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Idaho National Laboratory

IAEA Safeguards Monitoring Systems
&
Science and Technology Challenges for International Safeguards

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Topics

- **IAEA Safeguards and Unattended Monitoring Systems**
- **Gas Centrifuge Enrichment**
  - Recommendations
- **Reprocessing: Aqueous and Pyro-chemical**
  - Recommendations
- **Undeclared Facilities**
  - Recommendations
- **Conclusions**

The IAEA and Safeguards

As of December 2006: 925 Facilities were under IAEA Safeguards

Safeguarded Nuclear Material (excluding source material)

- **980 Metric Tons of Plutonium (Majority in Spent Fuel)**
- **16 Metric Tons of High Enriched Uranium**
- **1120 Metric Tons of Low Enriched Uranium**

"The IAEA should be able to provide credible assurance not only about the declared nuclear material in a State but also about the absence of undeclared material and activities."

Growth of nuclear power: 2007 estimate

"…growth in capacity from 370 GW(e) at the end of 2006, to 679 GW(e) in 2030. That would be an average growth rate of about 2.5%/yr."

Every State is a potential adversary

The Safeguards Challenge

At Declared Facilities: "..the *timely detection* of diversion of *significant quantities* of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."

- *Timeliness criteria* to draw conclusions varying from approximately one week to approximately one year depending on the form of the material, with metal having the shortest timeliness criteria and waste the longest (conversion or weaponization time)
- *Goal Quantities (or Significant Quantities)* Approximate quantity of nuclear material in respect of which, taking into account any conversion process involved, the possibility of manufacturing a nuclear explosive device cannot be excluded.

Significant Quantities

	Material	Significant Quantity	Safeguards apply to:
Direct-Use Nuclear Material*	Pu (<80% Pu-238)	8 kg	Total Element
	U-233	8 kg	Total Isotope
	U [U-235>/= 20%]	25 kg	U-235 Contained
Indirect-Use Nuclear Material**	U [U-235<20%]	75 kg	U-235 Contained
	Thorium	20 t	Total Element

* NM that can be converted into nuclear explosive components without transmutation or further enrichment

** All NM except direct-use material

Conversion Times (Weaponization)

Beginning Material Form	Conversion Time
Pu, HEU or U-233 Metal	Order of Days (7-10)
PuO2, Pu(NO3)4, or other pure Pu compounds; HEU or U-233 oxide or other pure compounds; MOX or other non-irradiated pure mixtures containing Pu, U [(U-233+U-235)>/=20%; Pu, HEU and/or U-233 in scrap or other miscellaneous impure compounds	Order of Weeks (1-3)
Pu, HEU or U-233 in irradiated fuels	Order of Months (1-3)
U containing < 20% U-235 and U-233; Th	Order of one year

Did You Know?

According to the International Atomic Energy Agency (IAEA), 25 kg of HEU (about the size of a grapefruit) or 8 kg of plutonium (about the size of a soda can represent a "significant quantity" required to make a crude nuclear weapon.

The Safeguards Challenge

IAEA High Level Diversion Scenarios

Primary safeguards goal is the timely detection of the diversion of a significant quantity

- **Abrupt Diversion**
  - The immediate diversion of a significant quantity or greater in a short time (typically a conversion period: 2 weeks to 1 month)
- **Protracted Diversion**
  - The diversion of portions of a significant quantity over extended periods of time leading to a significant quantity or greater (typically an inventory period: 6 months – 1 year)

INFCIRC/153 – The Structure & Content of Agreements Between the Agency & States in Connection with the NPT

- **PART I, paragraph 4, The Agreement should provide that safeguards shall be implemented in a manner designed:**
  - **(a) To avoid hampering the economic and technological development of the State … in the field of peaceful nuclear activities, including international exchange of nuclear materials;**
  - **(b) To avoid undue interference in the State's peaceful nuclear activities, and in particular in the operation of facilities; and**
  - **(c) To be consistent with prudent management practices required for the economic and safe conduct of nuclear activities.**

What is an Unattended Monitoring System (UMS)?

- It is a system that automatically monitors the flow of nuclear materials 24 hours a day / 365 days a year without the need for human interaction
- It is permanently installed in a nuclear facility
- It is computer based for data retrieval either on-site or remotely
- It may use a variety of sensors such as radiation, pressure, temperature, flow, vibration, & electromagnetic fields to collect qualitative or quantitative data
- All external components are in tamper indicating enclosures

Why does the International Atomic Energy Agency use UMS?

- It provides the highest level of safeguards assurance through continuous monitoring of activities in nuclear facilities.
- It minimizes impact on the facility operator by allowing uninterrupted facility operation
- It minimizes the impact on the Agency by reducing inspector visits and thereby inspection resources including the high cost of world-wide travel
- It reduces radiation exposure to personnel and can operate in radiation areas too dangerous for humans

Mid-2004 IAEA Worldwide Statistics of UMS

- **90 Systems Installed (+115 Mid-2005)**
  - 79 Radiation Based
  - 5 Thermo-hydraulic Based
  - 6 Process Monitoring Based
- **44 Facilities**
- **22 Countries**
  - SGOA - 30 Systems (SE Asia)
  - SGOB - 40 Systems (N. & S. America, Africa, India, Pakistan, Iran)
  - SGOC – 20 Systems (Europe, Kazakhstan, Ukraine)

What are the Primary Goals of UMS?

- No loss of safeguards significant data
- Assurance that the data is authentic

How are these Goals Obtained?

- Use of high reliability and/or redundant critical components and/or reduced reliance on low reliability components
- Use of uninterruptible power supply
- Employs multi-layer Security

Objectives for Unattended Measurement Systems

Collect SG-information without Inspector's Presence:

- Verify flow and inventory of nuclear materials
- Minimize intrusiveness on Operator
- Reduce IAEA & Operator manpower requirements
- Decrease radiation exposure
- Standardize hardware and software
  - Minimize maintenance
  - Minimize training

Security Methods

- Software controlled
- Tamper indicating enclosures
- C/S on detector head and electronics
- Visual Inspection of components and cables
- Efficiency check with normalization source
- Supervision of maintenance
- Cross correlation with other SG measures
- Use of unique data signature on all digital data
- Encrypted data transmission between cabinets and for remote monitoring
- Uninterrupted Power Supplies

IAEA Metal E-Cap Seals

Some Tamper Indicating Features

ENGM Detector

Tamper Indicating Conduit

Security Solution: VPN

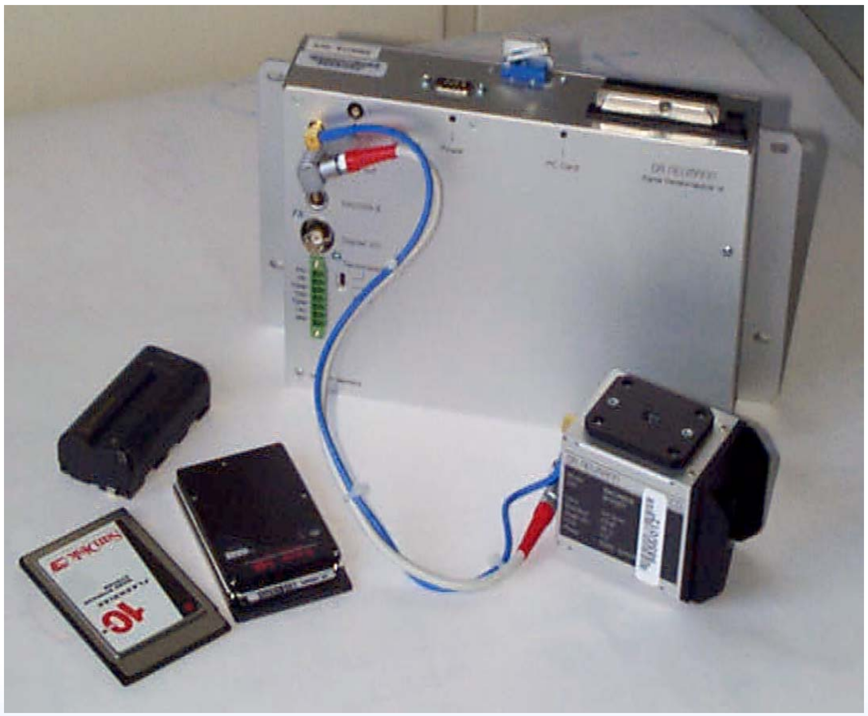
- Netscreen 5XP or 5XT
- Meets FIPS 140 Level 2
- Small, << $1000 each
- Doesn’t take firewall expert
- Wire or Wireless

Wireless Solution

- Alvarion AP-10 & SA-10
- AP-10 indoor wireless hub, ~$ 1,000 each
- SA-10 station adaptor for end user computer, ~$ 500 each
- 10BASE-T Ethernet using RJ-45
- Data rate - up to 3 Mbps
- Range – 150m (500 ft.)

HARDWARE STANDARDS

Surveillance Data Generator (German Support Program)

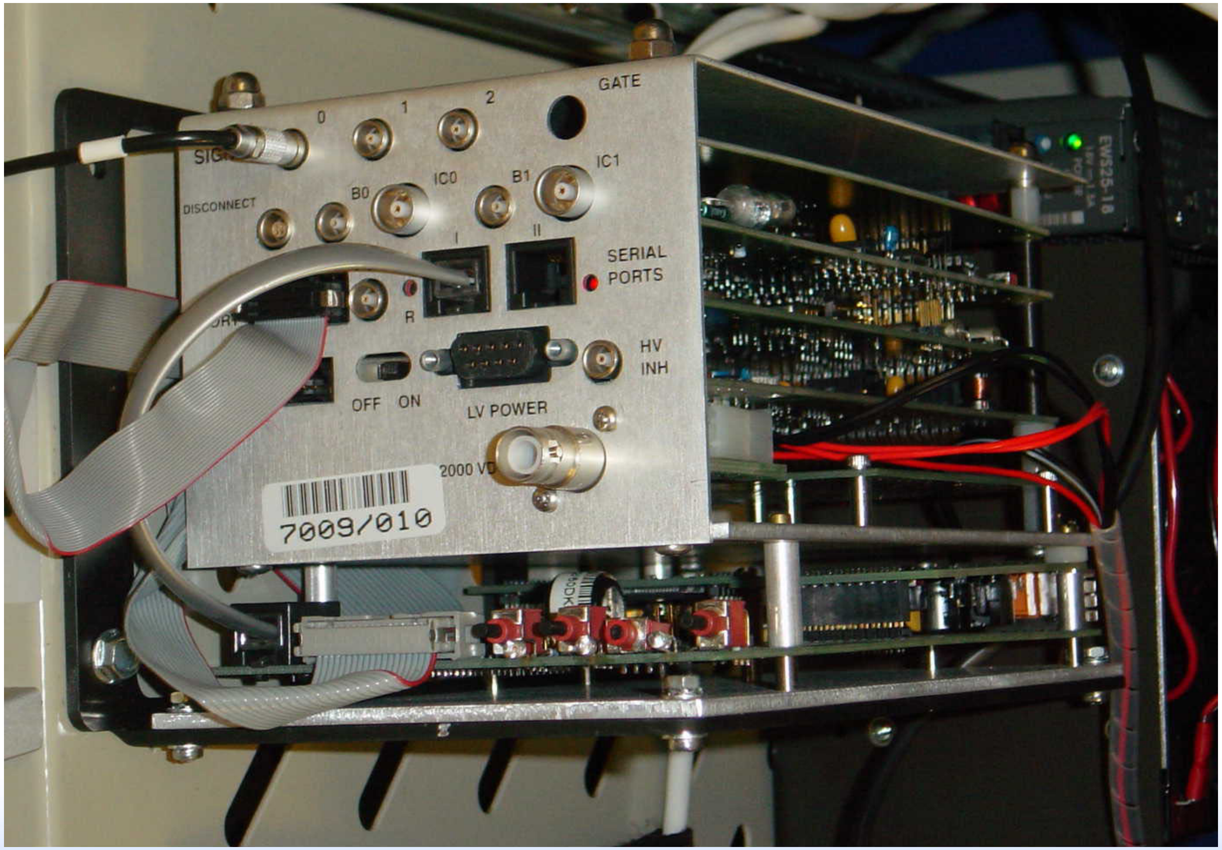


DCM 14

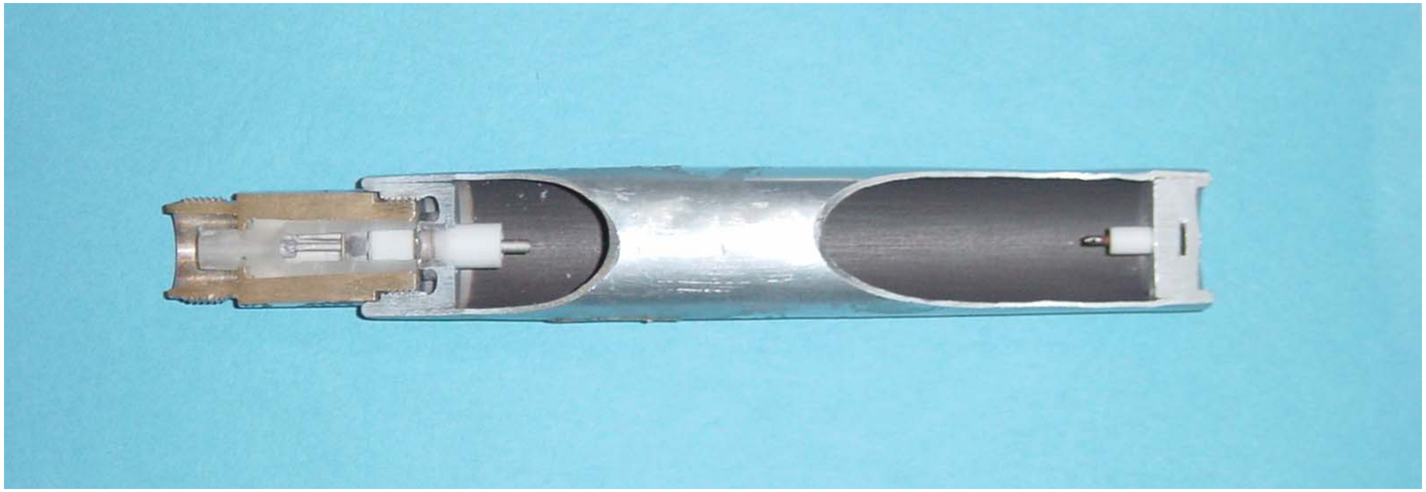
- Digital image
- Scene change detection
- Image compression
- Image/data authentication
- Image/data encryption
- Power management
- Battery back-up
- External triggers
- On board 100 days data storage
- State of health

Data Generators – continued

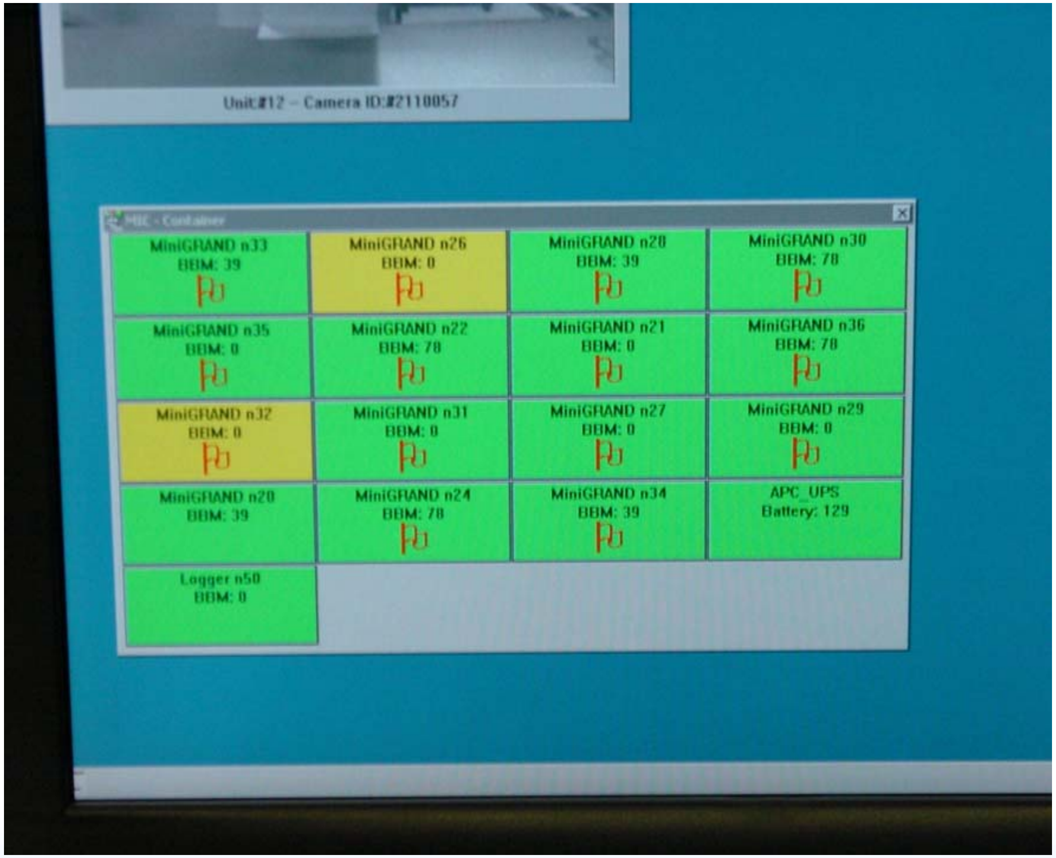
MiniGRAND (USA Support Program)



Radiation Sensor: Ionization cut away

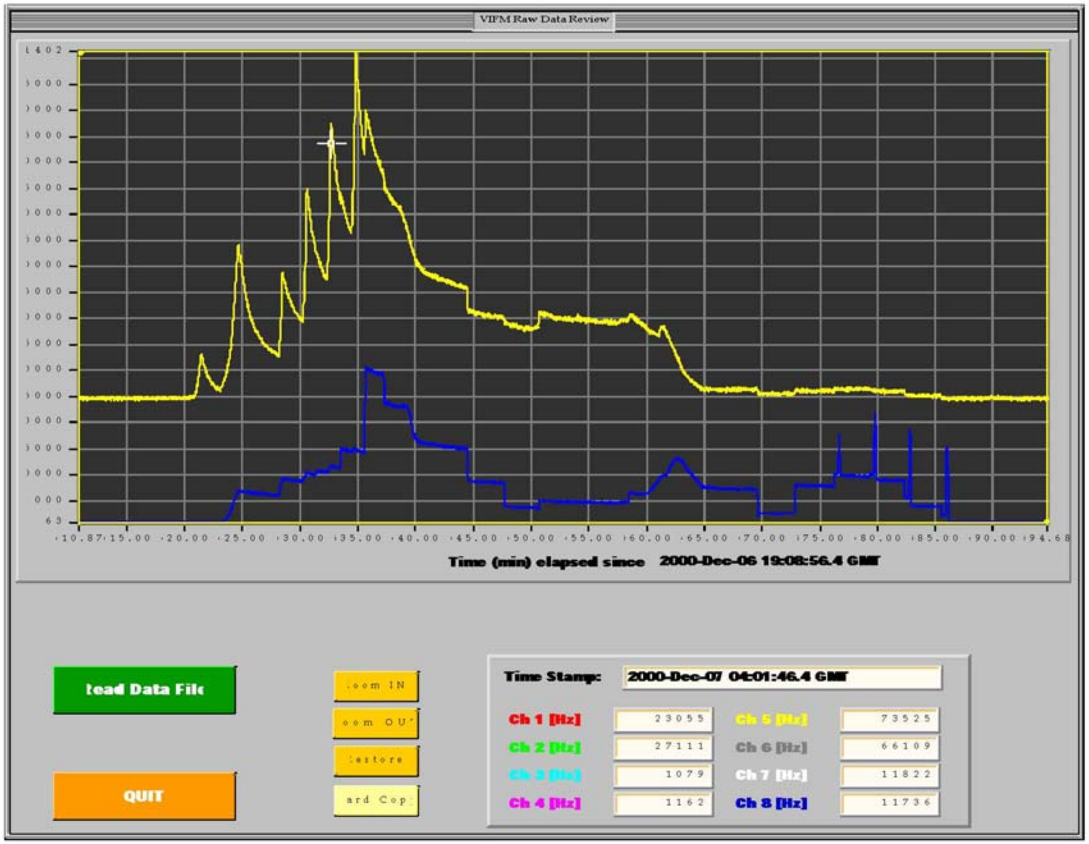


Chernobyl System
SOH – State of Health Flags

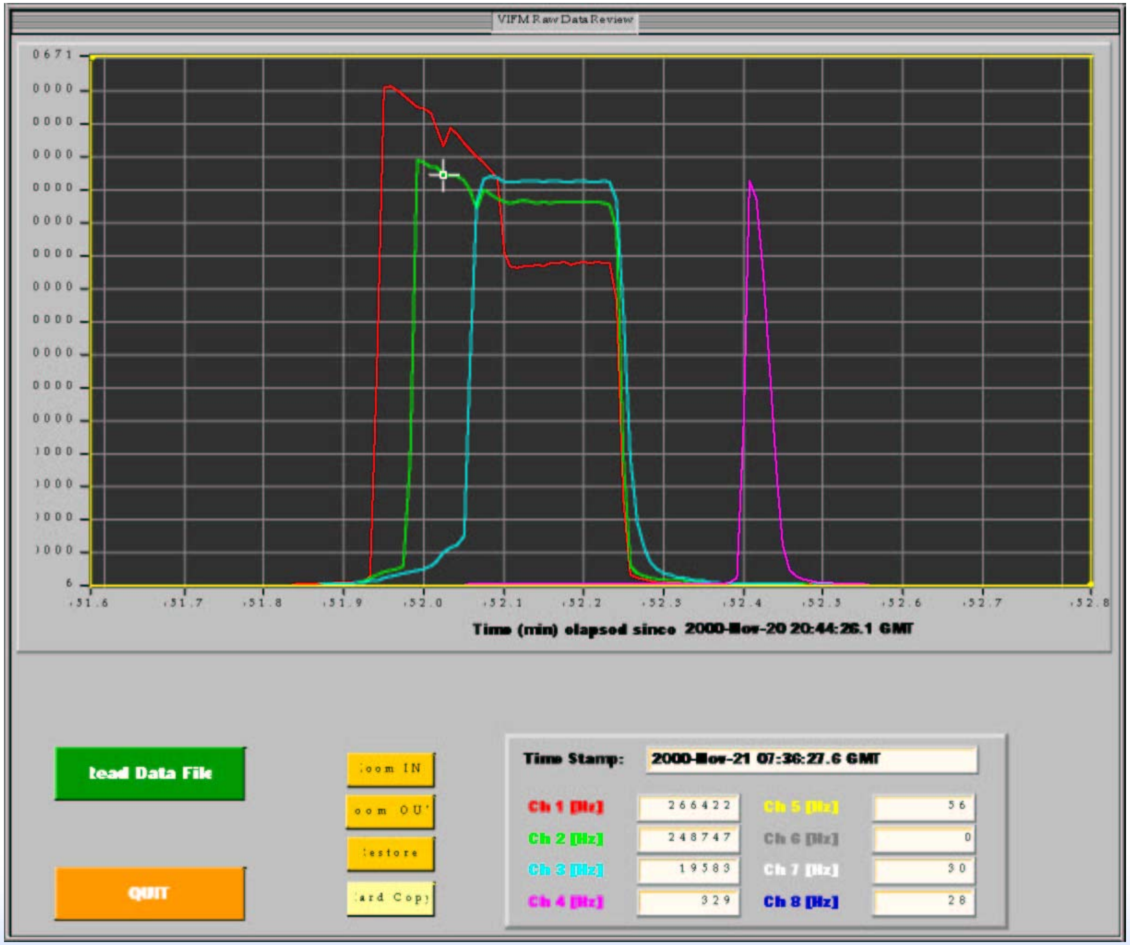


VIFM CABINET DESIGNED TO MONITOR SF BUNDLES FROM CANDU REACTORS (Canadian Support Program)

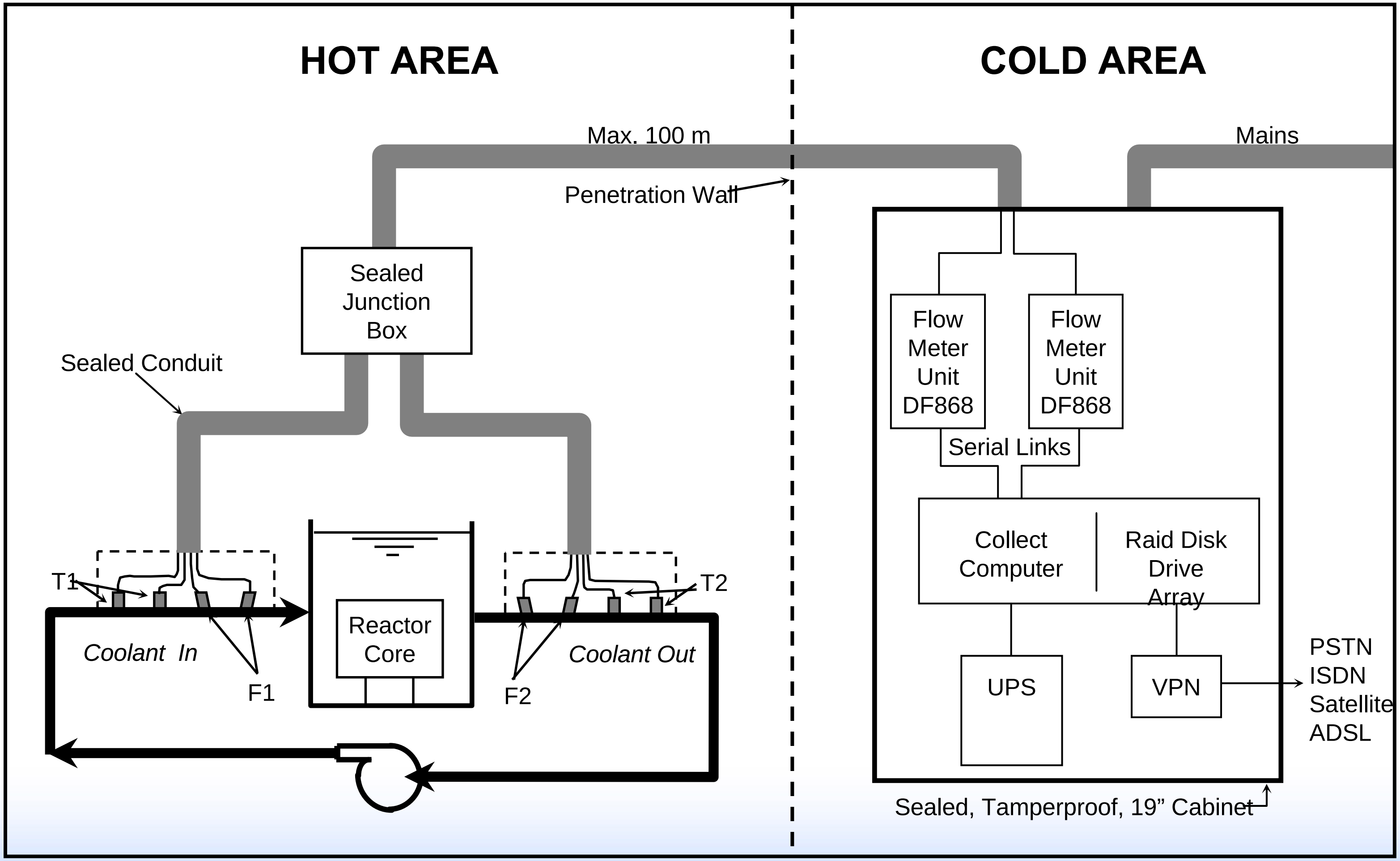
VIFM – VIFC: Core Discharge Monitor



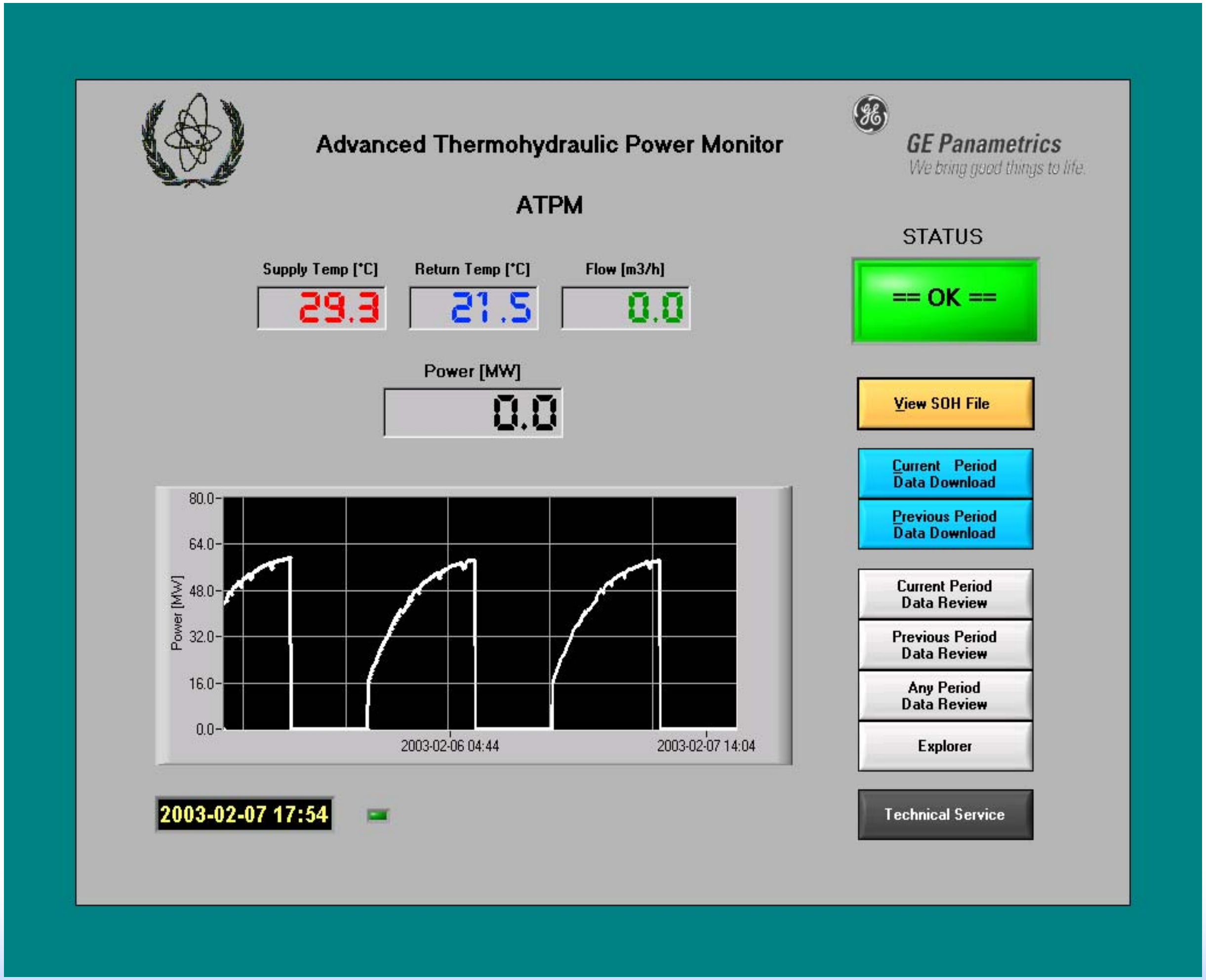
VIFM – VIFB: Bundle Counter



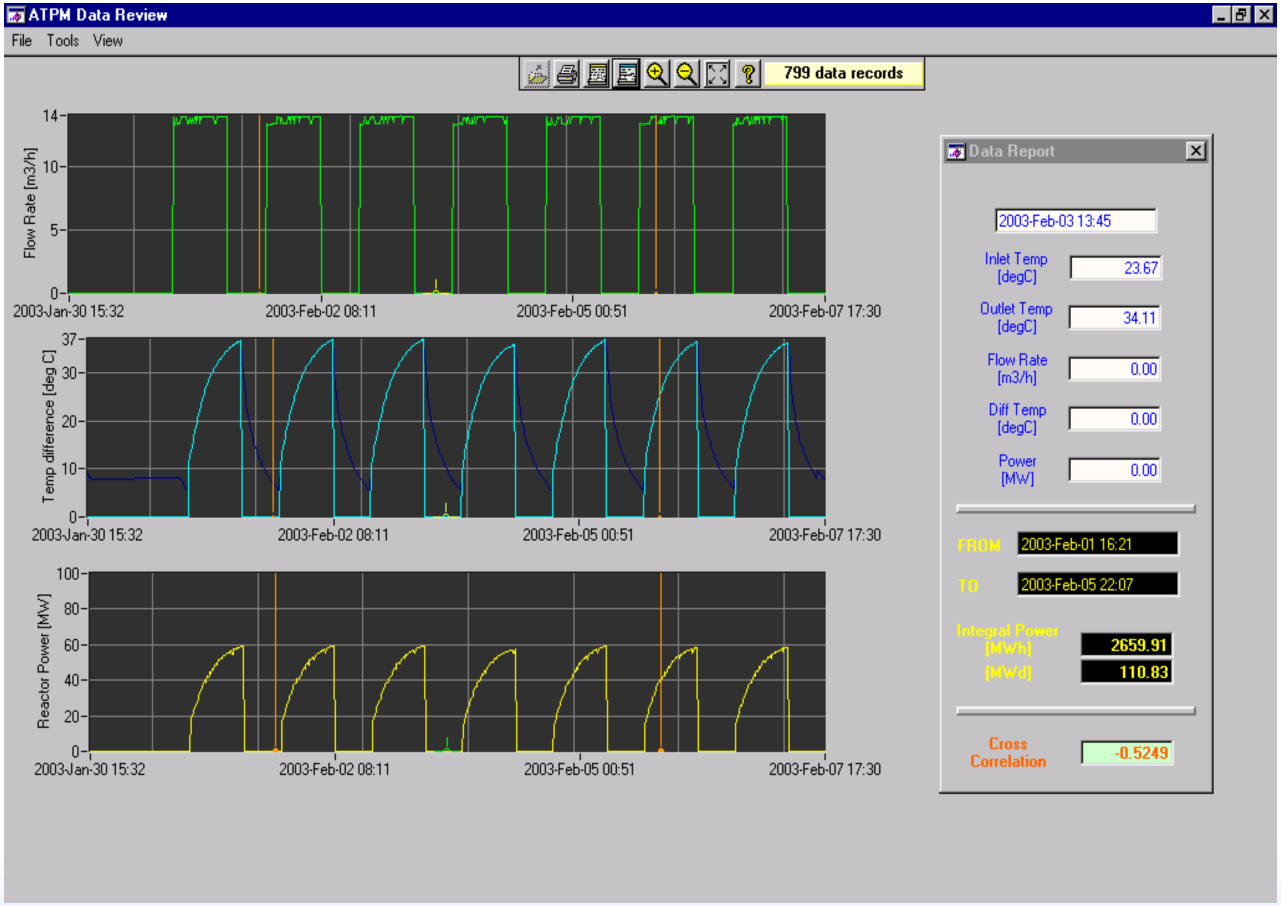
ATPM System Diagram (IAEA developed)



ATPM Front Screen



ATPM Sensor Data Screen



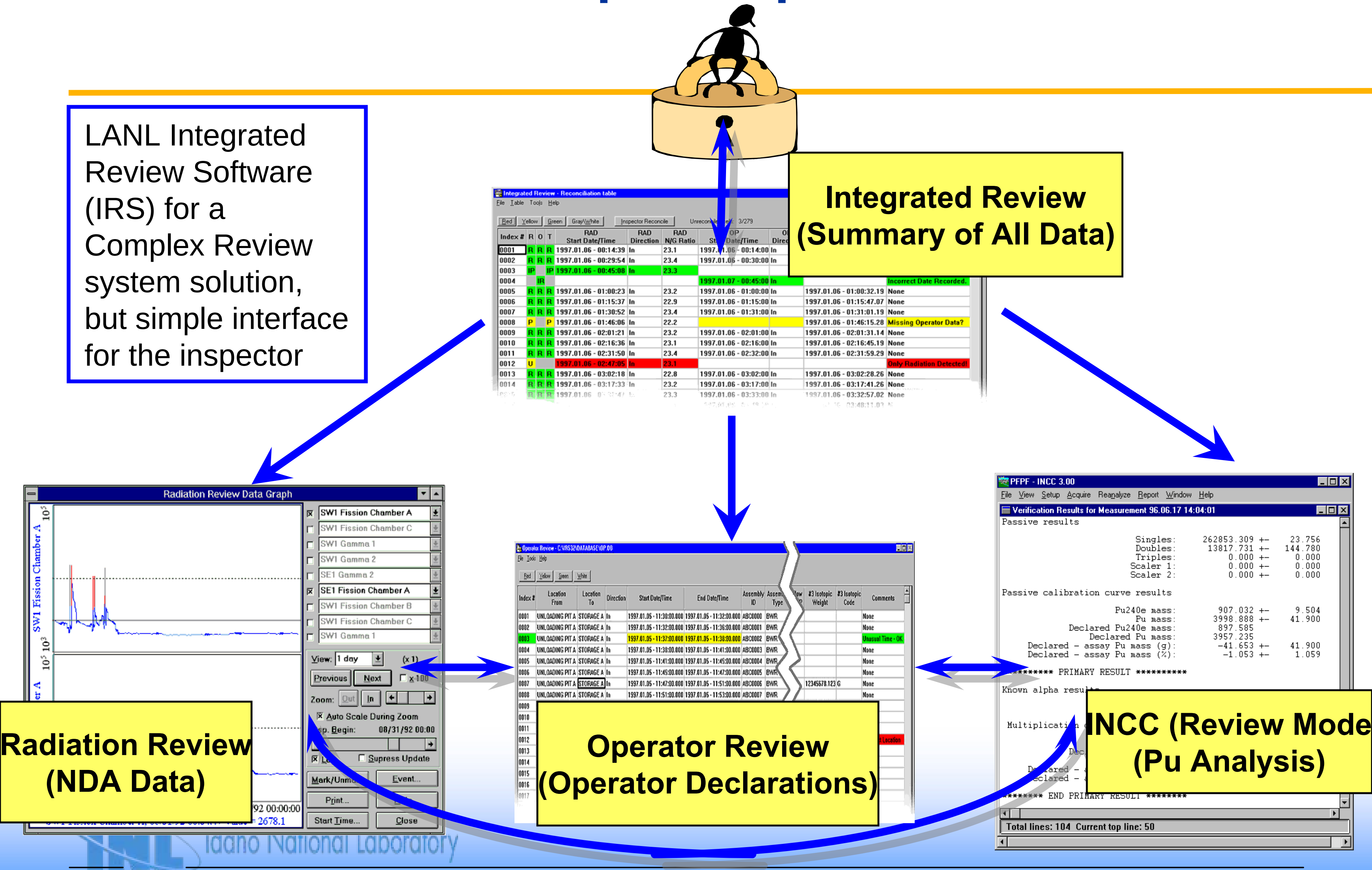
SOFTWARE STANDARDS

Collect Software
(Resides on PC in equipment cabinet: primary function is polling of data generators for collection and transmission data)

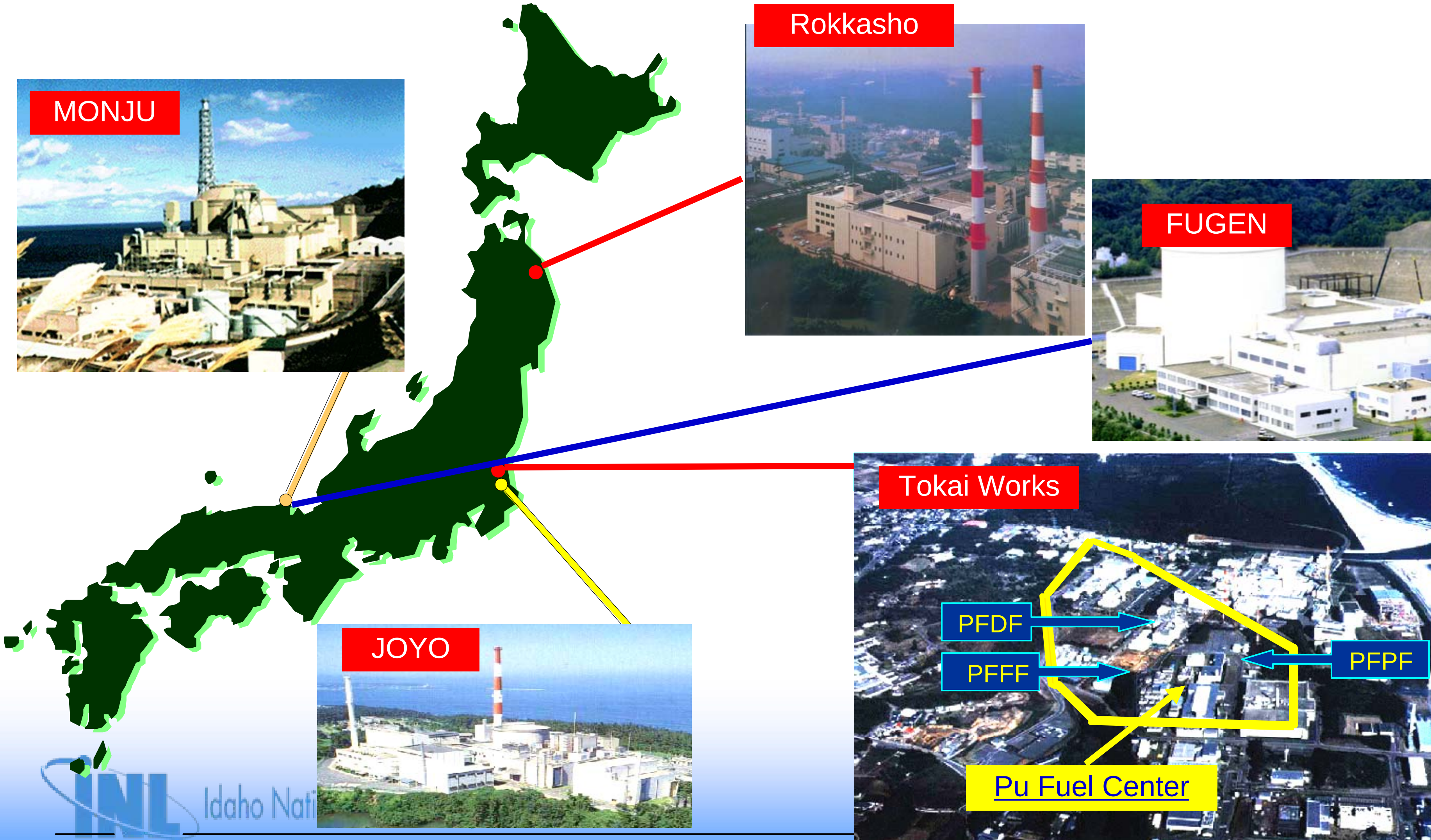
Review Software
(Resides on PC at inspector's work station: analysis to draw safeguards conclusions, note that IAEA does no real time data analysis)

IAEA assistance: Inspector point of view

LANL Integrated Review Software (IRS) for a Complex Review system solution, but simple interface for the inspector

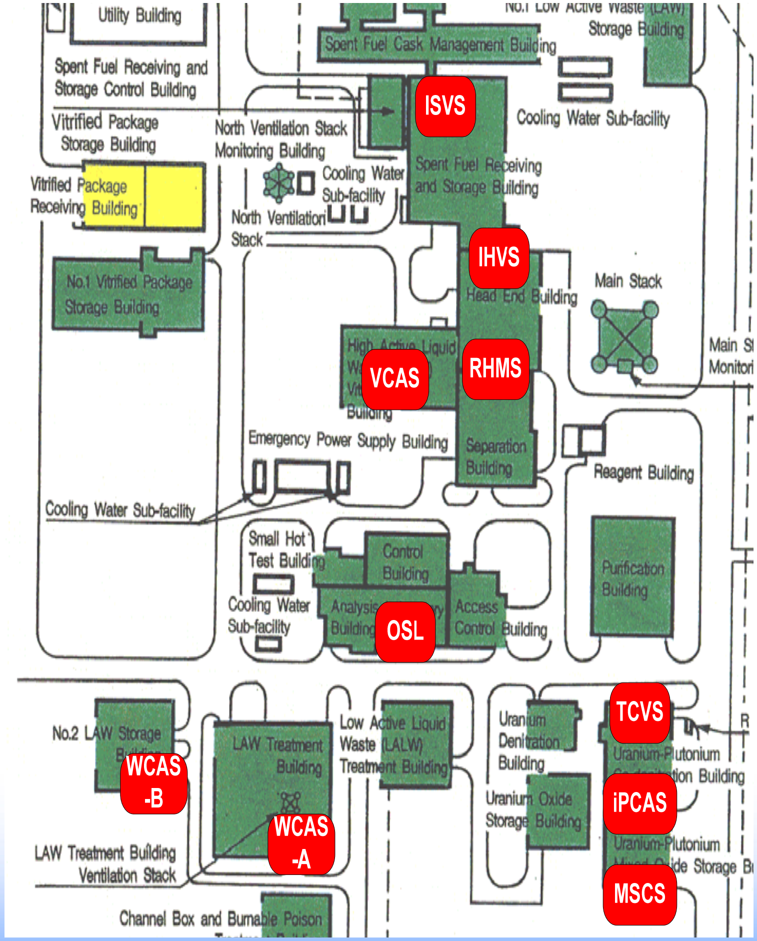


Japan: Largest non-weapons state with complete fuel cycle under IAEA safeguards



LANL assay systems at Rokkasho Reprocessing Facility are the State of the Art (USSP)

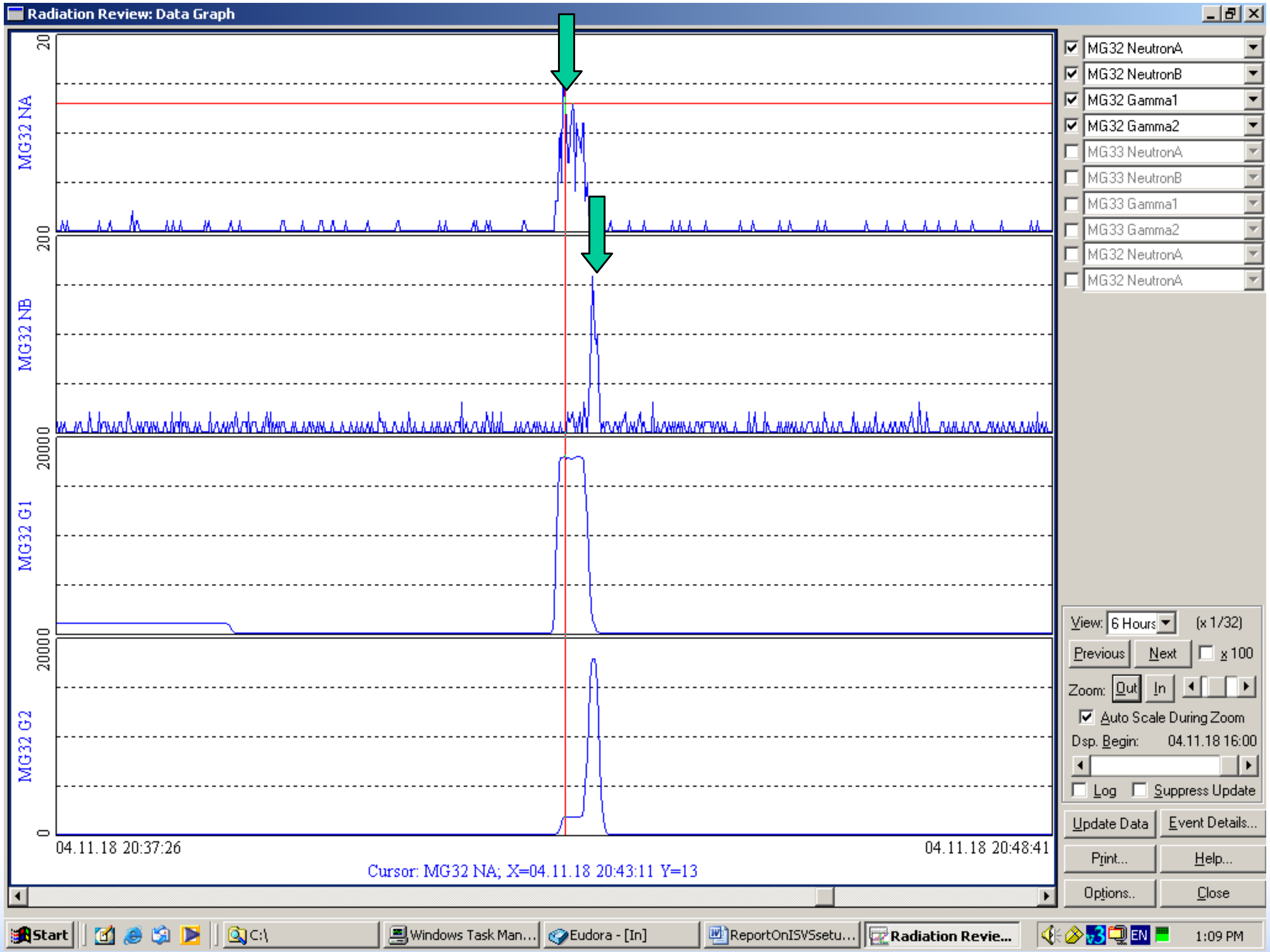
- •ISVS – Integrated Spent fuel Verification System
- •IHVS – Integrated Head end Verification System
- •RHMS – Rokkasho Hulls Measurement System
- •VCAS – Vitrified waste Canister Assay System
- •HKED – Hybrid K-Edge Densitometer
- •TCVS - Temporary Canister Verification System
- •iPCAS - improved Plutonium Canister Assay System
- •WCAS A/B - Waste Crate Assay System



Rokkasho Reprocessing Plant Characteristics

- Only large scale reprocessing plant outside a Nuclear Weapons State (full scope IAEA safeguards)
- Safeguards on bulk handling facilities (vs. item) 800 tons heavy metal ~ 8 tons Pu/yr
- Analytical error (~0.3% including sampling error) gives a 1σ error on throughput of Pu of ~24 kg per year
- 2σ is 48 kg = ~4 kg/month (compare to IAEA significant goal quantity 8kg, with 95% C.L. that reduces to ~2.5kg)
- Inspected jointly by IAEA and Japanese Domestic Safeguards (JSGO-NMCC) – some equipment shared

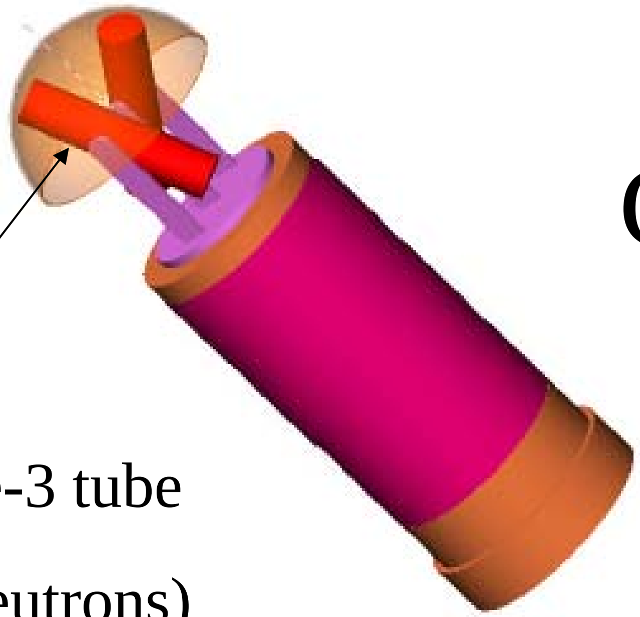
ISVS



Radiation Review: Data Graph
MG32 NA
MG32 NB
MG32 G1
MG32 G2
20
200
20000
20000
0
04.11.18 20:37:26
04.11.18 20:48:41
Cursor: MG32 NA; X=04.11.18 20:43:11 Y=13
MG32 NeutronA
MG32 NeutronB
MG32 Gamma1
MG32 Gamma2
MG33 NeutronA
MG33 NeutronB
MG33 Gamma1
MG33 Gamma2
MG32 NeutronA
MG32 NeutronA
View: 6 Hours
(x 1/32)
Previous
Next
x 100
Zoom: Out In
Auto Scale During Zoom
Dsp. Begin: 04.11.18 16:00
Log
Suppress Update
Update Data
Event Details...
Print...
Help...
Options..
Close
Start
C:\
Windows Task Man...
Eudora - [In]
ReportOnISVSsetu...
Radiation Revie...
1:09 PM

IHVS

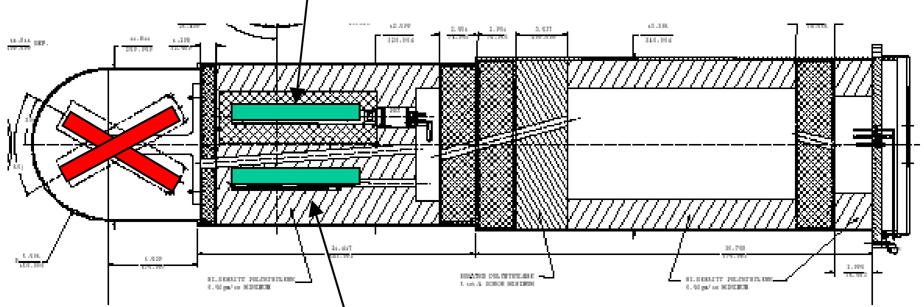
Camera Radiation Detector CRD



cameras

He-3 tube

(neutrons)



Ion chamber

(Gammas)

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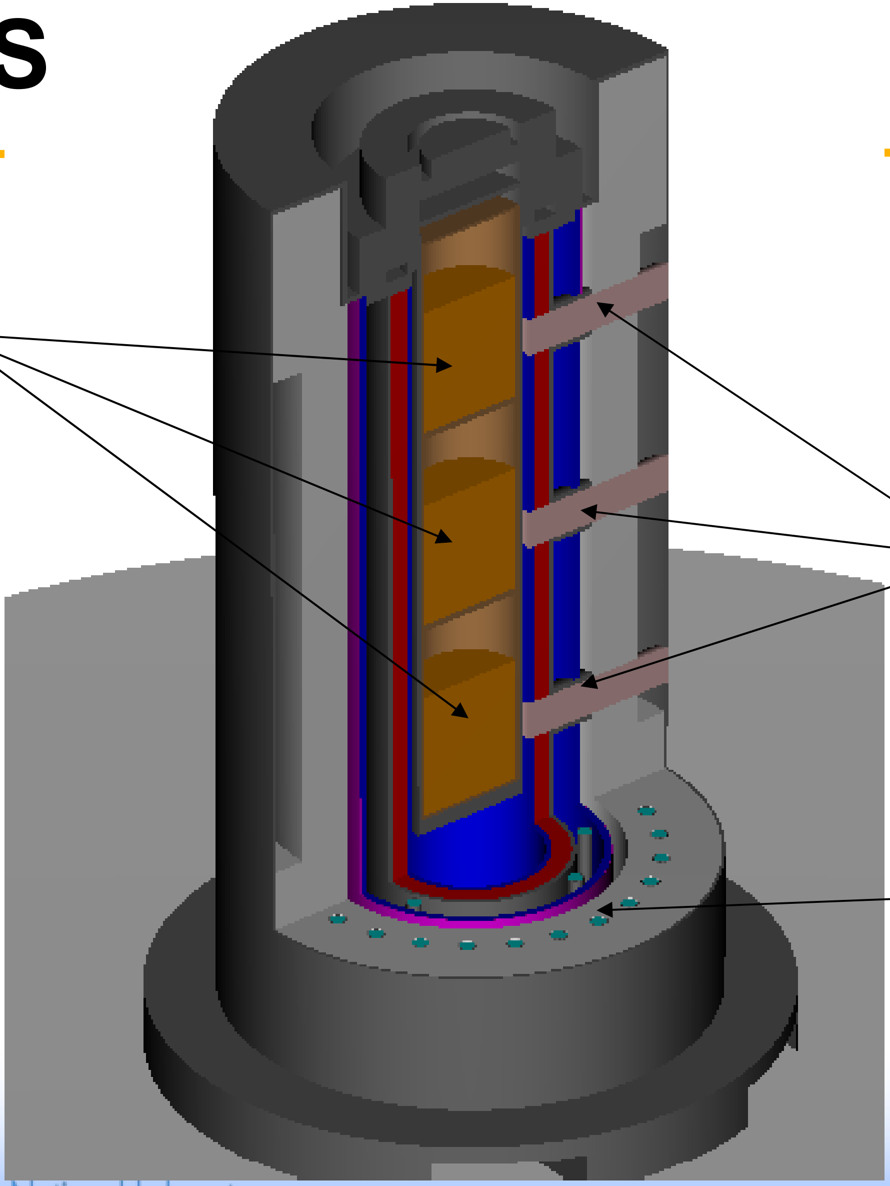
Camera Radiation Detector (CRD)

Improved Plutonium Canister Assay System (iPCAS)

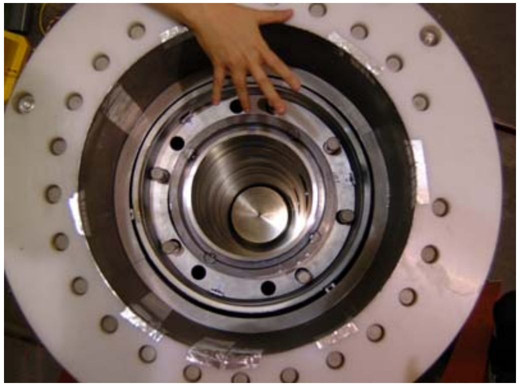
Designed for JSGO-NMCC

- Measure the Pu content and isotopic composition of containers of 36 kg MOX
- Need precise value (<0.85%) therefore monitor moisture content for mass correction (.0085*8000 kg-Pu/yr*1yr/12 mo) = 5.7 kg-Pu/mo @ 1σ
- NMCC-owned system used by IAEA

iPCAS



iPCAS



Installed in
RRP
March 2004

The Safeguards Challenge

Declared Facility Methodology

- SQ & Timeliness Criteria along with measurements is mathematically verifiable
  - Near real time accountability
  - Perform statistical sampling of NM and measure it
  - Propagate of measurement uncertainties at specific confidence levels.
  - Calculate a material balance

Primary Exception is Spent Fuel Assemblies (item)

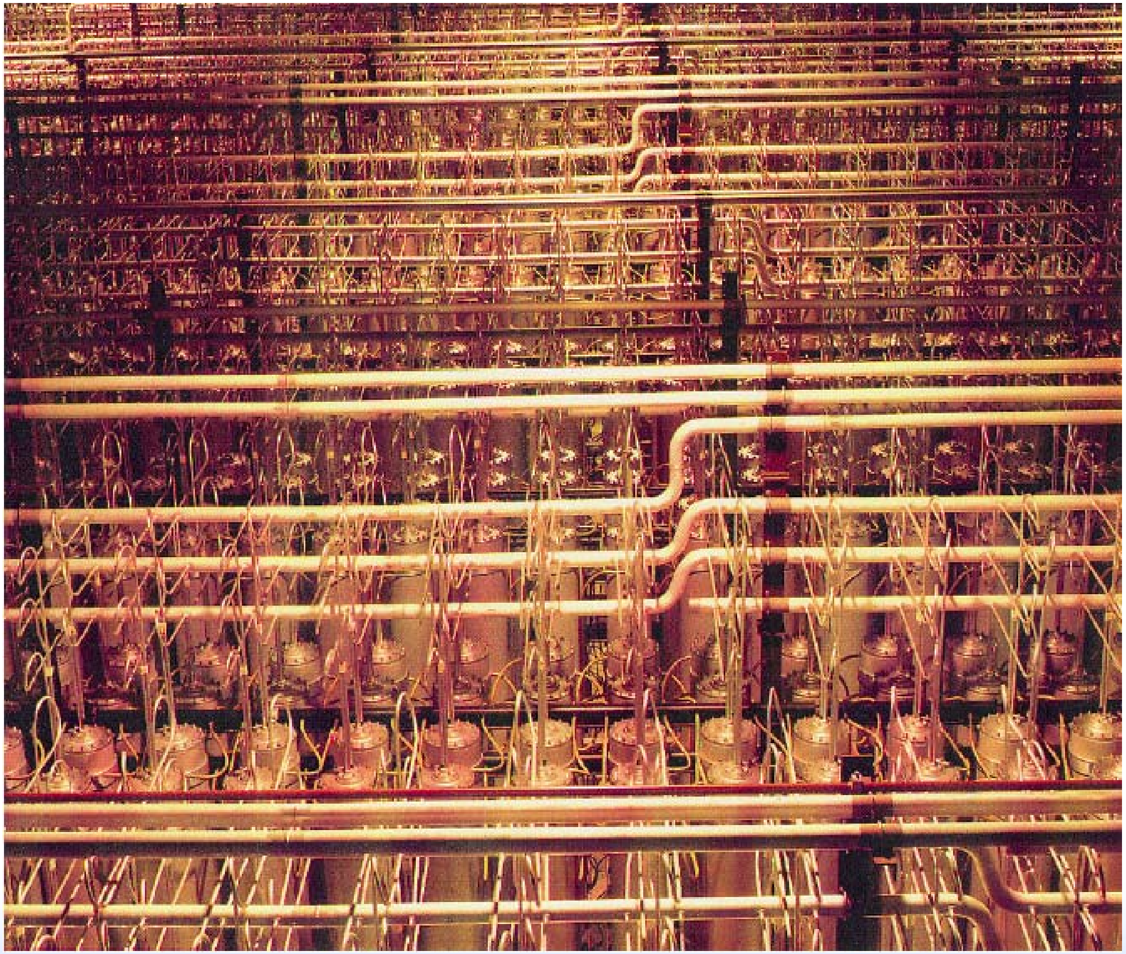
(Continuity of Knowledge)

The Safeguards Challenge

What changed to put this methodology at risk?

- More challenging technologies of enrichment and reprocessing matured outside of weapons states
- Need for economies of scale became important
- Facilities grew substantially in size
- Resulting in large quantities of bulk nuclear materials being processed in complex facilities
- Increases in throughput by orders of magnitude
- No corresponding reduction in measurement error for quantifying nuclear material nor efficient techniques to quantify in all areas of a facility
- Measurement uncertainty alone for a process stream or product exceeded the IAEA goal quantities within the timeliness criteria

Gas Centrifuge Enrichment



Gas Centrifuge Enrichment

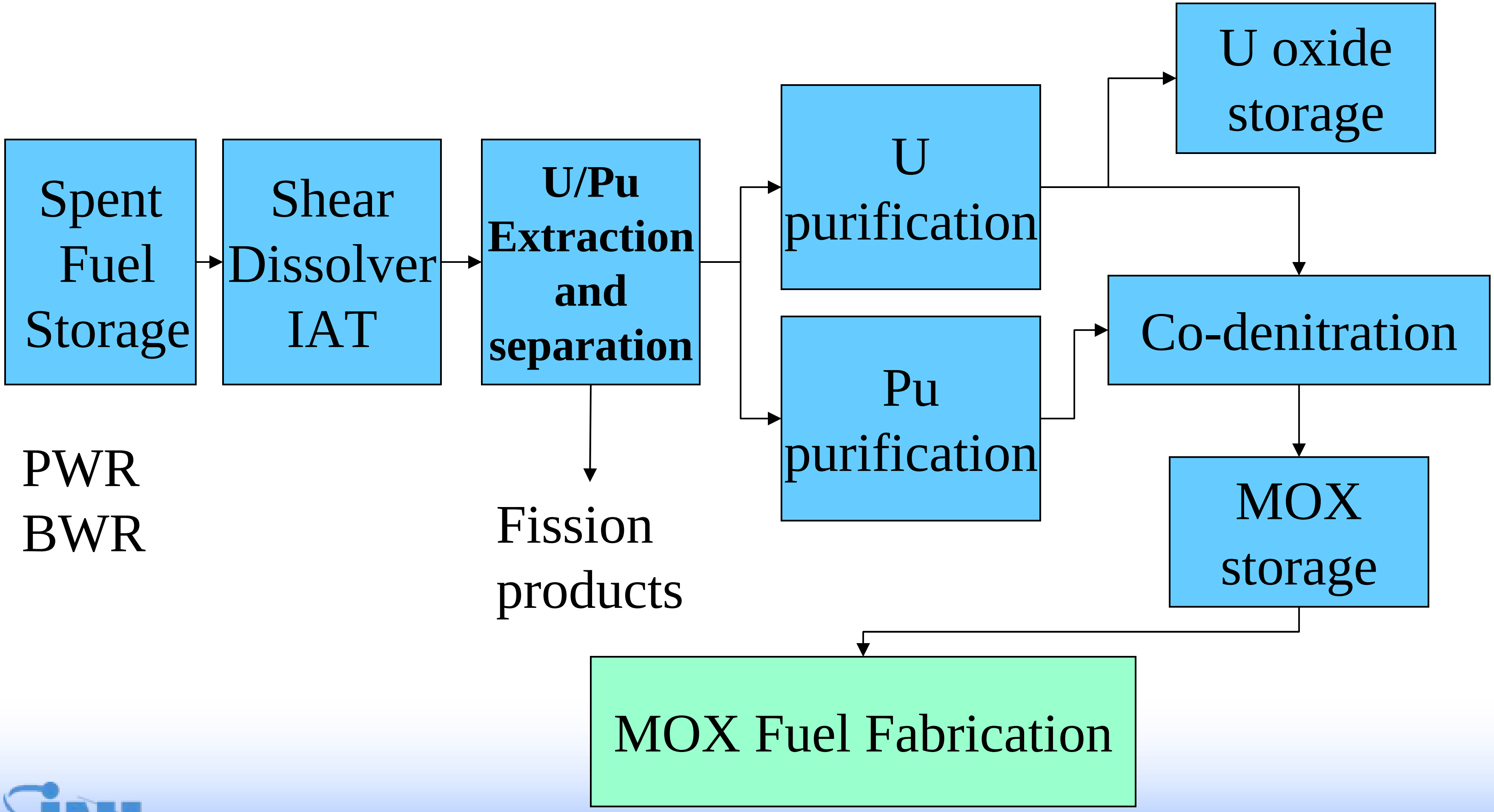
- **Sensitive Technology = Proprietary Information = Limited Access**
- **Modular in Nature = LEU Facility can make HEU**
- **Multiple Diversion Scenarios = HEU, undeclared LEU, diversion of LEU = All can be accomplished within the Cascade Hall**
- **Hexapartite Safeguards Project (HSP, from 1980s) = defined a cascade access regime known as Limited Frequency Unannounced Access (LFUA) allowing access from 4-12 times per year (the number is facility specific) = The cascade hall was turned into an effective black box**
- **HSP was determined to be an effective approach for facilities limited to an annual uranium separation of 1,000 tons = Newer facilities exceed this throughput**

Gas Centrifuge Enrichment

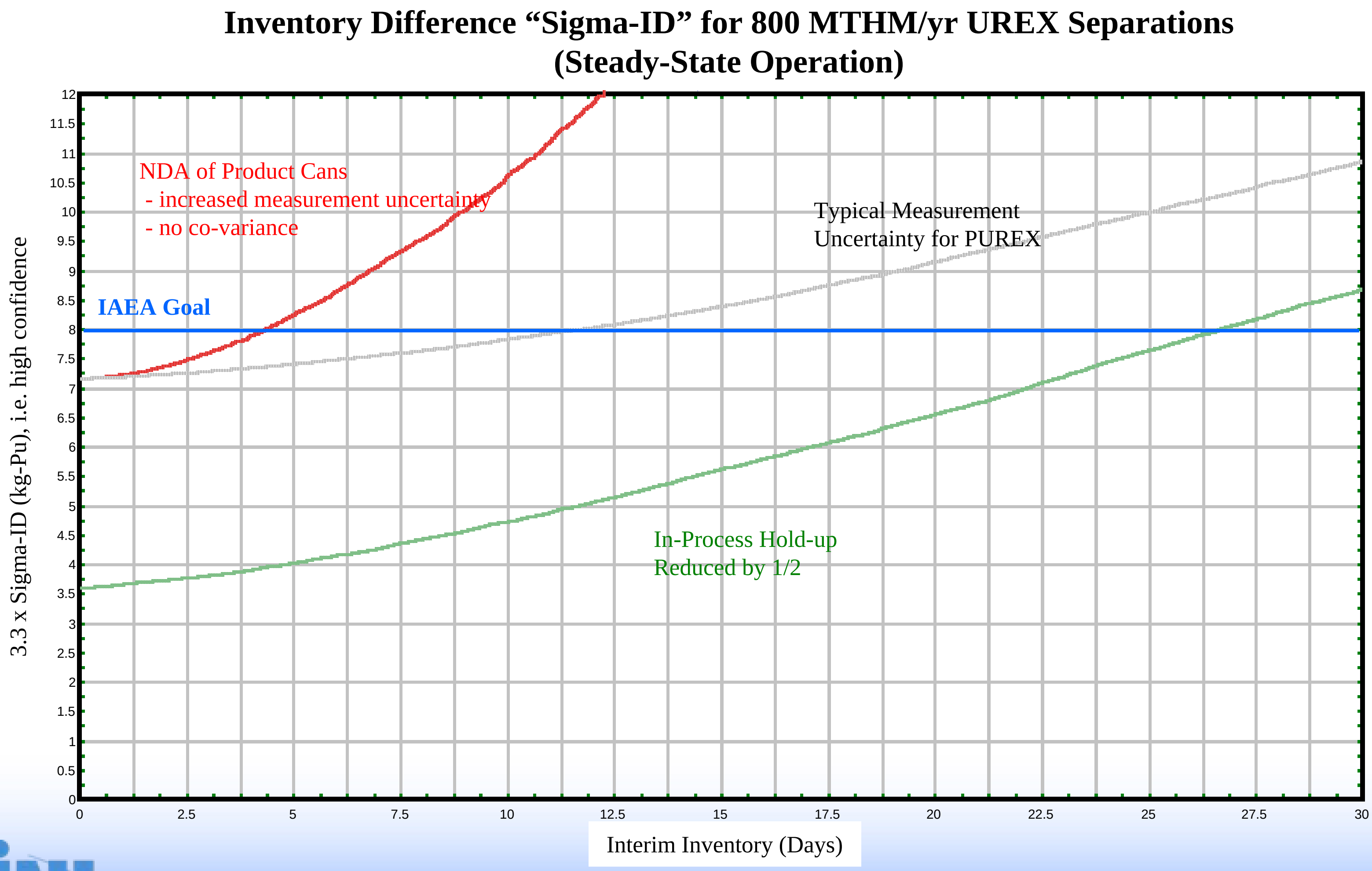
- With dramatic improvements in measurement technology, could an accurate material balance be determined that meets the IAEA goal quantities?
- Could this be done just in the feed and withdrawal area or must it include the cascade hall?

Recommendation #1: To pursue unattended non-destructive assay techniques that will allow accurate closure of the material balance and/or detection of all diversion scenarios in a timely manner with high confidence.

Reprocessing – Aqueous - PUREX



Advanced Safeguards: Cost Reduction Example (Reduced Number of Inventory Periods)



Reprocessing – Pyro-chemical

Spent fuel is placed in an anode basket which is immersed in a molten salt electrolyte.

- **An electrical current is applied, uranium metal or oxide plates out on a solid metal cathode**
- **other actinides (and the rare earths) can be absorbed into a liquid cadmium cathode.**
- **Fission products (such as cesium, zirconium and strontium) remain in the salt.**
- **many variations that have been explored, and the processes are well understood**
- **There is no initial accountability value for the spent fuel**

Spent Fuel Storage & Reprocessing: Aqueous and Pyro

- **No independently verifiable knowledge of plutonium in spent fuel**

  Recommendation #2: To pursue attended and unattended non-destructive assay approaches to quantify plutonium in spent fuel.

- **Effective black boxes in liquid and salt bulk processing areas**

  Recommendation #3: To pursue unattended on-line and at-line destructive assay techniques to replace off-line measurements.

Undeclared Facilities - S&O

- 1997 INFCIRC 540, the IAEA task: Providing credible assurance of the absence of undeclared nuclear activities in a State.

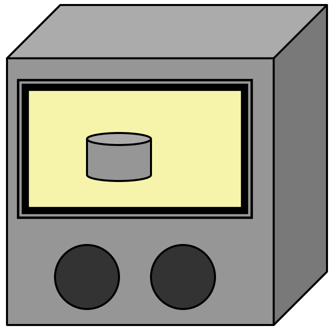
This is unequivocally the greatest challenge to the IAEA.

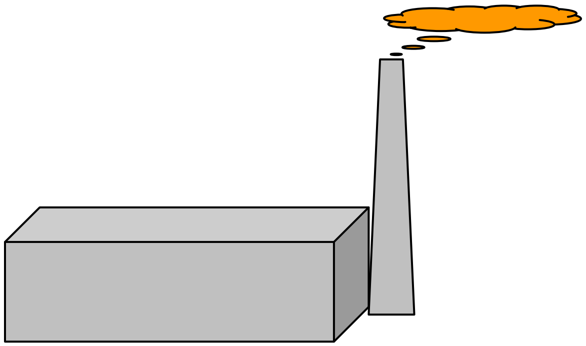
Definitions

- Signatures: An identifying characteristic or mark of one or more physical characteristics associated with a proliferant process or activity. Examples: acoustic signal, chemical.
- Observables: A physically measurable phenomenon, which can be observed, generated by an object of interest that conveys information about the object's properties. Examples: particles, waves, chemicals, effluent, electromagnetic signal.

Observables Change with Distance from Source

Observables for a Given Process Change





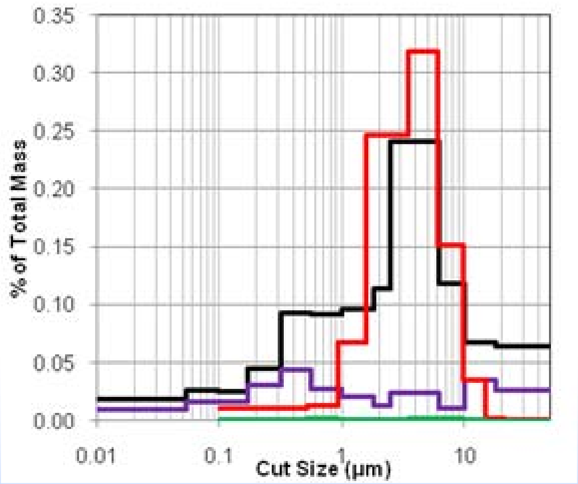
- **Process Cell**
- **Inside Plant**
- **Outside Fence**

- **Processes Effecting the Observable**
  - **Gravimetric Settling**
  - **Filtration**
  - **Conglomeration**
  - **Electrostatic forces**

Signatures and Observables

- What are the signatures and observables (S&O) for all of the elements of the nuclear fuel cycle and a nuclear weapons program?
- What is the range of detection for observables?
- What technologies are available to collect and analyze observables?
- What technologies need to be developed to collect and analyze observables?

Sampling Process



Signatures and Observables

Recommendation #4: To pursue a comprehensive assessment of all potential nuclear and non-nuclear signatures and observables.

Recommendation #5: To pursue a comprehensive assessment of all potential collection and analysis tools for nuclear and non-nuclear observables over near, medium, and long distances.

Environmental Sampling

Current primary in-field tool used by the IAEA in support of INFCIRC 540

- **Swipe sampling kits**
- **Samples sent to the IAEA Safeguards Analytical Lab (SAL) in Seibersdorf for analysis**
  - **Powerful destructive analysis tools are applied**
- **Timeliness is an issue, this impacts an inspector's effectiveness in the field**
- **Best transparency for a State would be unattended environmental monitoring**

Recommendation #6: To pursue attended and unattended in-field measurement capability for nuclear and non-nuclear observables.

Next Decade: Futures Toolkit

- Robust safeguards technical infrastructure: people, facilities, nuclear and non-nuclear materials, and stable/flexible funding
- Program should not be limited by
  - Current IAEA inspection regimes
  - Current safeguards concepts
  - Current treaty limitations
- Examples
  - Nano-Tags-chemically bind with elements of interest
  - Nano-Markers-unique component in a nuclear material flow stream
  - Nano-Sensors-nuclear & non-nuclear observables, powered by environment, wireless and self organizing, inexpensive

Conclusions

- **IAEA already faces significant science and technology challenges**
- **Expected rapid expansion of the nuclear fuel cycle will exacerbate these challenges**
- **Under existing IAEA resource constraints, technological advances are the key to success**
- **The most important technological thrust areas have been indicated for declared and undeclared facilities**

"Revitalization of international safeguards is critical and a prerequisite for the safe and secure expansion of nuclear power. IAEA safeguards provide irreplaceable assurances of peaceful use, deter diversion through the threat of detection, and ultimately help promote transparency and stability."