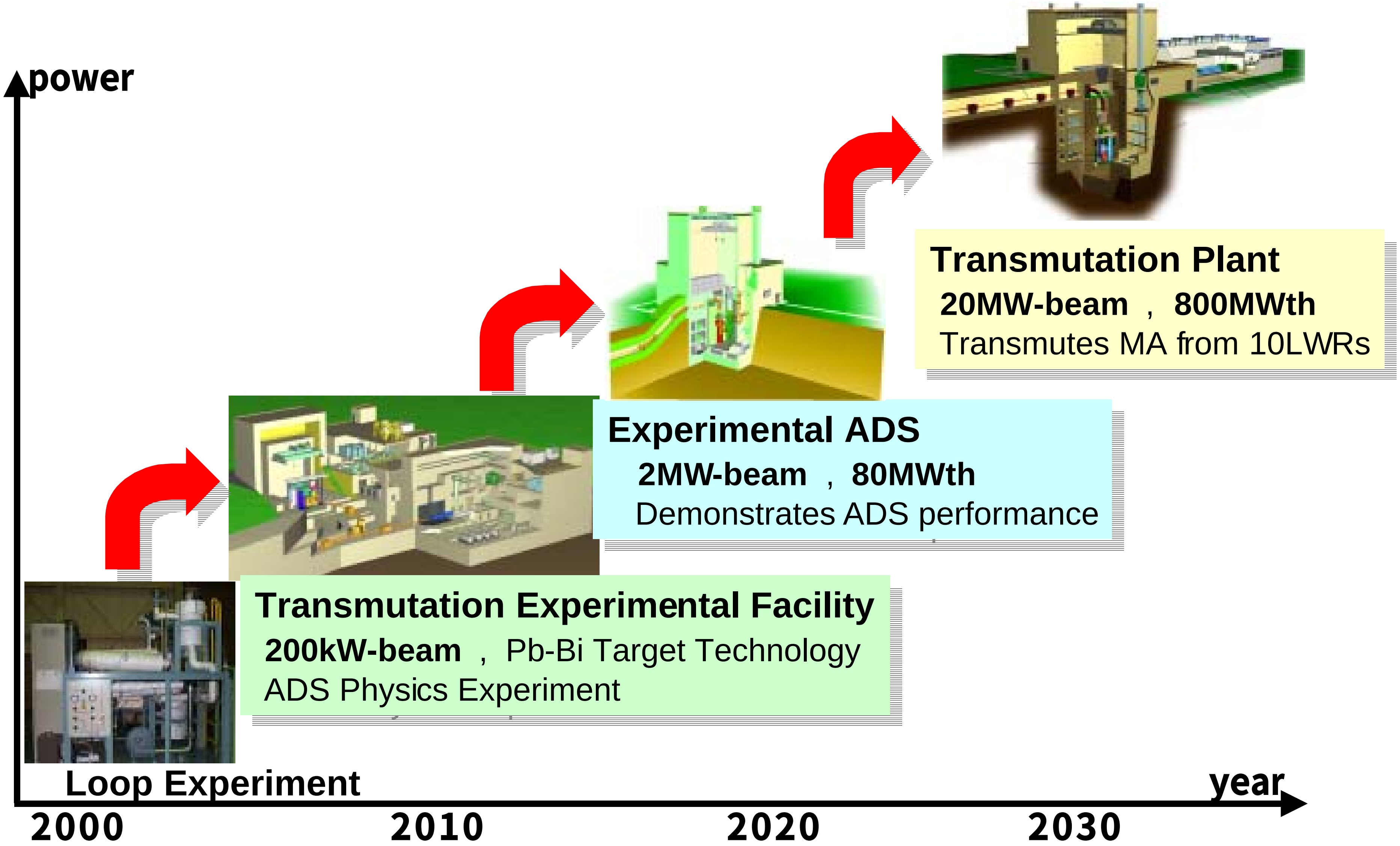
Beam window :
To assist returned flow and reduce the thermal stress.

Proton Beam



Perforated plate :
To improve heat removal at beam window and control a flow in sample region.

R&D Scenario of ADS



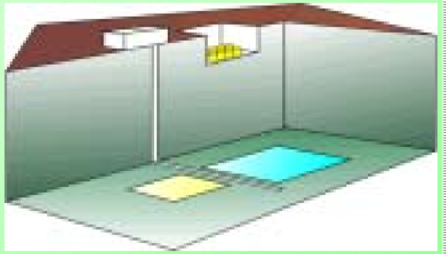
Other R&D Activities for P&T

Partitioning

- 4 Group partitioning process concept
- Labo-scale test
- High performance extract agent

Waste Disposal and Scenario Study

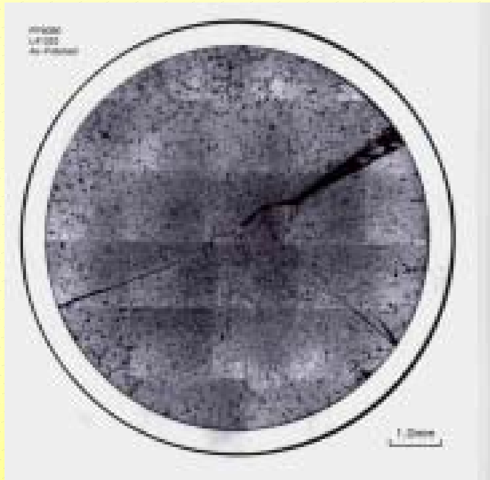
- Design study for advanced waste disposal using P&T technology
- Cost estimation
- Safety analyses



Nitride Fuel

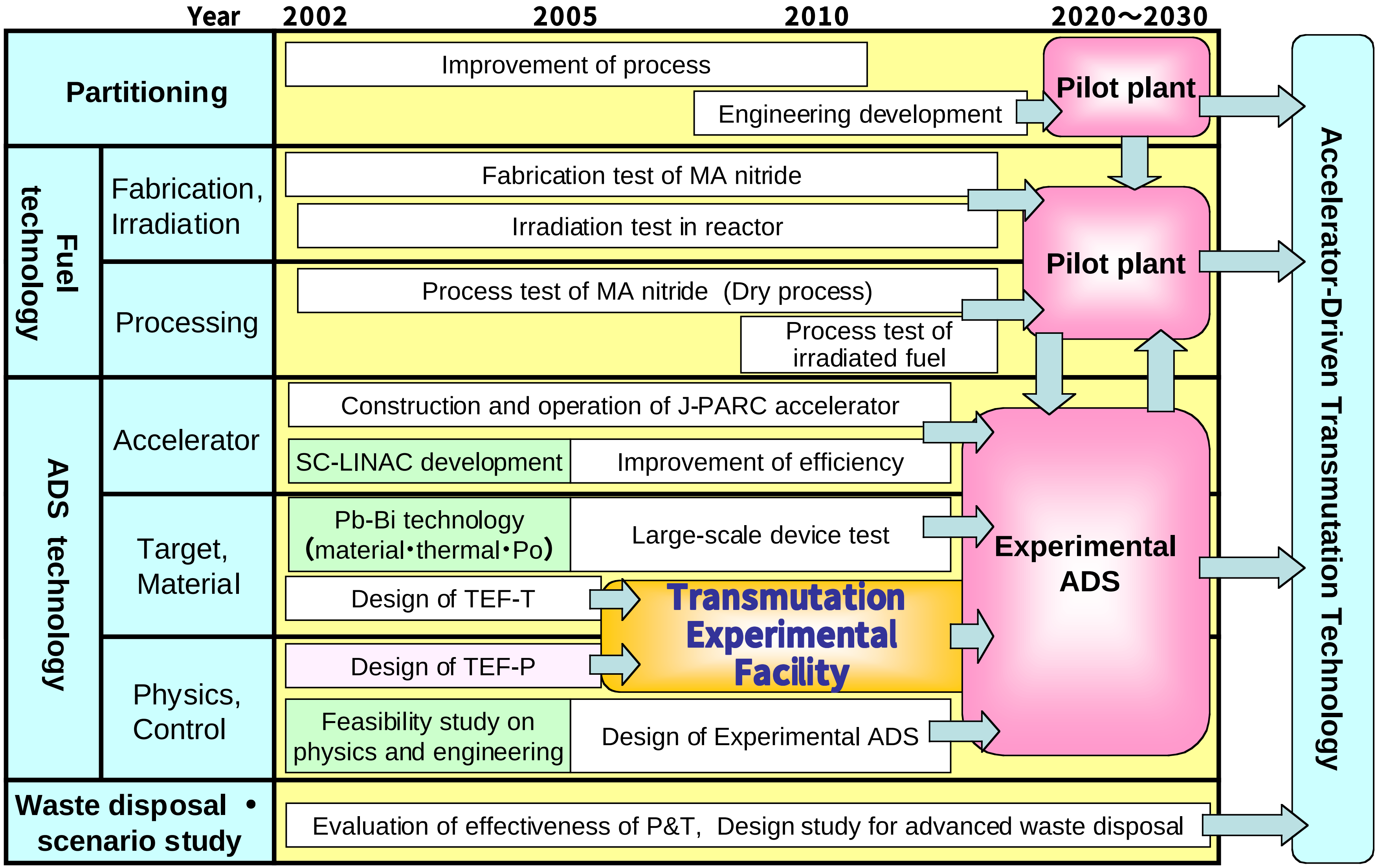
- MA fuel fabrication and irradiation
- Basic properties measurement
- Pyrochemical process research

(Pu,Zr)N pellet

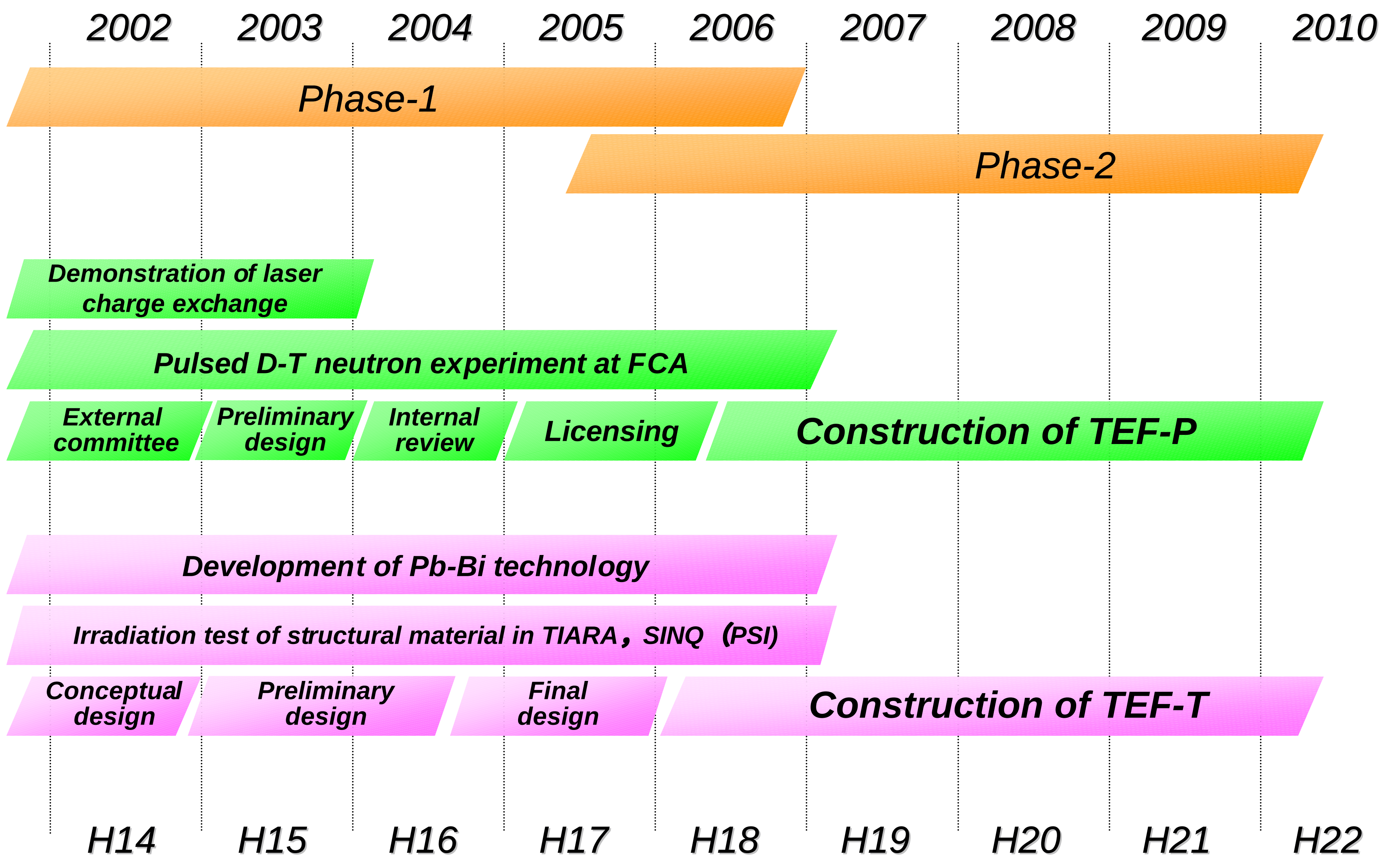


Irradiated (U,Pu)N fuel

Long Term Program for P&T using ADS



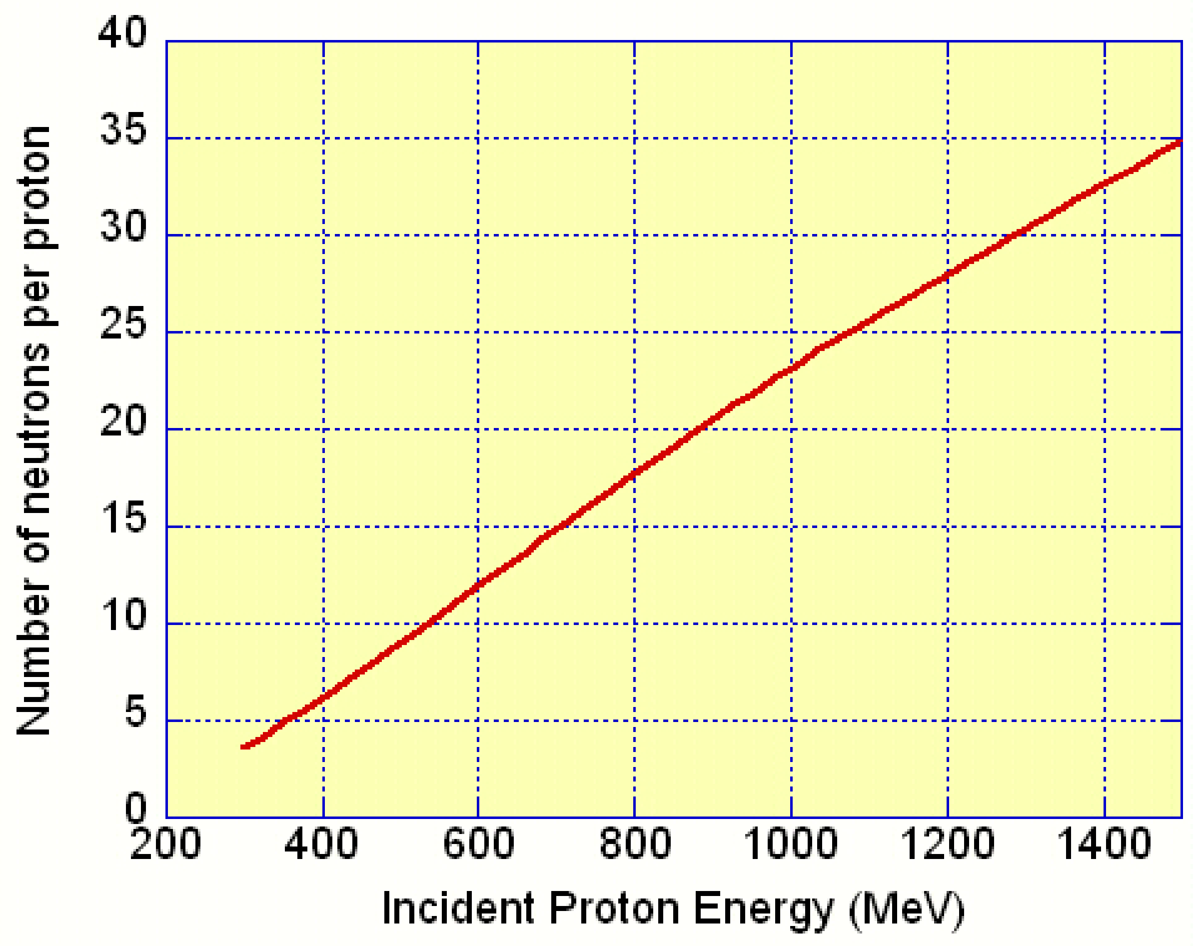
Perspectives toward the Establishment of Transmutation Experimental Facility (TEF)



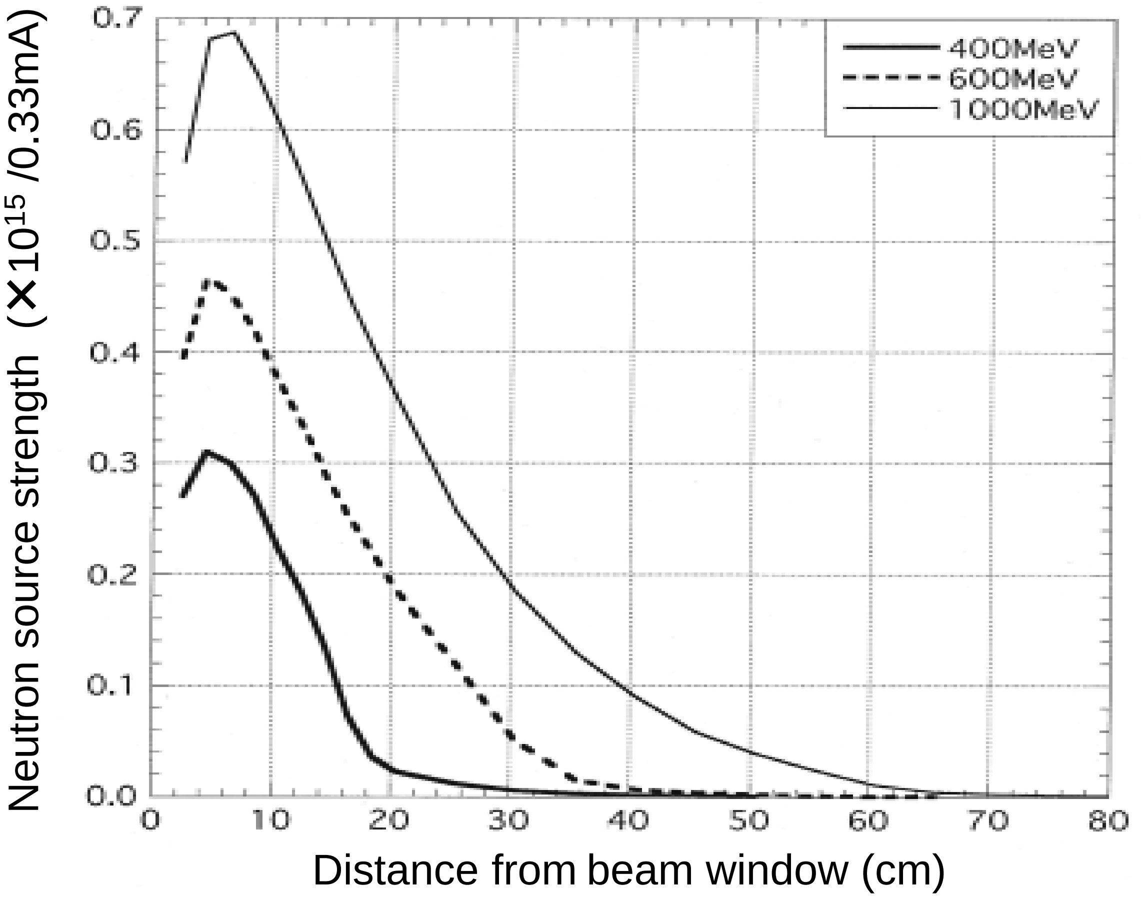
Summary

- To contribute to the HLW disposal in 2030-40s, early start is important.
- We will be ready to start design for TEF in one year.
- No major technological difficulty is found in the conceptual design of TEF.
- One of difficulties is in the arrangement of the facilities, when we consider the upgradeability of TEF to 600 MeV.
- Proton beam higher than 400 MeV is essential to the experiment. The recovery scenario of LINAC is serious concern for TEF.
- Collaboration with Japanese institutes (JNC, universities, etc.) , Asian countries (Korea, China, etc.) and other countries (Europe, USA, etc.) will be pursued further. We would appreciate IAC member's assistance.

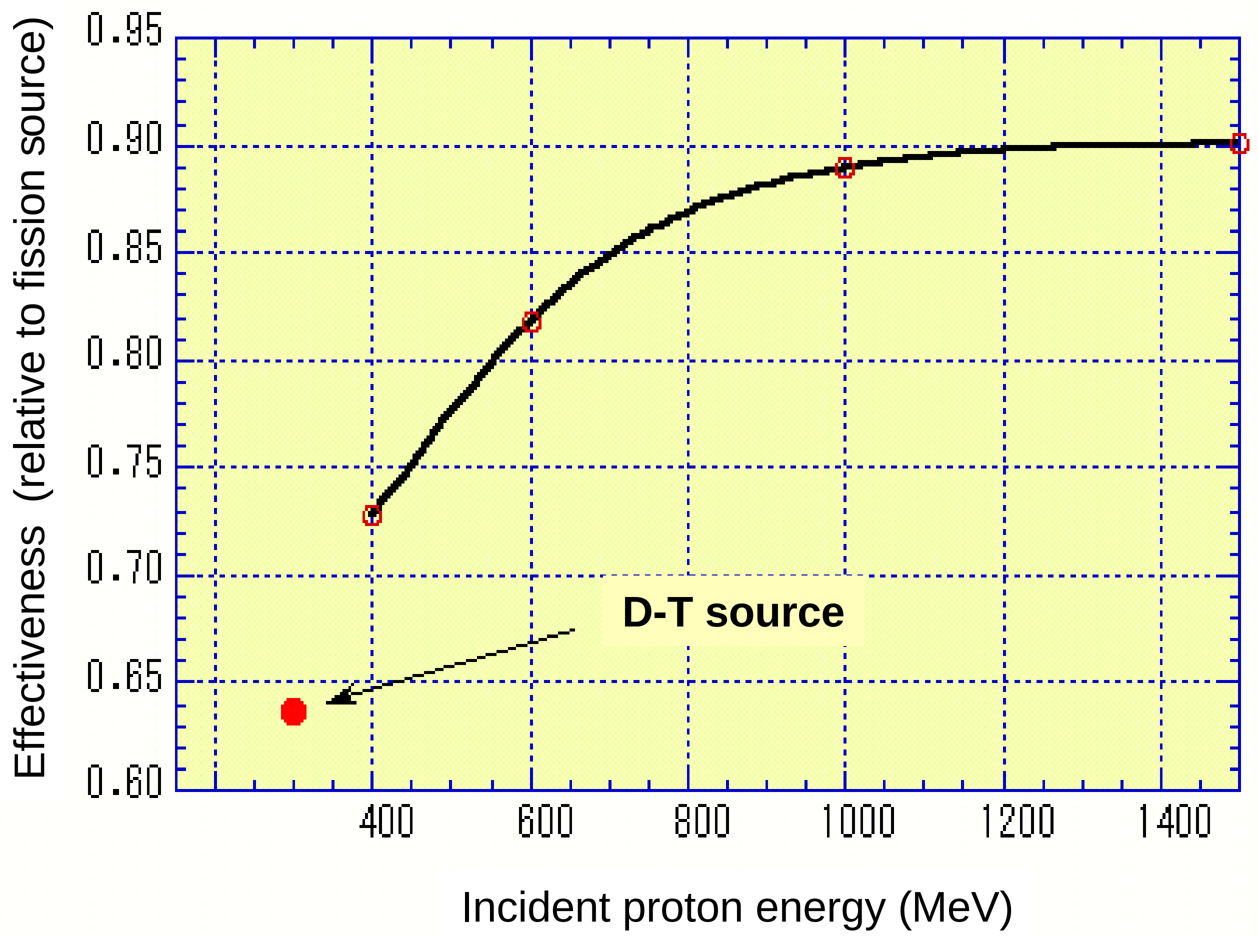
Number of Neutrons per Proton



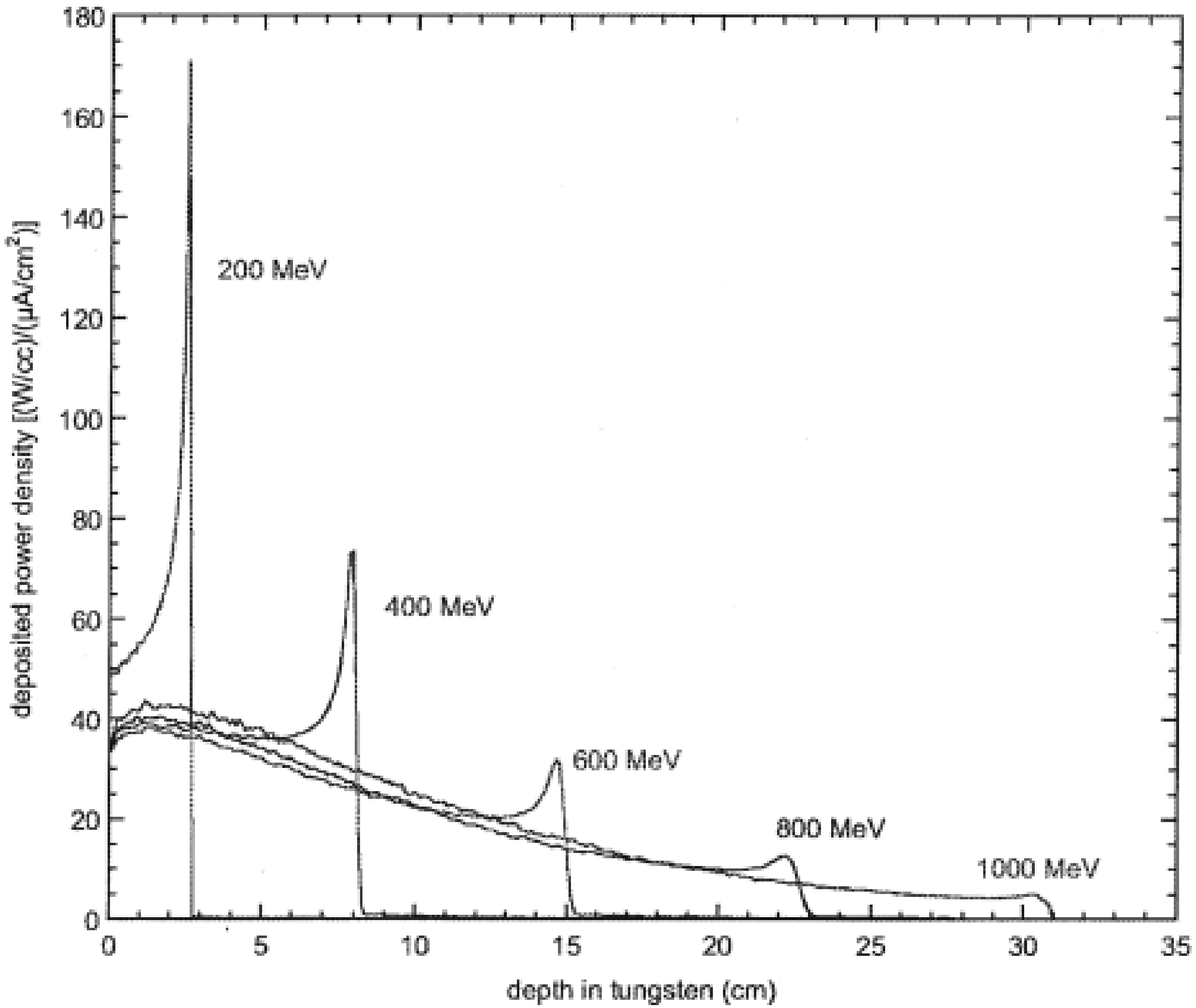
Neutron Source Distribution in Axial Direction



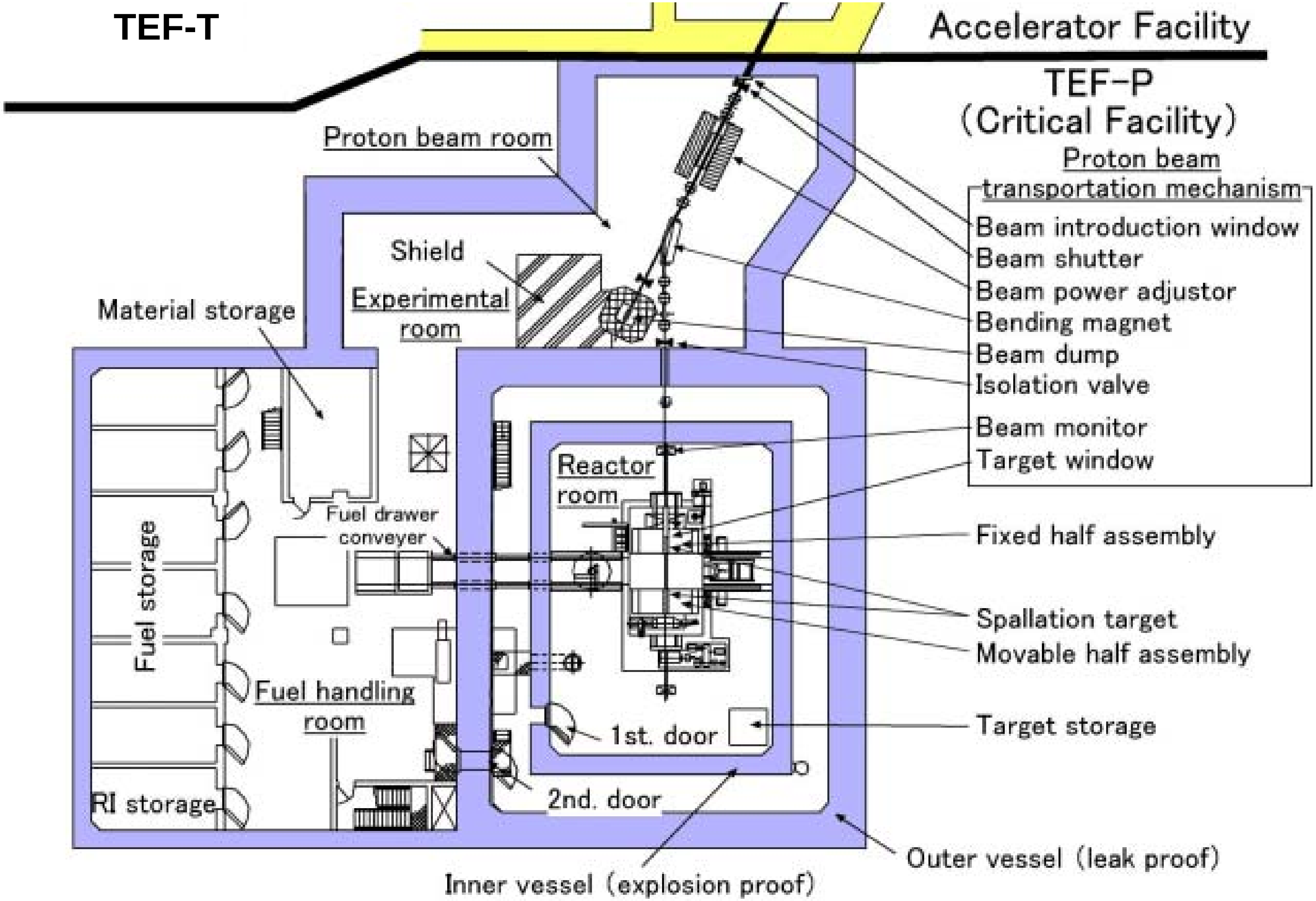
Neutron Source Effectiveness



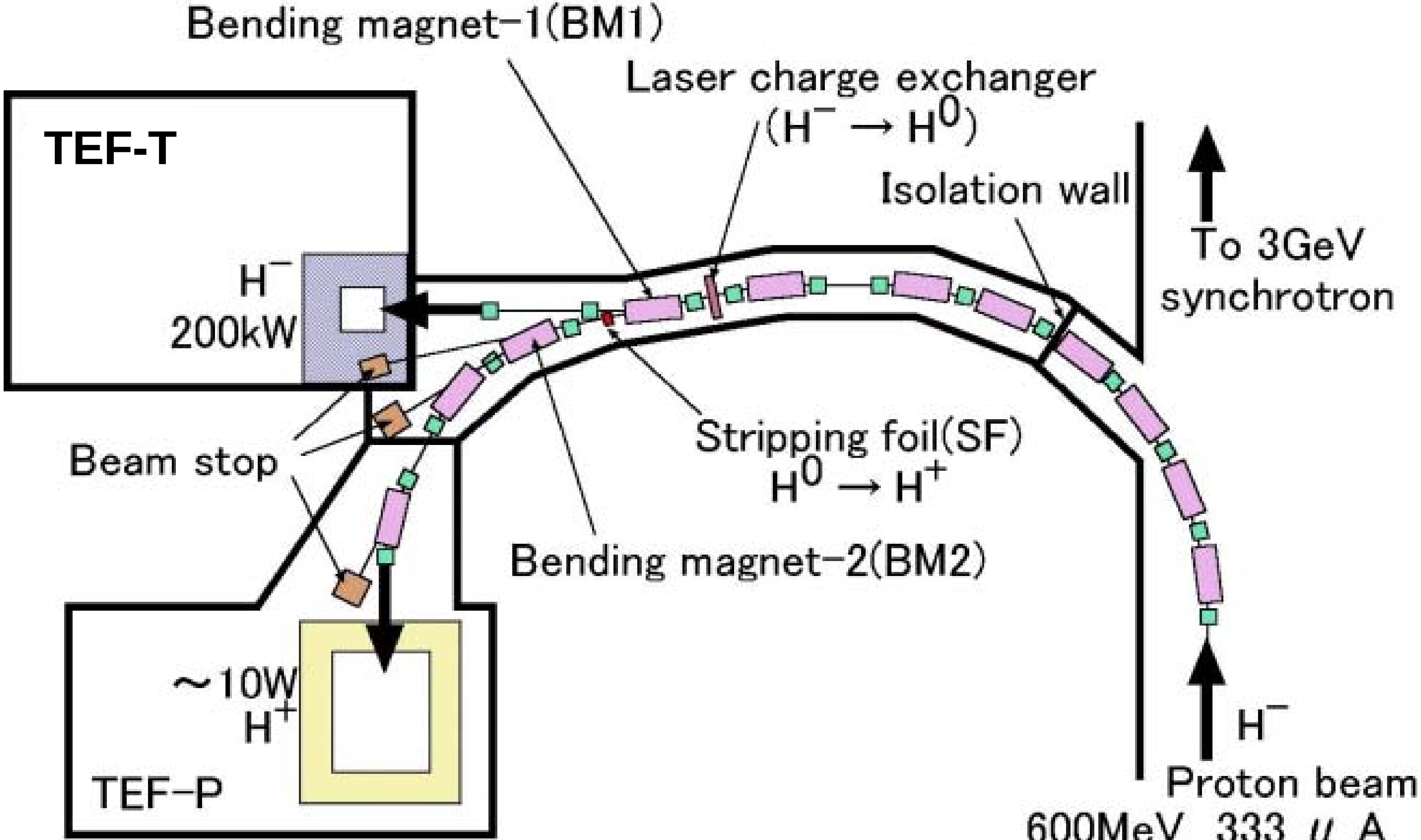
Deposited power density



Conceptual Design of TEF-P



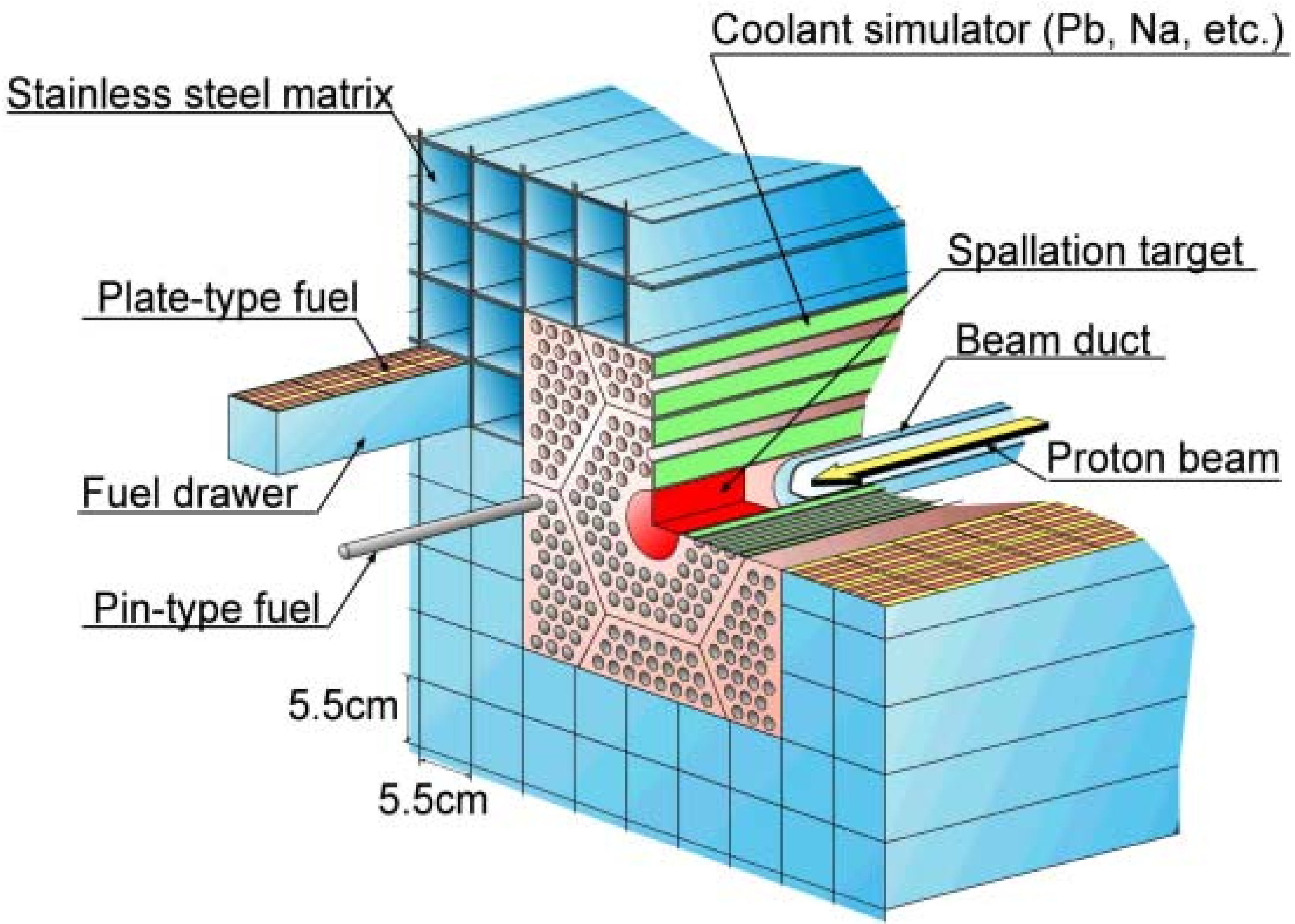
Proton Beam Introduction Mechanism



Pulse width : 1ns – 0.5ms

Pulse width : 0.5ms
Repetition : 25Hz

Conceptual View of Partial Simulation with Pin-type MA-nitride Fuel



R&D items using TEF-P

Purpose of R&D	*R&D items*
Validation of data & method to predict the neutronics in a fast subcritical system with a spallation source	**Measurement of power distribution in sub-critical system**
	Determination of k_{eff} and effective source strength
	Evaluation of influence of high energy neutrons
	Evaluation of influence of target, beam window and void in beam duct
	Simulation of Pb-Bi coolant
Performance test of a hybrid system driven by an accelerator	**Feedback control of reactor power by beam intensity adjustment**
	Investigation of system behavior at beam trip and re-start
	Evaluation of temperature effect of core and target
	Investigation of instability of system caused by subcriticality and annular arrangement of core
	Determination of energy gain factor
Transmutation performance of MA and LLFP	**Measurement of cross section data by TOF technique**
	Measurement of MA transmutation rate
	Measurement of MA and LLFP sample reactivity worth
	Study of moderated region for LLFP transmutation
	Simulation of MA-loaded nitride core

Performance of Irradiation Field

Proton beam : 600MeV-200kW

Beam profile : ϕ4cm - Flat top

Maximum neutron flux : 4 X 10^{14} n/cm^2/s

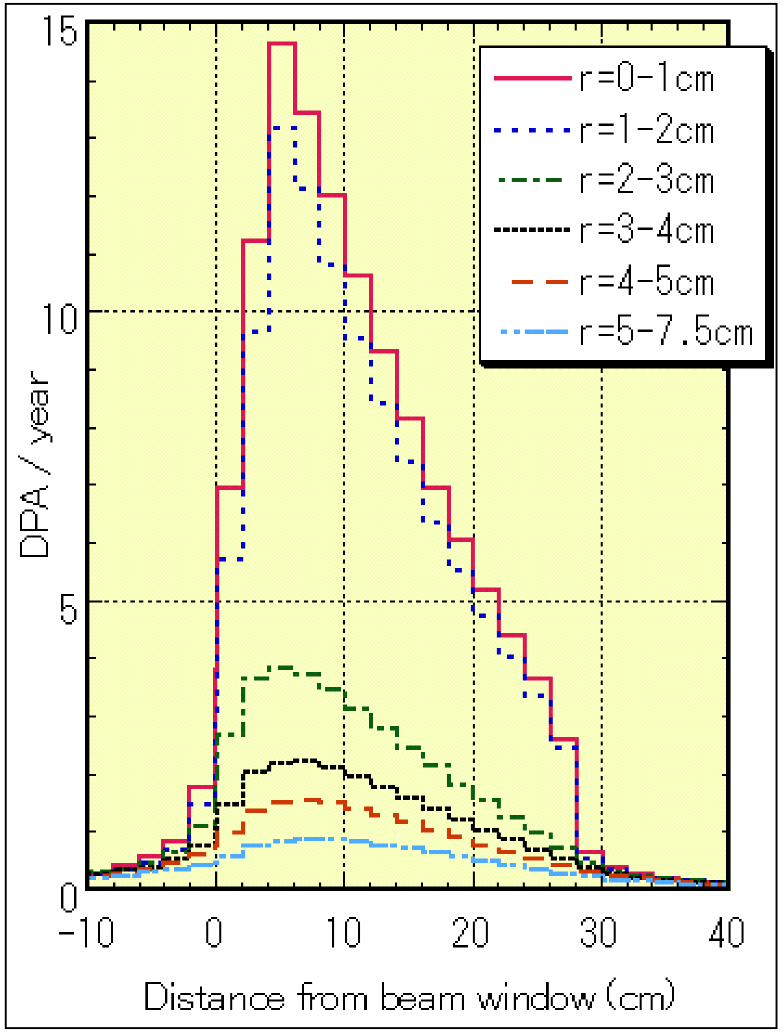
Maximum annual DPA : 15 DPA/year

Irradiation Area over 10 DPA/y :

3cm ^{f} X 15cm^L

Coolant velocity : about 2m/s

Temperature range : 350 ~ 450ºC



Annual DPA Dose of 316SS in Pb-Bi Target (r : radius)

R&D items using TEF-T

Purpose of R&D	*R&D items*
Irradiation damage of beam window and structural material by protons and neutrons	**Evaluation of soundness and lifetime of beam window**
	Duplicated irradiation damage by protons and neutrons
	Establishment of material database for fast neutron irradiation
	Irradiation effect under stressed condition
Compatibility of material with flowing liquid metal under strong irradiation condition	**Liquid metal corrosion and liquid metal embrittlement under proton and neutron irradiations**
	Compatibility of material with liquid metal as a function of temperature, velocity and oxygen concentration of the liquid
	Affect of spallation products
Operation and control of liquid metal spallation target system	**Demonstration of performance of pump, flow meter, heat exchanger, oxygen controller under actual liquid metal spallation target**
	Transient behavior of system at beam trip and re-start
	Containment of spallation products and polonium
	Technical issues on system operation and maintenance