International Nuclear Safeguards

INMM Tutorial

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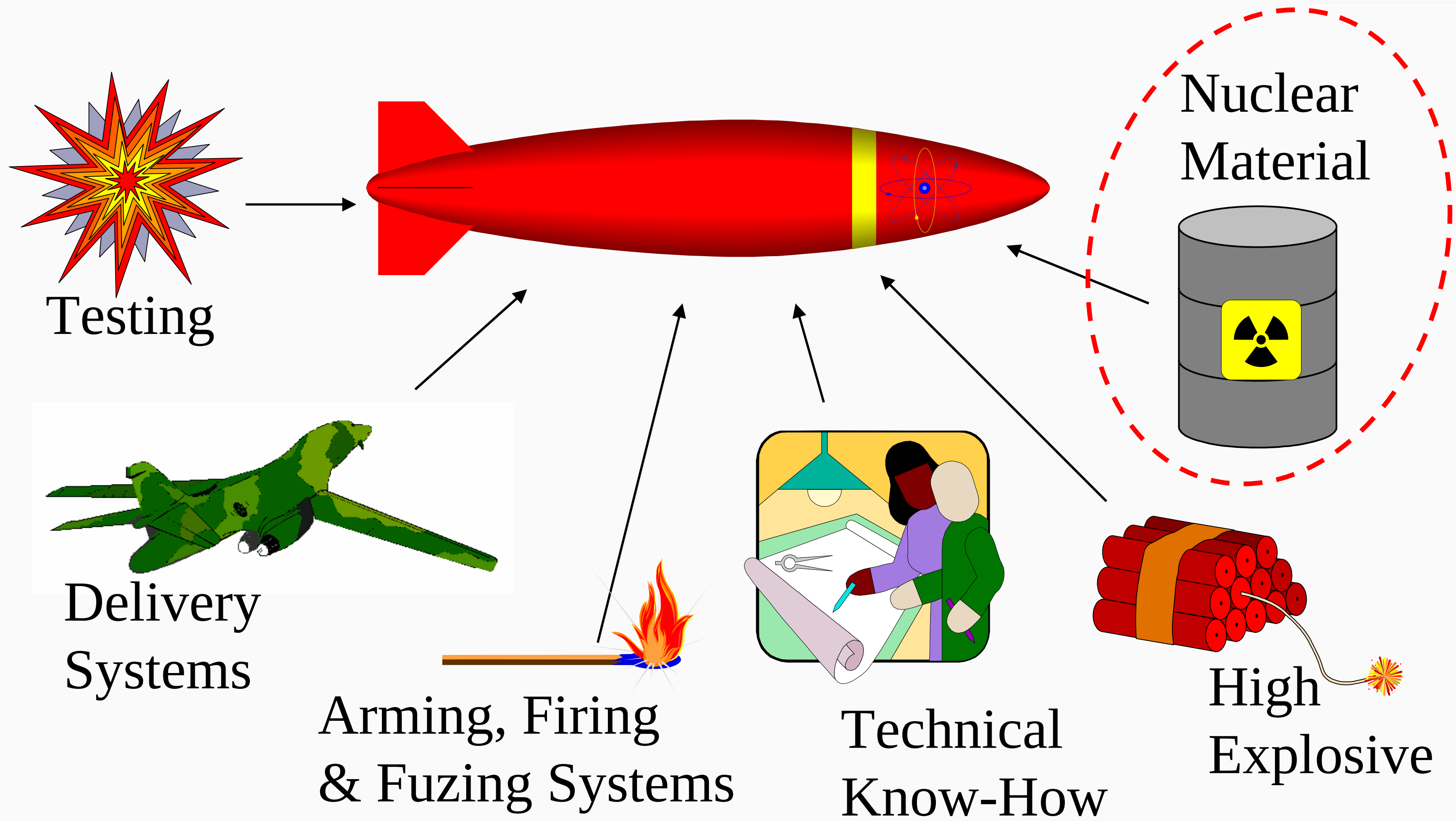
SAND 2006-4071P

Sandia is a mulitprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy under contract DC-AC04-94AL85000

International nuclear safeguards play an essential role to help ensure that nuclear materials are not used to make weapons.



Note: Here "safeguards" are <u>not</u> the same as nuclear safety.

The technical objective of International Nuclear Safeguards is:

"…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 risk of early detection."

IAEA Information Circular (INFCIRC)153
paragraph 28

International Nuclear Safeguards have been enormously successful for non-proliferation: How do they work?

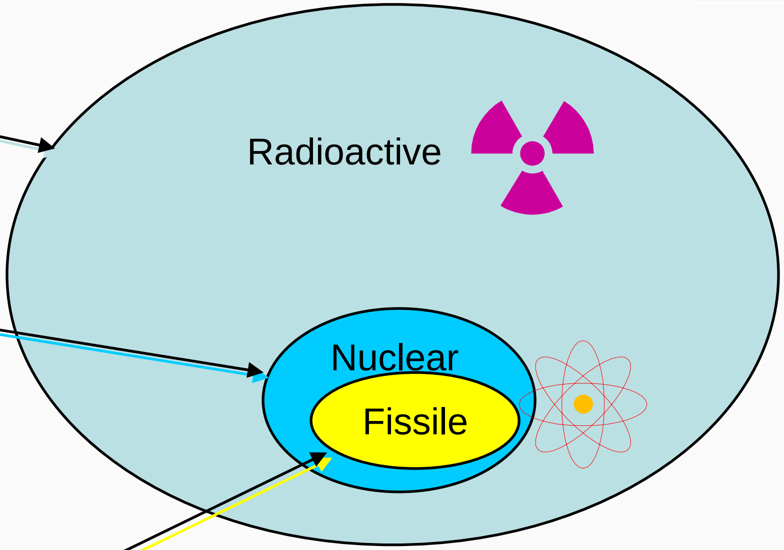
Outline of this tutorial:

- What are “nuclear” and “fissile” materials?
- What are the technical tools that can be used for nuclear material safeguards?
- How are the technical measures applied to achieve a Safeguards objective?
- How are Nuclear Safeguards applied internationally?
- How have Safeguards evolved to meet challenges to the nuclear nonproliferation regime?

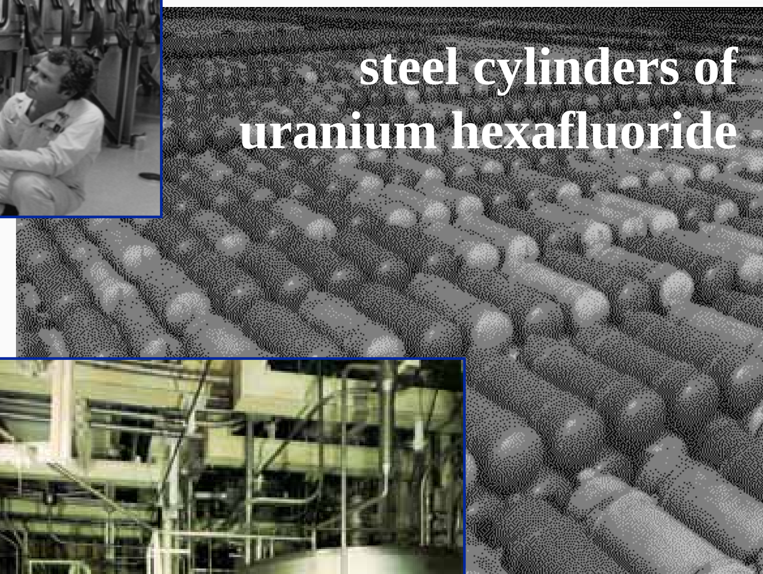
What are nuclear and fissile materials?

Safeguards are concerned with nuclear—especially *fissile*—materials and associated technology.

- Radioactive Materials
- Nuclear Materials:
  - Uranium (U)
  - Plutonium (Pu)
  - Thorium (Th)
  - Includes metals, alloys, and chemical compounds
  - Does not normally include ore and ore residue
- Fissile Materials
  - Weapons-usable
  - Dual use

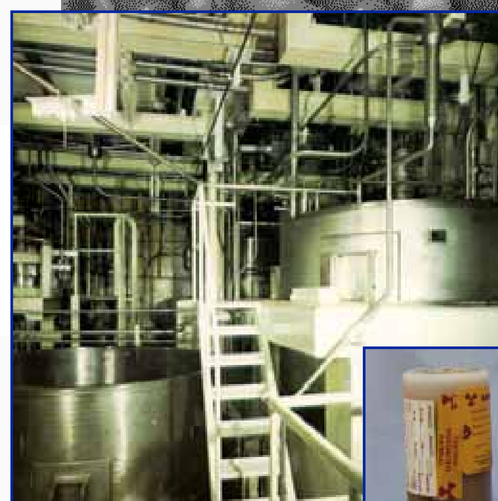


Nuclear materials exist in a wide variety of physical forms, chemical forms, and containers.



steel cylinders of uranium hexafluoride

plutonium nitrate solution



fuel pellets and assemblies for nuclear power reactors

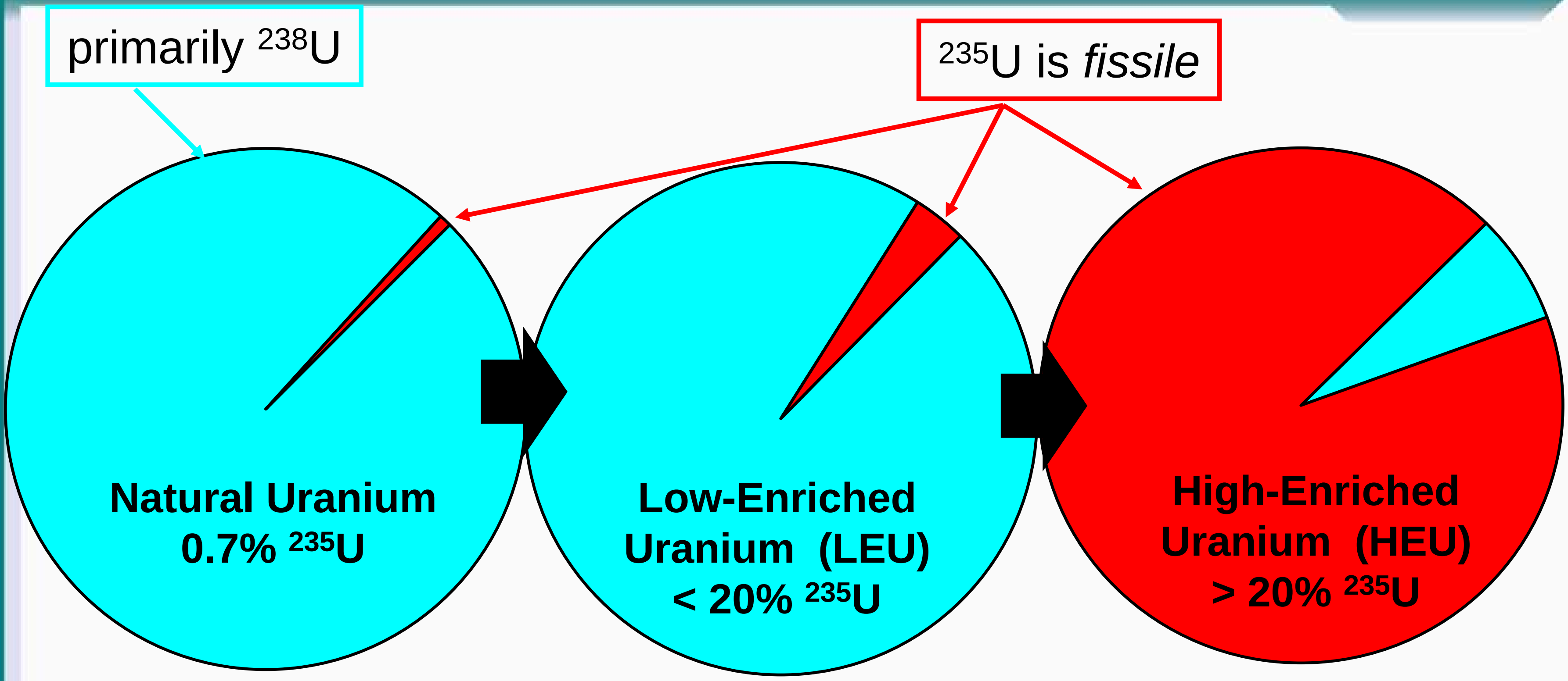
oxide powder

Nuclear material has different isotopic composition.

- Nuclear material is present in different nuclear forms called *isotopes*
  - same element, but different numbers of neutrons in the nucleus
  - for example: important isotopes of uranium include ^{235}U, ^{238}U
- Nuclear reactions and radioactive decay can change ("transmute") isotopes from one type to another
- Isotopes have different nuclear properties
- However, isotopes have the same chemical properties

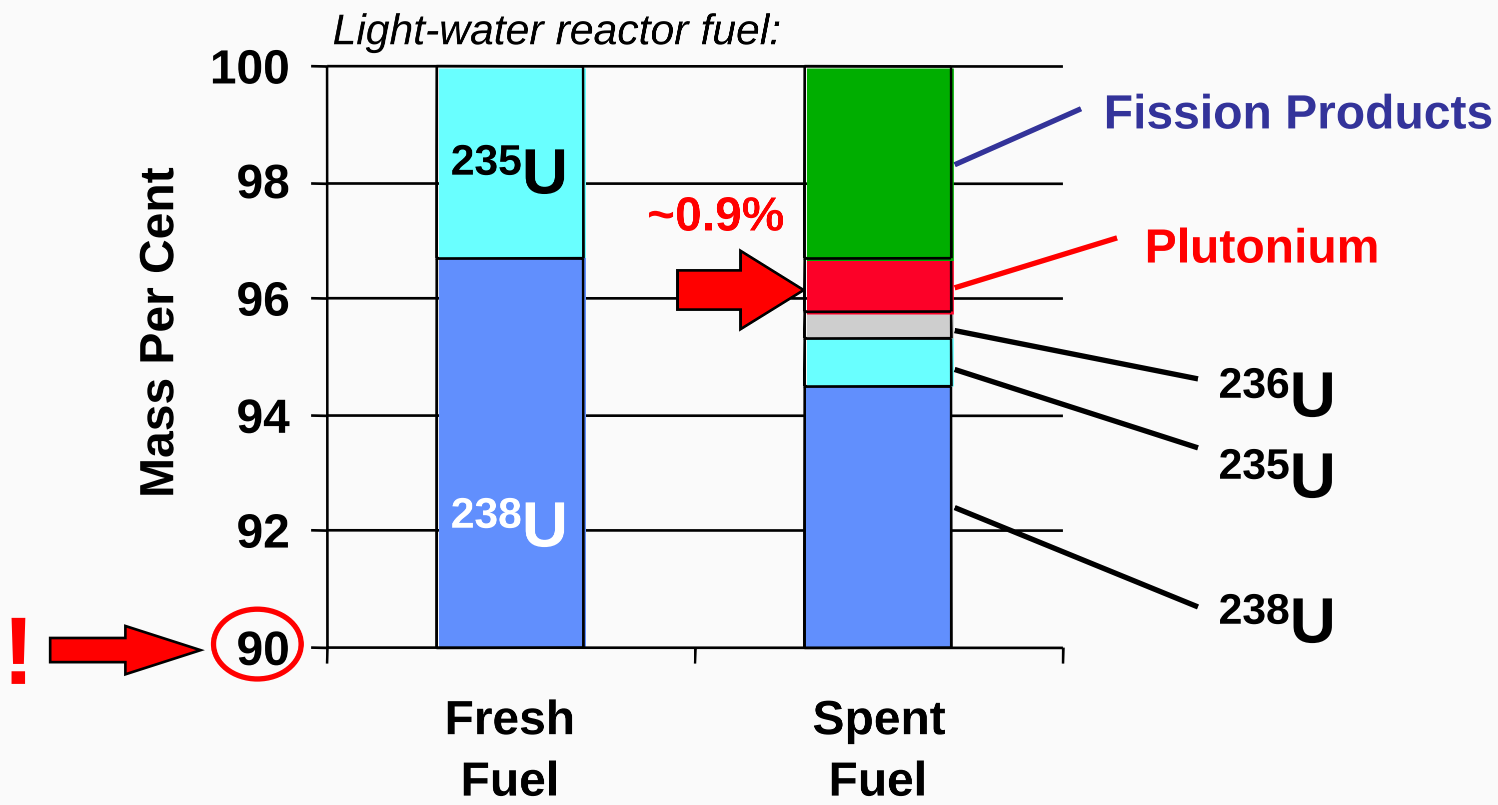
It is very difficult to separate isotopes

Uranium is dug out of the ground, processed and enriched in the isotope ^{235}U.

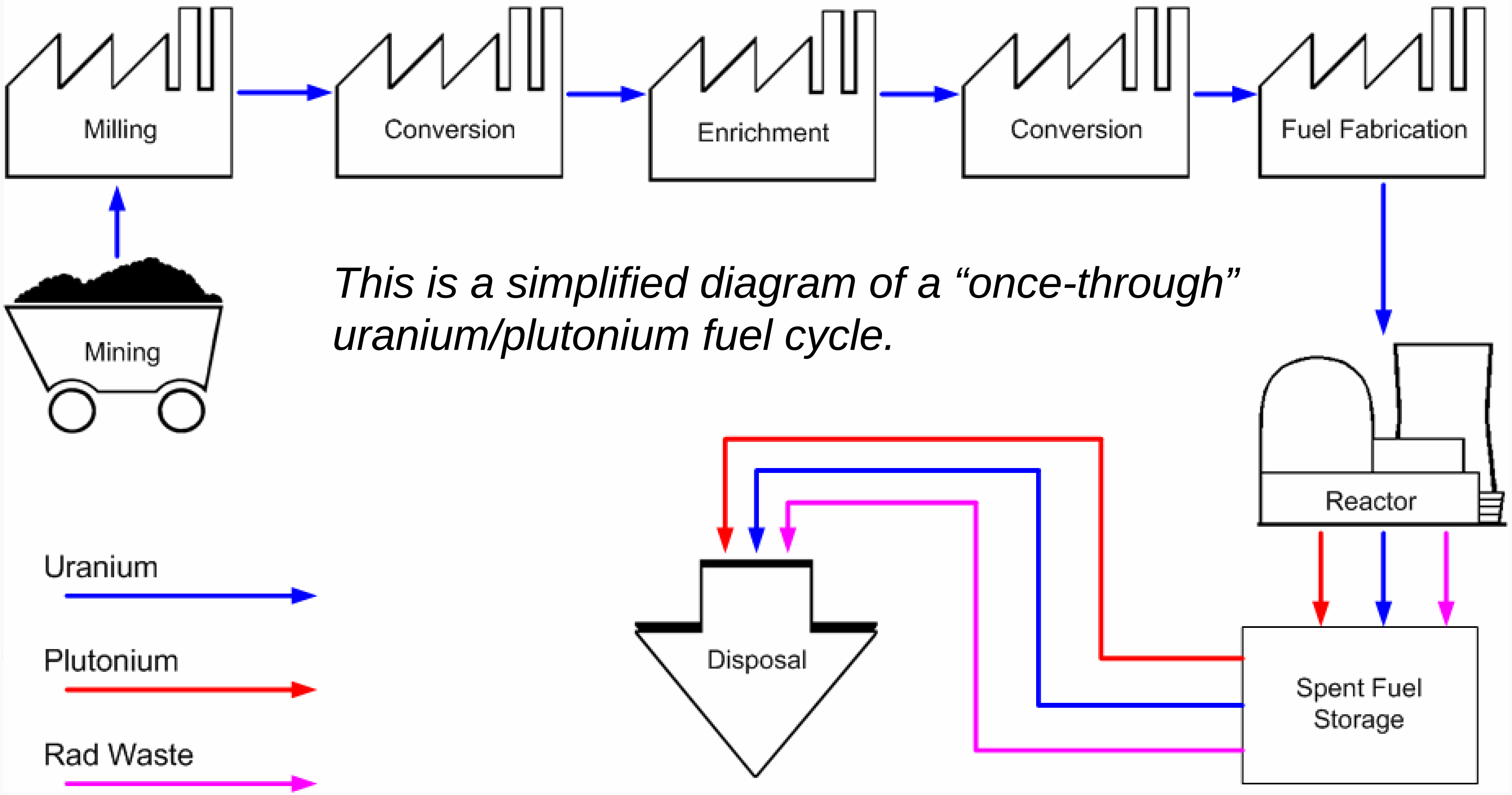


- Natural uranium, LEU and HEU are all useful in reactors.
- Only HEU is useful for making a nuclear explosive.
- Depleted uranium (<0.7% ^{235}U) is a byproduct of enrichment.

Plutonium does not occur in nature, but is instead produced from ^{238}U in a reactor.

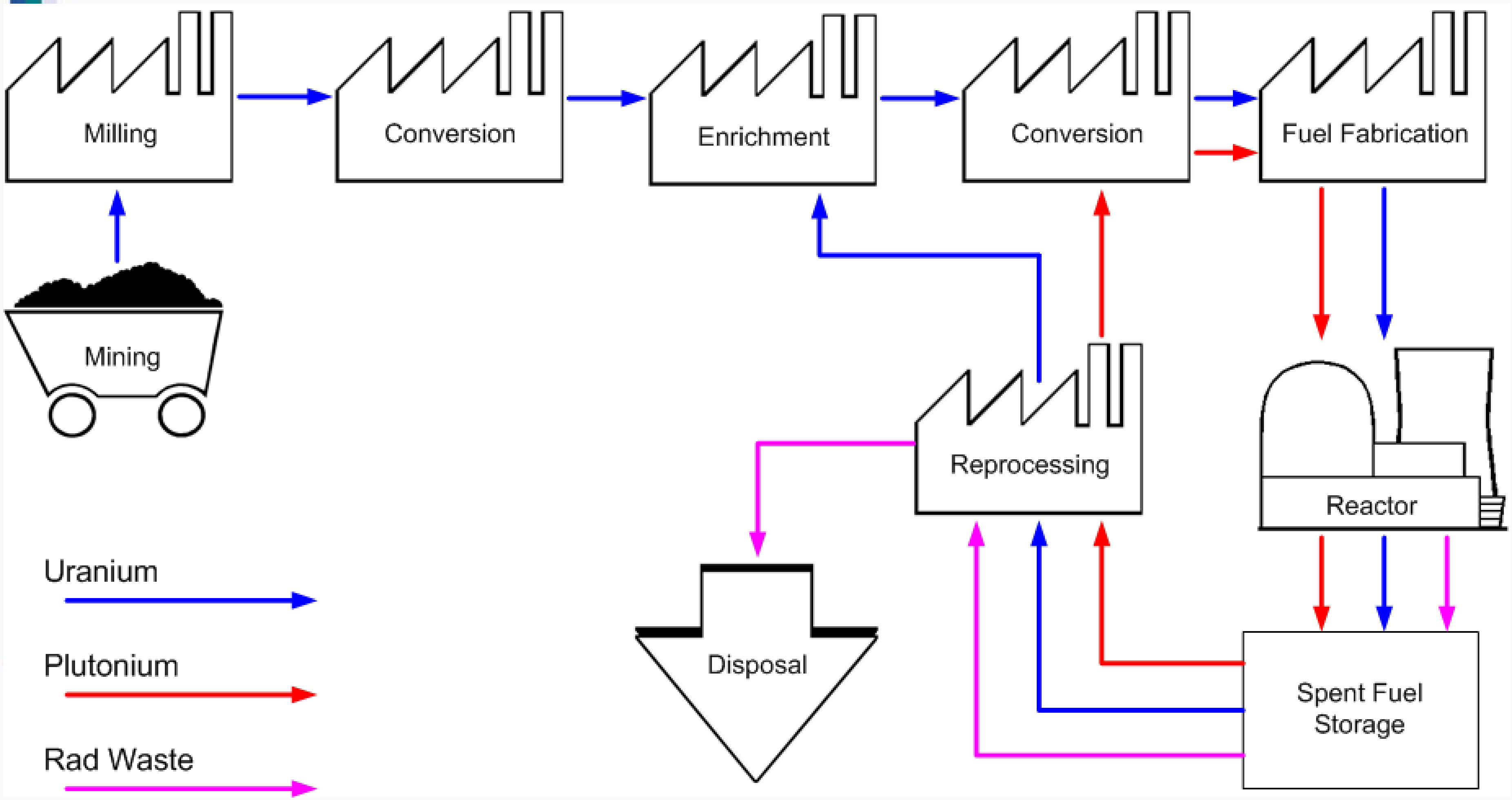


The use of nuclear materials is described by the "Fuel Cycle".

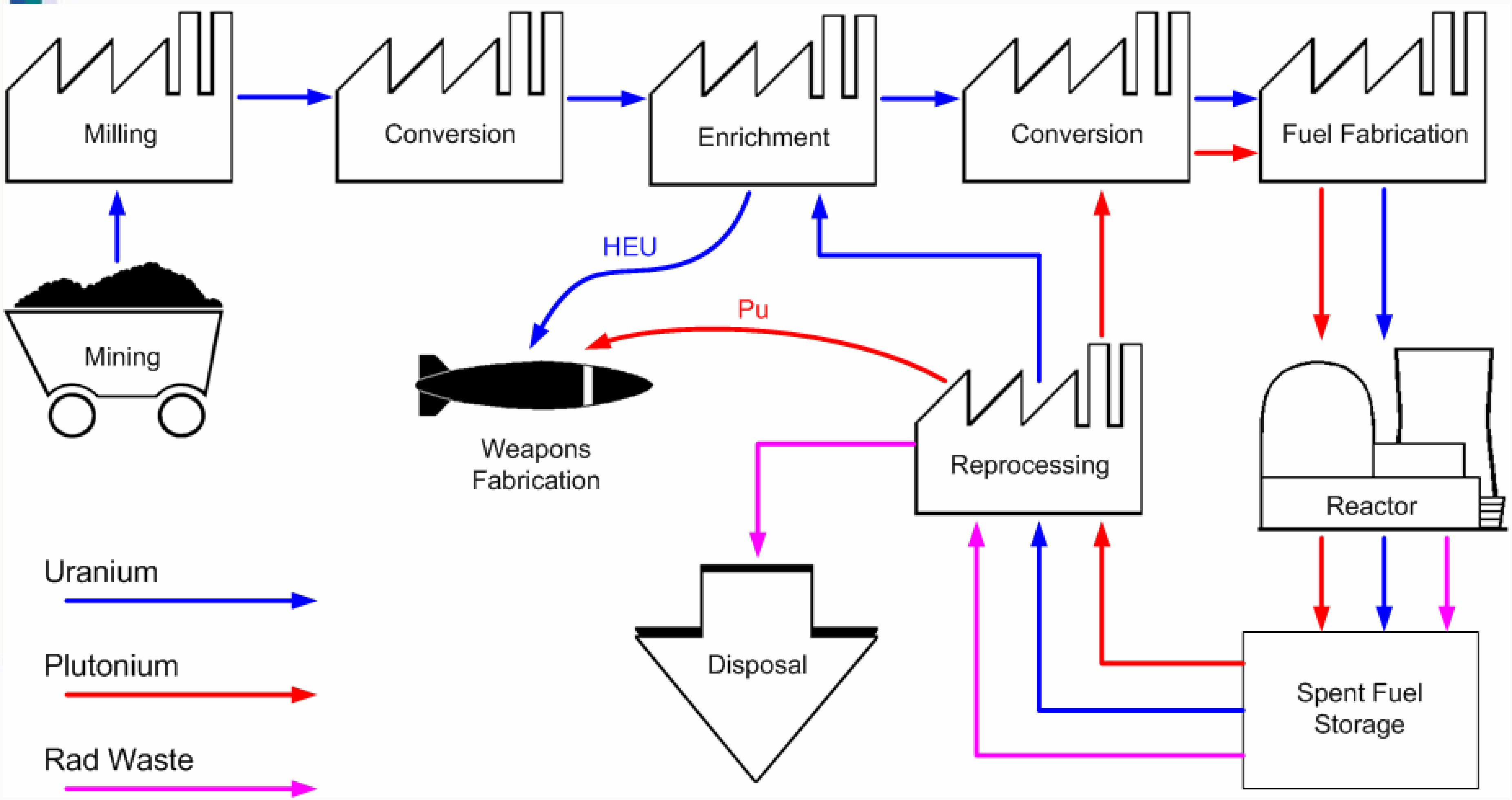


This is a simplified diagram of a "once-through" uranium/plutonium fuel cycle.

Recycle: A fuel cycle with reprocessing recovers unburned ^{235}U and plutonium from spent reactor fuel.

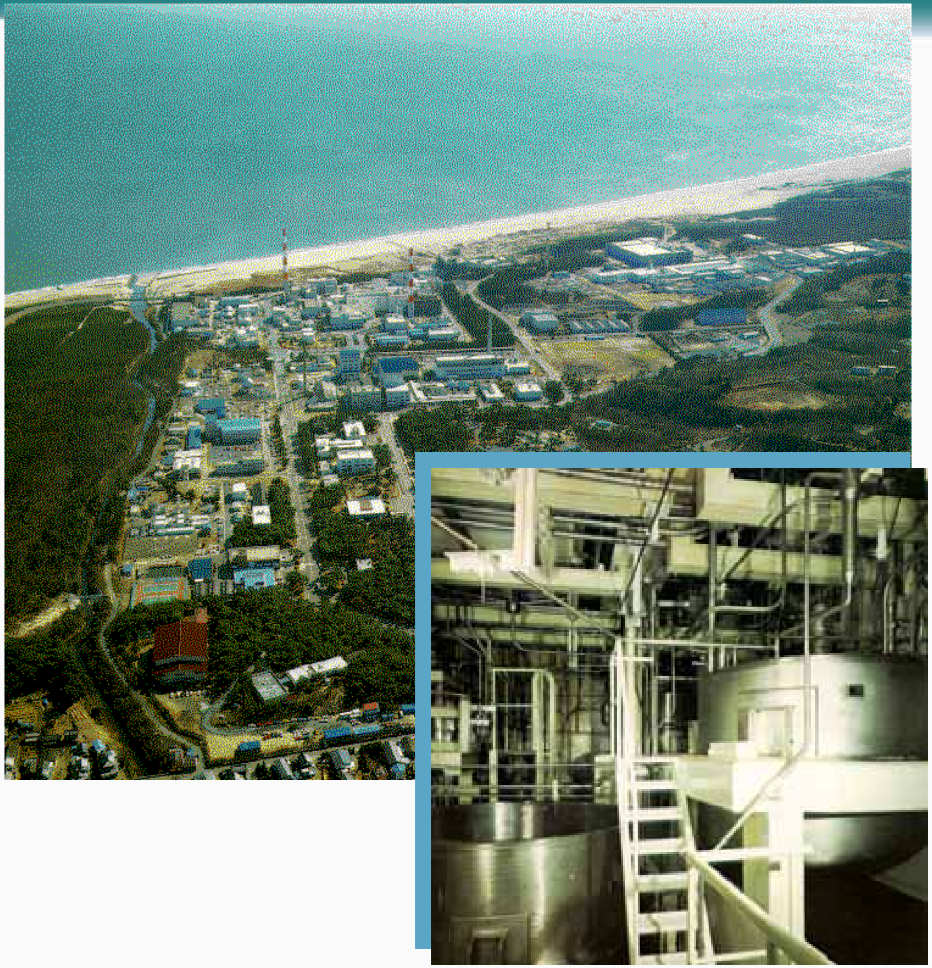


Plutonium and high-enriched uranium might be used to produce nuclear weapons.



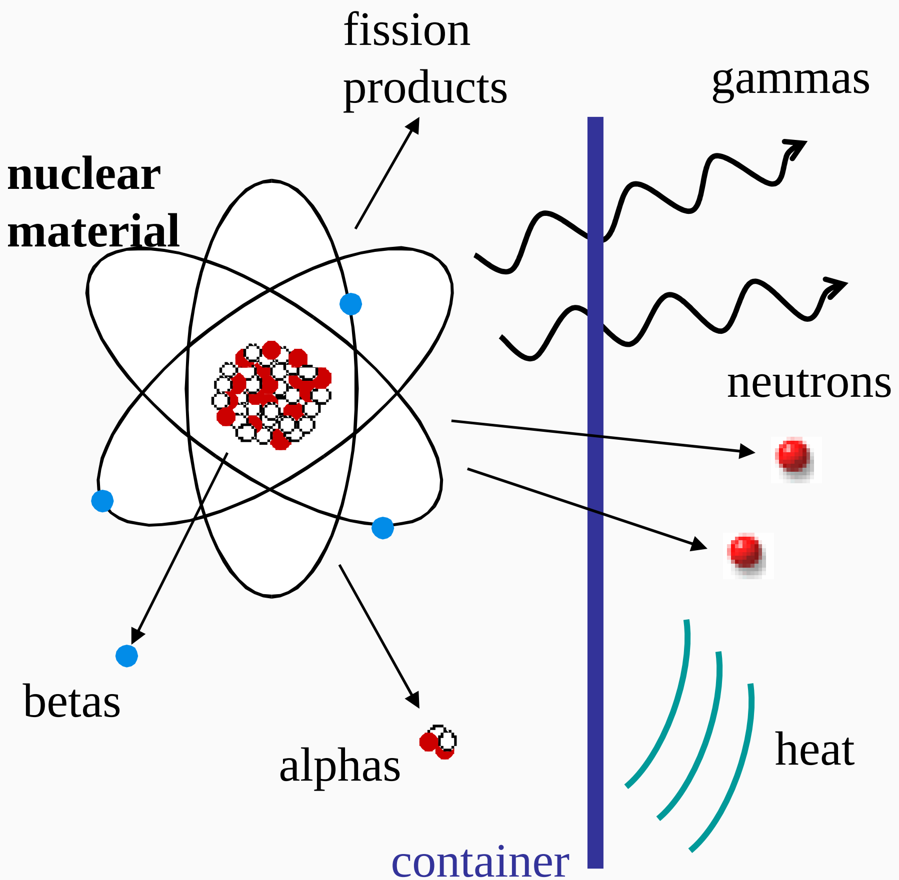
The nuclear fuel cycle can become very complex.

- Nuclear materials have potential dual use, both civilian and military.
- Paths of nuclear materials within facilities are often complicated, and may be inaccessible for monitoring.
- The fuel cycle may involve more than one country.



What are the technical tools that can be used for nuclear material safeguards?

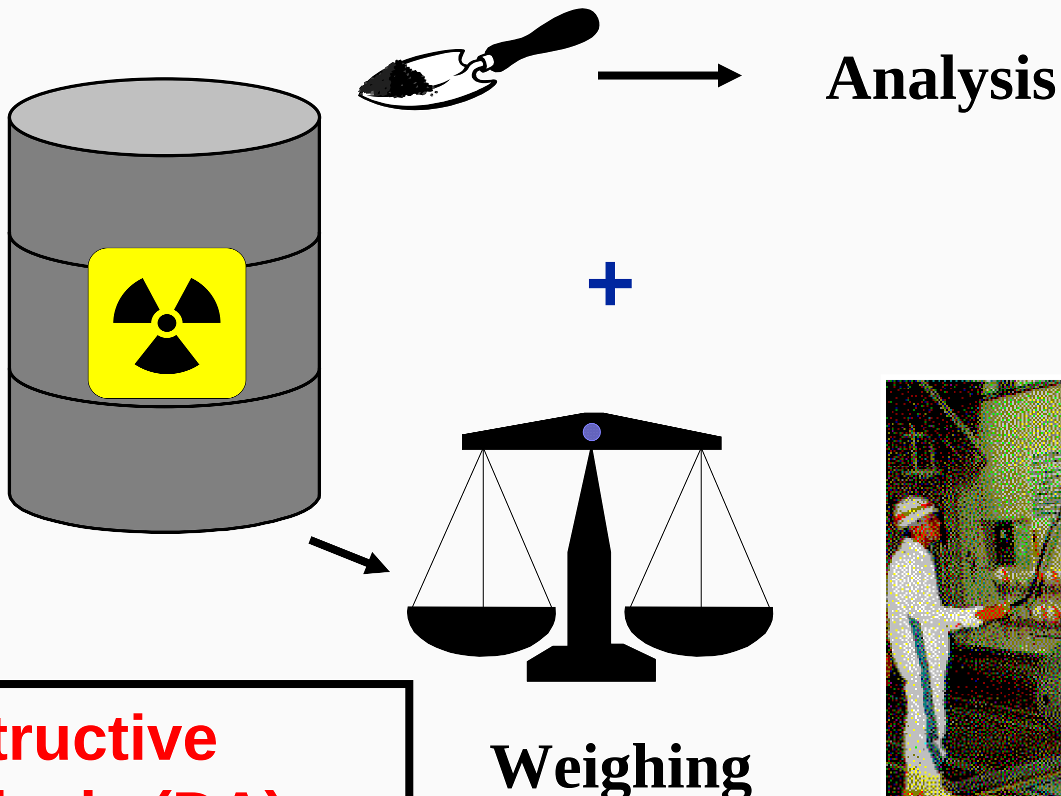
Nuclear materials emit penetrating neutron and gamma radiation, which can be monitored readily.

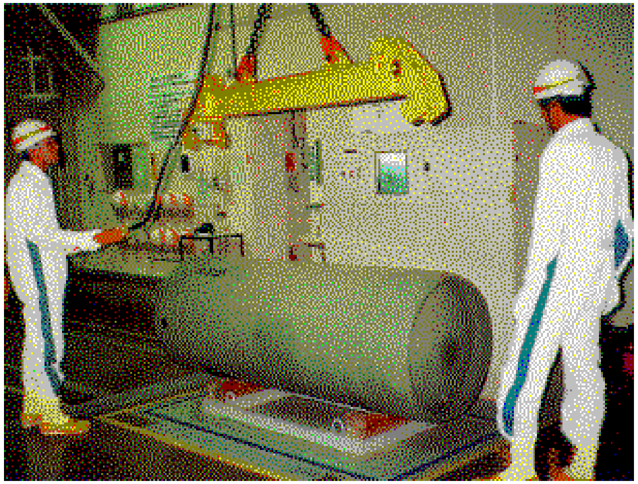


- The type and intensity of the radiation can reveal precisely what nuclear material (and how much of it) is present. It is a "*signature*" of the nuclear material.
- Emission is affected by other elements present.
- The time distribution of neutrons can also convey information.

A wide variety of technical measures exist to detect, identify and assay nuclear and fissile materials.

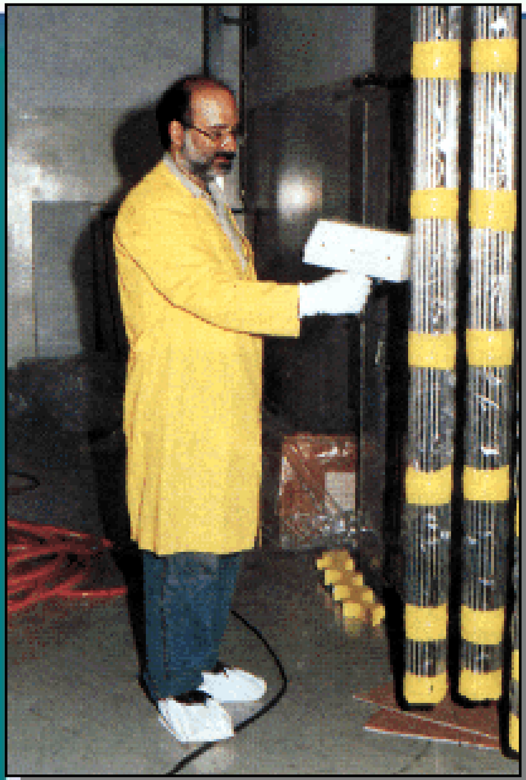
Nuclear materials can be sampled for analysis and weighed.



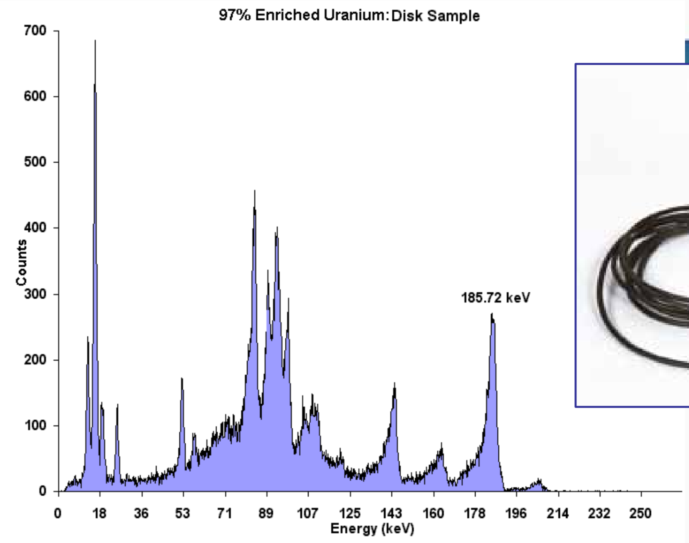


Destructive Analysis (DA)

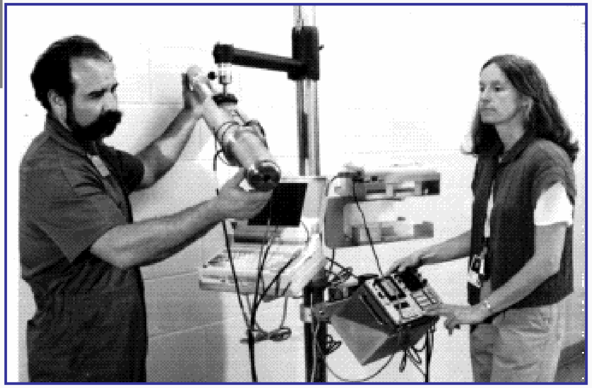
Detection of gamma radiation is used in a variety of nuclear material measurements.



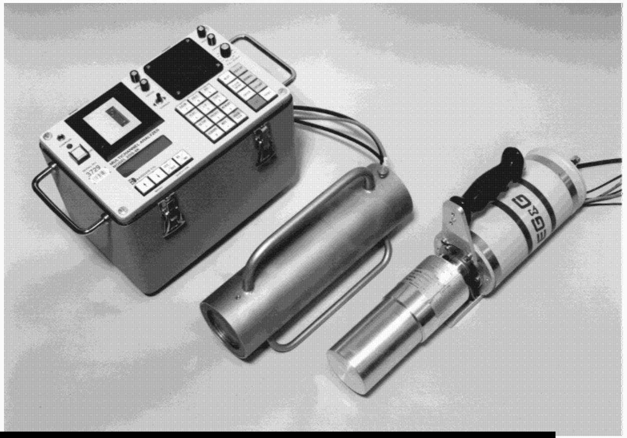
Attribute Measurement for Uranium-235



Portable gamma spectroscopy



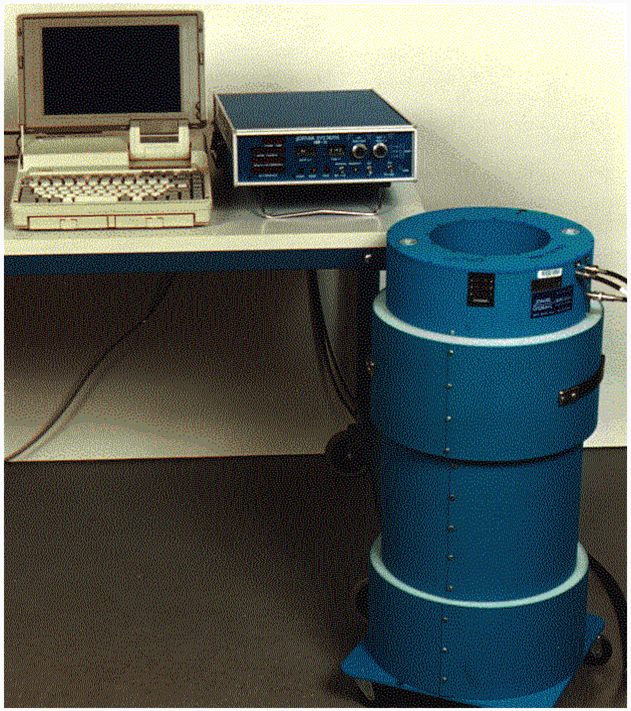
Measurement of holdup



Non-Destructive Assay (NDA)

Passive NDA using coincidence neutron detection is used to assay plutonium.

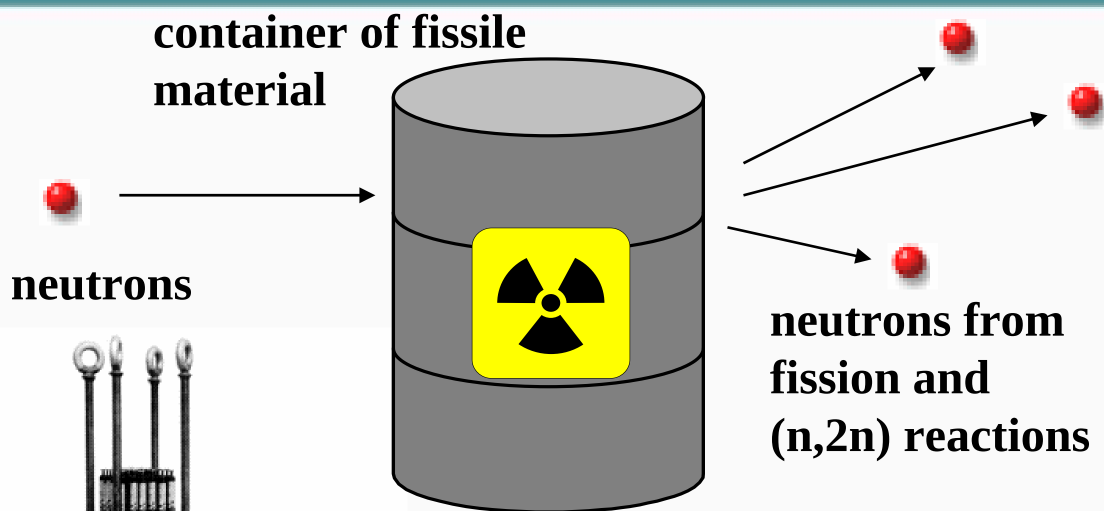
- Most nuclear materials emit neutrons, but as singles (one at a time)
- Plutonium fissions spontaneously, so it can also release multiple neutrons simultaneously
- Coincidence counting identifies this fission neutron signal to assay plutonium

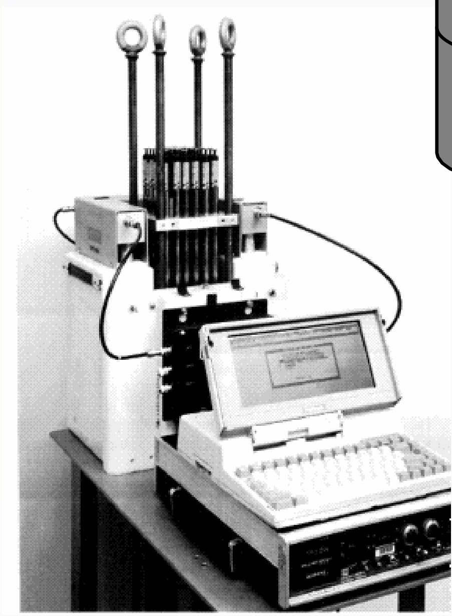


High Level Neutron Coincidence Counter

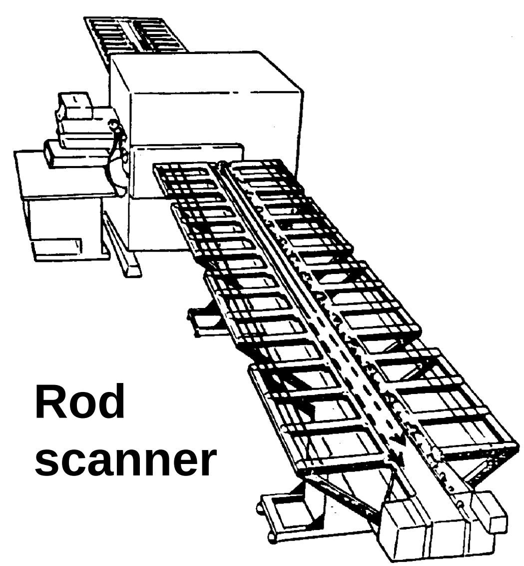
Combination of neutron counting and gamma spectroscopy

Active NDA uses an external source of neutrons to excite nuclear materials; especially useful to assay ^{235}U.





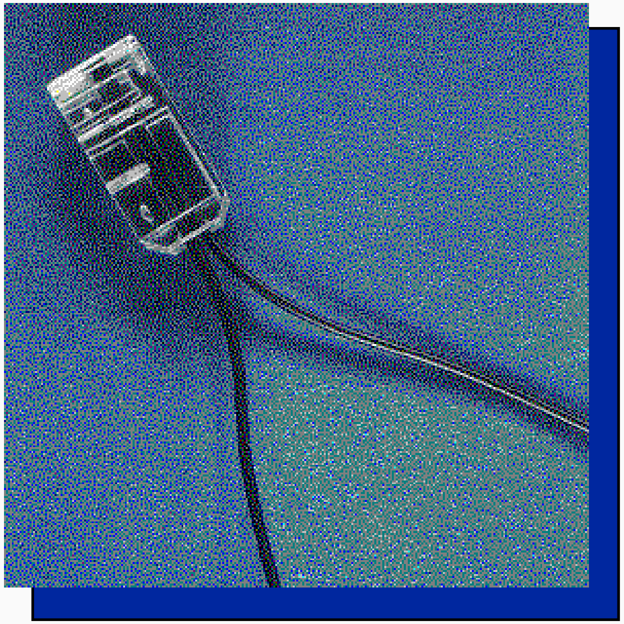
Active neutron coincidence “collar”



Rod scanner

Active well coincidence counter

Containment & Surveillance methods assure "continuity of knowledge" about nuclear materials.

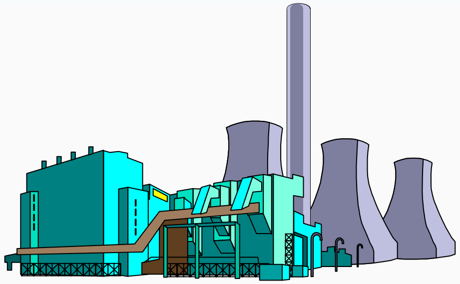


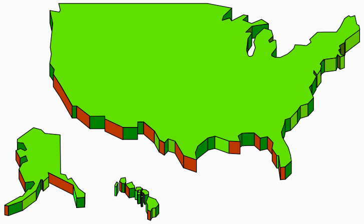
Cobra seal

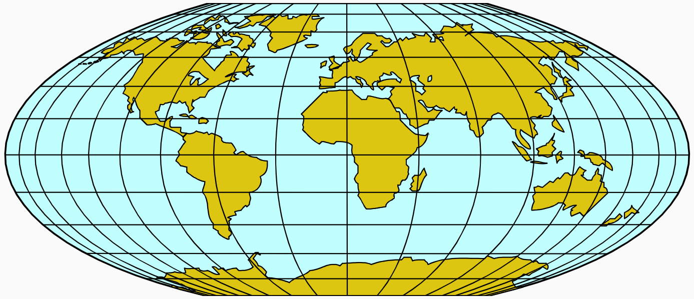
DCM-14 video camera

How are the technical measures applied to achieve a Safeguards objective?

In general, nuclear safeguards exist on different levels, each with different motivations.

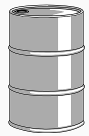


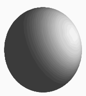




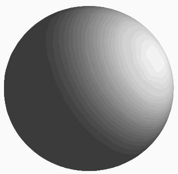
- Facility operator
  needs to protect valuable assets, ensure safety, and assure higher-level authorities that nuclear materials are being used properly
- National authority
  needs to exercise control over facilities, regulate transport, and provide information to the international authority
- International authority
  needs to assure other countries that nuclear material is properly protected, controlled, and used appropriately

Measures for nuclear material safeguards depend upon the form, amount, and strategic value of the material.

- Form: Item  , or Bulk 
- Amount:
  - “Significant Quantity” (SQ)
  - as defined by the International Atomic Energy Agency



Plutonium
8 kg

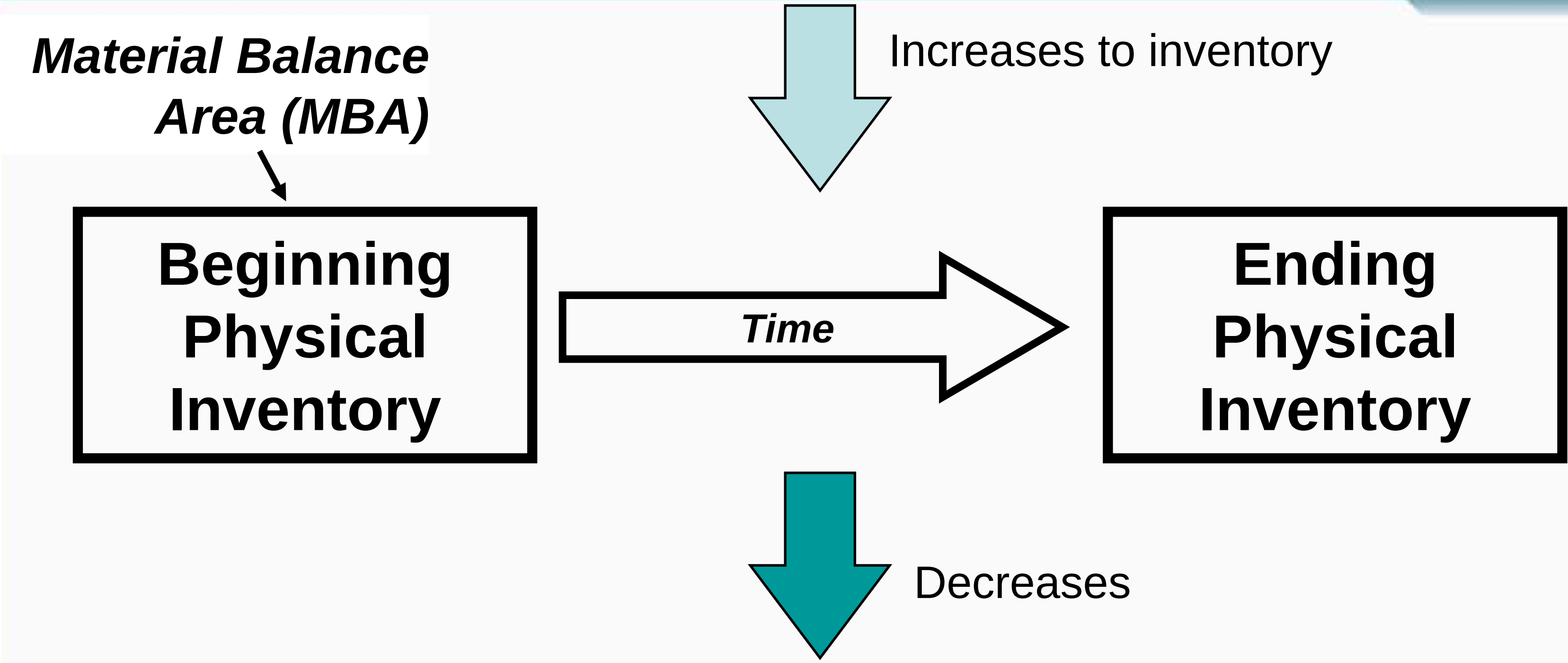


HEU
25 kg

- Strategic Value:
  - “Direct Use”: plutonium, HEU, and ^{233}U
    - unirradiated
    - irradiated
  - “Indirect Use”: uranium except HEU, and thorium

The *timeliness* of Safeguards measures is dictated by the strategic value of the material.

Safeguards are based on *accountancy*, which seeks to verify the “material balance” for a “material balance area”.



Material Balance:

(Beginning Inventory) + (In) - (Out) = (Ending Inventory)

But it’s never perfect:

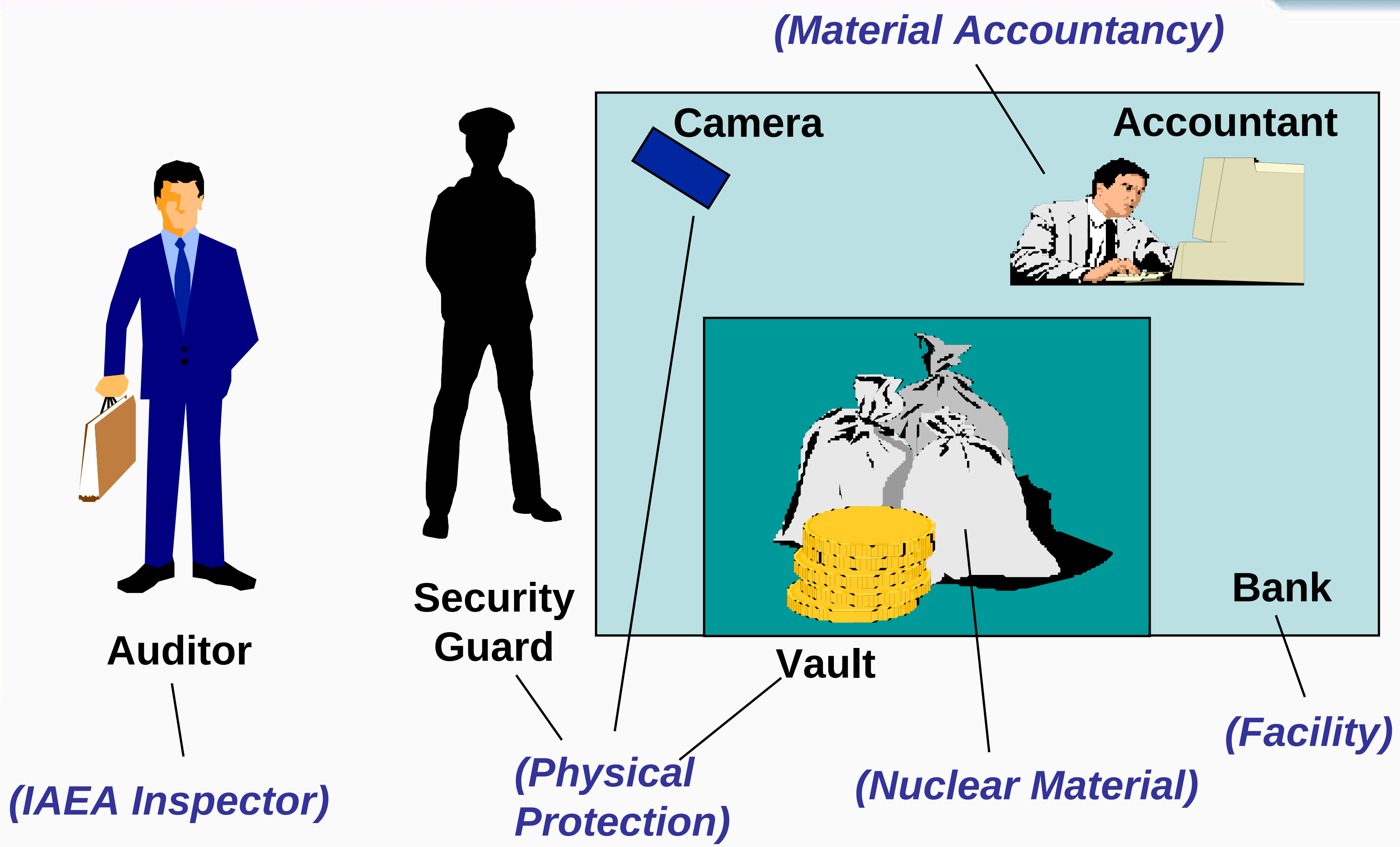
the difference is termed “Material Unaccounted For” (MUF)

MUF = (Beginning Inventory) + (In) - (Out) - (Ending Inventory)

For international nuclear safeguards, accountancy assures that nuclear materials are present and used as intended.

- State declares nuclear materials and facilities
- Independent inspections periodically verify the declaration:
  - confirm facility design information
  - examine operator records & reports
  - identify & count items
  - assay nuclear materials
- Containment and surveillance measures ensure “Continuity of Knowledge”: i.e., that no changes occur between inspections
  - tags & seals
  - video cameras

International nuclear safeguards resemble the auditing function in banking:



A variety of other forms of control complement international nuclear safeguards.

- Domestic material control & accounting
- Physical protection
- Licensing of facilities
- Regulation of transport
- Import/export restrictions
- Engineering standards & certification

Portal monitoring

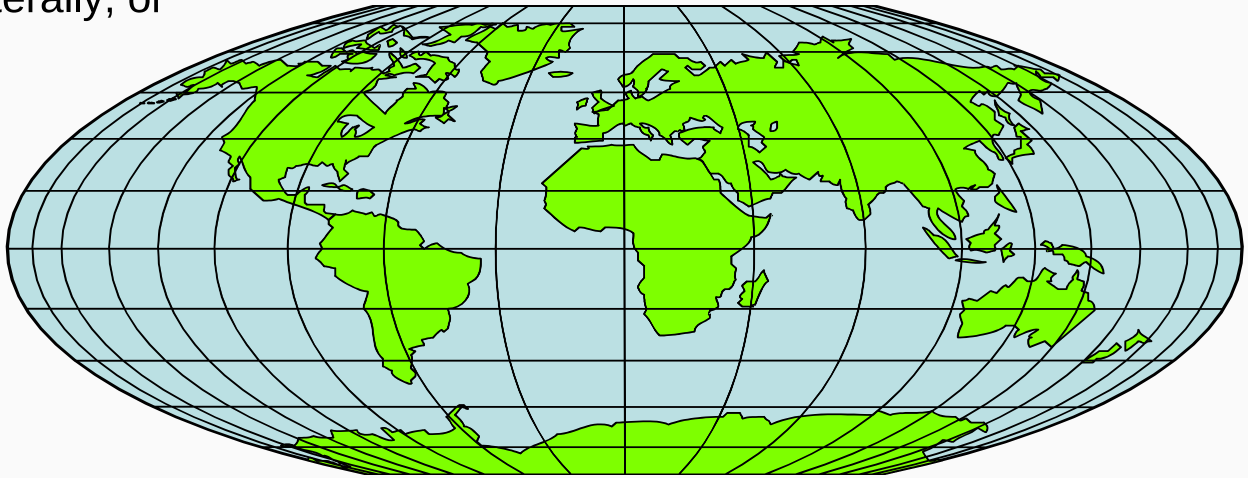
How are Nuclear Safeguards applied internationally?

“Traditional” IAEA Safeguards

International safeguards are called for by treaties and other agreements between parties.

For assurance that nuclear materials are properly protected, controlled, accounted for, and used for peaceful purposes:

- Parties monitor each other bilaterally, or

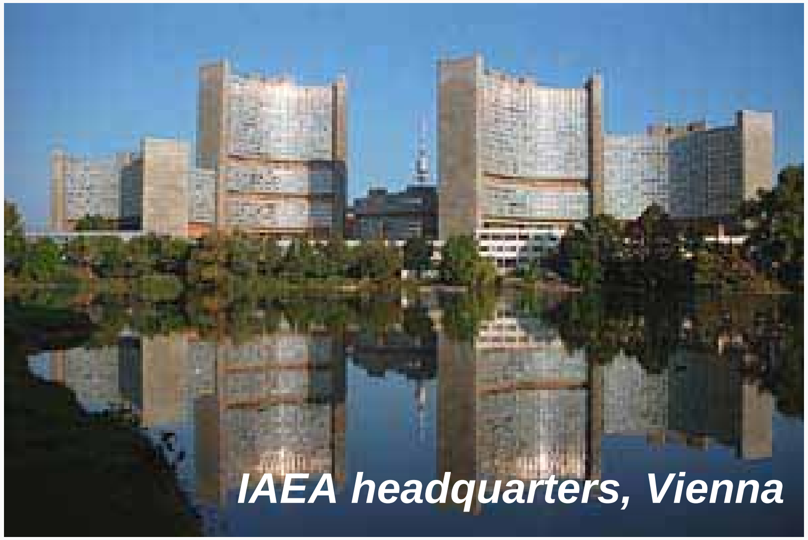


- A 3rd party (international authority) is delegated the monitoring function

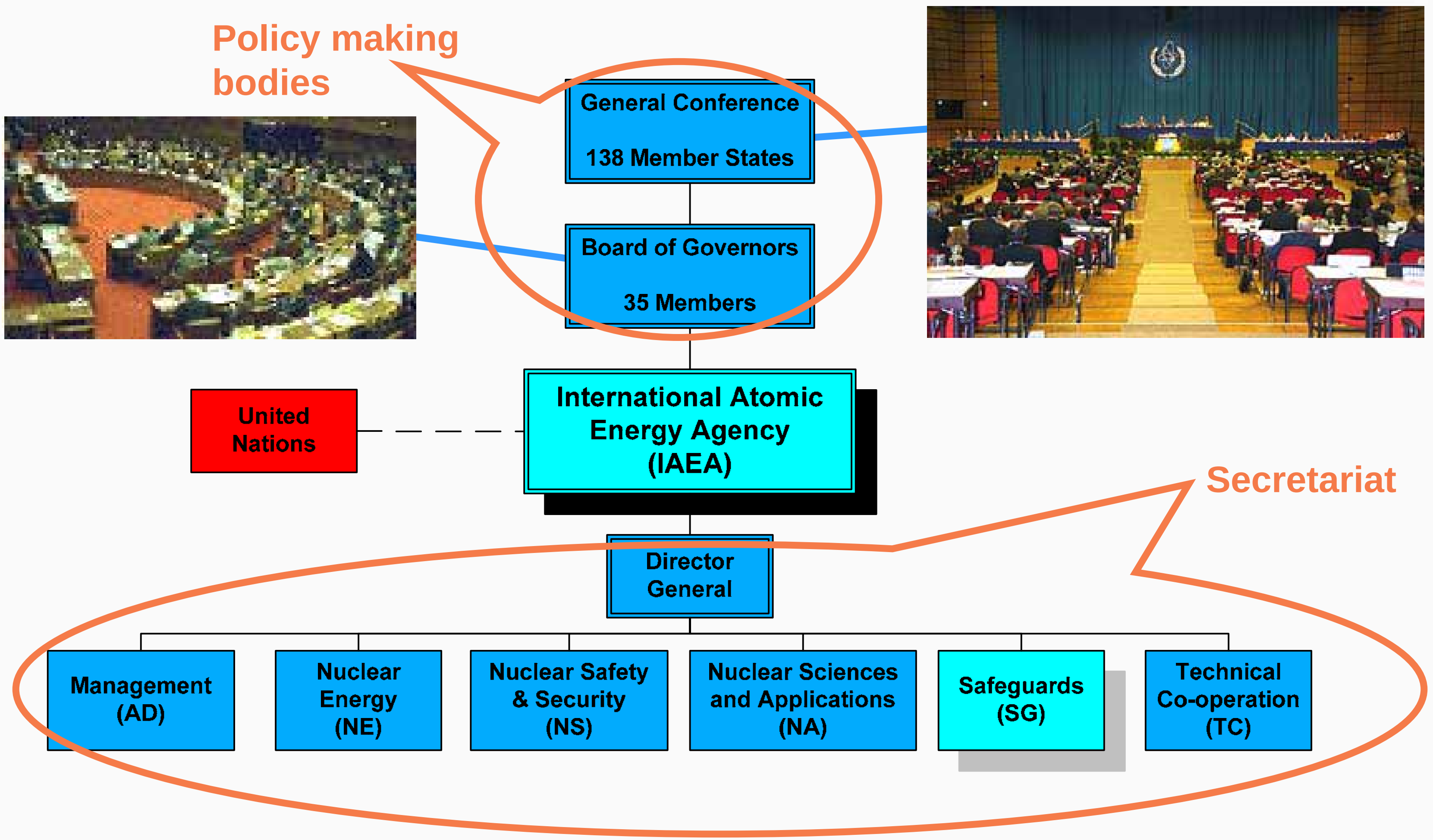
The International Atomic Energy Agency (IAEA) both promotes and safeguards atomic energy.

- Created in 1957 by Statute
- Affiliated with the United Nations
- Objective:

  "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world."
- Now comprises 140 Member States, which
  - participate in formulating Agency policies
  - are eligible for technical assistance in the peaceful use of nuclear energy
  - share the costs of its operation


IAEA headquarters, Vienna

Nuclear Material Safeguards is just one effort within the IAEA.

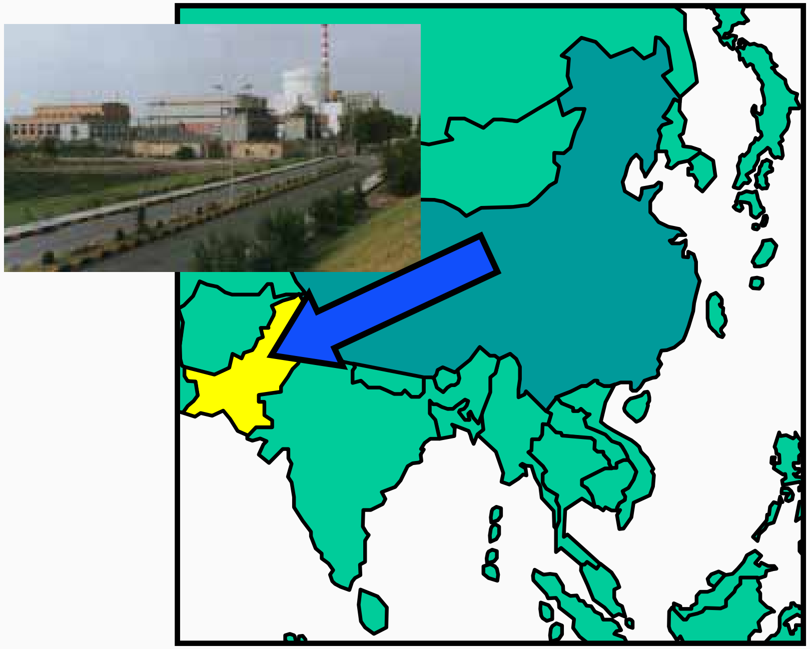


IAEA INFCIRC 66 describes how Safeguards are applied to individual projects, such as an international reactor sale.

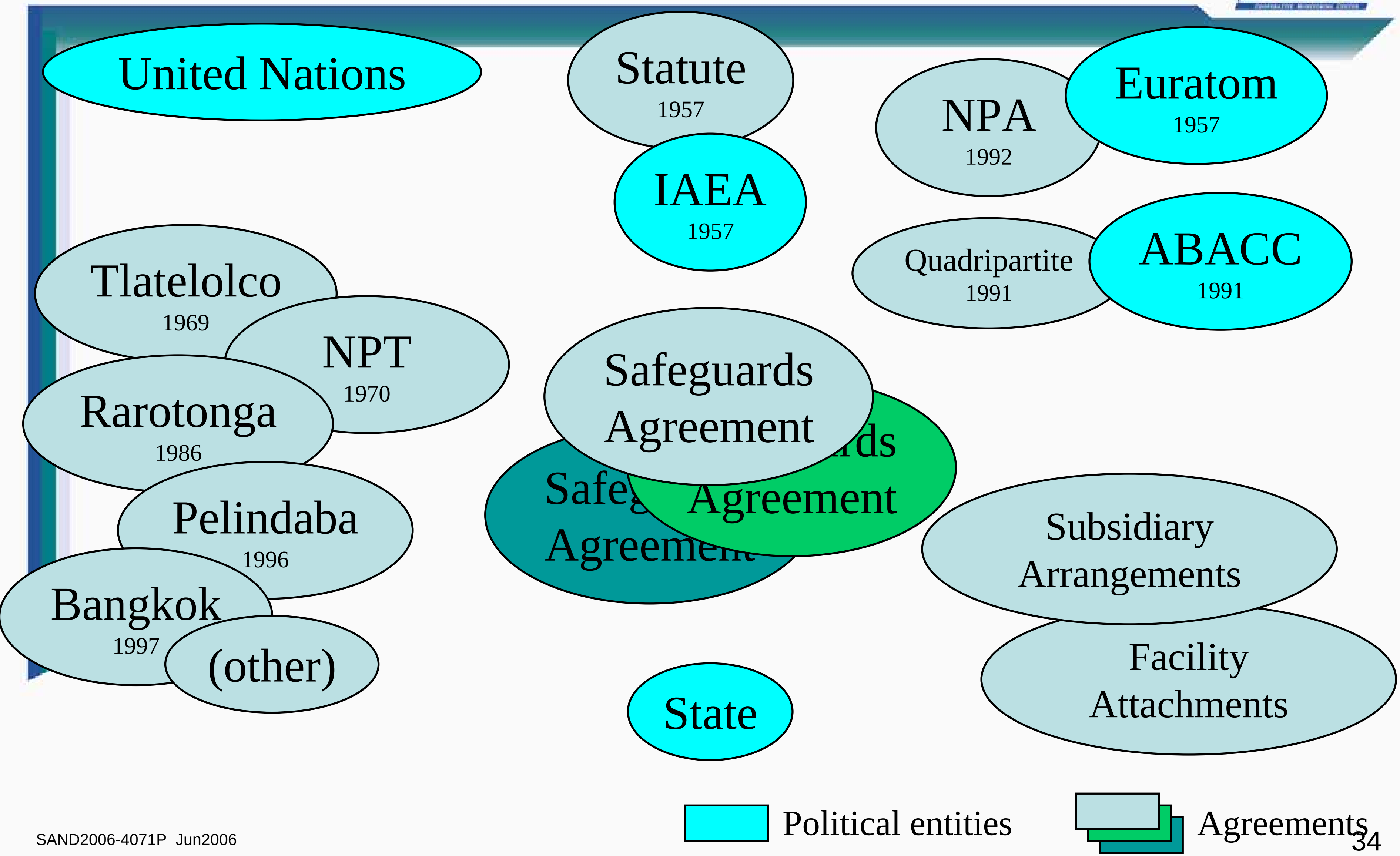
- Example of an INFCIRC 66 project agreement:

  "Agreement of 24 February 1993 Between the International Atomic Energy Agency and the the Government of the Islamic Republic of Pakistan for the Application of Safeguards in Connection with the Supply of a Nuclear Power Station from the People's Republic of China"
  (INFCIRC 418)

- 300 MWe pressurized light water reactor at Chashma, built by China National Nuclear Corporation



Safeguards Agreements, required by a variety of agreements, provide the legal context for international nuclear safeguards.



The Treaty on the Nonproliferation of Nuclear Weapons (NPT) led to Comprehensive Safeguards Agreements (CSAs).

- Under a CSA, Safeguards are applied to all nuclear activities within a state
- All non-nuclear weapons state (NNWS) parties to the NPT are expected to conclude a CSA with the IAEA
- IAEA Safeguards for a CSA are documented in Information Circular (INFCIRC) 153, as corrected:

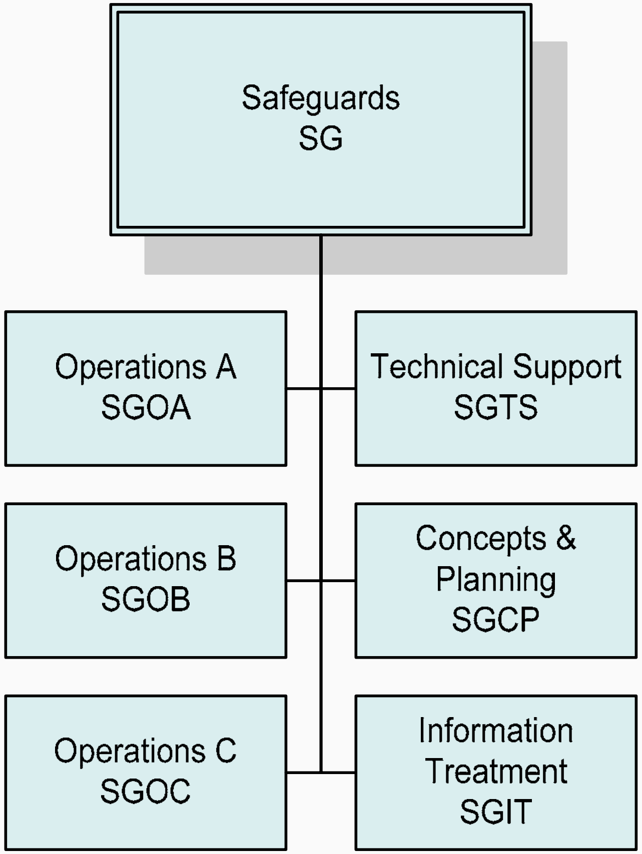
> "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons"

Five Nuclear Weapon State parties to the NPT have concluded "Voluntary Offer Agreements."

- NPT does not require Safeguards in the nuclear weapon states (NWS)
  - Major industrialized non-nuclear weapon states objected (unfair competitive advantage)
  - NWS offered to accept Safeguards on all nuclear activities, except national security
  - Compromise solution to limit cost:
    - NWS submit lists of "eligible facilities"
    - IAEA selects which facilities to inspect
- Framework for NPT Article VI
  - 1993 U.S. placed materials "excess to defense needs" under IAEA Safeguards

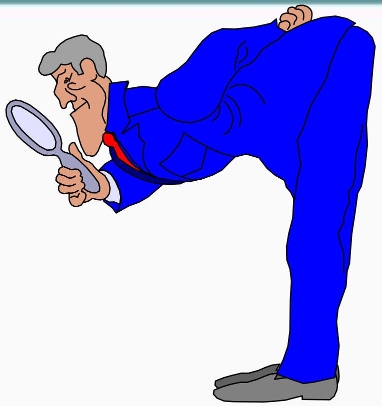
- United Kingdom
  - Aug. 1978
  - INFCIRC 263
- United States
  - Dec. 1980
  - INFCIRC 288
- France
  - Sep. 1981
  - INFCIRC 290
- Russia
  - Jun. 1985
  - INFCIRC 327
- China
  - Sep. 1989
  - INFCIRC 369

The Safeguards Department of the IAEA is divided into Operations and Support Divisions.



An IAEA Inspector is expected to perform a wide range of tasks.

- audit bookkeeping records of a facility
- determine stratification & sampling
- verify inventory of materials
- perform nondestructive assay measurements
- service containment & surveillance equipment
- count controlled items
- take samples for destructive analysis
- perform design information verification



- carry out complementary access
- write reports & documentation
- travel
- other
  - negotiate facility attachments
  - develop new measurements
  - train other inspectors

IAEA Safeguards serve to audit a state's declaration of its nuclear materials and facilities.

- Declaration:
  - A party to a Safeguards Agreement establishes and maintains a State System of Accounting and Control (SSAC) for its nuclear materials.
  - The party declares its nuclear materials and facilities to the IAEA.
- Verification:
  - The IAEA inspects the nuclear materials and facilities periodically to verify accuracy of the declaration.
  - The IAEA reports its conclusions.
- Many states having little or no nuclear activity qualify for a reduced inspection and reporting regime:
  - Small Quantities Protocol (SQP)

The IAEA announces a Safeguards conclusion annually, but does not share Safeguards data.

- For states with a Comprehensive Safeguards Agreement (CSA) only, the affirmative conclusion states:

  "All declared nuclear material in these… States has remained in peaceful nuclear activities or has been otherwise adequately accounted for."

- For states with both a CSA *and* an Additional Protocol in force, the positive conclusion goes on to say:

  "In addition… the Agency completed sufficient activities and evaluation and found no indication of undeclared nuclear material or activities for the State as a whole. On this basis, the Agency concluded that all nuclear material in these States remained in peaceful nuclear activities or was otherwise adequately accounted for."

From the IAEA 2004 Annual Report

EURATOM: European Atomic Energy Community

- Nuclear energy in Europe was poised for rapid development in the mid- to late- 1950's
- 1957: Euratom established by treaty
  - six Member States originally, 25 parties in 2006
  - operates its own professional Safeguards inspectorate
  - Summary report by European Commission to the European Assembly (annual)
- IAEA-Euratom Cooperation
  - 1973 agreement concerning Safeguards for NPT (INFCIRC/193)
  - 1990's: New Partnership Approach (NPA)
  - Efforts are ongoing to coordinate overlapping responsibilities to ensure effectiveness and efficiency

ABACC:
Argentine-Brazilian Agency for Accounting and Control

- Chronology
  - 1979: Start of gradual bilateral confidence building steps
  - July 1991: ABACC created by bilateral treaty
  - December 1991: Quadripartite Agreement included IAEA
  - Argentina, Brazil later joined Tlatelolco (1994) and the NPT (1995, 98)
- Structure of ABACC
  - Commission: monitors implementation, reports to both States
  - Secretariat: small professional staff, carries out inspections (each State inspects the other), 30 inspectors from each country
- Significance
  - regional solution that addressed regional issues
  - success due to both executive leadership and institutionalized cooperation

How have Safeguards evolved to meet challenges to nuclear nonproliferation regime?

IRAQ

- NPT signatory state with IAEA Safeguards Agreement
  - before 1991: no diversion of declared nuclear materials

- following the 1991 Gulf War
  - UNSCOM/ IAEA inspections under UN Security Council Resolution 687
  - revealed a clandestine nuclear weapons development program on a huge scale

NORTH KOREA

- Prompt detection of undeclared activities
  - possibility of undeclared plutonium
  - late 1992: IAEA alerted UN Security Council
- IAEA was already using additional tools
  - enhanced data analysis
  - third party information
  - authority to request additional information and special inspections
- Initial crisis
  - DPRK withdrew from IAEA membership but its Safeguards agreement remained binding
  - 1994 deal: Freeze program and accept two power reactors

- Status
  - DPRK claims to be reprocessing fuel to recover plutonium
  - IAEA verification work was halted in December 2002
  - Application of safeguards under the DPRK's INFCIRC/66 safeguards agreement has been suspended
  - DPRK status under the NPT is not clear
  - Six-Party Talks attempting to resolve the current impasse

The IAEA "Programme 93+2" responded to the new demands on Safeguards.

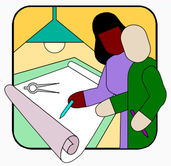
- How can the charter of IAEA Safeguards be expanded to:
  - Detect clandestine nuclear activities?
  - Make safeguards more efficient?
- Important to verify not only the *correctness* of a declaration, but also its *completeness*
- "Programme 93+2" began in 1993, intended to be completed within two years
- Additional measures were identified to strengthen Safeguards

Additional Safeguards measures were split into two categories.

- Part I
  - No additional legal authority would be required
  - IAEA Board of Governors agreed to implement these measures in June 1995
- Part II
  - Additional legal authority would be required
  - "Model Additional Protocol" drafted as the basis for negotiating this authority with parties to existing Safeguards Agreements
  - approved by the IAEA Board of Governors in May 1997

INFCIRC 540 (corrected)

Part I measures had already been available to the IAEA, but had not been fully utilized.

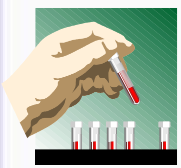


•Early provision of design information on new facilities or changes in existing facilities with safeguarded material

•Use of unattended and remote monitoring

•Greater use of short notice inspections

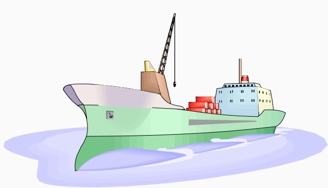
•Enhanced training



•Environmental sampling at locations where inspectors already have access, under existing safeguards agreements

•Enhanced collection and analysis of information from safeguards declarations and from open sources

•Closer co-operation between IAEA and State (regional) systems for accounting and control of nuclear material



•Voluntary reporting of imports and exports of nuclear material, specified equipment and non-nuclear material

Part II measures extended the scope of IAEA Safeguards.

- Provision of information about, and inspector access to, all aspects of a State's nuclear fuel cycle;
- Provision of information on, and short notice inspector access to, any place on a nuclear site;
- Provision of information about and access to nuclear fuel cycle related R&D;
- Provision of information on the manufacture and export of sensitive nuclear related technologies, and access to manufacturing and import locations;
- Environmental sampling at locations beyond those provided under safeguards agreements;
- Improved access: Simplified procedures for designation of inspectors, and issuance of multiple-entry visas
- Right to use internationally established communications systems.

The Additional Protocol is gradually being implemented.

- Status of Protocols Additional to Safeguards Agreements (as of 17 May, 2006)
  - Additional Protocol in force in 75 States and Euratom
  - 107 states have signed an Additional Protocol
  - 114 states have been approved by the Board of Governors
- Implementation
  - Declarations and verification inspections underway since 1997
  - Field trials to test verification measures (e.g., two sites in Japan)
  - Euratom agreement in force since April 2004
- Current IAEA Safeguards incorporate two main elements
  - a much enhanced role of “all source” information collection, review and analysis
  - an emphasis on state-level evaluation, supporting the state-level safeguards conclusions

Summary

- International Nuclear Safeguards have been enormously successful for non-proliferation.
- 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.