




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



Jeremy Whitlock
Manager, Non-Proliferation and Safeguards
whitlockj@aecl.ca

2007 December 13



- 
- **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*

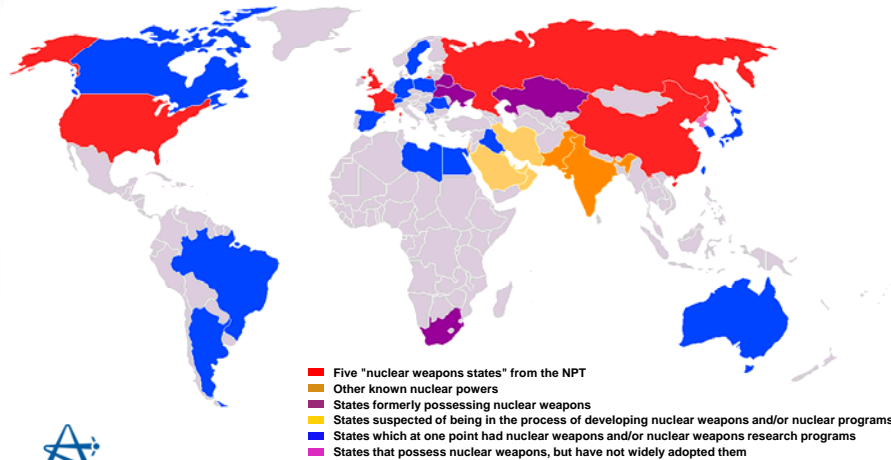
HISTORY OF NUCLEAR NON-PROLIFERATION (cont'd)

- **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”:

- **Detection Time** : 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*	Inventory KMPs
– Receipts	– Fresh fuel
– Shipments	– Reactor core (?)
– Nuclear production	– 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 ($\text{kg}_{\text{Pu}}/\text{kg}_{\text{SPENT FUEL}}$) in spent fuel is low (~half that of LWR), despite higher production rate ($\text{kg}_{\text{Pu}}/\text{MWd}_e$) – 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 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...



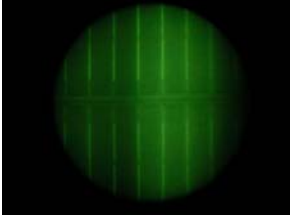
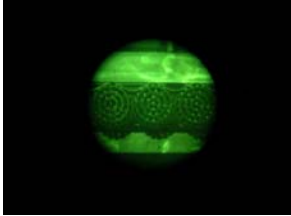
AECL SAFEGUARDS TECHNOLOGY PROGRAM

Digital Imaging CVD (CVD-DIS)

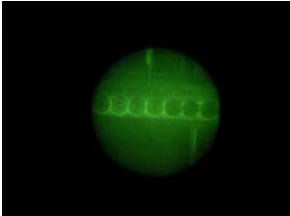
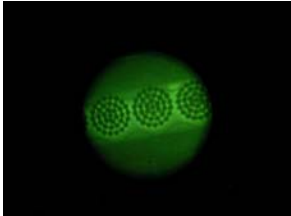


CVD-DIS images from G-2 Bays


Underwater Lights on ...

Underwater Lights off ...

7-year cooled CANDU 6 fuel bundles



AECL SAFEGUARDS TECHNOLOGY PROGRAM

Silicon Diode Radiation Detector



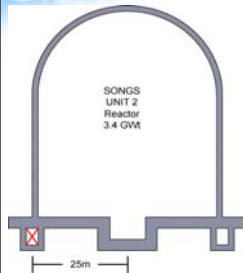



- Inexpensive
- Disposable
- Readily available
- Works for very high fields
- Small - Can fit anywhere
- Very simple design



INTERNATIONAL COLLABORATION:

Anti-neutrino detectors



25 meters standoff
from core



20 metre overburden

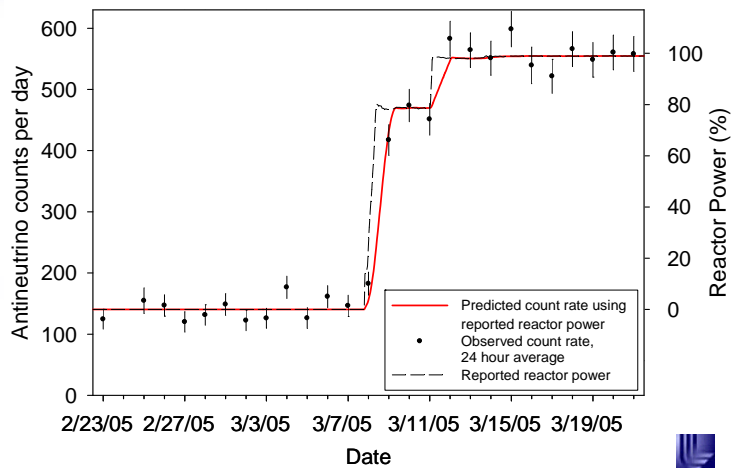



San Onofre Nuclear Generating Station
Unit II – 3.46 GWt



INTERNATIONAL COLLABORATION:

Daily Power Monitoring Using Only Antineutrinos





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)

TRANSPARENCY
FRAMEWORK

- Can detect host diversion, theft and safety issues
 - Relies solely on plant data
- Uses extrinsic sensors and monitors to verify changes in diversion risk

REMOTE
MONITORING


- Only applicable for host diversion
 - Relies solely on extrinsic sensors and monitors

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**

