CANDU Non-Proliferation and Safeguards: "A Good Story Seldom Told"

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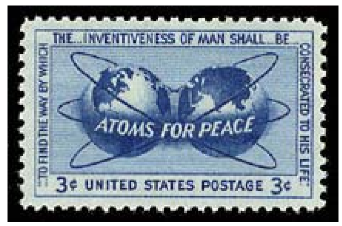
AECL
Atomic Energy of Canada Limited

Canada

- History of nuclear non-proliferation
- IAEA Safeguards
- CANDU Proliferation Resistance
- AECL Safeguards Technology Program
- International collaboration

HISTORY OF NUCLEAR NON-PROLIFERATION

- **1945:** **"Agreed Declaration on Atomic Energy" signed by USA, UK, Canada**
  - *prevent nuclear proliferation*
  - *promote peaceful use of nuclear energy*
- **Prior to mid-1950s:** **Information denial policy (USA)**
- **Dec.8, 1953:** **"Atoms for Peace" (not "Atoms ONLY for Peace")**
- **1954-1960s:** **Export controls & safeguards (initially between USA and others)**



HISTORY OF NUCLEAR NON-PROLIFERATION (cont'd)

- **1957:** **IAEA…**
  - *promotion of nuclear energy*
  - *international safeguards*
  - *Canada on Board of Governors since inception*
- **1965:** **Canada ends uranium exports for weapons use (USA, UK); will only export for peaceful use, with safeguards (Pearson)**
- **1968:** **Tlatelolco Treaty (Latin America)… full-scope safeguards**
- **1970:** **Treaty on the Non-Proliferation of Nuclear Weapons (NPT):**
  - *5 NW states vow to not spread weapons, and get rid of theirs (eventually).*
  - *NNW states vow to not acquire weapons, and pursue only peaceful uses of nuclear energy.*

HISTORY OF NUCLEAR NON-PROLIFERATION (cont'd)

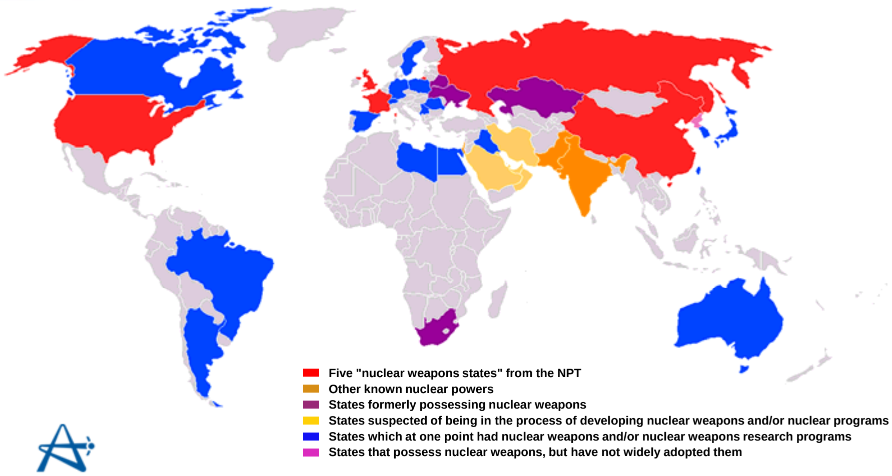
- **1974:** Zangger List (NPT): "trigger list" of sensitive export materials
- **1974:** India detonates nuclear device using Pu from CIRUS
  - *Canada adopts more stringent export safeguards, established in formal bilateral Nuclear Co-operation agreements (1974 Policy Stmt.)*
- **1976:** Canada nuclear cooperation only with signatories to NPT
  - *1974 and 1976 Policy Statements form basis of Cdn. non-proliferation policy (most stringent?)*
- **1978:** Nuclear Suppliers Group (NSG)
  - *Export controls*
  - *Subset of Canadian policy*

HISTORY OF NUCLEAR NON-PROLIFERATION (cont'd)

- **1990:** Canada re-instates limited safety assistance for Pakistan and India, under recommendation of IAEA
- **1995:** Indefinite extension of NPT (25-year review)
- **1997:** IAEA adopts "additional protocol" safeguards
  - *Information on (and access to) all parts of fuel cycle (incl. locations where nuclear material for non-nuclear use is stored), all buildings on nuclear sites, manufacturing of sensitive equipment*
  - *Expanded environmental sampling (locations, wide-area sampling)*
  - *Enhanced inspection access rights and communication abilities*
- **2002:** IAEA adopts "integrated safeguards"
  - *Optimum application of comprehensive safeguards, based on State-level approach*
  - *Requires annual IAEA conclusion about state-wide peaceful use of nuclear material (Canada received this in Sept. 2005)*

NUCLEAR WEAPONS PROLIFERATION

… a political decision



(source: Wikipedia)

IAEA SAFEGUARDS

- Timely detection of diversion of significant quantities of nuclear material (and resulting deterrence)
- Based on material accountancy, including "declared" nuclear material as well as "undeclared" production, and independent verification.
- Power reactors have not been attractive targets for proliferation
- CANDU technology sets the standard for effective and comprehensive safeguards
- Canada a founding member of IAEA, a leader in the development of a global safeguards regime

IAEA SAFEGUARDS

"Timeliness":

- <u>Detection Time</u> : Maximum time that may elapse between diversion and its detection by Agency safeguards
  - ✓ Assumes that necessary facilities exist to convert material;
  - ✓ Processes already tested
  - ✓ Non nuclear components of the device already assembled and tested

Material	Detection Time (Inspection Frequency)
Unirradiated direct-use (MOX)	1 month
Irradiated direct-use (spent fuel)	3 months
Indirect-use (fresh fuel)	12 months

IAEA SAFEGUARDS

"Significant Quantity":

- Amount for which possibility of nuclear explosive cannot be excluded.
- Takes into account losses due to conversion and other processes.

	Material	Significant Quantity, SQ	Relevance to CANDU
"Direct-Use" Nuclear Material	Pu (<80% Pu-238)	8 kg	>100 bundles spent fuel
	U-233	8 kg	NA
	U [U-235>/= 20%]	25 kg	NA
"Indirect-Use" Nuclear Material	U [U-235<20%]	75 kg (U-235) or 10 t (NU)	>500 bundles
	Thorium	20 t	NA

IAEA SAFEGUARDS

"Nuclear Material Accountancy"

- **Items: fuel bundles**
- **Material Balance Area: fresh fuel storage, reactor core, spent fuel bays**

Flow KMPs*
- Receipts
- Shipments
- Nuclear production

Inventory KMPs
- Fresh fuel
- Reactor core (?)
- Spent fuel Reception Bay
- Spent fuel Storage Bay

*Key Measurement Points

IAEA SAFEGUARDS

"Nuclear Material Accountancy" (cont'd)

- **Facility maintains near real time NM accounting records for shipments, receipts, and fuel movements within the MBA.**
  - ***Bar coding supports fresh fuel accounting.***
- **Facility files reports to SSAC* when bundles enter or leave the MBA, which are submitted to the IAEA**
- **For inspections, facility prepares a detailed List of Inventory Items containing the location of each bundle.**
- **Once a year the facility performs a physical inventory check and prepares a Physical Inventory Listing for submission to the IAEA.**

***State System for Accounting and Control**

IAEA SAFEGUARDS

"Verification": Reactor Inspections

1. Annual Comprehensive Physical Inventory Verification
   - *Fresh and spent fuel*
2. Quarterly Interim Inventory Verification
   - *Spent fuel (3 month timeliness for Pu)*
3. Design Information Verification, Follow up to discrepancies and anomalies, Maintenance of IAEA equipment, etc.
4. Transfers
   - *Receipts of fresh fuel*
   - *Shipments of spent fuel*

HOW DO WE MEASURE PROLIFERATION RESISTANCE?

- Several expert groups (e.g. GIF, INPRO) have considered the targets and pathways for Proliferation, and have come up with "measures" that address these:

  - Technical Difficulty
  - Time
  - Cost
  - Fissile Material Quality

  } "Intrinsic"

  - Detection Probability (or Safeguardability)
  - Detection Resources (Cost of Safeguards)

  } "Extrinsic"

"INTRINSIC" PROLIFERATION RESISTANCE OF CANDU REACTORS

- **Technical Difficulty, Proliferation Time & Cost:**
  - CANDU NU fuel cycle **does not require and enrichment facility**.
  - **Large mass of CANDU spent fuel** (standard burnup) is required to extract one "Significant Quantity" of reactor-grade Pu: >2 tonnes, comprised of >100 CANDU fuel bundles (~twice the mass of LWR spent fuel for equivalent Pu production)
  - **Pu concentration ($kg_{PU}/kg_{SPENT\ FUEL}$) in spent fuel is low** (~half that of LWR), despite higher production rate (kg_{PU}/ MWd_e) – this important distinction is due to much higher fuel throughput
  - Excess reactivity low (**cannot tolerate added absorbers**)
  - On-power refuelling requires **complex, automated, monitored process** (daily refuel needed, at coolant temp. & pressure, in ~1000 rem/hr fields)
  - Refuelling frequency near **maximum capability of fuelling machine**

"INTRINSIC" PROLIFERATION RESISTANCE OF CANDU REACTORS (cont'd)

- **Fissile Material Quality:**
  - Pu isotopic quality "**reactor grade**" (similar to LWR), despite relatively low average burnup – this is due to high flux per unit power in CANDU, and use of natural uranium.

	Pu Isotopic Composition of Spent Fuel					
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	%fissile
CANDU NU[1]	0.1%	66%	27%	5%	1%	71%
CANDU SEU[1]	0.4%	44%	39%	8%	9%	52%
PWR[2]	1.3%	63%	25%	6%	5%	69%

1 Dyck, Gary R., unpublished transport calculations using WIMS-AECL, 1999 November
2 National Academy of Sciences, "The Spent Fuel Standard for Disposition of Excess Weapons Plutonium", National Academy Press, Washington, DC, 2000.

"EXTRINSIC" PROLIFERATION RESISTANCE OF CANDU REACTORS (SAFEGUARDS)

- **Detection Probability (Safeguardability):**
  All power reactors must meet same IAEA safeguards criteria and goals.
- **Detection resources (Cost of Safeguards):**
  Higher than LWR but small compared with detection resources for a bulk facility, e.g. enrichment (i.e. detection resources relative low for full fuel cycle). Cost is minor compared to O&M cost of facility.

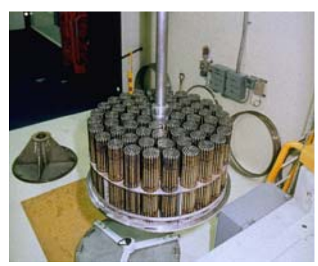
SAFEGUARDS APPROACH IN CANDU

- **Focus:** ***Accountability for Spent Fuel***
- **Approach:**
  - **Detailed accounting of fissile material inventory**
  - **IAEA Inspections:**
    - **Independent verification of facility accounts by counting and verifying authenticity of randomly selected fresh and spent fuel**
    - **Verification that station changes do not compromise safeguards effectiveness**
  - **Safeguards technology:**
    - **Counting spent fuel bundles as they are removed from the reactor**
    - **Monitoring spent fuel movement and storage**
    - **Monitoring for removal of spent fuel along non-standard paths (e.g. airlock, rehearsal port, fresh fuel loading port)**

CERENKOV VIEWING DEVICE (CVD)

TRANSFERS TO DRY STORAGE

- Approx. 3000 bundles per year transferred in a campaign lasting ~2 months
- Bundles transferred from trays/modules into baskets with welded covers holding 60 bundles each
- 1-2 baskets loaded, dried, welded and transferred per day
- Neutron/gamma detectors and used to monitor transfer, and dual seals placed on dry storage



DEFENSE IN DEPTH:
Complementary and Redundant Safeguards System

- Both gamma and neutrons monitored
- Detection contiguous and overlapping (e.g. core discharge + bundle counter)
- Both cameras and sealing (spent fuel bay)
- Camera views overlapping
- Two redundant seals (spent fuel bay, dry storage)

AECL SAFEGUARDS TECHNOLOGY PROGRAM
Background

- Not a “Program”
- Cross-cutting capability for support of CANDU safeguards through technology development, coordinated by Manager, Non-Proliferation & Safeguards
- Historically, as a supplier to IAEA, CNSC (legacy support for ARC sealing, CVDs)
- Presently, still in supplier mode but taking a proactive stance (e.g. Safeguards by Design)
- Increase visibility/activity in this area

AECL SAFEGUARDS TECHNOLOGY PROGRAM

Legacy Support Items

- ARC Sealing
- CVD

New and Innovative Items…

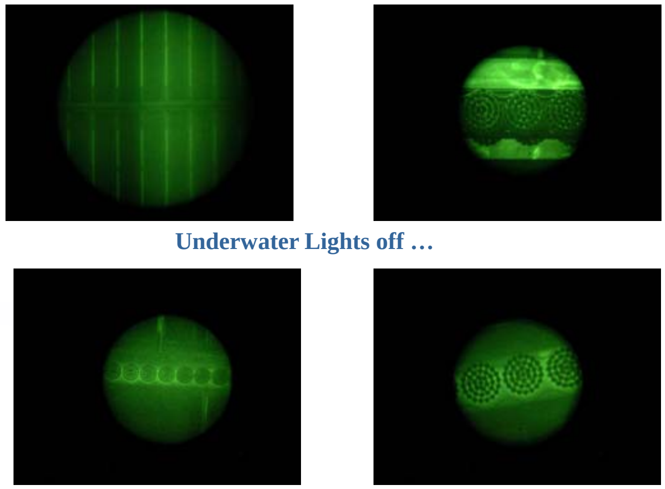
AECL SAFEGUARDS TECHNOLOGY PROGRAM

Digital Imaging CVD (CVD-DIS)

CVD-DIS images from G-2 Bays

Underwater Lights on …

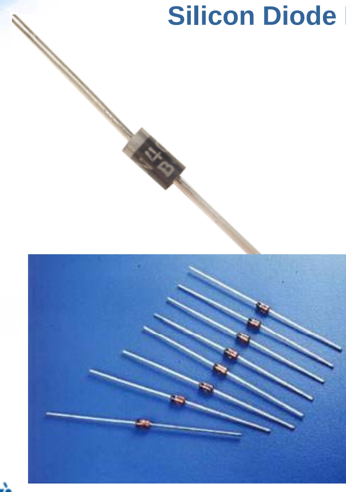
Underwater Lights off …



7-year cooled CANDU 6 fuel bundles

AECL SAFEGUARDS TECHNOLOGY PROGRAM

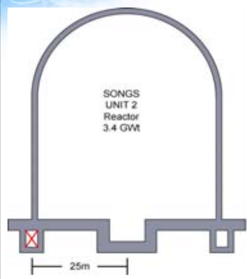
Silicon Diode Radiation Detector



- Inexpensive
- Disposable
- Readily available
- Works for very high fields
- Small - Can fit anywhere
- Very simple design

INTERNATIONAL COLLABORATION:

Anti-neutrino detectors



25 meters standoff from core

San Onofre Nuclear Generating Station
Unit II – 3.46 GWt

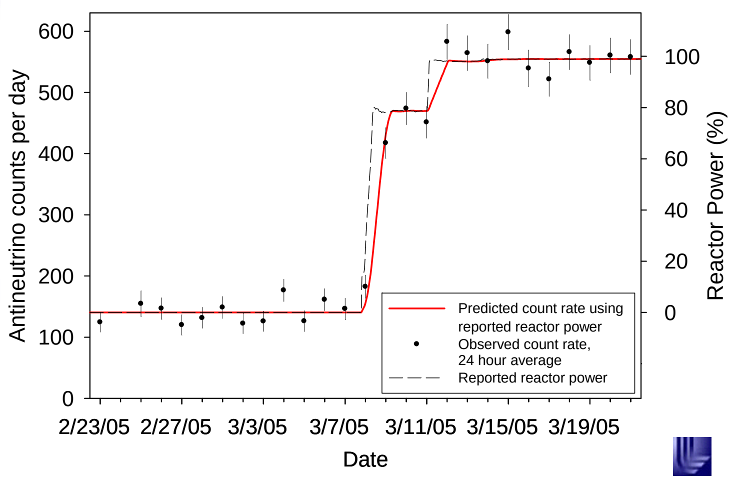
20 metre overburden

LLNL

Sandia National Laboratories

INTERNATIONAL COLLABORATION:

Daily Power Monitoring Using Only Antineutrinos



LLNL

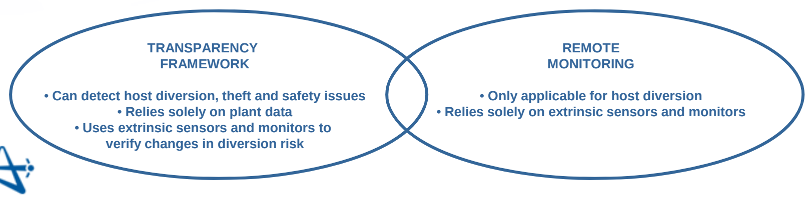
Sandia National Laboratories

INTERNATIONAL COLLABORATION:

CANDU Safeguards Transparency (Sandia)

- Reactor power history
- Individual bundle tracking at all times
- Tracking of on-load fuel handling (FM position, bundles entering/leaving core, etc.)

→ with verification (remote monitoring)



INTERNATIONAL COLLABORATION:

International working groups on PR

- GIF Proliferation Resistance & Physical Protection (PRPP) Working Group
  - *Co-chair (R. Nishimura)*
  - *PRPP assessment methodology published*
- INPRO Collaborative Projects
  - *Proliferation Resistance assessment manual for new Nuclear Energy Systems (to be published)*
  - *CANDU DUPIC PR analysis (Korea, Canada, U.S., Russia, JRC-Ispra)*

SUMMARY

- CANDU safeguards are **proven**
  - *Approach successfully used to safeguard 31 CANDU reactors for past 25 years.*
  - *Second generation safeguards systems support remote monitoring and provides enhanced robustness*
- CANDU has **intrinsic features** that provide proliferation resistance
- CANDU has a **unique and historically relevant role** to play in new proliferation-resistant fuel cycle development

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