RMCC-X Workshop, Khalifa University
Abu Dhabi, UAE, 19 – 21 October 2015

Overview of Nuclear Safeguards Measures and Instrumentation

Alexander Solodov
Khalifa University
Nuclear Engineering Department
Abu Dhabi, UAE

What are IAEA Safeguards?

- The safeguards system comprises measures by which the IAEA independently verifies the declarations made by States about their nuclear material and activities
- Safeguards are designed to ensure that safeguarded items are not used in such a way as to further any military purpose
  - applied by the IAEA to verify that commitments made by States under safeguards agreements with the IAEA are fulfilled
- Measures are implemented under various types of agreements and protocols

Source: http://iaea.org

Objectives of IAEA Safeguards

- **Objective 1:**
  - 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

- **Objective 2:**
  - The detection of *undeclared nuclear material and activities* in a State

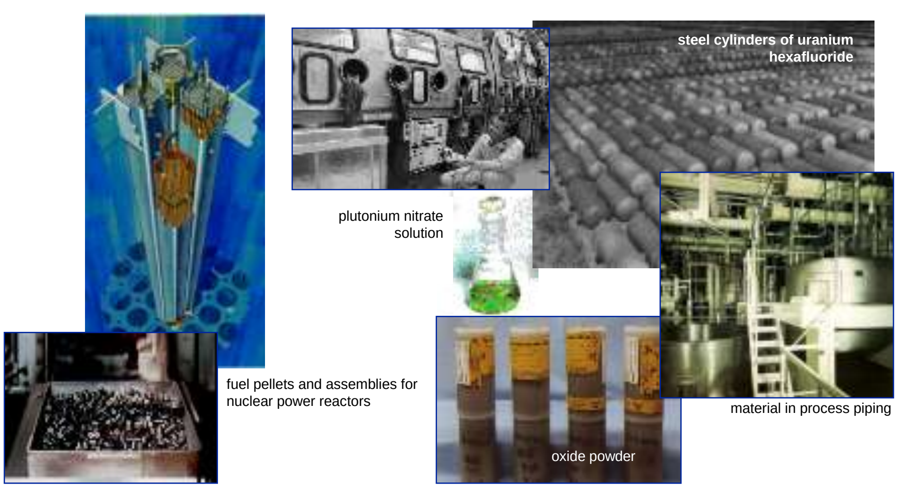
Components of the IAEA Safeguards System

- Nuclear Material Accountancy
- Containment and Surveillance
- Design Verification
- Reports
- Inspections

Special Nuclear Materials

- What are the materials that are subject to safeguards?
- To produce a nuclear explosive device one must acquire:
  - Special Nuclear Material (SNM)
    - plutonium
      - produced from ^{238}U irradiation in a nuclear reactor
    - high enriched uranium (HEU, >20% ^{235}U)
      - acquired by enriching natural uranium from the ground
    - ^{233}U
      - produced from ^{232}Th irradiation in a nuclear reactor
  - note: none of these materials exist naturally

Wide Variety of Physical and Chemical Forms, and Containers



Source: INMM International Safeguards Tutorial

Safeguards Agreements

Safeguards Agreements and Applications

- An agreement for the application of safeguards concluded between the IAEA and a State or a group of States
  - in certain cases, with a regional or bilateral inspectorate, such as Euratom and ABACC
  - agreement is concluded either because
    - of the requirements of a project and supply agreement
    - to satisfy the relevant requirements of bilateral or multilateral arrangements (treaties)
    - at the request of a State to any of that State’s nuclear activities
  - there are several types of safeguards agreements

Types of Safeguards Agreements

INFCIRC/66-type safeguards agreement: based on INFCIRC/66

- Agreement specifies the nuclear material, non-nuclear material, facilities and/or equipment to be safeguarded
- Prohibits the use of the specified items in such a way as to further any military purpose

Types of Safeguards Agreements

INFCIRC/153-type safeguards agreement: concluded on the basis of INFCIRC/153 rev.2

Comprehensive safeguards agreement (CSA):

Applies safeguards on all declared nuclear material in all declared nuclear activities in a State

Voluntary offer agreement (VOA): concluded between the IAEA and a NWS

- NWS voluntarily offers to allay concerns that safeguards could lead to commercial disadvantages
- Some or all material/facilities
- Follows format of INFCIRC/153, but not comprehensive
- IAEA has concluded VOAs with each of the five NWS's

Small Quantity Protocol (SQP):

Concluded between the IAEA and a State

- The state has less than specified minimal quantities on nuclear material
- The state has no nuclear material in the facility

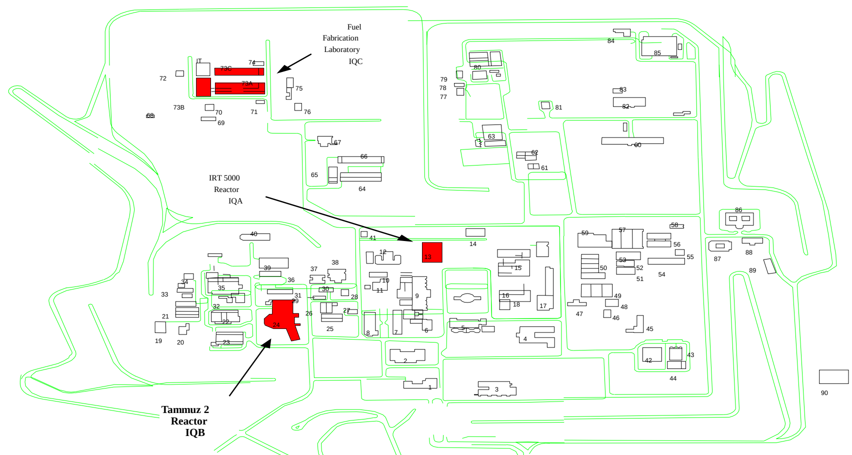
Limitations of Safeguards - INFCIRC/153

- Focus is on *declared materials* at strategic points at *declared facilities*
- Only partial coverage which is not continuous [mines, waste]
- Assumes a State declares everything

The Case of Iraq

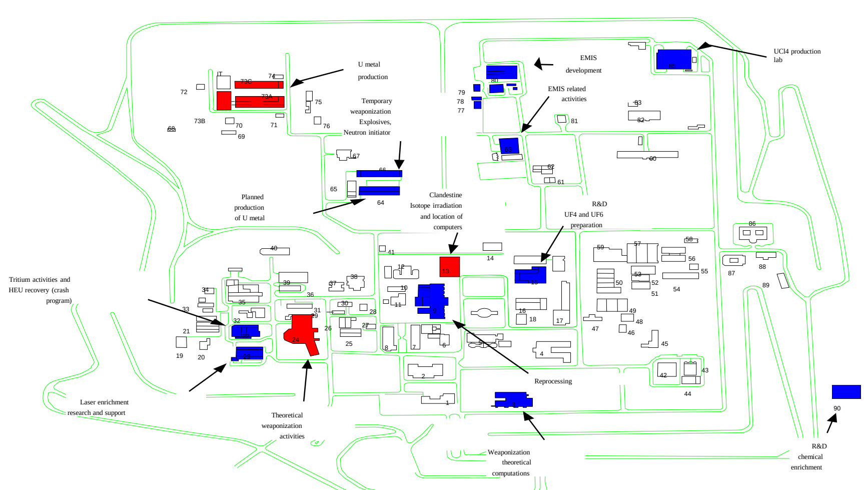
- Violated NPT Article III commitment not to acquire nuclear weapons
- Undeclared enrichment activities were discovered during the Gulf War in 1991
- Activities were next to inspected facilities
- IAEA did not have the authority to request access
- Post-war revelations resulted in widespread conclusion that broader access and additional information as needed for the IAEA to detect future violations

Al Tuwaitha Nuclear Center, Iraq
Activities Declared Prior to 1991



Picture provided by the IAEA

Al Tuwaitha Nuclear Center, Iraq
Clandestine Nuclear Weapons Activities



Picture provided by the IAEA

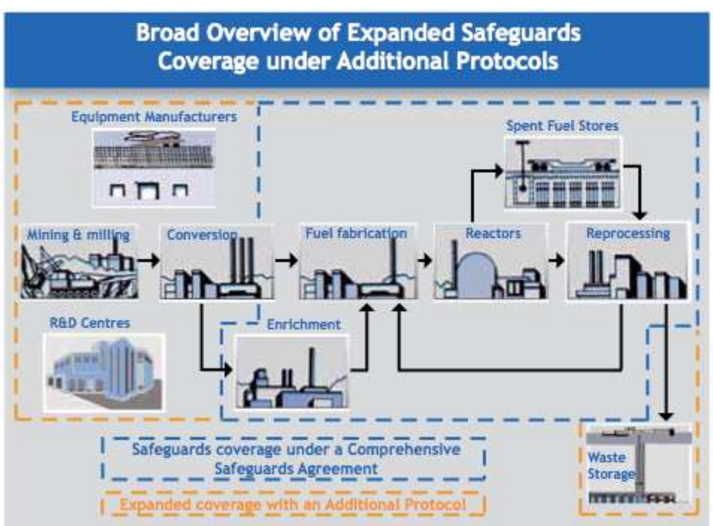
Additional Protocol

– A protocol additional to a safeguards agreement concluded between the IAEA and a State following the provisions of INFCIRC/540

  – requires the State to declare all fuel cycle facilities

  – allows for environmental sampling, multi-entry visas for inspectors, increased access to shipping and receiving records, and information on all facilities related to the nuclear fuel cycle (includes non-nuclear materials)

Additional Protocol Coverage



Source: http://www.iaea.org/Publications/Booklets/Safeguards3/safeguards0707.pdf

Integrated Safeguards

- Optimum combination of all safeguards measures available under *comprehensive safeguards agreement* and *additional protocol*
  - To achieve maximum effectiveness and efficiency in meeting the IAEA's safeguards obligations within available resources
  - Implemented in a State only when the IAEA has drawn a conclusion of the absence of undeclared nuclear material and activities

- Under integrated safeguards, measures may be applied at reduced levels at certain facilities

Technical Tools for Nuclear Material Safeguards

Safeguards Technical Tools

- The IAEA has the task of providing continuing assurance to the international community that States that have entered into safeguards agreements with the IAEA are meeting their obligations

- Variety of technical means are used to verify correctness and completeness of states' declarations:
  - non-destructive analysis
  - unattended monitoring
  - containment and surveillance
  - remote monitoring systems
  - destructive analysis
  - environmental sampling

Non-Destructive Analysis

- The IAEA uses more than 100 different NDA systems to verify, check and monitor nuclear materials without changing their physical or chemical properties
- NDA instruments range in size and complexity from small portable units used by safeguards inspectors during on-site verification activities to large in-situ NDA systems designed for continuous unattended in-plant use
- The most widely used NDA instruments rely on detection of nuclear radiation such as gamma-rays and/or neutrons
- Physical measurement techniques are also used, with available instruments that measure
  - heat
  - weight
  - volume (of liquids)
  - thickness
  - light emission/absorption

Non-Destructive Assay

NDA Instrument Examples

Handheld potable gamma-ray detector HM-5

Cerenkov Viewing Device (for distinguishing spent fuel from voids, etc.)

Fork Detector for Measuring Defects in Irradiated Fuel Assemblies (fission chambers and ion chambers)

Passive Neutron NDA

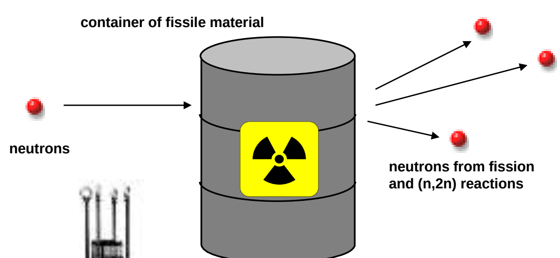
- Most nuclear materials emit alpha particles, which then react locally to produce (single) neutrons
- Plutonium also fissions spontaneously, so it can simultaneously release *multiple* neutrons
- Coincidence counting identifies this fission neutron signal to assay plutonium

Combination of neutron counting and gamma spectroscopy

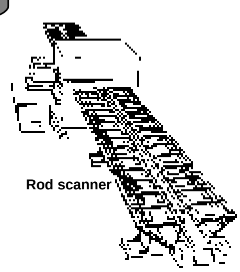
High Level Neutron Coincidence Counter

Source: INMM International Safeguards Tutorial

Active Neutron NDA



Active neutron coincidence "collar"



Rod scanner

Active well coincidence counter

Source: INMM International Safeguards Tutorial

Unattended Monitoring

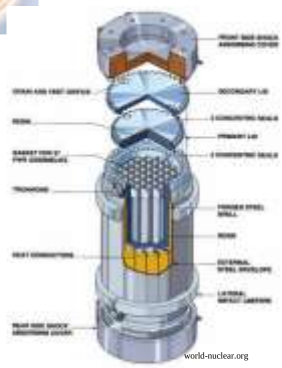
- Unattended monitoring systems (UMSs) run 24 hours a day, 365 days a year without requiring the presence of an inspector in the field
- They continuously perform a wide variety of qualitative or quantitative measurements of processes throughout the nuclear fuel cycle, including:
  - uranium enrichment
  - conversion
  - fuel fabrication
  - reactor operation (light water reactors (LWRs), heavy water reactors (HWRs), fast reactors, research reactors)
  - spent fuel reprocessing
  - spent fuel management (wet storage, dry storage)
  - intermediate and high active waste management

Containment and Surveillance

- Containment and surveillance (C/S) techniques, based mainly on optical surveillance and sealing systems, are applied to supplement nuclear material accountancy by providing means by which access to nuclear material can be controlled and any undeclared movement of nuclear material detected
  - Flexible and cost effective
  - Reduce inspection costs and the level of intrusiveness of the IAEA Into normal operational activity of nuclear facilities under safeguards
- C/S measures are applied in a systematic manner to monitor all diversion paths considered credible at the boundary of a facility, to ensure that transfers of nuclear material take place only at declared key measurement points

C&S Measures Examples

Containment: loop seals



world-nuclear.org

Surveillance: digital video camera

Source: INMM International Safeguards Tutorial

Remote Monitoring Systems

- Remote monitoring in the safeguards context is generally considered to mean the transmission off-site to IAEA Headquarters or to an IAEA regional office of data collected from
  - Sealing systems
  - Unattended monitoring systems
  - Optical surveillance systems
- Safeguards approaches using remote monitoring offer the potential to reduce inspection effort while improving the timeliness of results
- Cost effectiveness is a prime justification and is achieved primarily by reducing the frequency of inspection visits and shortening inspections (as the need to service sealing, surveillance and NDA equipment is reduced and in some cases eliminated)

Destructive Analysis

- Destructive analysis measurements for element assay and determination of isotopic composition can be made of all types of solid and liquid materials encountered in bulk handling nuclear plants
- Destructive analysis is used in the following ways:
  - to verify that protracted diversion of safeguarded nuclear materials has not occurred
  - to certify working standards used for the calibration of NDA and installed verification instruments
  - to provide assurance of the quality and independence of on-site measurements (e.g. validation of facility specific procedures)
  - to carry out periodic verification of operator measurement systems

Thermal Ionization Mass Spectrometer

Environmental Sampling

- Environmental sampling was introduced in 1996 as one of a number of new IAEA safeguards measures that contribute to confirming the absence of undeclared nuclear material or nuclear activities
- The collection of environmental samples at or near a nuclear site combined with ultrasensitive analytical techniques such as mass spectrometry, particle analysis and low level radiometric techniques can reveal signatures of past and current activities in locations where nuclear material is handled

Sampling Team

- Consists of a team of at least two persons performing swipe sampling:
  - Sample comes into direct contact with the piece of cloth used to take swipe samples
  - Assistant does not (except when taking a control swipe sample)

- This system is intended to keep the risk of cross-contamination during the sampling process as low as possible

Sampling Kit

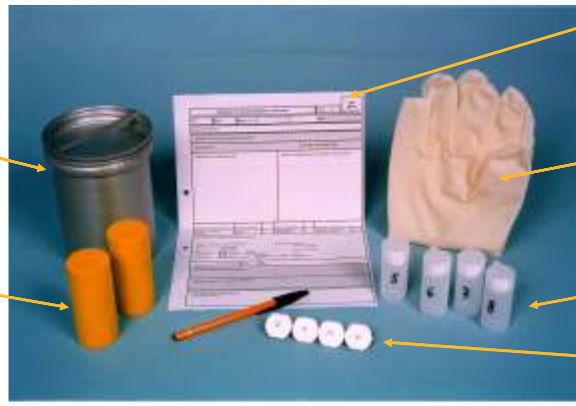
- A kit of items to be used for taking environmental samples,
  - Preassembled in a strictly controlled environment of a clean laboratory to guarantee the absence of unacceptable contamination

- Two types of kit are used:
  - Standard swipe sampling kit containing several pieces of cotton cloth or other sampling media, intended to be used for point or composite sampling
  - Hot cell sampling kit with several sampling tools intended for sampling inside hot cells

Standard Swipe Sampling Kit

Source: http://iaea.org

Hot Cell Sampling Kit



Source: http://iaea.org

IAEA Clean Laboratory

- The IAEA maintains its own clean lab as part of the Safeguards Analytical Laboratory (SAL) to provide analytical services to support the environmental sampling program

- Clean Lab is responsible for the:
  - Provision and certification of sampling kits
  - Receipt, screening and distribution of environmental samples taken by IAEA inspectors

- Maintains part of its laboratory space at ‘Class 100’ cleanliness level
  - To reduce the risk of cross-contamination

Some Analytical Tools Used

- Fission Track analysis
- Thermal Ionization Mass Spectrometry (TIMS)
- Scanning Electron Microscopy (SEM)
- Secondary Ion Mass Spectroscopy (SIMS)

Calibrations

- Safeguards measurements have important legal and political ramifications,
  - So physical standards are used extensively to calibrate measurement equipment and provide a basis for determining the accuracy of measurements
- We use these standard reference materials to determine the measurements systems characteristics with respect to:
  - Accuracy: characterizes the measurement systems ability to provide a result close to the true value when a sample is measured
    - Related to systematic error
  - Precision: characterizes the measurement system's probability of providing the same result every time a sample is measured
    - Related to random error

Conclusions

- Main objective of safeguards is to prevent diversion of nuclear materials from the peaceful use for weaponization activities
- International Nuclear Safeguards are a fundamental pillar of the non-proliferation regime, they continue to play an important role in curbing the spread of nuclear weapons
- Safeguards require international cooperation and a legal framework for implementation
- A variety of technical tools enables safeguards to provide accountancy and continuity of knowledge of nuclear materials
- Challenges to the international safeguards regime have led to major, but evolutionary improvements

SHUKRAN