SAFEGUARDS APPROACHES OF THE SPENT NUCLEAR FUEL:THE ROUTE TO DETECT PARTIAL AND GROSS DEFECTS

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Abstract

Operations that extend from the process of uranium ore mining to the step of reprocessing are well known as nuclear fuel cycle (NFC). NFC consists of two ultimate parts the first part is called "frond end" while the other is named "back end". The back end of the NFC involves managing the spent fuel after irradiation. IAEA executes safeguards system on sates under the non proliferation umbrella. This system ensures not only nuclear material (NM) but also the activities within facilities are subject to supervised criteria accredited internationally and supported by states acceptance. Safeguards approaches and the application of safeguards is facility specific. Implementation of safeguards includes inspection on facilities that contain spent fuel. The paper high lights the SNF signatures such as physical signature, gamma radiation, Cerenkov radiation, neutron radiation, and combined radiation. Each signature gives safeguards inspector a piece of information concerning the nuclear fuel and the process it passes through. Discussions on spent fuel safeguards and verification objectives are presented also. NMA verification objectives are to detect gross defects like missing a spent fuel assembly also to verify the identity of SNF to ensure that a spent fuel assembly is the assembly that declared by the facility operator another verification objective is to detect partial defects like verification of the integrity of SNF object. The Containment and surveillance (C/S) verification objectives are to verify continuity of knowledge over SNF assemblies and to verify no use or production of undeclared nuclear material. Design Verification objectives are to verify facility design (no new unsafeguarded SNF transfer paths). Eventually, nuclear abuse scenarios are suggested and the role of any robust accounting system in safeguarding SNF was discussed to stand up to these concealment tricks.

Keywords: Spent Nuclear Fuel, Nuclear Safeguards, Nuclear Material Accountancy.

1. INTRODUCTION

1.1. The nuclear fuel cycle

NFC refers to processes that make benefit from nuclear reactions to produce electricity. It begins with ore mining step passing through extraction, purification, conversion…etc [1]. till the step of nuclear waste disposal. The nuclear fuel irradiated in a reactor to generate electricity then the spent fuel is produced. The spent fuel undergoes successive steps that form what is called 'backend' of the NFC [2]. It originates at nuclear power plants and then it can be transferred to interim storage or directly high-level radioactive waste disposal [3]. It can also go to the reprocessing plant for recycling where it is made into MOX fuel.

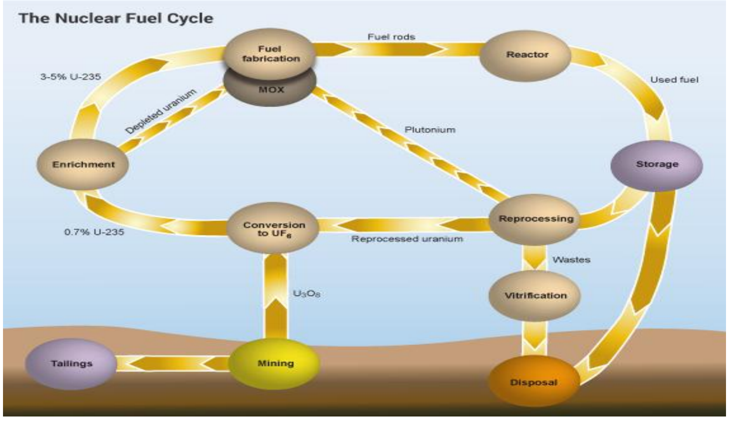

FIG. 1. The stages of nuclear fuel cycle.[4]

1.1.1. Generation of electricity

Uranium 235 atoms loaded into nuclear reactors as fuel undergoes fission and energy released. The released energy is used for heating water and producing vapor that operates a turbine which in turn produce electricity by means of generator. This electricity is distributed by an electricity network. when reactor is in operation, some of uranium atoms is turned to other elements by fission or by absorbing of neutrons. These elements contain fission products and nuclear wastes of different radioactivity level [5].

1.1.2. Used fuel

Spent fuel stays in the reactors for certain years. After this period, fuel rod becomes less efficient due to the increase in fission products. The spent nuclear fuel radiates heat and radiation and therefore cannot be treated in such a situation, so it is stored in certain facilities to reduce the proportion of radiation and to facilitate its use for other purposes.

1.1.3. Reprocessing and recycling

Spent nuclear fuel is nuclear fuel elements that have been used at nuclear reactors. Used fuel contains uranium, plutonium and radioactive wastes. This fuel is reprocessed to benefit from the waste through recycling to get a fuel valid for use. Reprocessing has an impact on the environmental and economic level as it diminishes the waste quantity and saves uranium resources. Separation of uranium and converting it to fresh fuel or blending with plutonium to form nuclear fuel (MOX) that can be used again in another type of reactor.

1.1.4. Waste

Nuclear fuel cycle produces waste products which need careful treatment and handling to make sure it obeys the appropriate standards of safety. The resulted waste of certain radioactivity is reduced to limits at which it can be reused or recycled practicably.

Radioactive wastes are categorized to three categories (high, medium and low). Low-level waste outcomes at most of NFC steps. The medium level of waste outcomes basically from the processes that occur when reactor is operating as well as the stage of reprocessing. Spent fuel and reprocessing products are considered highly radioactive waste. The previous classification was built on the basis of how intense the emitted radiation is.

2. INTERNATIONAL SAFEGUARDS

Safeguards aims at getting credible assurances to the international community that any supervised nuclear material not abused or deviate from the peaceful usage. Safeguards implemented by IAEA inspectors Derive their legitimacy from article no (3) of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) [6].

Under this treaty, non-nuclear-weapon States are obliged to sign the Comprehensive Safeguards Agreement with the world represented by IAEA INFCIRC/153 represents the backbone of the implementation of CSAs [7]. The Agency's safeguards system aims to prevent the spread of nuclear weapons through a series of inspections of Member States to ensure their commitments to the non-proliferation issue [8]. The IAEA is the world sponsor for applying the international regime of nuclear non-proliferation [9]. The Agency carries out its tasks with regard to the nuclear arms embargo and the implementation of the Safeguards agreement not only through legal protection supported through the agreement but also through the Additional Protocol (AP). AP was created through a series of efforts to bridge gaps in the safeguards agreement [10].

2.1. Nuclear material

Nuclear material consist of two fundamental categories: on is called "bulk material" and the other named "item material". Bulk material can exsist in different shapes such as powders, solutions…etc. whereas the second type may be fuel rods. Nuclear materials include special fissile materials and source materials.

Verification of nuclear materials is a fundamental principle of the safeguards regime. Safeguards inspections are performed by international inspectorates. The verification process can be accomplished by certain tools and methods such as Destructive assay technique, Non-Destructive Assay techniques, Containment and Surveillance (C/S) and Unattended Remote monitoring (URM) [11].

3. SAFEGUARDS MEASURES

3.1. Nondestructive assay

NDA Is to conduct measurements on nuclear materials without prejudice to their physical or chemical state[12]. The scientific idea of this type of measurement depends on the measurement of emission from the sample to be measured. An example of NDA is gamma ray measurements. Passive assay is a category of NDA that depends on measuring spontaneous emissions of radiation while stimulated radiation is measured by active assay [13].

3.2. Destructive analysis

Destructive analysis is measurements in which the physical form of the sample is normally destructed. UV spectrophotometer, Inductively coupled plasma optical emission spectrometer, mass spectrometer, auto titrator…et. are examples of DA techniques that are usually used by safeguards analyst to reveal information concerning the samples such as concentration and isotopic ratio [13]. DA differs from NDA in some points such as accuracy, cost , sample preparation and the suitability to be performed in situ or in lab.

3.3. Nuclear Safeguards Using Cherenkov Light

A characteristic blue Cherenkov light is emitted in the water surrounding the fuel assembly when spent nuclear fuel is stored in water. Gamma radiation that outcomes from fission products interact with electrons in the water leading to the creation of Cherenkov light as electromagnetic shock fronts from the electrons moving faster than light through the water. The amount of Cherenkov light can be estimated to characterize the fuel in a storage pool. This can be done using the Digital Cherenkov Viewing Device (DCVD). This apparatus is approved by the Agency to verify the nuclear fuel with in case of gross and partial defects [14].

4. SPENT NUCLEAR FUEL CHARACTERISTICS

The nuclear fuel assemblies have physical characteristics such as fuel material, initial enrichment, cladding material, cladding diameter, cladding thickness, pellet diameter, pellet height, and assembly array. The characteristics of NSF are of types: physical and operational characteristics. The physical one differs from a type of a reactor to another while the operation one is dependent on the processes that occur during the journey that starts from irradiating the fuel assembly till the fuel is spent. Irradiation history, burn up, initial enrichment and cooling time are the main parameters that give us a view on the reactor operations. Irradiation history is a record of the specific power or energy released from the nuclear reactor at certain time. It can give us information concerning the working days of the reactor and the specific power for each period and through that, we can know the shutdown periods. Burn up is the extracted from the nuclear fuel in other words, you can say it is the integral of the irradiation history. Initial enrichment is a physical characteristic of the fuel assembly but it affects operation. It impacts the potential final burn up. The higher the content of fissile material the higher is the burn up. Cooling time is the amount of time after the final irradiation of the spent fuel assembly. Spent fuel isotopic characteristics gives us information concerning the burn up, shutdown periods (short or long) and the specific power (lower or higher) [15].

5. SPENT NUCLEAR FUEL SIGNATURES

SNF has signatures such as physical signature, gamma radiation, Cerenkov radiation, neutron radiation, and combined radiation. The ID code is an example of a physical signature, the inspector can see this code to verify the identity of the fuel assembly. Corrosion and deformation that occurs to nuclear fuel during its life in the reactor through the surrounding is also a physical signature[16]. Corrosion may happen due to deposition of crud on the shiny and clean fuel assembly while deformation may occur due to structural changes. Total gamma activity is a signature for irradiation, burn up and cooling time. Fission product gamma-ray activity (Cs-134/ Cs-137/Eu-154), Fission product gamma-ray activity ratio is a signature for irradiation, burn up and cooling time. Also, Cerenkov radiation intensity, neutron activity, Neutron to gamma radiation are signature for burn up and cooling time except the combined radiation is the only signature for burn up [17].

6. NUCLEAR MATERIAL ACCOUNTANCY OBJECTIVES

NMA verification objectives are to detect gross defects like missing a spent fuel assembly also to verify the identity of SNF to ensure that a spent fuel assembly is the assembly that declared by the facility operator another verification objective is to detect partial defects like verification of the integrity of SNF object (missing fuel rods). The final objective is to verify the nuclear material content of the SNF object (U-Th-Pu). The C/S verification objectives are to verify continuity of knowledge over SNF assemblies and to verify no use or production undeclared nuclear material. Design verification objectives are to verify facility design (no new unsafeguarded SNF transfer paths).

6.1. Objectives of the system of accounting nuclear material in a state (SAAC).

The SSAC has national and international objectives [18].

(a) National:

(i) Inventory of nuclear materials inside the state,

(ii) Participate in the detection and prevention of unauthorized use of nuclear materials, (detect loss of nuclear materials, and provide information that could lead to the recovery of missing material)

(iii) Support the right use of nuclear materials between operators.

(b) International:

(i) Supply states with the essential basis required to implement the IAEA safeguards.

6.2. The Role of SAAC in combating some diversion proposed scenarios.

The SSAC has a vital role in detecting and responding to any trial to misuse or divert nuclear materials or facility. The most famous scenarios for diversion are undeclared production and diversion of declared materials. This can occur by a scenario in which removal of fuel assembly from the reactor core or spent fuel pool, it could be substituted with dummies or could be falsified records or borrowing from another facility. Another example of diversion is irradiation of undeclared fuel assemblies or use of target material within the reactor core. Also, another example of diversion is undeclared design changes. All these scenarios could be prevented by NMA using the terms of NMA and KMPs (flow-inventory).

7. CONCLUSION

Safeguards tools are effective to counter any misuse of material or activities involving nuclear material within facilities. The state system responsible for accounting and controlling nuclear material is the technical tool for practical execution of nuclear safeguards. Spent fuel is a strategic component of the back end nuclear fuel cycle. Safeguarding such item facilities that contain Spent Fuel is an important process and need more effort in order not to allow these materials to be in the wrong hand. It is obvious that SNF characteristics and signatures give the most effective information on NMA. Proposing scenarios for misuse and diversion by SSAC lead to well established and robust safeguards system.

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