Current Status of Safeguards R&D for Advanced Fuel Cycle at KAERI

Nov. 13, 2007

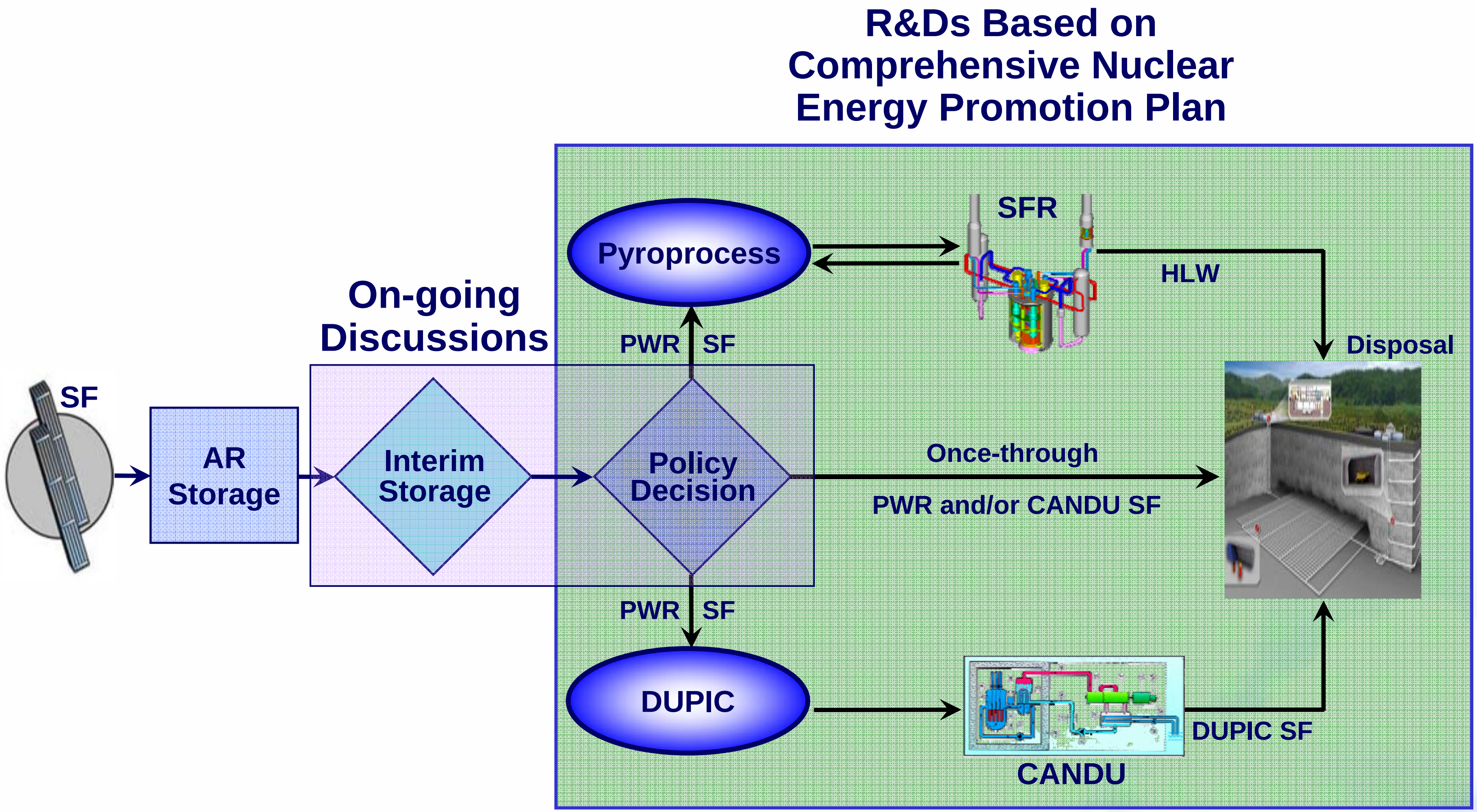
Ho-Dong Kim
KAERI

Outline

- Introduction of Future Fuel Cycle Options at KAERI
- History of Safeguards R&D at KAERI
- DUPIC Safeguards System
- ACPF Safeguards System
- Other Safeguards R&D for Pyroprocess at KAERI
- International Cooperation
- Summary

Introduction of Future Fuel Cycle Options at KAERI

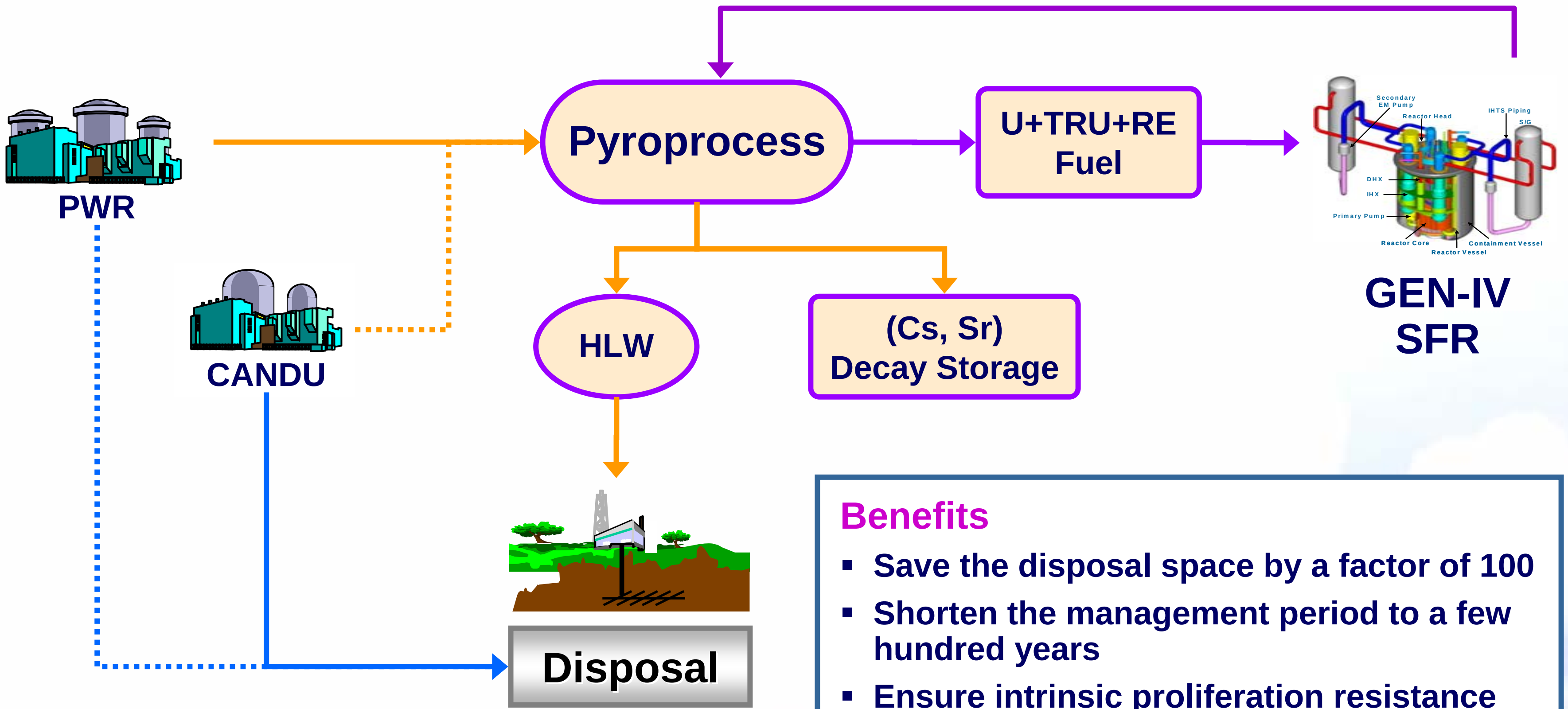
Spent Fuel Management Options



Current Conclusion

Korean, Innovative, Environmentally Friendly, and Proliferation Resistant System for the 21st C (KIEP-21)

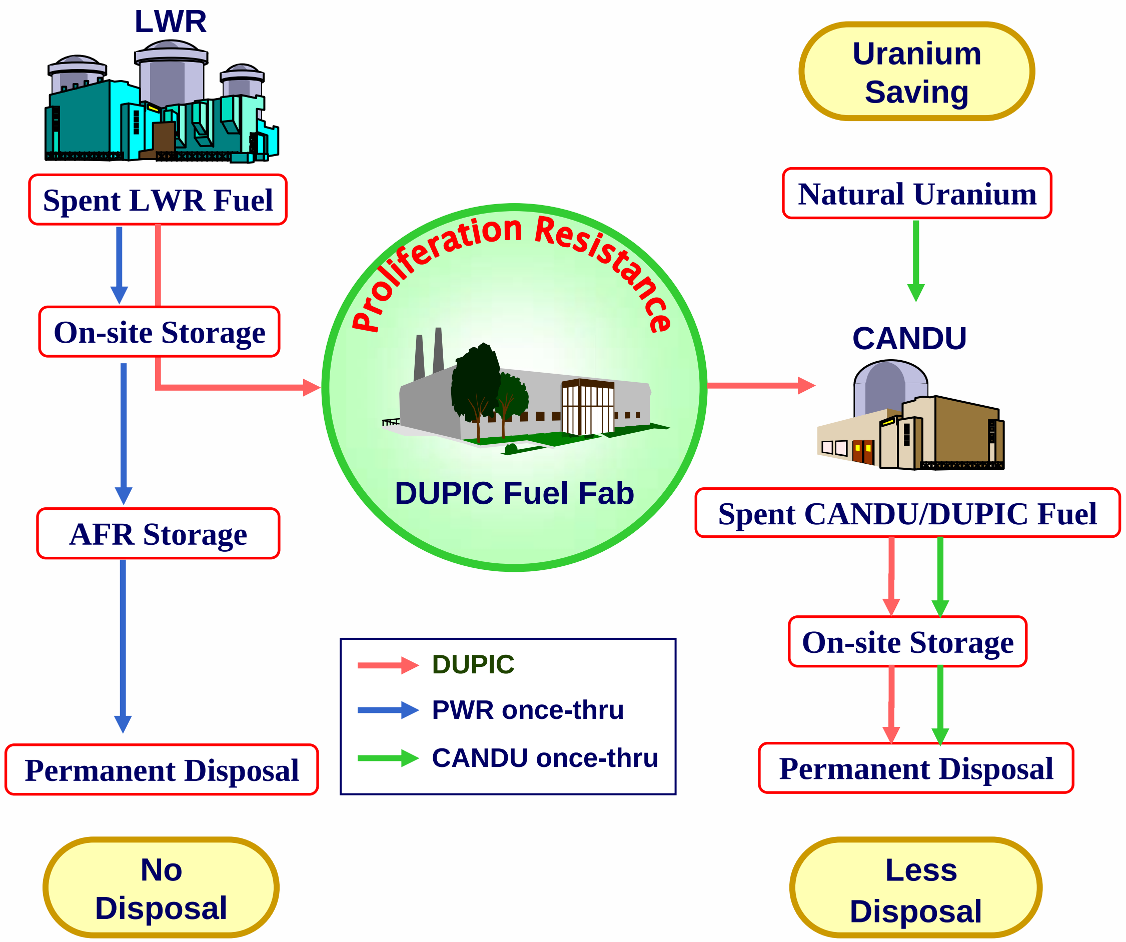
Volume Reduction	FR Closed Fuel Cycle



Benefits

- **Save the disposal space by a factor of 100**
- **Shorten the management period to a few hundred years**
- **Ensure intrinsic proliferation resistance**

DUPIC Fuel Cycle Concept



DUPIC: Direct Use of Spent PWR Fuel In CANDU Reactors
(Termed by KAERI/AECL/USA Joint Research in 1991)

Benefits

- Getting rid of spent LWR fuel
- Reducing the amount of SF generation from CANDU reactors by a factor of 2
- Significant (~25%) reduction in natural uranium requirement

Technical Challenges

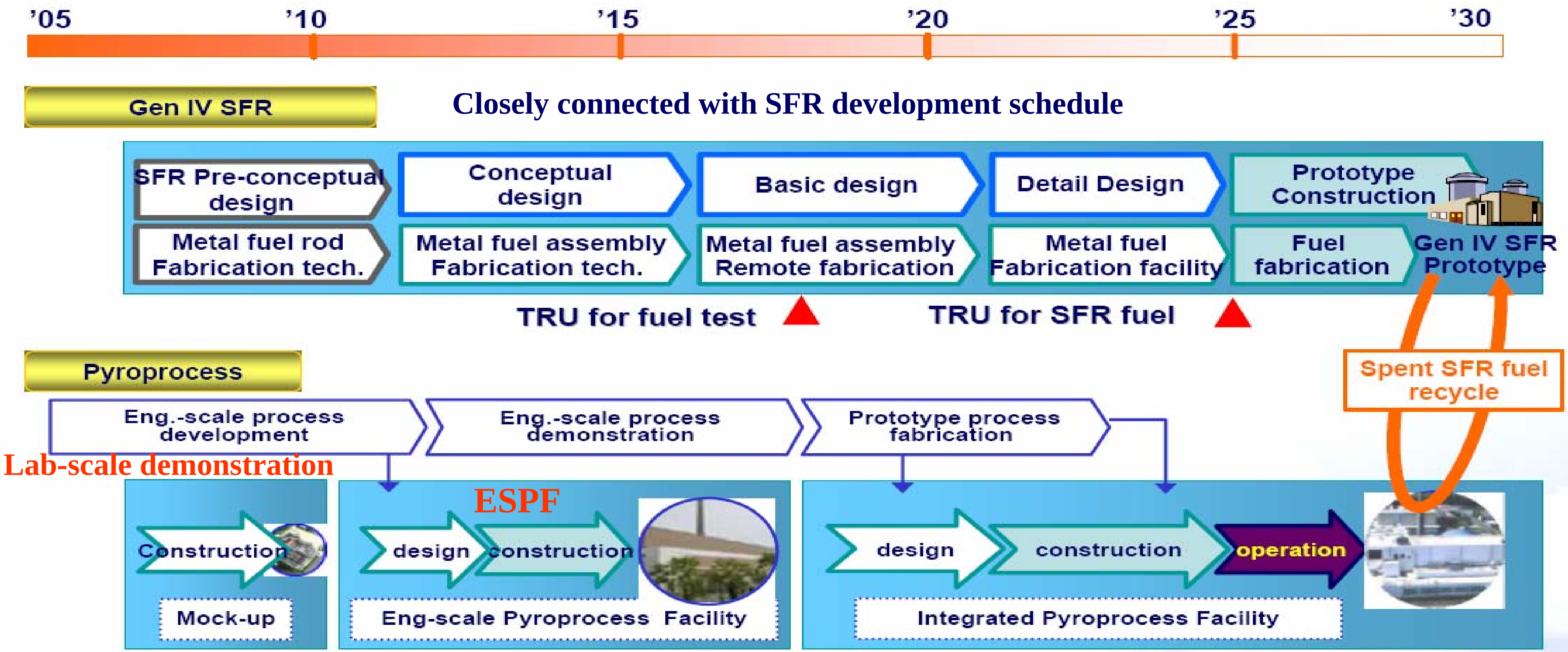
- Development of remote fuel fabrication technology
- Verification of performance and safety of DUPIC fuel
- Development of remote fuel handling method in CANDU plant

DUPIC Technology Development

- Objective
  - Development of a proliferation-resistant fuel cycle technology for the spent PWR fuel management
  - Demonstration of the DUPIC fuel cycle technology in terms of the remote fabricability, fuel performance, compatibility, safeguardability and economic feasibility
- On-Going and Future R&D Activities
  - 1st stage('92~'01) : Experimental Verification of DUPIC Fuel Development Technology
  - 2nd stage('02 ~'06) : Improvement of Key Technologies for DUPIC Fuel Fabrication
  - 3rd Stage('07~'12) : Development of DUPIC Fuel Bundle Manufacturing Technology

DUPIC Fuel Development Facility (DFDF)

A Long-term Plan for Development of Pyroprocess



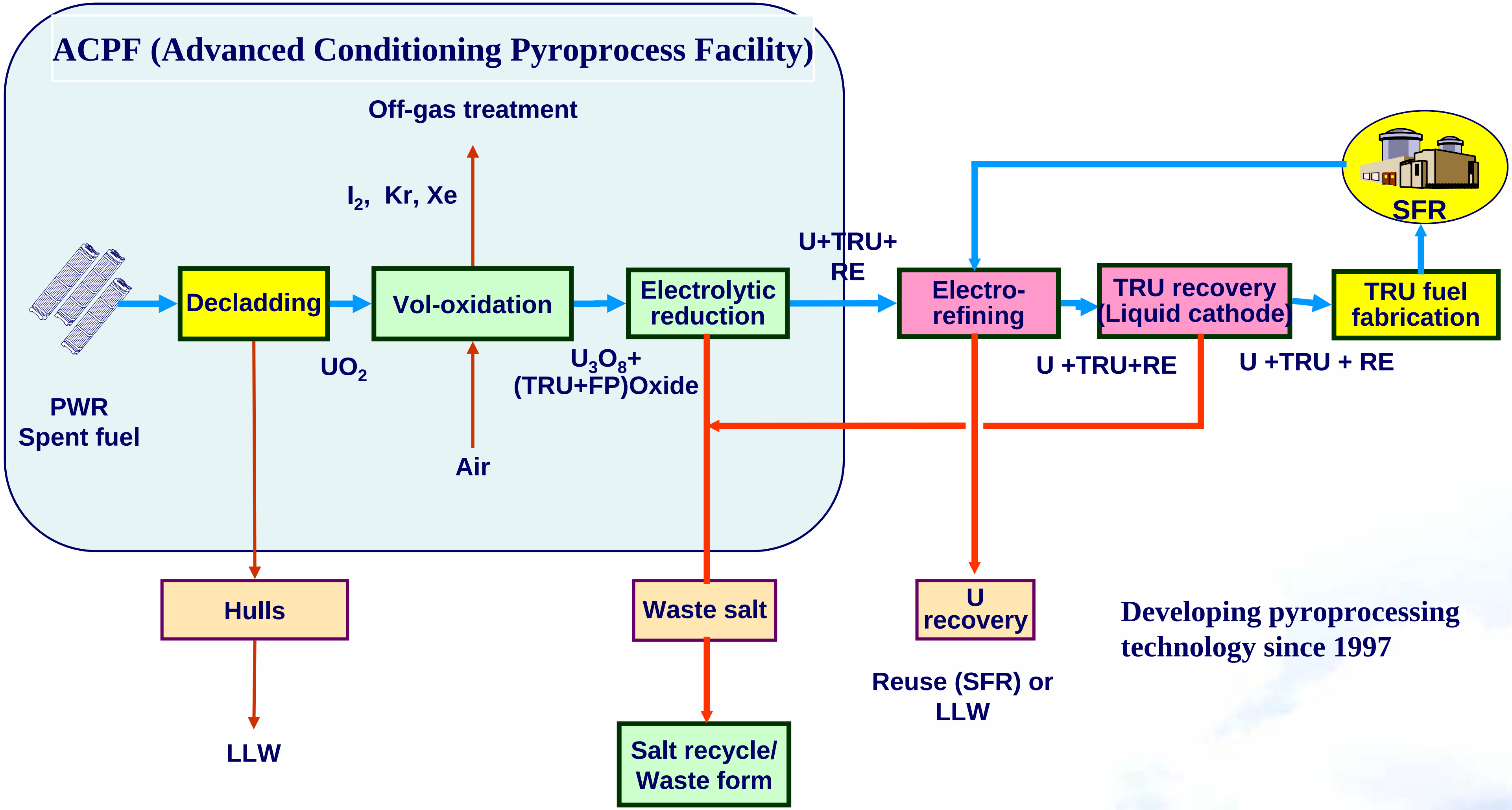
❖ ~ 2009: Lab. Scale [1 t HM/yr] : Innovative Technology Development [continuous type process and waste minimization]

❖ ~ 2011: Eng. scale MOCK-UP [10 t HM/yr]

❖ ~ 2016: Establishment of ESPF [10 t HM/yr]

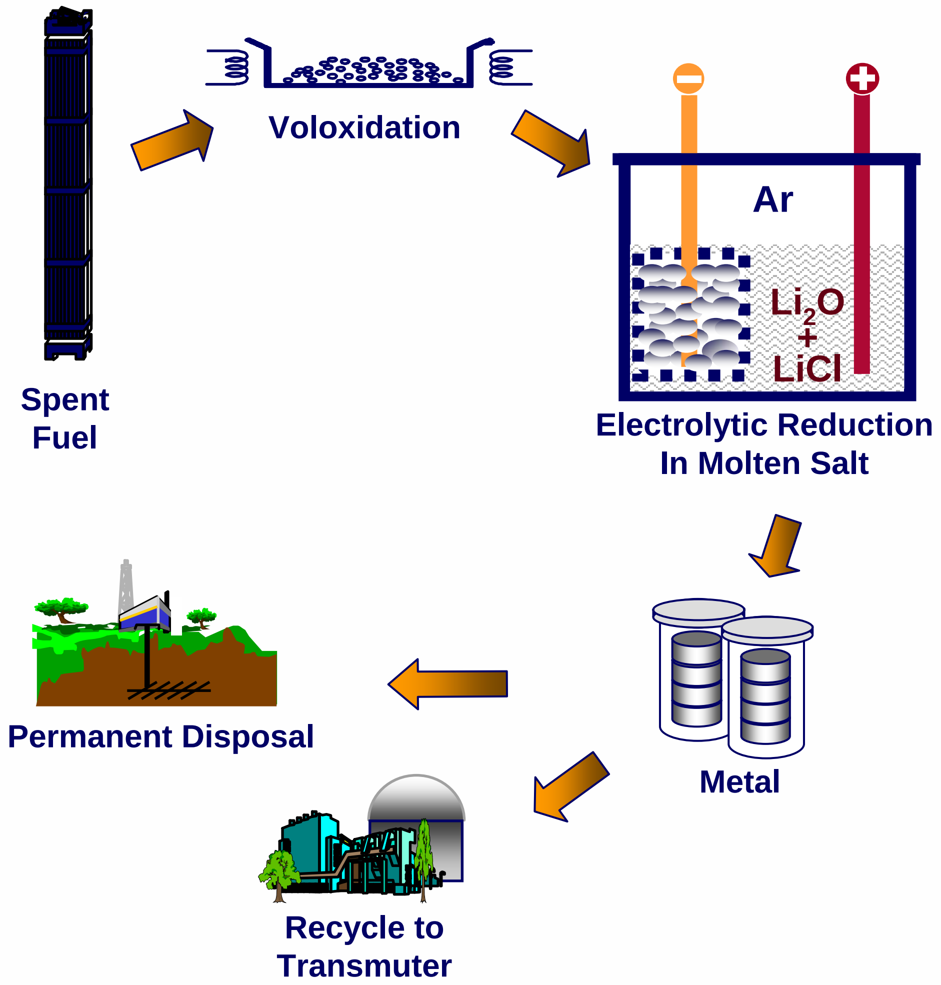
❖ ~ 2025: Establishment of Integrated Pyroprocess Facility [100 t HM/yr]

A Flow Diagram of Pyroprocess being Developed by KAERI



Developing pyroprocessing technology since 1997

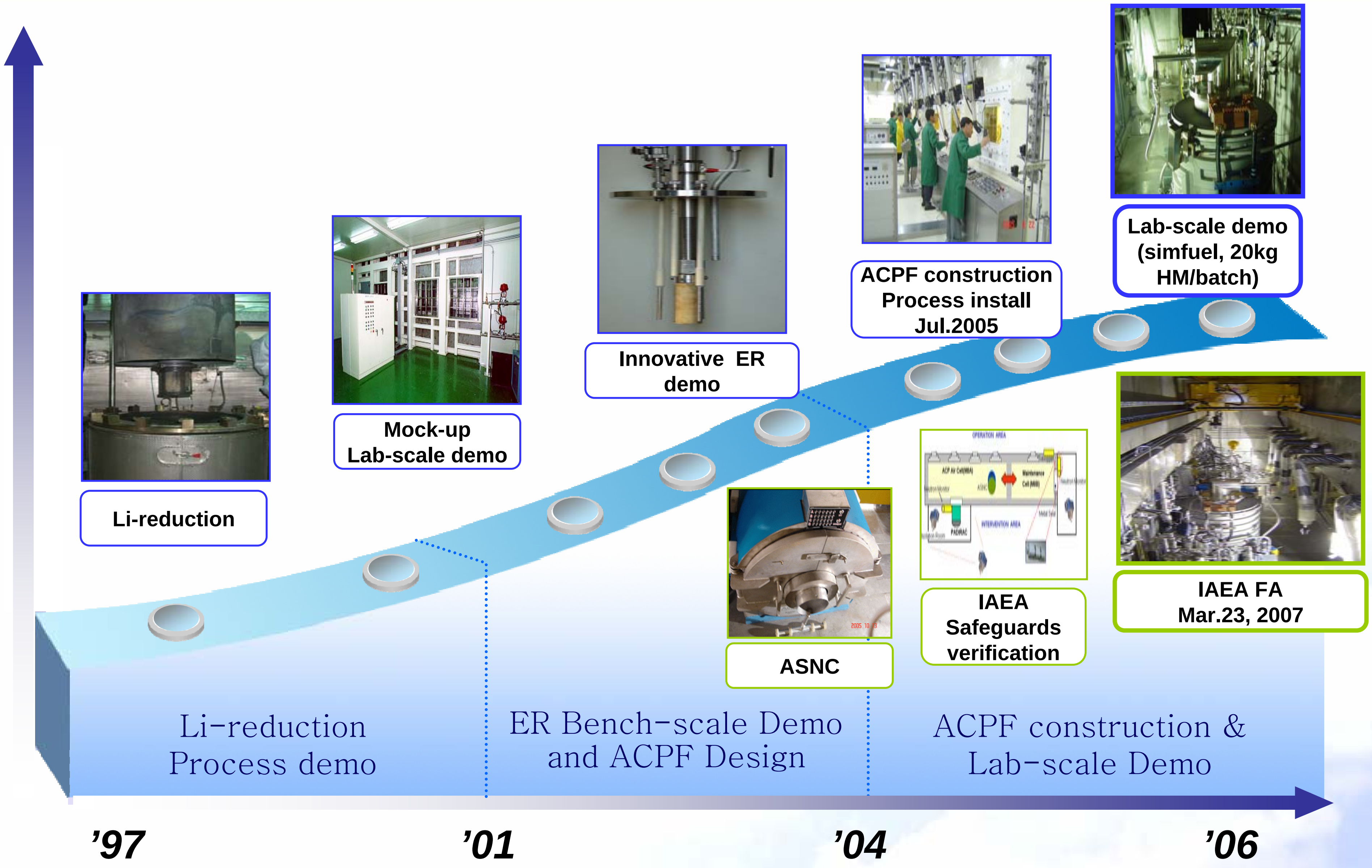
Introduction of ACP (Advanced spent fuel Conditioning Process)



- **What are the final products ?**
  - **Metal (U+TRU+ some FPs)**

- **What is the final destination?**
  - **Permanent disposal**
    - ✓ **Reduction of spent fuel heat power, volume and radioactivity**
  - **Recycling to GEN IV reactors**
    - ✓ **Direct link with TRU burning in SFR**

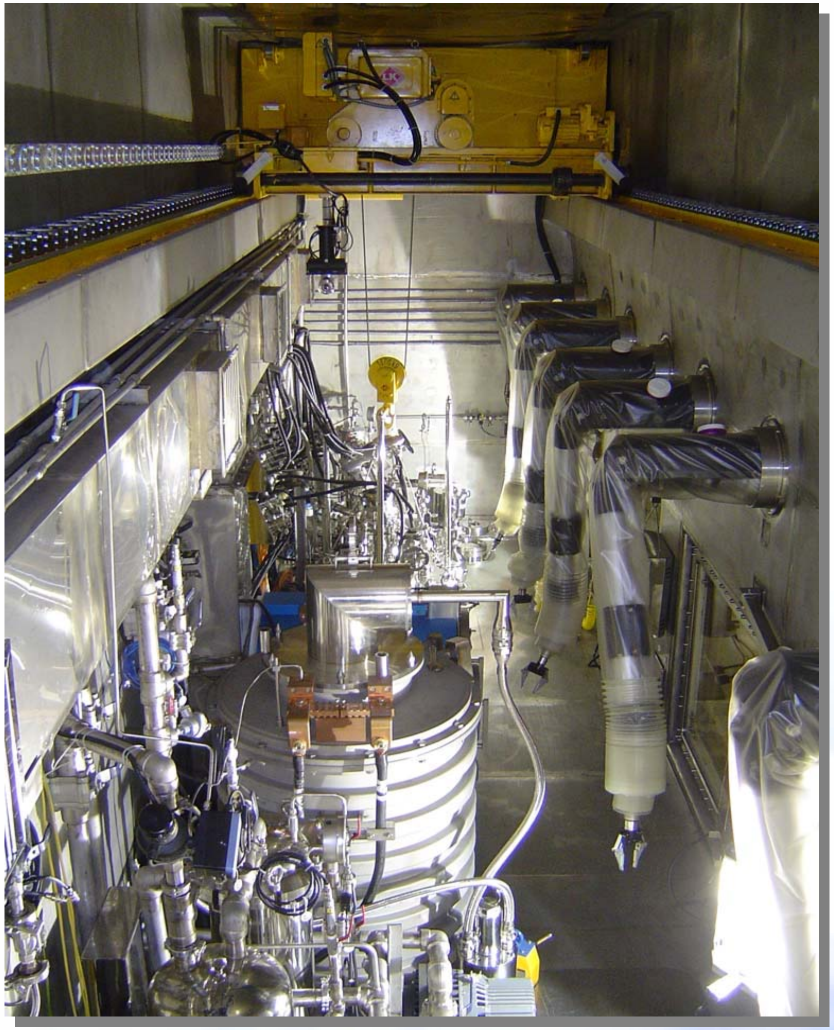
10 Year History of ACP Development



Lab-scale ACPF

- **20 kgHM/batch Demonstration Process**
  - **Remote Operation and Maintenance**
  - **Interface Systems between Process Steps**
  - **Performance Evaluation of Process Systems**

Working Area



Inside Process Hot Cell

History of Safeguards R&D at KAERI

KAERI Safeguards History

National Nuclear R&D Program Started in 1992

1st CNEPP ('97~'02) (Comprehensive Nuclear Energy Promotion Plan)

2nd CNEPP ('02~'06)

3rd CNEPP ('07~'11)

Fuel Cycle R&D

- S/G R&D General Front end fuel cycle ~'92
- DUPIC S/G Study '92~
- DFDF S/G Dev. ~'97
- DFDF S/G Install & Implementation '97~
- ACP S/G Study & Dev. '02~
- ACPF S/G Install & Imp. '05~
- Pyroprocess S/G Study '07~

Control

- Dept. of S/G ~'94
- KAERI Facility S/G Control
- **TCNC** (Technology Center for Nuclear Control) at KAERI '94~

Setting up National Nuclear Control System

Independent Organization

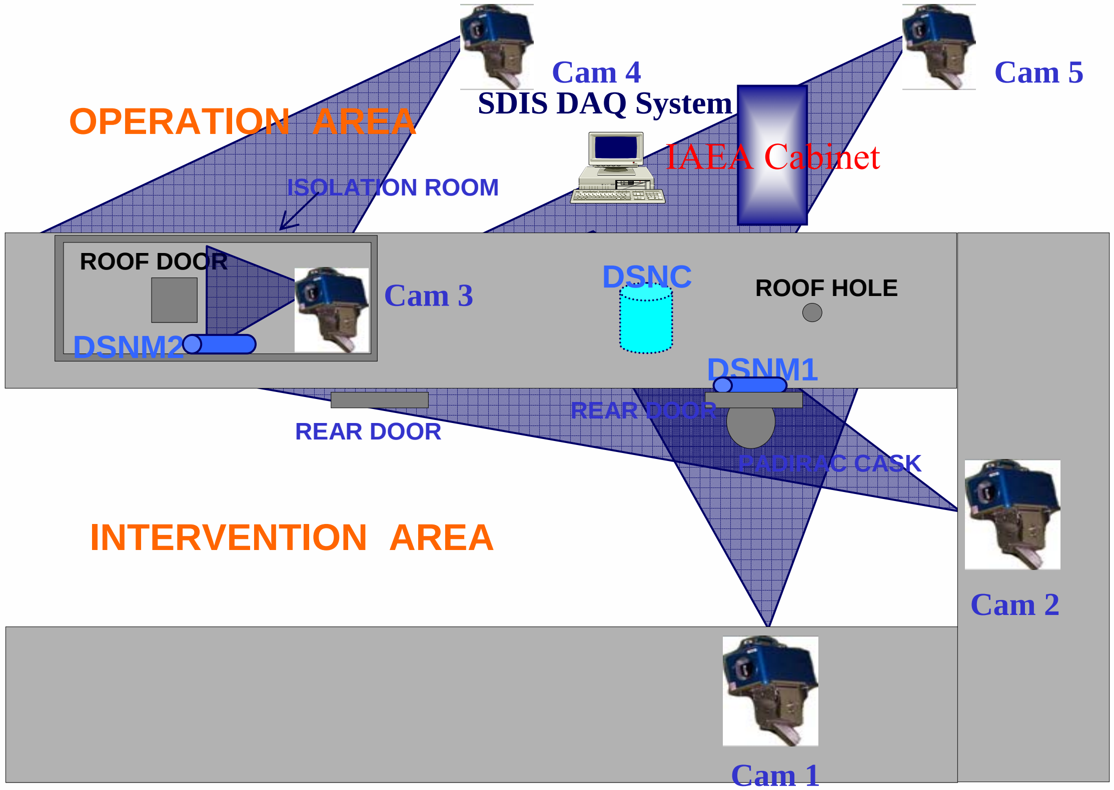
- **NNCA** (National Nuclear Management & Control Agency) '04~
- **KINAC** (Korea Institute of Nucear Nonproliferation and Control) '06~

'90 '95 '00 '05

KAERI

DUPIC Safeguards

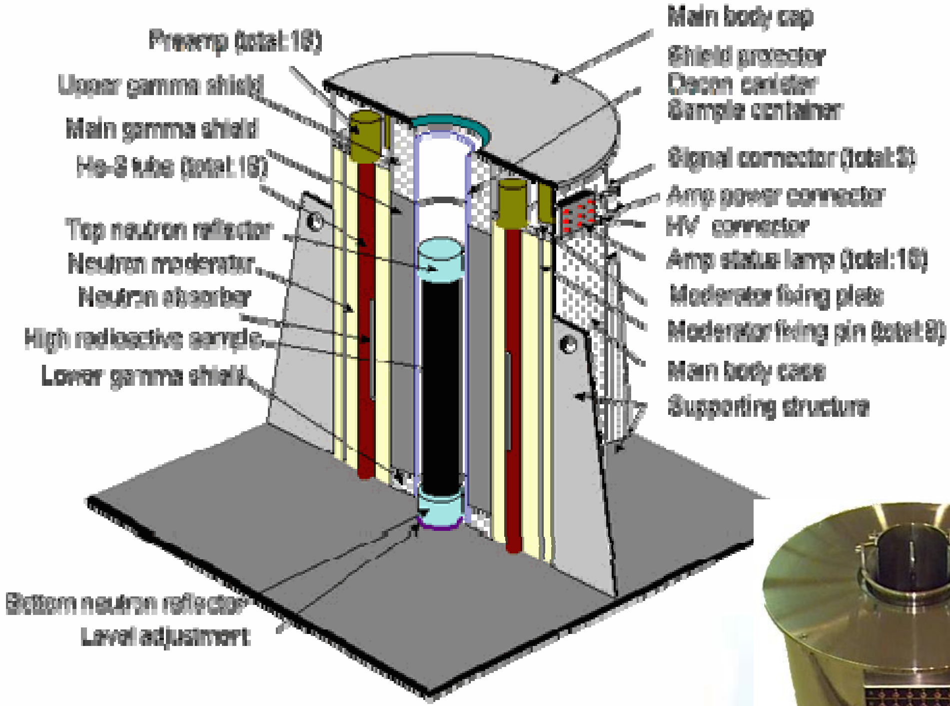
DUPIC S/G System Installation



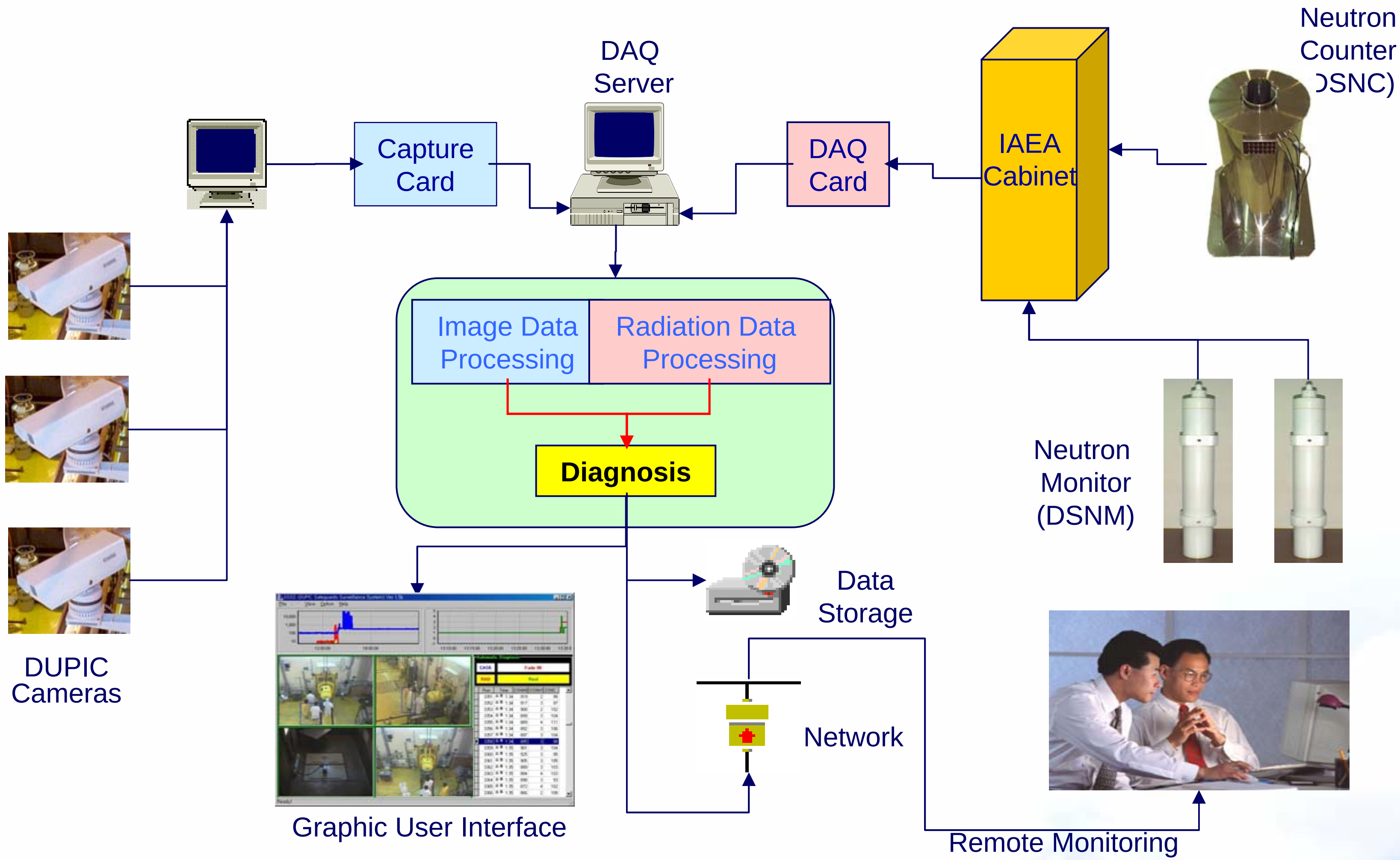
- **Phase I : Feasibility Study**
  - **Optimum Fabrication Process**
  - **Safeguardability**
- **Phase II : DUPIC Fuel Design & Fabrication**
  - **Safeguards Technology Development**
  - **Safeguards Implementation**
- **Phase III : Demo. of Fuel Performance**
  - **Upgrade of Safeguards System**

DUPIC Material Measurement

- **DSNC**
  - **DUPIC Safeguards Neutron Counter**
  - **Well-type neutron coincidence counter**
  - **All types of DUPIC process material**
  - **Remotely measurable in hot cell**
  - **SNM Analysis**
    - ✓ **Pu, U contents from measured Cm-244 contents**



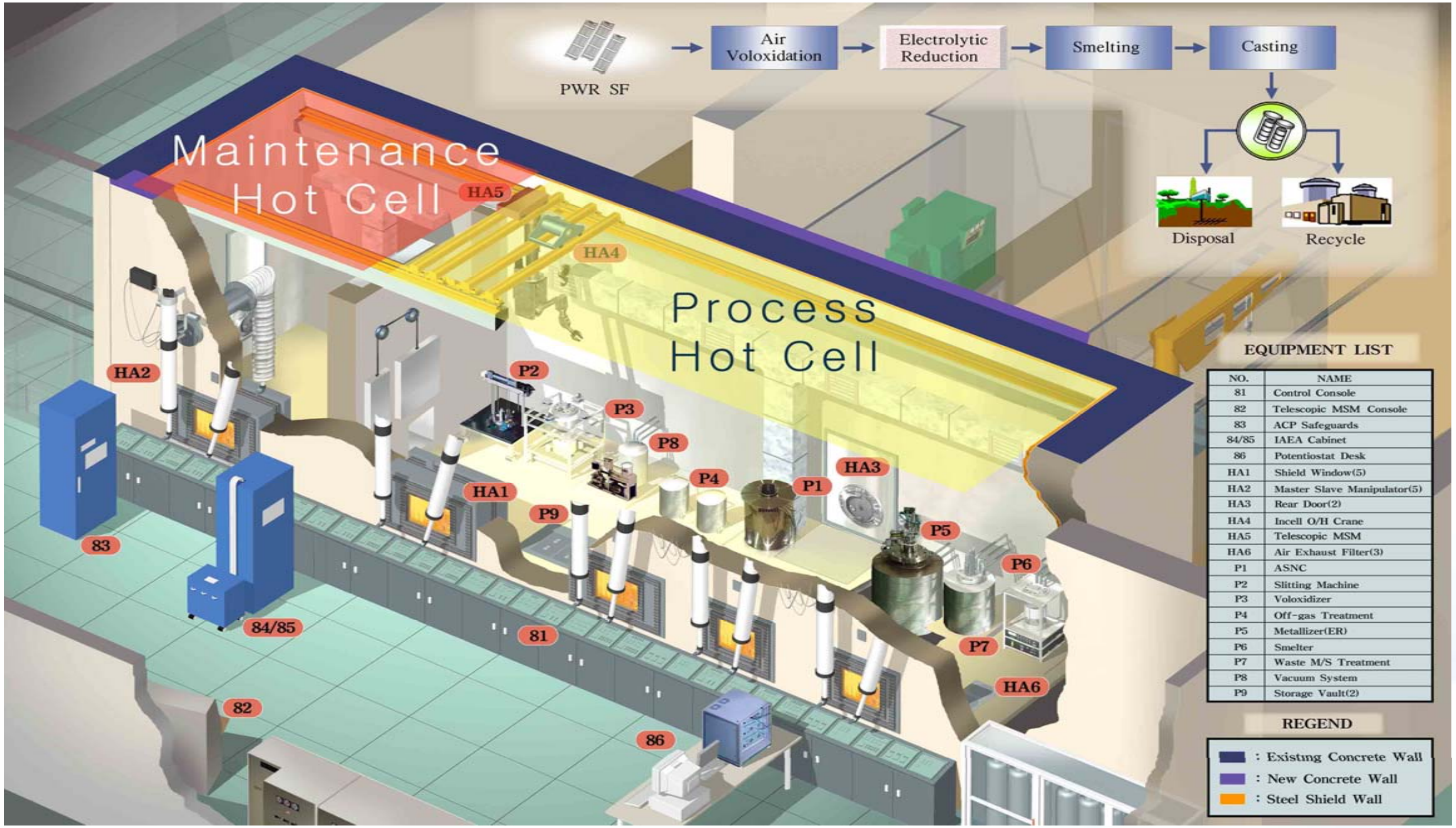
DUPIC Intelligent Surveillance System



DISS User Interface

ACPF Safeguards System

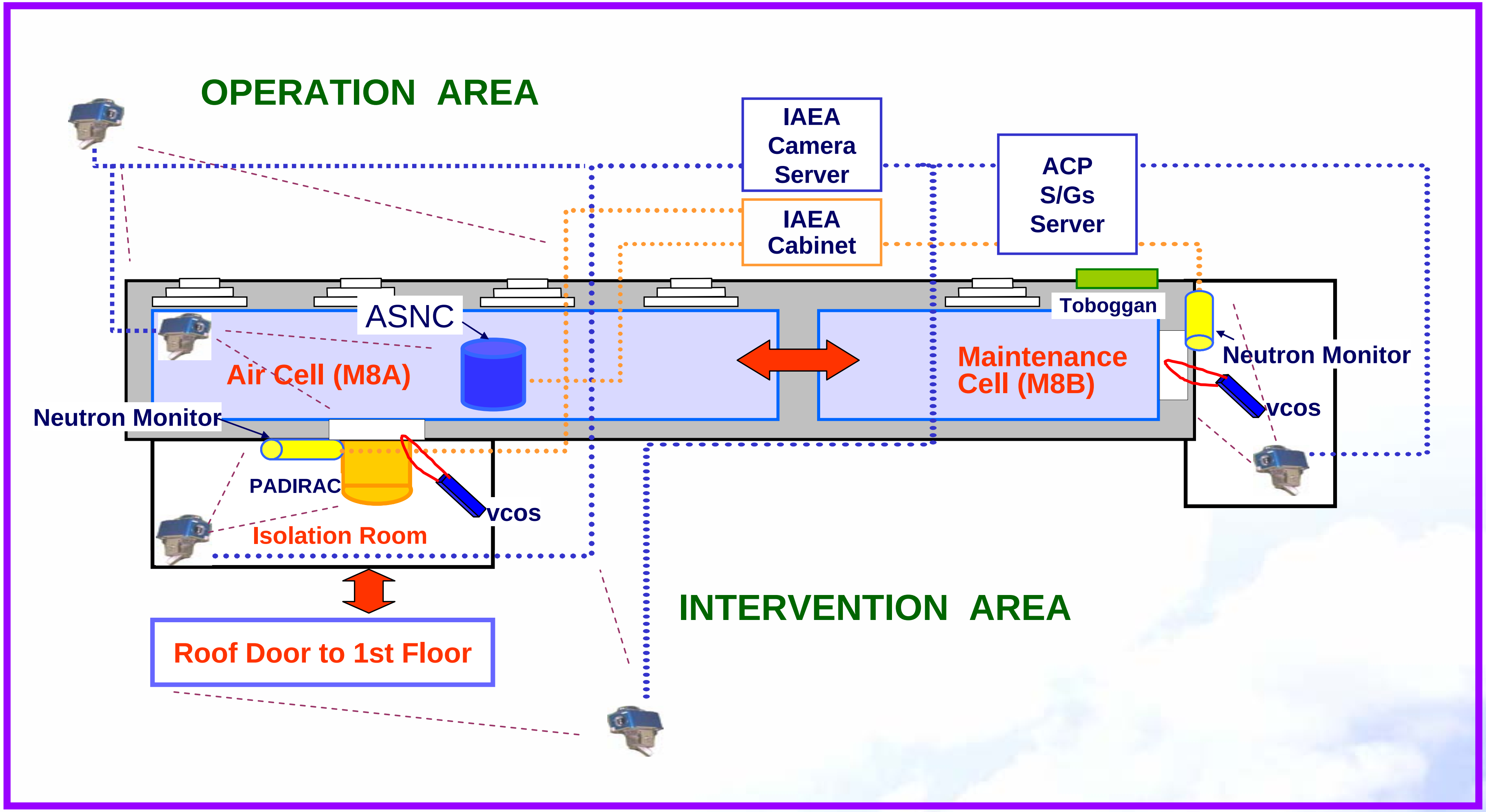
ACPF



- **Input material of the hot cell is spent fuel rodcuts**
- **Anticipated throughput: 100 kgU of PWR SF to be processed in several batches**

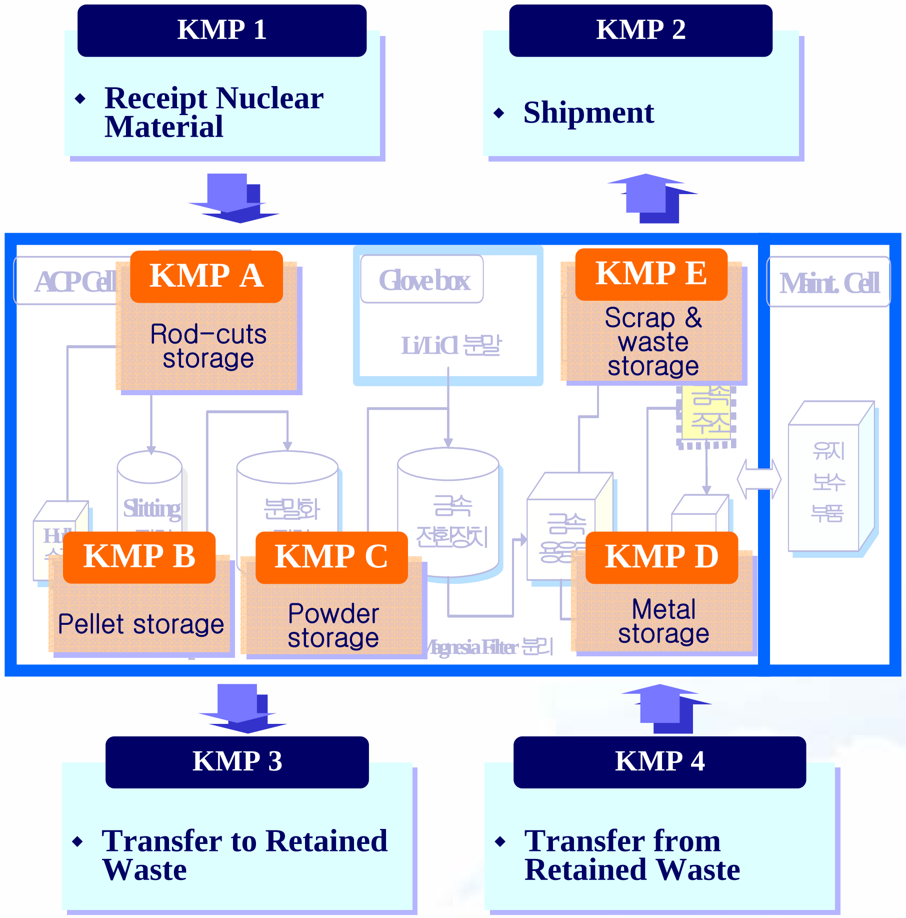
ACPF Safeguards System

❑ **cooperation with LANL and IAEA**

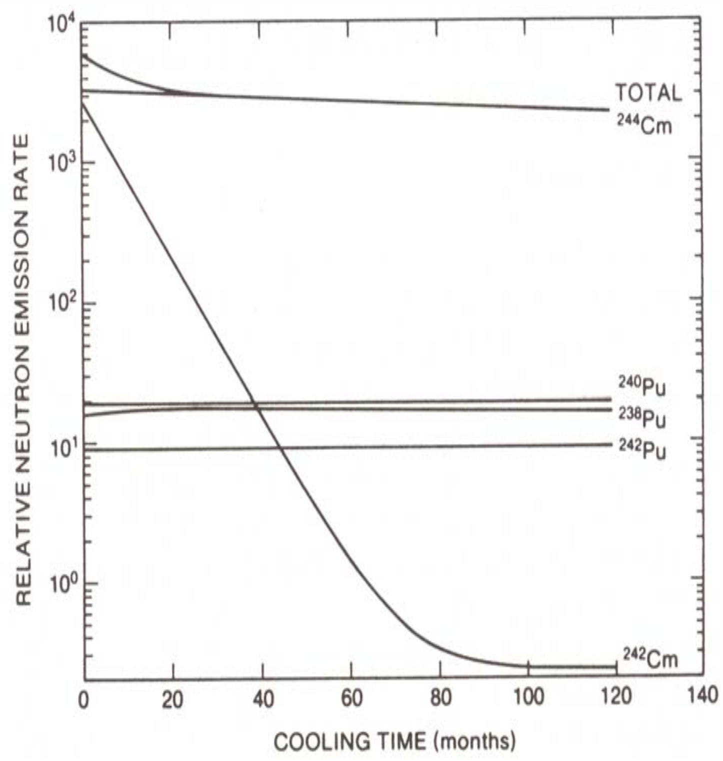


Safeguards Implementation

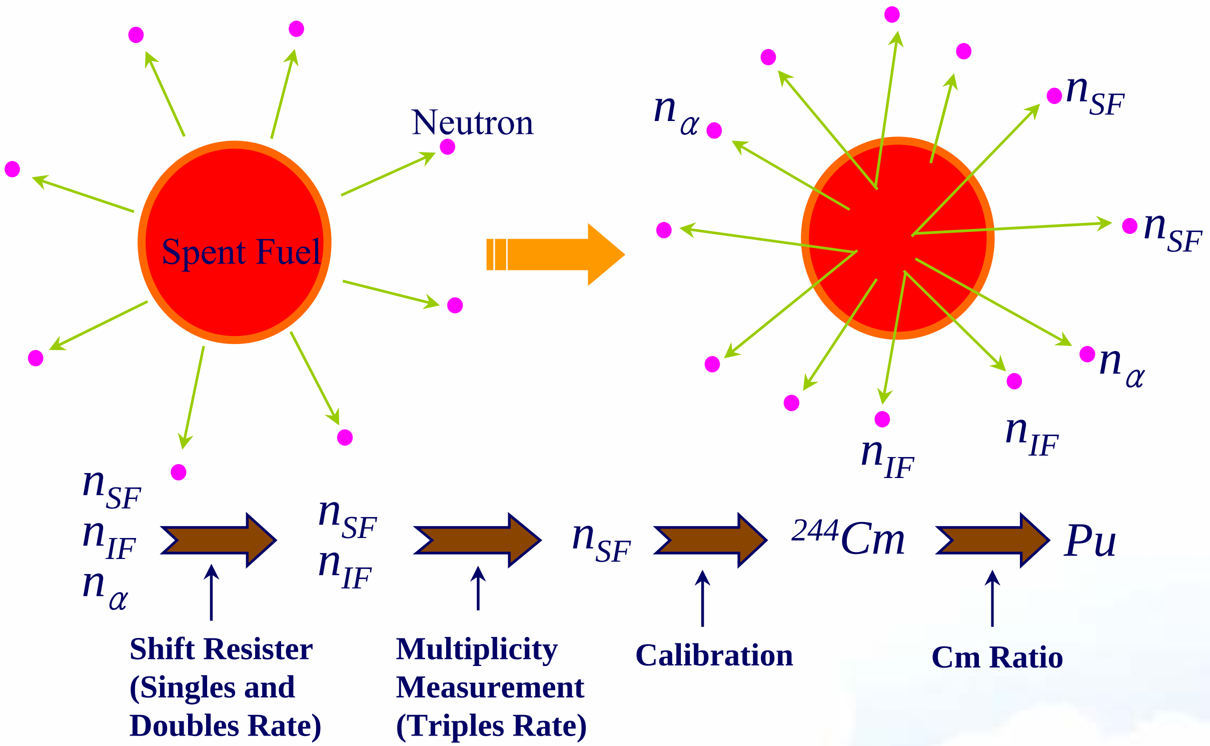
- **History of IAEA Safeguards in ACPF**
  - **Submission of DIQ**
    - ✓ Preliminary DIQ : Dec. 8, 2004
    - ✓ Completed DIQ : Mar. 23, 2005
    - ✓ Revised DIQ : Jul. 10, 2006 (2nd Revision)
  - **IAEA Facility Attachment**
    - ✓ The PIV/DIV and ES were performed on Aug. 1, 2006.
    - ✓ A working group meeting took place in Vienna in June 2006 to discuss the implementation of safeguards at ACPF and the FA contents.
    - ✓ The FA has been completed and is in force as of Mar. 23, 2007.
    - ✓ ACPF is classified as an "other" R&D facility (H6)
    - ✓ The facility constitutes one Material balance Area (Identification Code : KOV1), 4 material flow KMPs and 5 physical inventory KMPs.



Principle of Nuclear Material Accounting by Neutron Measurement



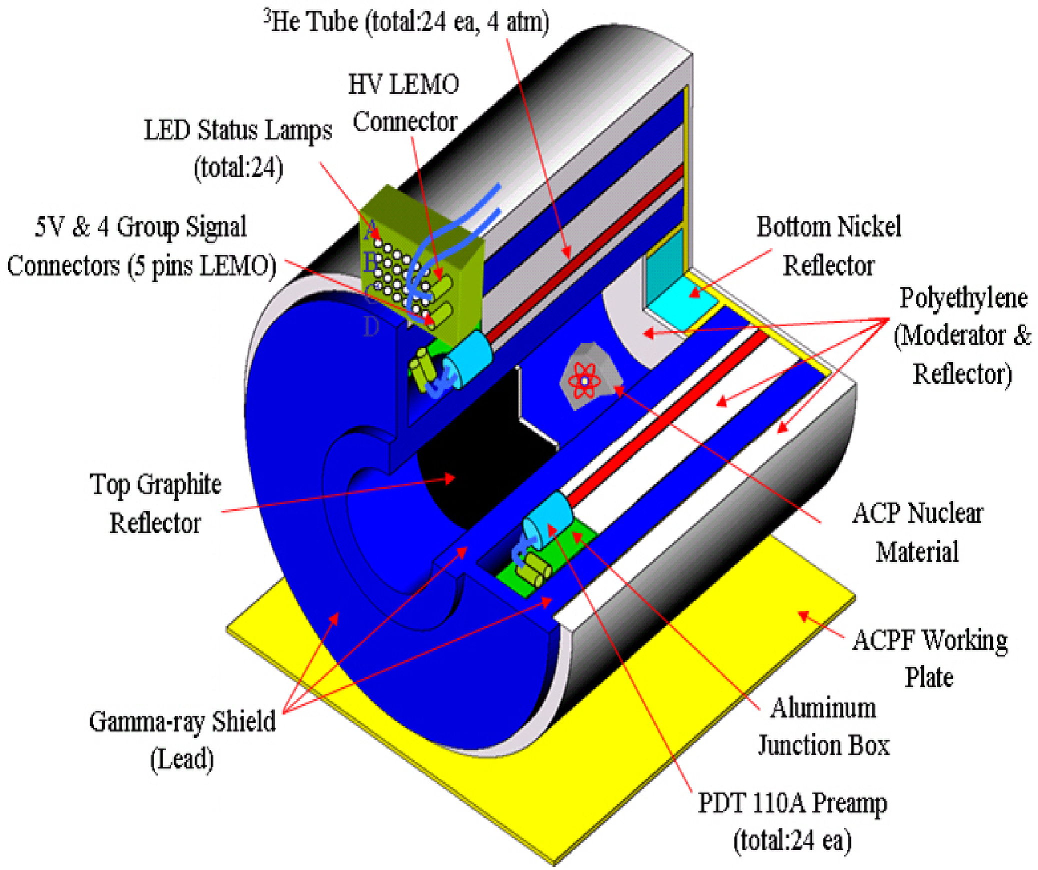
The five principal neutron sources in a PWR fuel assembly with an exposure of 31.5 GWd/tU



- n_{SF}: spontaneous fission neutron
- n_{IF}: induced fission neutron
- n_{α}: (α,n) neutron

Neutron Counter (ASNC)

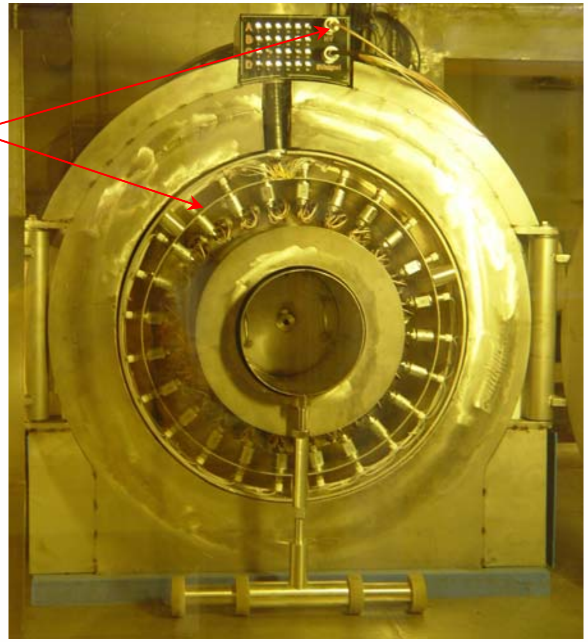
- **ACP Safeguards Neutron Counter (ASNC) installed in 2005**
  - **Passive neutron coincidence counter**
  - **Gamma-ray shield: Lead 6 cm (Inner/Outer)**
  - **Neutron detection efficiency: 21 %**
  - **Sample cavity: Φ21 cm × 33 cm**
  - **Horizontal geometry**
  - **Cold tests with Cf-252 sources were completed**
  - **Full remote maintenance capabilities**
  - **Hot tests for verification of the ASNC with PWR spent fuel rod-cuts were performed**



ASNC Installation

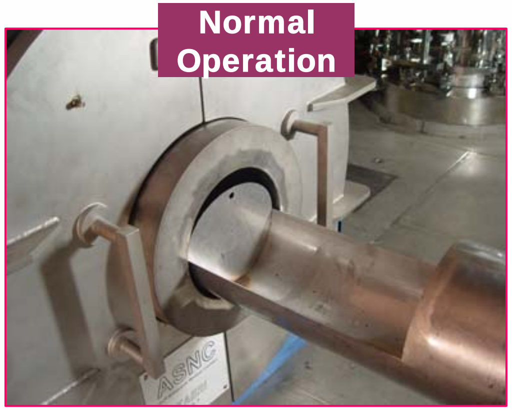
Front view of ASNC (Normal operation)

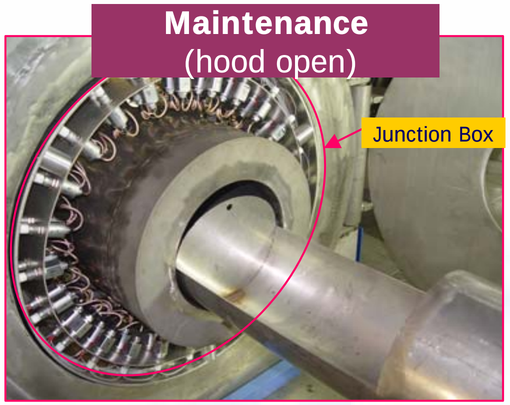
LEMO Connectors

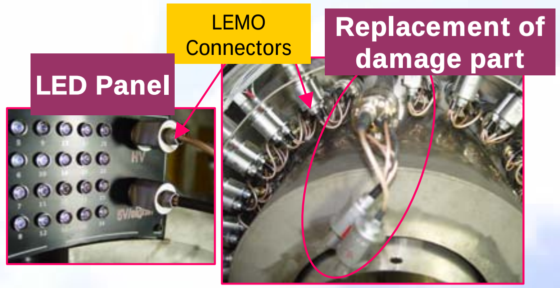


Front view of ASNC - Open hood (Maintenance)

ASNC installed in the ACPF hot cell





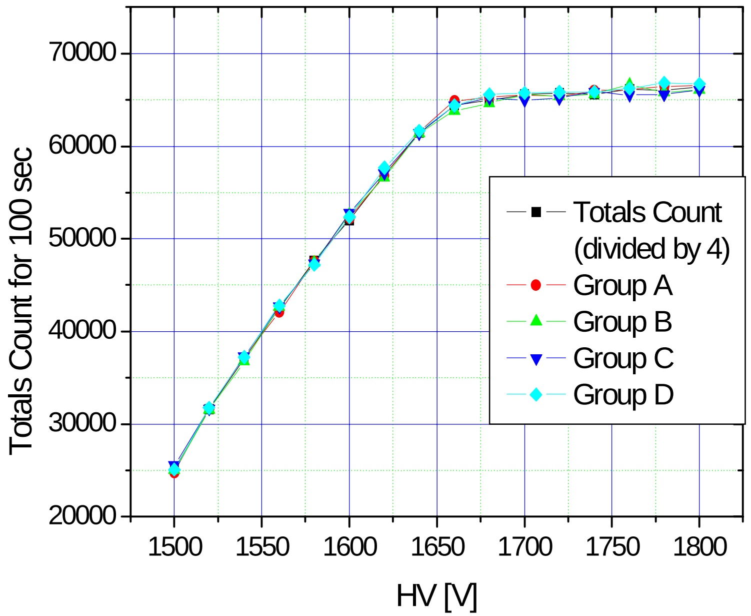


LED Panel, Junction Box, LEMO con-/disconnection of the ASNC

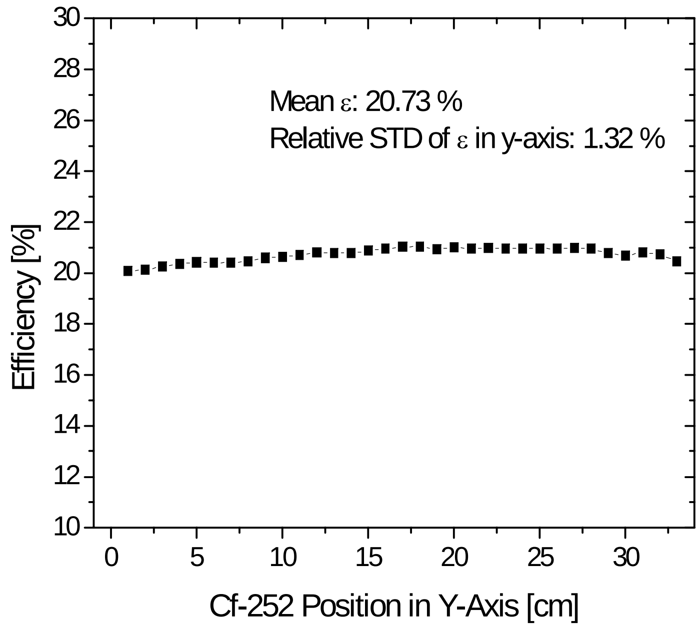
KAERI

Performance of ASNC

- Confirmed a *flat spatial response* ($\sigma < 2\%$) and *reasonable detection efficiency* ($\varepsilon = 21\%$) of the ASNC (A test with ^{252}Cf neutron source)



Gain matching curves for 4 groups

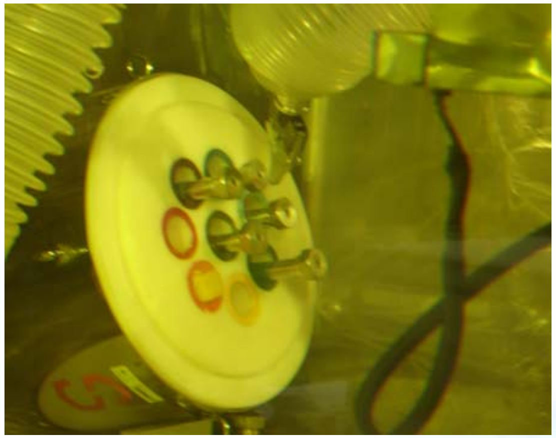


Y-axis efficiency profile

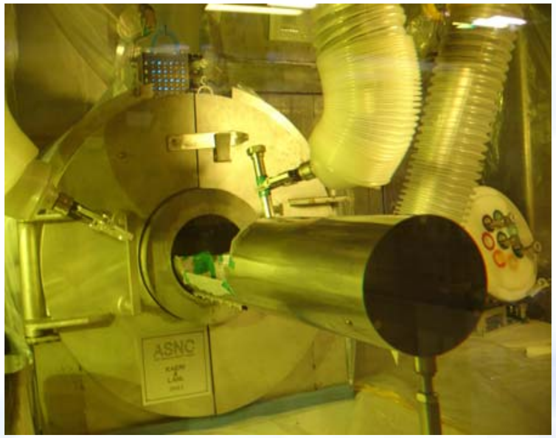
ASNC Hot Test

- The hot test verification of ASNC using the spent fuel rod-cuts was performed with cooperation between KAERI and LANL in Aug., 2007.
- IAEA expert participated in the test as an observer.
- Test objectives
  - Calibration of the ASNC for the real hot materials including Cm-244
  - Gamma pileup check and HV setting
- Spent Fuel Specifications
  - Total 8 rod-cut samples, 2 years cooling
  - PWR SF 3 rod-cuts 1 cm long (52 GWD/MTU)
  - PWR SF 5 rod-cuts 25 cm long from J502 Assembly C16 rod (60 GWD/MTU)

Drs. Menlove and Belian at the ACPF



Spent fuel rod cuts stored in a PE cask



ASNC hot test with spent fuel rod cuts

Spent Fuel Rod-cuts Spec.

❑ Burnup History of J502 Assembly, Young-Kwang Unit 4

Young-Kwang Unit 4	Rod Array 16x16	EFPD (Days)	Assembly Cycle Burnup (GWD/MTU)
Irradiated History	Cycle 6	469	19.799
	Cycle 7	490	20.628
	Cycle 8	465	7.362
Discharged Date			2005.08.25
Cooling Time at 2007.08.04 (Days)			709

Avg. Burnup of J502 Assembly	47.789	GWD/MTU
Enrichment	4.49	w/o
Cladding	Zirlo	
U/rod	1.831	kg
Rod	J502-R13	J502-C16
Avg. Burnup (GWD/MTU)	48.973	55.362

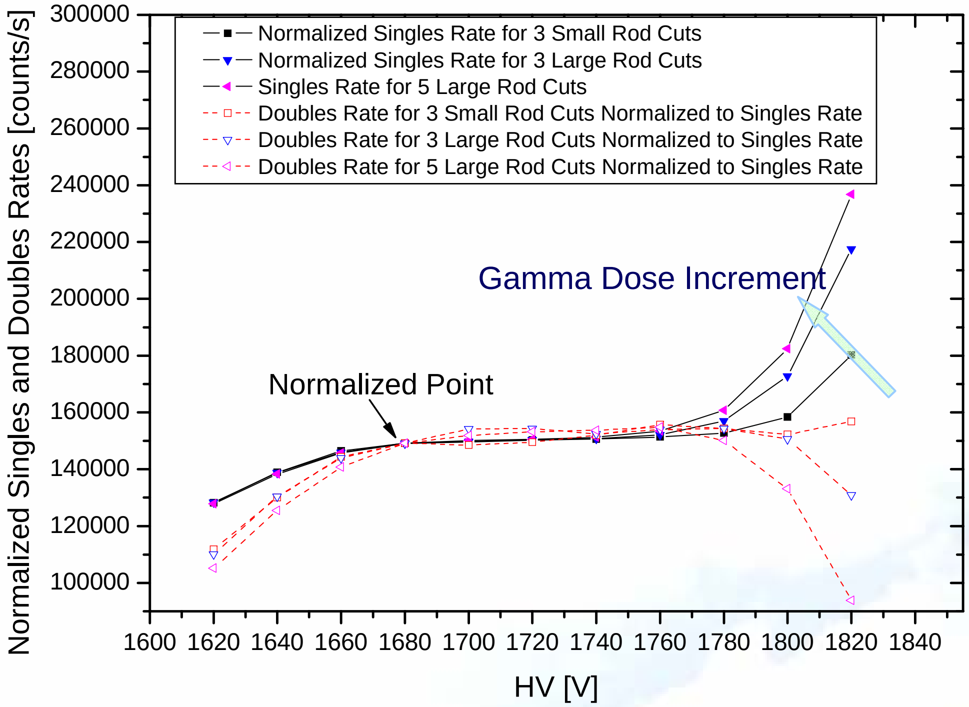
❑ ORIGEN-ARP and MCNPX Simulation Results

Id	Average Burnup (GWD/MTU)	Length of Rod-Cuts	Expected Doubles Rate (#/s)	Expected Singles Rate (#/s)	Cm-244 SF Neutron Contribution (%)	Total Fissile Content (w/o)	U-235/Cm Ratio	Pu/Cm Ratio	Activity (Ci)	α	Dose Rate (R/h) @ He-3 with 6cm Lead	Cm-244 (mg)	U (g)	U-235 (g)	Pu (g)
C16-7	59.907	25 cm	8,486	65,427	97%	1.44%	25	52	264	0.013	1.38	26.53	111.71	0.72	1.50
R13-4	53.465	25 cm	5,184	40,101	97%	1.61%	54	82	234	0.015	1.13	16.26	112.82	0.95	1.44
R13-7	53.277	25 cm	5,083	39,320	97%	1.62%	55	83	233	0.015	1.11	15.94	112.40	0.95	1.43
R13-9	53.013	25 cm	4,976	38,490	97%	1.63%	57	84	232	0.015	1.10	15.61	112.52	0.96	1.43
R13-13	53.056	25 cm	4,990	38,599	97%	1.63%	57	84	232	0.015	1.11	15.65	112.44	0.96	1.43
C16-12	58.121	1 cm	299	2,309	97%	1.49%	30	58	10	0.013	0.05	0.94	4.46	0.03	0.06
C16-10	58.787	1 cm	312	2,407	97%	1.47%	29	56	10	0.013	0.05	0.98	4.46	0.03	0.06
R13-10	49.517	1 cm	146	1,129	97%	1.74%	89	112	9	0.017	0.05	0.46	4.51	0.04	0.06
Total			29,476	227,781							6.00	92.37	575.32	4.64	7.39

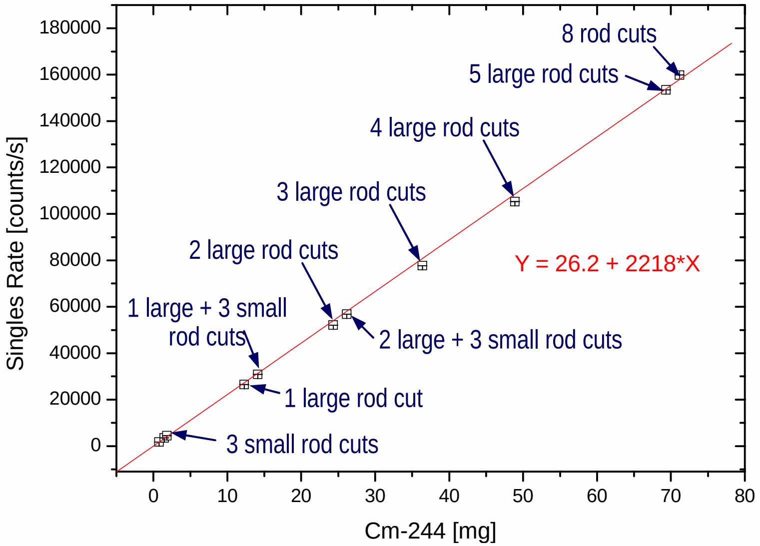
KAERI

ASNC Hot Test Results (1)

- ❑ Gamma dose rate to He-3 tubes by SFS
  - 4.6 R/h from all the rodcuts
  - 20 times higher than that from the ACP reference SF of 35 GWD/MTU and 21 yrs cooling
- ❑ Setup of operating HV
  - 1,680 volt was determined for the operating HV of ASNC
  - This operating HV is well below the gamma pileup region

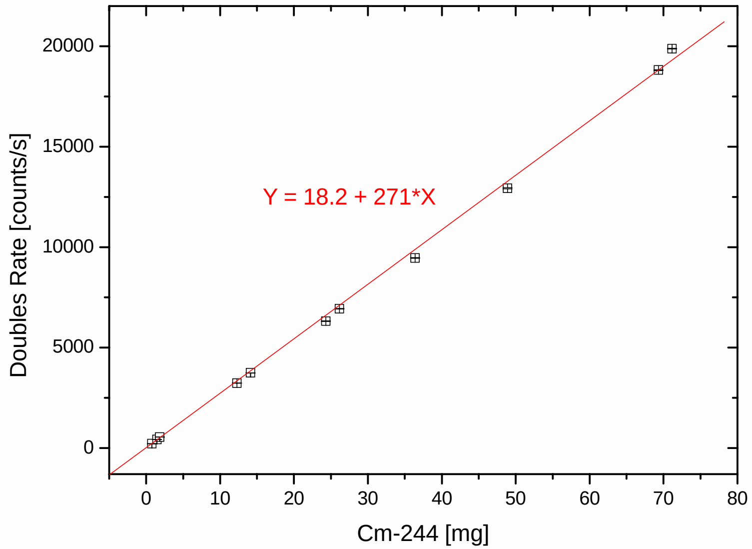


ASNC Hot Test Results (2)

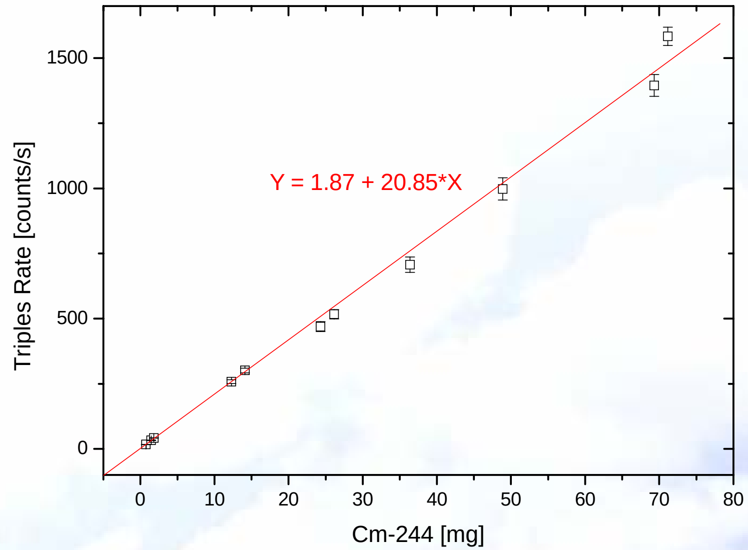


Measured Singles rate with the declared mass of Cm-244 (from ORIGEN-S)

- **Well linear behavior of Singles, Doubles, and Triples rates with the mass of Cm-244.**
- **"The ASNC is one of the most advanced neutron counter with a capability of Triples rate measurement for the spent fuel." (LANL's estimation)**
- **Based on performance test, it seems that NDA system is reliable enough to be used for the measurement of ACPF process materials.**



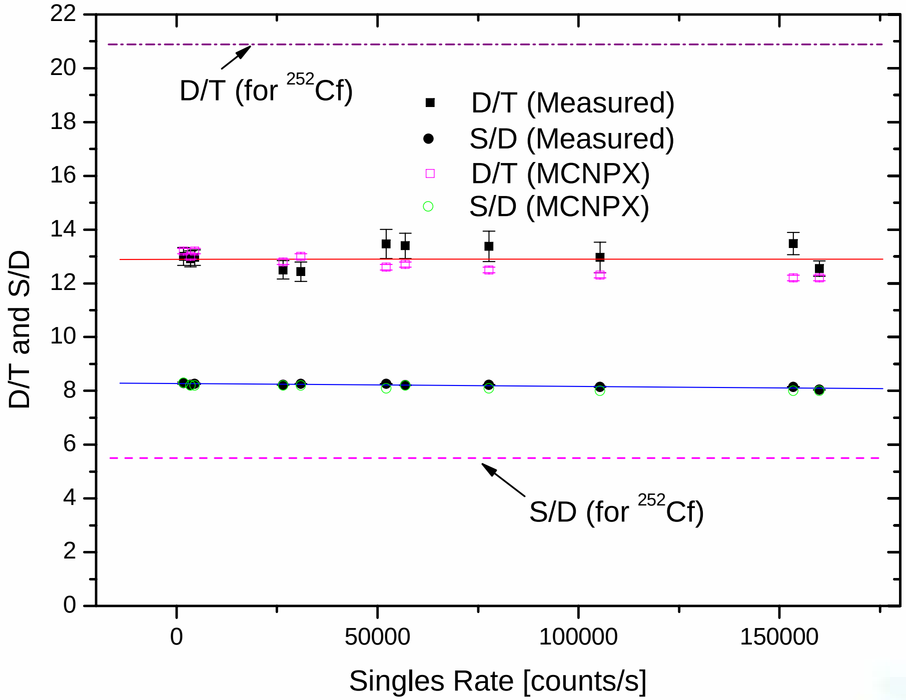
Measured Doubles rate with the declared mass of Cm-244 (from ORIGEN-S)



Measured Triples rate with the declared mass of Cm-244 (from ORIGEN-S)

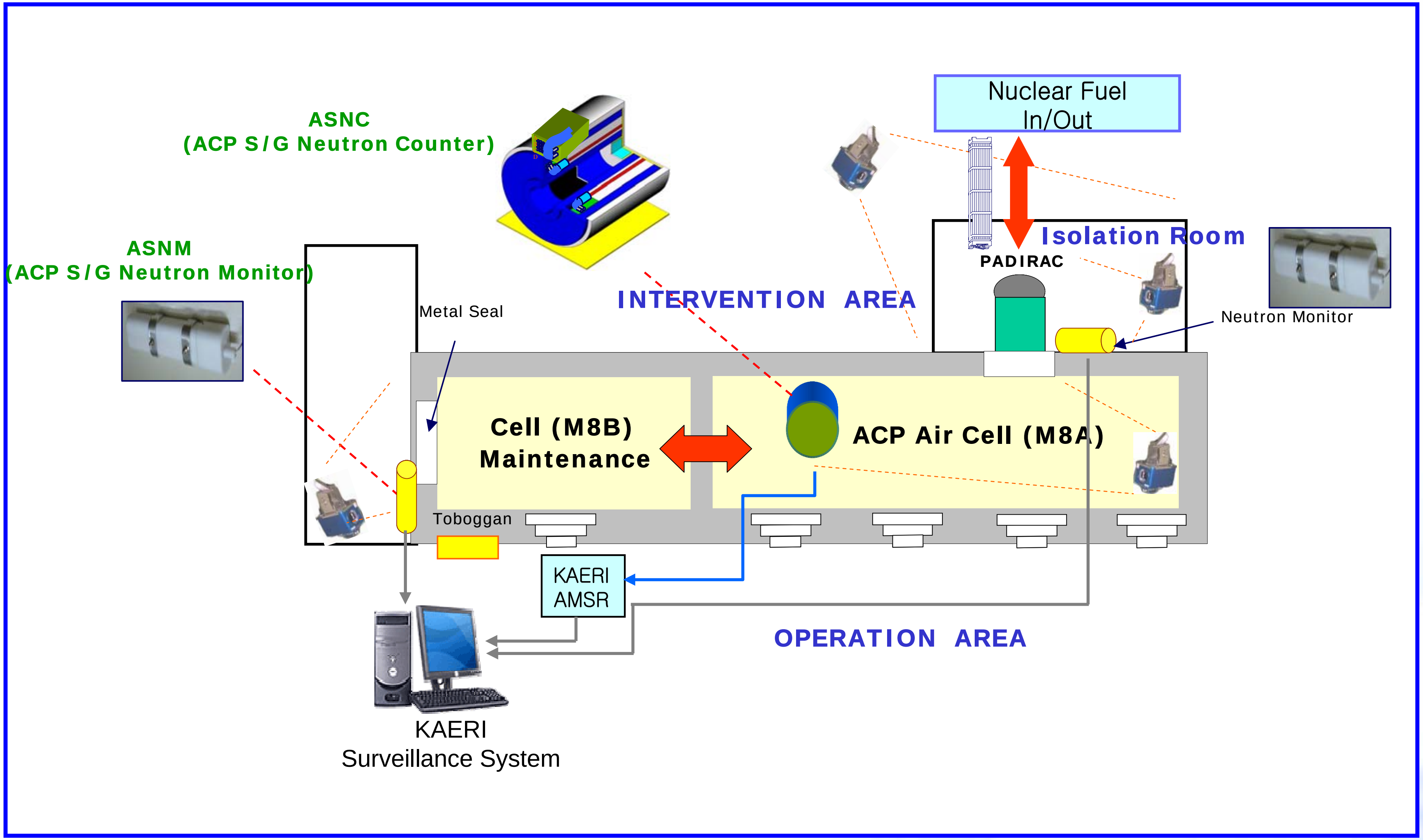
Singles/Doubles and Doubles/Triples Ratios

- Application to IAEA Authentication and Process Monitoring
  - Different ratio values for every neutron counter
  - Good Triples rate measurement results of ASNC for spent fuel (No former example)
  - S/D and D/T ratios are available for IAEA authentication and process monitoring

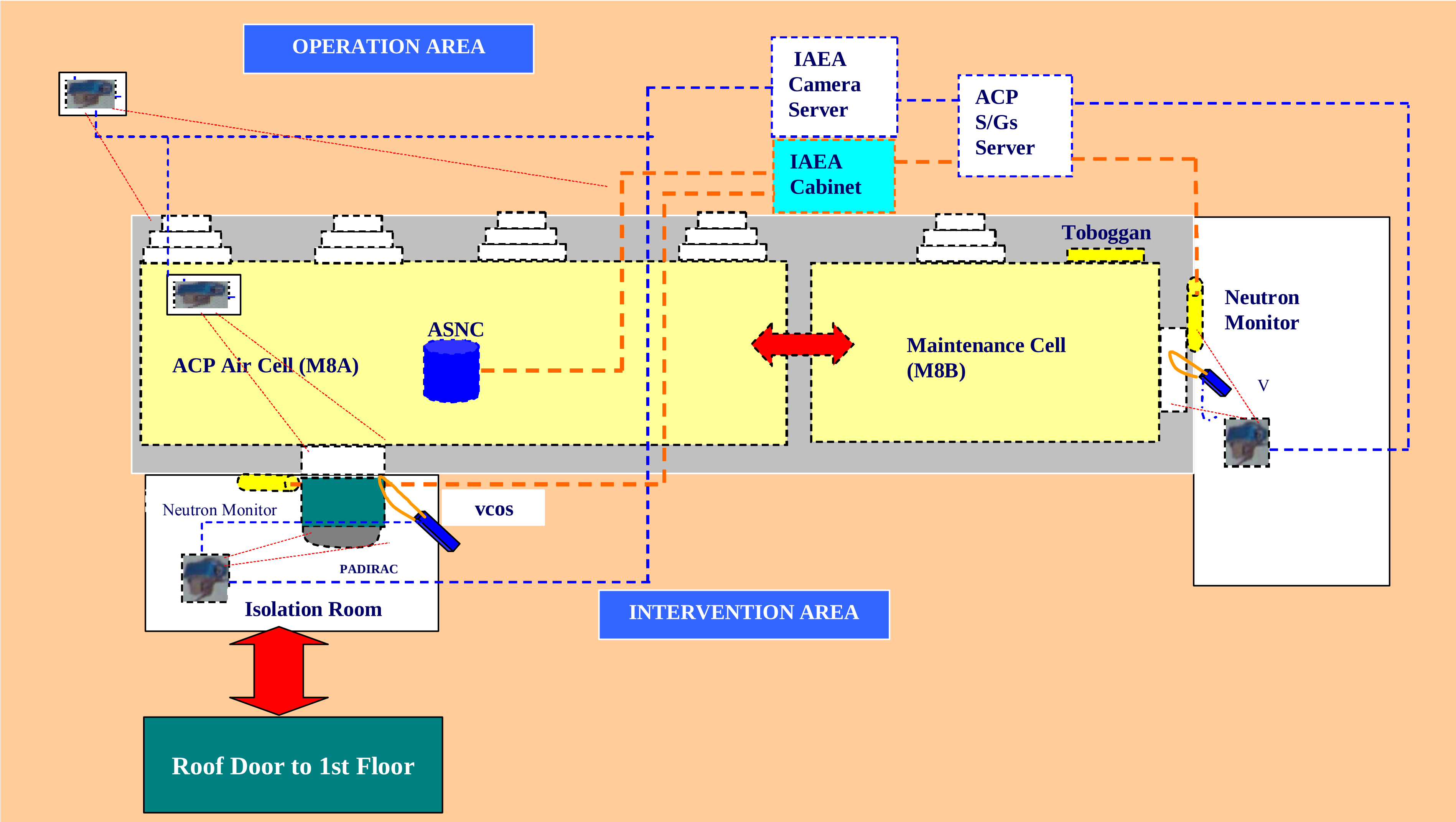


D/T and S/D ratios vs. the singles rate of the ASNC for the spent fuel rod-cuts and a ^{252}Cf neutron source

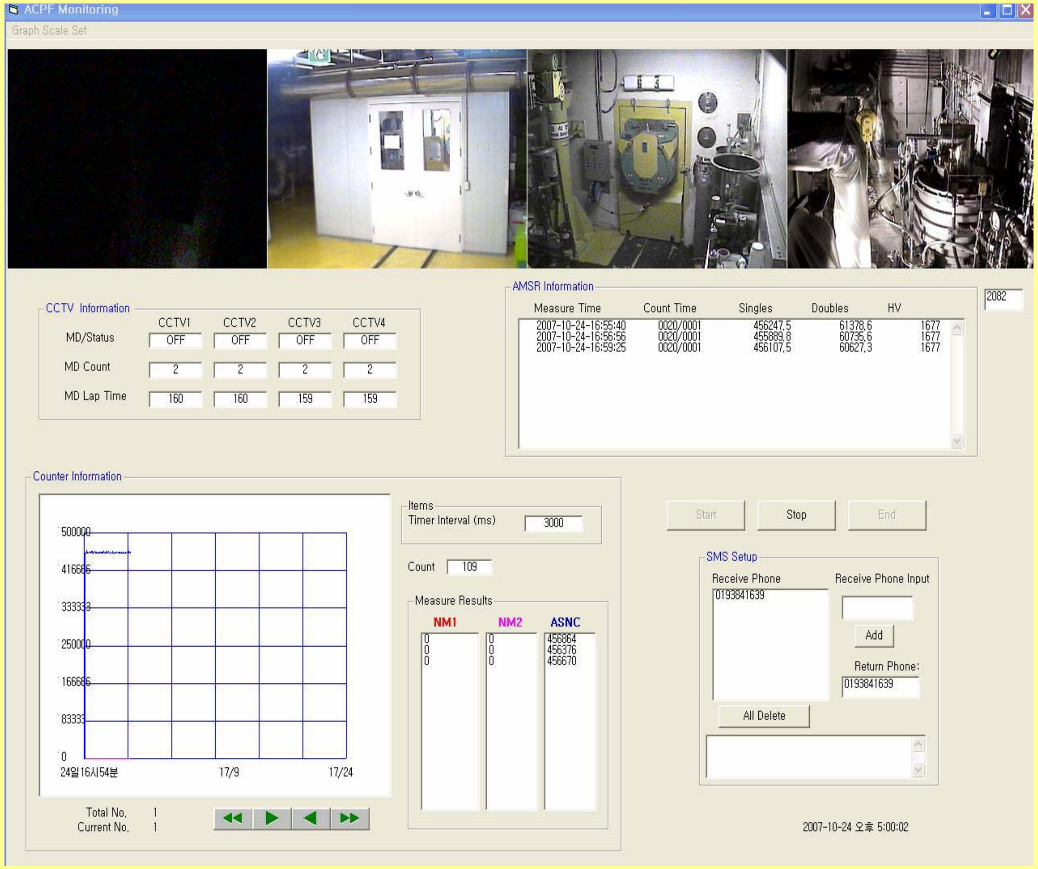
KAERI's Surveillance System

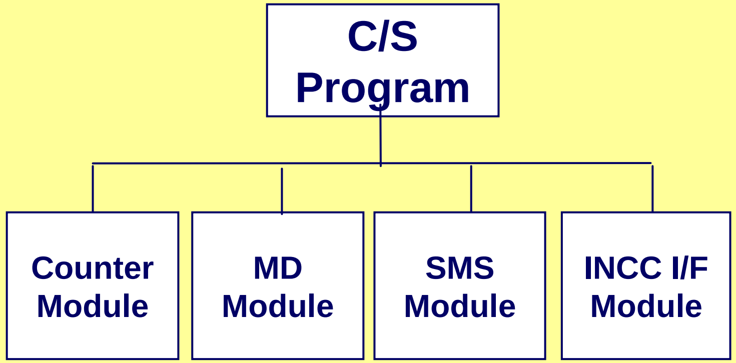


C/S Plan during Hot Test



Advanced Monitoring System



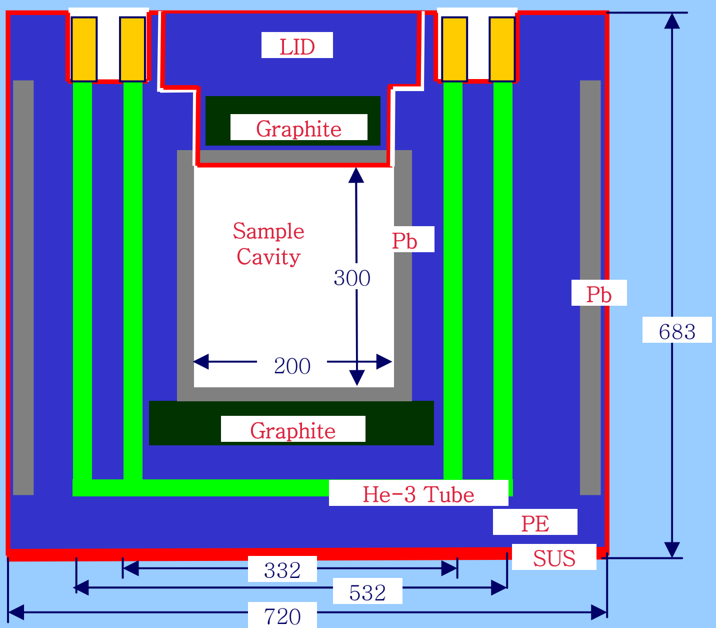


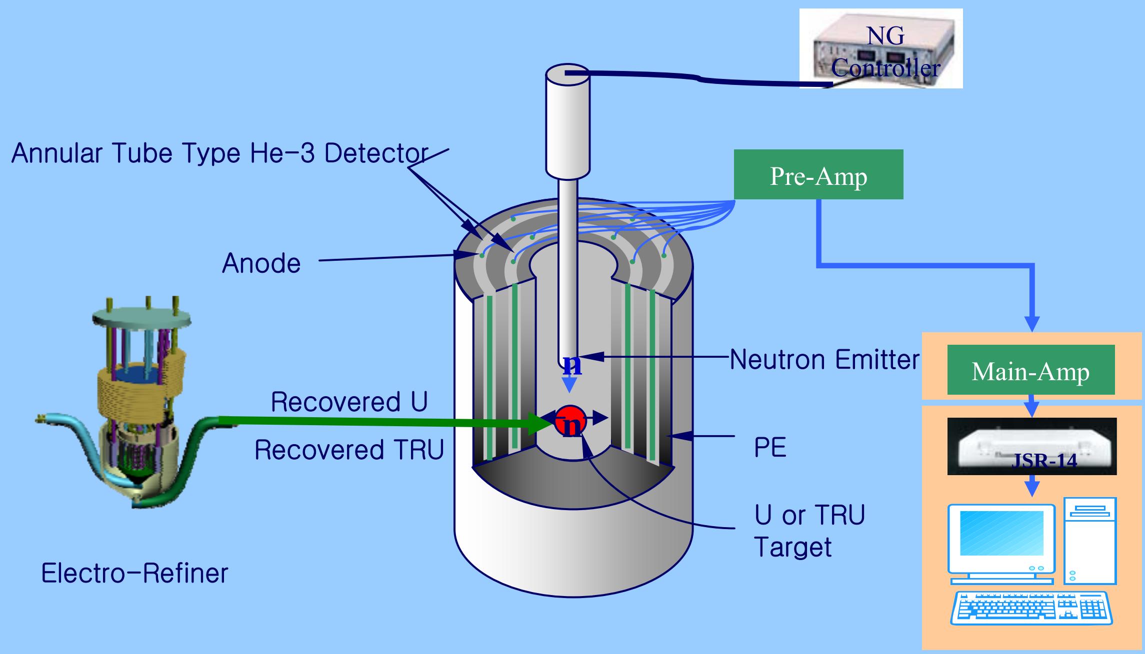
- Counter Module : Neutron Count for ASNM1, ASNM2, ASNC
- MD Module : Motion Detection for 4 CCTV's
- SMS Module : Shot Message Service by Cellular Phone
- INCC I/F Module : Shift Register Interface

KAERI

Other Safeguards R&D for Pyroprocess at KAERI

New Neutron Counter Based on an Annular Tube Type He-3 Detector





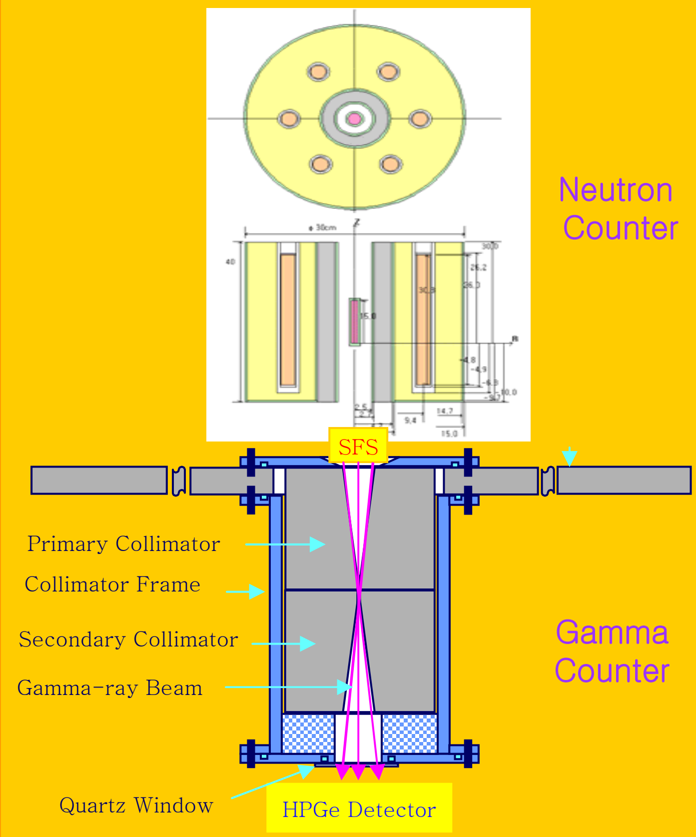
ϕ 72cm x H 68.3cm
Two rings of an annular tube type He-3 detector of 2.5 cm in thickness.
Efficiency : >45 %
Dieaway Time : 70-75 uS
Cavity Error : <4 %

An Active neutron counter for measuring the recovered U and TRU in the Electro-refiner, which will be composed of the Neutron Generator (D-D type, 2×10^6 n/sec, made by Sodern) and electronic system.

Current R&D Tasks

Shielded Glovebox Neutron/Gamma Counter (SGNGC)

Simultaneous neutron coincidence counting and gamma isotopic analysis for small spent fuel samples before pyro-processing



-Neutron Measurement

-Determination of Singles/Doubles Rate

-Determination of Pu/U Ratio

-γ Spectrum Analysis

-Determination of Isotope Concentration

-Determination of Pu/U ratio by Isotope Ratio

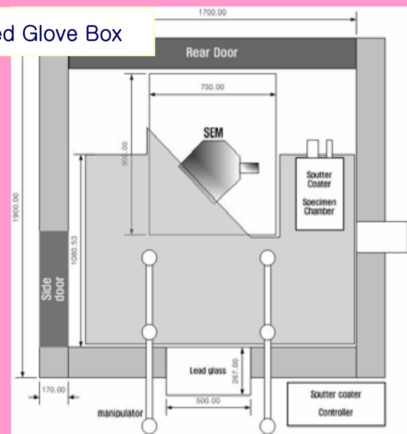
KAERI

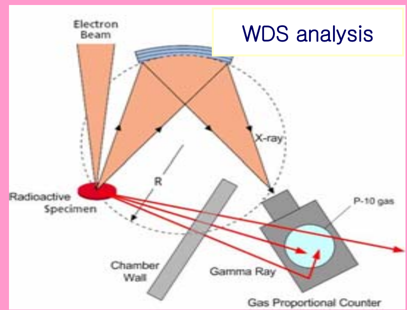
Current R&D Tasks

Shielded Scanning Electron Microscopy (SSEM)

Destructive analysis of nuclear materials from pyroprocessing products by Shielded Scanning Electron Microscopy (SSEM)

Specimen Transportation



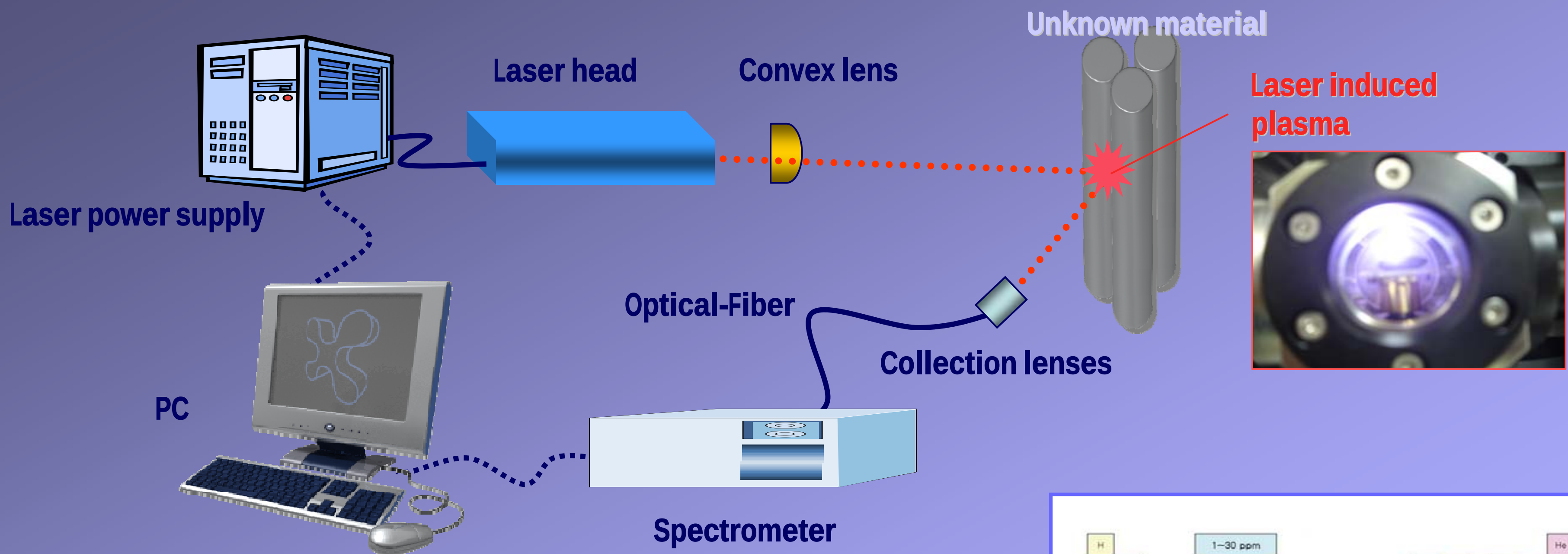


Surface Analysis of Spent Fuel Sample

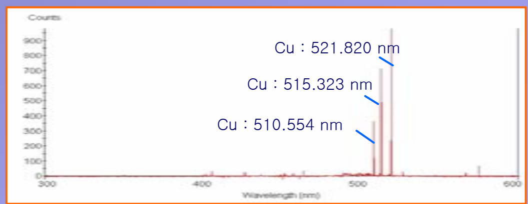
- WDS function addition
- Qualitative analysis
- Quantitative analysis
- Surface analysis

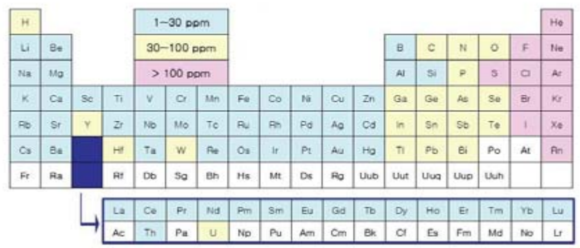
Laser-induced breakdown spectroscopy (LIBS)

Determining the nature and history of compounds and elements by on-site sampling and analysis using laser induced breakdown spectroscopy (LIBS)



Ele...	Rating...	Wavelength
Cb	30.3	405.894
Cr	24.84	427.48
Cu	362.96	510.554
Cu	712.2	515.323
Cu	977.32	521.82
Pb	30.3	405.782
Pr	30.3	406.282





[Typical detection limits for LIBS]

International Cooperation

R.O.K	IAEA	U.S.A
KAERI	Safeguards Department	USDOE - *LANL etc.*

- ❑ **Safeguardability and PR Study : DUPIC, ACP, ESPF, KAPF**
- ❑ **NMC&A**
  - ➢ **NDA Equipment : INVS, DSNC, ASNC, PNAR, SINRD…**
  - ➢ **Standard Sources, Data management S/W, Electronics etc.**
- ❑ **C/S**
  - ➢ **Unattended Continuous Monitoring, Intelligent System**
  - ➢ **Remote monitoring, VPN**

Summary

- The lab-scale Fuel Cycle Facility safeguards system in KAERI was successfully designed and established under an international cooperation program.
- Based on performance test, it seems that NDA system is reliable enough to be used for the measurement of the process materials.
- Some R&D for increasing PR and IAEA authentication method will continue.
- Pyroprocess material measurement system, Surveillance system, and near real time accountability system will be integrated into a single safeguards system in the next R&D stage.
- The KAERI will continue to work closely with the IAEA and international partners for the future nuclear fuel cycle
  - Safeguardability and PR evaluation
  - Advanced NDA and monitoring technology development
  - Safeguards system development

khd@kaeri.re.kr