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Nuclear Security Related Attributes and Characteristics of Different Types of Nuclear Facilities

Nukleáris létesítmények nukleáris védettségi szempontból lényeges tulajdonságai

The existing International Atomic Energy Agency (IAEA) Nuclear Security Series (NSS) publications do not provide specific guidance for the different types of nuclear facilities; these are typically meant as a general guidance for nuclear facilities rather than having specific application to any specific facility type. Accordingly, the question may rise whether operators of different nuclear facilities would need to take account of the specific characteristics of their facilities during the implementation of the recommendations and guidance provided in IAEA NSS publications. The comprehensive answer to the question (regarding each type of nuclear facility) requires the identification of the above mentioned specific characteristics of all nuclear facility types and the systematic assessment of the exiting IAEA NSS publications, including IAEA Nuclear Security Series No. 13 and other implementing and technical guides. The identification of specific characteristics of different nuclear facilities that may influence the design and implementation of their physical protection systems and measures is the starting point of this comprehensive review process.

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A Nemzetközi Atomenergia Ügynökség Nukleáris Védettségi Sorozatban eddig megjelent útmutatók nem adnak specifikus útmutatást a különböző típusú nukleáris létesítményekre vonatkozóan. A meghatározott követelmények és ajánlások általános érvényűek az összes nukleáris létesítményre. Felmerül a kérdés, hogy a különböző típusú nukleáris létesítmények üzemeltetőinek figyelembe kell-e venni a saját létesítmények specifikus tulajdonságait a NAÜ-követelmények és -ajánlások alkalmazásakor. A kérdés átfogó megválaszolásához meg kell határozni a különböző típusú nukleáris létesítmények nukleáris védettségi szempontból releváns tulajdonságait és értékelni kell, hogy ezek befolyásolják-e a követelmények és ajánlások alkalmazhatóságát. A különböző nukleáris létesítményeknek a fizikai védelmi rendszer tervezése és megvalósítása szempontjából releváns tulajdonságainak meghatározása és vizsgálata az első lépése ennek az átfogó feladatnak.

Kulcsszavak: **nukleáris védettség, nukleáris létesítmények védettségi szempontból releváns tulajdonságai, NAÜ, fizikai védelem**

IAEA Nuclear Security Series

Nuclear security issues relating to the prevention and detection of, and response to, theft, sabotage, unauthorised access and illegal transfer or other malicious acts involving nuclear material and other radioactive substances and their associated facilities are addressed in the publications of IAEA Nuclear Security Series. These publications are consistent with, and complement, international nuclear security instruments, such as the amended Convention on the Physical Protection of Nuclear Material [1], the Code of Conduct on the Safety and Security of Radioactive Sources, United Nations Security Council Resolutions 1373 and 1540, and the International Convention for the Suppression of Acts of Nuclear Terrorism.

Publications in the IAEA Nuclear Security Series are issued in the following categories:

- Nuclear Security Fundamentals contain objectives, concepts and principles of nuclear security and provide the basis for security recommendations.
- Recommendations present best practices that should be adopted by Member States in the application of the Nuclear Security Fundamentals.
- Implementing Guides provide further elaboration of the Recommendations in broad areas and suggest measures for their implementation.
- Technical Guidance publications include: Reference Manuals, with detailed measures and/or guidance on how to apply the Implementing Guides in specific fields or activities; Training Guides, covering the syllabus and/or manuals for IAEA training courses in the area of nuclear security; and Service Guides, which provide guidance on the conduct and scope of IAEA nuclear security advisory missions [2].

Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities

In the hierarchy of the Nuclear Security Series, IAEA Nuclear Security Series No. 13 [3] together with IAEA Nuclear Security Series No. 14 [4] comprehensively cover the area of nuclear security of nuclear material and other radioactive material, associated facilities and associated activities, including the use, storage and transport of such material. As a recommendation level document, IAEA Nuclear Security Series No. 13 contains recommendations and recommended requirements which apply to the physical protection of nuclear material against unauthorised removal with the intent to construct a nuclear explosive device, and to the physical protection of nuclear facilities and nuclear material against sabotage. Protection requirements against unauthorised removal of nuclear material (as radioactive material) for potential subsequent off-site dispersal are provided in IAEA Nuclear Security Series No. 14.

By definition contained in IAEA Nuclear Security Series No. 13, nuclear material is that material which is listed and categorised in its Table 1 (i.e. unirradiated and irradiated plutonium and uranium). A nuclear facility is defined as a facility (including associated buildings and equipment) in which nuclear material is produced, processed, used, handled, stored or disposed of and for which a specific licence is required.

The recommended requirements for the physical protection against unauthorised removal in IAEA Nuclear Security Series No. 13 follow a graded approach, applying a categorisation system which is based on the attractiveness of the nuclear material for the construction of a nuclear explosive device. The recommended requirements on physical protection against sabotage apply to nuclear material and nuclear facilities. They are based on the inventory, not considering the characteristics of different types of nuclear facilities. The basis for the graded approach of protection against sabotage is not the category of the nuclear material, but the concern on potential radiological consequences resulting from the radioactive inventory present in the facility as a result of a successful sabotage. The recommended requirements apply to all nuclear facilities, including nuclear reactors (nuclear power plants and research reactors) and nuclear fuel cycle facilities (including conversion, enrichment, fabrication, reprocessing, and storage facilities). There is one set of requirements for material in use and storage, which implies that this material is located in a facility and another set of requirements is defined for nuclear material during transport.

Existing IAEA Nuclear Security Series publications do not provide specific guidance for different types of nuclear facilities; these are typically meant as a general guidance for nuclear facilities rather than having specific application to any specific facility type. While in the area of nuclear safety, the safety standards series provide safety fundamentals, safety requirements, and facility type specific requirements and guidance for all relevant types of nuclear facilities.

Different Types of Nuclear Facilities

Conversion and enrichment facilities

In conversion and enrichment facilities, most of the uranium is in the chemical form UF_6. The physical form of UF_6 could be either gaseous, liquid or solid. Depending on the enrichment of the final product, the nuclear material would be of Category III (uranium enriched above natural, but less than 10% U_{235} or Category II (Uranium enriched to 10% U_{235} but less than 20%) nuclear material.

A significant potential hazard associated with these facilities is a loss of the means of confinement resulting in a release of uranium hexafluoride (UF_6) and hazardous chemicals such as hydrofluoric acid and fluorine. In addition, for enrichment facilities and conversion facilities that process uranium, criticality can also be a significant hazard. The radiotoxicity of the uranium is low, and any potential off-site radiological consequence following a sabotage would be expected to be limited; however, the radiological consequences of an accidental release of reprocessed uranium would be likely to be greater.

The enrichment process relies to a large extent on operator intervention and administrative controls to ensure safety, in addition to active and passive engineered safety measures. Since for enrichment of nuclear material to the required level, the nuclear material will be imported from conversion facilities, moved on-site, heated and processed, filled into containers, stored and exported to customers, e.g. fuel fabrication facilities, the administrative control must manage all these activities in a way that safety and security is well coordinated and robust against insider threat activities. In addition to protection against unauthorised removal and sabotage, protection of enrichment technology plays an important role.

Fuel fabrication facilities

In uranium fuel fabrication facilities, large amounts of radioactive material are present in a dispersible form. This is particularly so in the early stages of the fuel fabrication process. In addition, the radioactive material encountered exists in diverse chemical and physical forms and is used in conjunction with flammable or chemically reactive substances as part of the process. Depending on the requested fuel enrichment degree, these facilities used and stored Category III and Category II nuclear material.

The main hazards in these facilities are the potential criticality and the release of UF6 and uranium dioxide (UO_2), from which workers, the public and the environment must be protected by means of adequate design and construction and by safe operation.

The fuel fabrication processes rely to a large extent on operator intervention and administrative controls to ensure safety, in addition to active and passive engineered safety measures. The potential for a release of energy in the event of an accident at a uranium fuel fabrication facility is associated with nuclear criticality or chemical reactions. The potential for release of energy is small in comparison with that of a nuclear power plant, with generally limited environmental consequences.

Nuclear power plants

Several decades have passed since the appearance of the first nuclear power plants. The different types and generations of these energy producing facilities can be well characterised from a safety point of view [5], but these aspects are not always relevant from the perspective of nuclear security.

The nuclear fuel in most commercial nuclear power plants is made of low enriched uranium and belongs to Category III when fresh. Some plants operate with fresh mixed uranium-plutonium fuel belonging to Category I because of its unirradiated plutonium content. During burnup, the fuel becomes irradiated and as spent fuel, it belongs to Category II. During operation, the fission process produces a significant inventory of radioactive substances of very high activity. Physical protection against sabotage dominates the concern on unauthorised removal in most NPPs. The physical protection of nuclear material would be an integral part of the PPS at NPPs.

IAEA Nuclear Security Series No. 13 associates the nuclear power plants as facilities having high radiological consequence regarding sabotage and formulates requirements similar to a facility where Category I nuclear material is in use or storage. Similarly, general safety requirements assign facilities, such as nuclear power plants, for which on-site events (including those not considered in the design) are postulated that could give rise to severe deterministic effects off the site that would warrant precautionary urgent protective actions to the highest emergency preparedness category.

Fulfilment of the following fundamental safety functions for a nuclear power plant shall be ensured for all plant states. These safety functions are the control of reactivity; removal of heat from the reactor and from the fuel store; and confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases. In order to prevent an attempt of sabotage from becoming successful, these functions must also be maintained during and after malicious acts performed by insider or external threats.

Main overhauls for maintenance and refuelling, or major repairs require extensive human interactions, a huge number of contractors' staff needs to be authorised for access to conduct technical inspections, maintenance, or repair. In addition, different equipment and material needs to be cleared when entering the facility.

Moreover, when the reactor pressure vessel is open, the vulnerability to malicious acts rises. Security measures should be adjusted to the situation in order to maintain security on an appropriate level and to enable the work.

Small modular reactors

A variety of types of large reactors that have been developed in the past are considered small modular reactors. Such facilities represent not a newly defined reactor technology, but are differentiated by the power level and the modular concept from nuclear power plants. The electricity production of a typical small modular reactor is less than 300 MW, which requires a smaller fuel inventory, and a lower frequency of fuel loading and unloading. In addition, the amount of radioactive waste stored on the site will be less than in existing nuclear power plants.

Some small modular reactors use fuel enriched at the top end of what is defined as low-enriched uranium (i.e. a bit below 20% enrichment), other designs use fuel made of uranium enriched around 5%. Accordingly, their inventories belong to Category II.

Depending on the type of facility, such as floating, underground, capsuled unmanned and remote controlled, the specific facility has features representing robustness against unauthorised removal as security is part of its specific design.

In harmony with the smaller inventory and power level, a successful act of sabotage may result in less severe radiological consequences.

Research reactors

Research reactor fuel today typically is enriched to less than 20% and belongs to Category II. The fuel assemblies are typically plates or cylinders of uranium-aluminium alloy clad with pure aluminium. In an open pool reactor, the fuel is in principle accessible under water. The sizes and weights of research reactor fuel bundles are much smaller than of those used in nuclear power plants; therefore, they are relatively easily portable, if radiation is not considered.

Some research reactors are used to produce isotopes which would represent an additional inventory of other radioactive material.

The potential for radiological consequences of a sabotage at a research reactor depends on its power, design, inventory, lay-out and location.

Spent fuel storage

The inventory of a spent fuel storage facility is composed of spent fuel generated by operating nuclear reactors. After a typically 1–5 year storage period in the spent fuel pool next to the reactor, the spent fuel is stored prior to reprocessing or disposal in a wet or dry spent fuel storage facility. A spent fuel storage facility is by definition not a disposal facility, thus its operating lifetime is limited but could last several decades.

Applying the categorisation table, spent fuel is assigned to Category II. The required retrievability would enable removal of the fuel assemblies including their unauthorised removal.

The potential radiological consequences of a spent fuel storage facility are typically a magnitude lower than those of a nuclear power plant. The driving force represented by the high thermal and nuclear power of a nuclear power reactor is missing so that indirect sabotage is less attractive. The success of a sabotage depends on the robustness of casks and building structures.

Reprocessing facilities

Large quantities of fissile material, radioactive material, radiotoxic and other hazardous materials are present (stored, processed and generated) in a fuel reprocessing facility, often in easily dispersible forms (e.g. solutions, powders and gases) and sometimes subjected to vigorous chemical and physical reactions.

Separation and purification processes will lead to significant amounts of uranium and plutonium belonging to Category I.

The fuel reprocessing processes are a mixture of high and low hazard, chemical and mechanical processes, including high hazard fine particulate processes and processing involving hazardous solid, liquid, gaseous and particulate (dry, air and water-borne) wastes and effluents. Reprocessing facilities have the potential for serious nuclear and radiological emergencies. The main risks of a sabotage are criticality, loss of confinement, radiation exposure and associated chemical hazards.

Disposal facilities

The nuclear material in a disposal facility is generally processed to produce stable and solid forms, and reduced in volume and immobilised, as far as practicable, to facilitate their transport and disposal.

The content of nuclear material would belong to Category II. The term "disposal" implies that retrieval is not intended, but it does not mean that retrieval is not possible. Unauthorised removal of radioactive waste, also for off-site dispersal needs to be considered when securing the facility.

The inventory of radioactive waste represents a potential hazard to the biosphere.

Attributes and Characteristics of Security Relevance

As recommended in IAEA Nuclear Security Series No. 13: "Three types of risk should be taken into consideration for the protection of nuclear material and nuclear facilities [3]:

- Risk of unauthorized removal with the intent to construct a nuclear explosive device;
- Risk of unauthorized removal which could lead to subsequent dispersal;
- Risk of sabotage."

Different types of nuclear facilities represent different levels of these risks. The risk is a function of severity of consequences of an event and the probability that the event would occur. The categorisation table in IAEA Nuclear Security Series No. 13 and the thresholds for radiological consequences are related to the severity. The probability of an event leading to these consequences would be strongly determined by the type and design of a facility.

IAEA Nuclear Security Series No. 13 requires the consideration of specific facility characteristics when implementing physical protection.

The different types of nuclear facilities, including research reactors [6] with regard to the implementation of nuclear security measures, can be characterised according to the following attributes and their characteristics.

Security vulnerabilities inherent in design and operational practice

The older facilities were not designed with security as a priority, which can complicate the task of providing physical protection. The designs of these facilities were typically optimised around their specific objectives. The focus on these objectives often led to the inclusion of features that are not conducive to nuclear security and could be exploited by an adversary intent on committing unauthorised removal or sabotage, such as easy access to nuclear material, frequent reconfiguration of the core, glass walled control rooms, access to computer systems through open network, open fuel storage, accessible tools and equipment like cranes, forklifts, casks.

Specific safety design

The safety design including provisions against natural or human made external events generate robustness against malicious acts. More robust safety systems require more complicated attack scenario to be developed for a successful malicious act. Safety requirements to be met and the robustness of the required safety features, including the required level of redundancy and diversity depend on the radiological hazard meant by the facility that correlates with the type of the facility. As safety standards are developed continuously and lessons learned during the years are taken into account, a new facility is built according to more stringent safety requirements.

Attractiveness of material

The categorisation system of nuclear material basically takes into account the applicability of the material to build a nuclear device, but higher enrichment level and lower fuel burnup make the nuclear material more attractive as a target of unauthorised removal. In addition, lower dose rates from spent or irradiated material may be less likely to be incapacitating to an adversary.

Colocation with other facilities

A nuclear facility can be a part of a larger organisation operating other nuclear related and also non-related facilities and activities. These other facilities and activities may mean security concerns for the nuclear facility. Such security concerns can be raised by armed security forces employed in another facility, the adverse consequences of an accident or a security event occurring at the other facility that may result in difficulties of the implementation of the nuclear security measures.

Openness of access, exchange of information

Some facilities or certain areas of some facilities are easily accessible to contractors, staff, guests, students and other visitors. A large number of temporary personnel with unescorted access may require special considerations during the design and implementation of the nuclear security system and measures. In addition, the environment of information sharing and data transparency may create vulnerability for the security of computer based systems.

Variety of uses

Some facility types are designed to fulfil different specific purposes, such as training, research, irradiation, experiments, radioisotope production, medical therapy or neutron activation. Such diversity complicates the standard approach of meeting security requirements.

Funding

The extent and predictability of funding, including that for security can be adversely influenced by the budget basis and provision of the facility, especially for those which do not have income from the operation. Funding limitations may influence the maintenance of security system elements.

Regulatory and operator issues

An operating organisation(s) may lack an appropriate nuclear security culture, at times believing that the purpose or mission is more important than compliance with regulatory nuclear security requirements [7]. This can be exacerbated by a lack of nuclear security expertise and/or organisational independence in the regulatory body in States where operation/promotion and regulatory oversight responsibilities are within the same government organisation. Such conditions may result in the lack of effective regulatory oversight. This, combined with the lack of a nuclear security, can significantly complicate effective implementation of security measures.

The staff responsible for security often lack specialised experience and knowledge of the security system or of security measures. This can be exacerbated by a lack of security expertise in senior management within the organisation and/or at the regulatory authority, which limits the ability to perform effective checks and balances. Lack of expertise can result in the following:

- The responsibility for overseeing and implementing security is effectively ignored.
- The security responsibility is undertaken, but the resulting security is ineffective due to the limited depth of knowledge and experience in security.
- The security responsibility is transferred to a commercial contractor, whose primary motivation is profit rather than effective security.

Site location

Certain geographic locations might be undesirable from nuclear security perspective, such as close proximity to densely populated areas, dense traffic in the surrounding area, harsh weather conditions, seismic activity, site topography, remote location. Depending on the location, such facilities may provide increased robustness against sabotage, i.e. off-site or airborne attacks, when located underground or underwater. The latter will change the paths for radiological releases. At the same time, sea contamination and vulnerability to marine/sub-marine threats or underground threats may need to be considered in the nuclear security design.

Facility ageing

The effectiveness of those security and safety features that were present originally may have degraded with age. The maintenance of older security system elements may require special parts, non-standardised methods and expertise. Protection against emerging threats may be difficult with the ageing security system.

Number of employees

The implementation of security measures, especially those related to trustworthiness verification, access and regress control, including package checks, recording and verification of access rights, operation of turnstiles, verification of identities become more complex with the growing number of employees.

Public acceptance, rejection

The public awareness regarding local security threats would be higher, if the public accept and support the operation of the facility.

Potential radiological consequences

Depending on the radioactive material inventory of the facility, the radiological consequences of a successful sabotage may be different with magnitude.

Complexity of the site

The development of attack scenarios based on the current threat statement should consider the complexity of the site. A more complex site allows more complex attack scenarios and require more complex security system, including a larger number of response personnel.

Specific nuclear material accounting and control requirements

Protracted theft is easier in bulk facilities. More stringent accounting and control requirements, including more frequent inventory taking and verification support the effectiveness of the detection of unauthorised removal.

Conclusion

The existing IAEA NSS publications do not provide specific guidance for different types of nuclear facilities; Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (IAEA NSS No. 13) and implementing guides address technical areas such as nuclear security culture, measures against insider threat, design basis threat and computer security; but these are typically meant as a general guidance for nuclear facilities rather than having specific application to any specific facility type (i.e. enrichment facilities, fuel fabrication facilities, nuclear power plants, research reactors, small modular reactors, storage facilities and disposal facilities). Accordingly, the question whether operators of different nuclear facilities would need to take account of the specific characteristics of their facilities when implementing recommendations and guidance provided in IAEA NSS publications and thus additional guidance or technical documentation would be beneficial for them to be developed, or the recommendations and guidance are applicable to each type of nuclear facility.

The comprehensive answer to the question (regarding each nuclear facility type) requires the identification of the above mentioned specific characteristics of all nuclear facility types, and the systematic assessment whether exiting IAEA NSS publications, including IAEA NSS No. 13 and other implementing and technical guides can be unambiguously implemented or require further guidance.

The identification of specific characteristics of different nuclear facilities that may affect their physical protection systems and measures was the starting point of this comprehensive review process.

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