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INTERNATIONAL SAFEGUARDS IN NUCLEAR FACILITY DESIGN AND CONSTRUCTION

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

The great majority of States have concluded comprehensive safeguards agreements with the IAEA, pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Performed under such agreements, the safeguards verification activities carried out by the IAEA are a central part of international efforts to stem the spread of nuclear weapons. In implementing safeguards, the IAEA plays an independent verification role, ensuring that States adhere to their safeguards commitments.

Cooperation between States, the IAEA and also all other stakeholders can make safeguards implementation more cost effective and minimize its impact on nuclear operations without compromising the safeguards objectives. This guide is principally intended for stakeholders such as vendors, designers, and facility operators, and it complements, Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols and other documents, in the IAEA Services Series. This publication serves as a reference, which will be supported by detailed facility-type-specific guidance to be published separately. It addresses safeguards by design (SBD), which is defined as the consideration of safeguards throughout the lifetime of the facility from preliminary conceptual design to decommissioning.

It is in the interest of both the States and the IAEA to cooperate to facilitate the implementation of safeguards. Indeed, this is explicitly required under comprehensive safeguards agreements. Effective cooperation depends upon States and the Secretariat sharing a common understanding of their respective rights and obligations. This guide is aimed at enhancing the understanding of vendors and designers regarding the safeguards obligations of both the State and the IAEA, and at improving the cooperation between all stakeholders in safeguards implementation. States and the IAEA both attach great importance to enhancing understanding, capability and performance in safeguards implementation, as well as keeping costs low.

SBD considers international nuclear material safeguards throughout all phases of a nuclear facility project, from initial conceptual design through construction and including operations. It does not introduce any new requirements, but rather presents an opportunity to engage voluntarily earlier than might be required in order to reduce project risk. While safeguards potentially has a small impact on project cost and schedule, lack of consideration to detail sufficiently early can result in a much larger impact. The task of avoiding such increases is best assigned to the facility design and construction project management, which can better address the issues once informed about them.

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1. INTRODUCTION

1.1. BACKGROUND

This publication is part of a series from the IAEA that provides guidance on safeguards topics [1]. The focus of this guide is on safeguards by design (SBD), which provides State authorities, designers, equipment providers and prospective purchasers of nuclear facilities[1] with guidance to facilitate the implementation of international safeguards. The IAEA is promoting SBD as an approach whereby international safeguards is fully integrated into the design process of a nuclear facility. The IAEA invites both States and designers considering new nuclear facilities or related activities to engage it as soon as possible in the design process. By having a general knowledge of safeguards, a designer can make informed design choices that are the result of an optimum confluence of economic, operational, safety and security factors and which include the application of international safeguards. To reduce project risk, a designer needs to be aware of all the regulatory issues and considerations before working on the design details.

SBD complements the activities related to proliferation resistance carried out under the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)[2] and the Generation IV International Forum (GIF)[3]. INPRO's nuclear energy system assessments (NESAs[4]) using the INPRO methodology and GIF's Proliferation Resistance and Physical Protection (PR&PP) working group methodology allow a user to systematically compare the relative proliferation potential associated with various nuclear processes and facilities. SBD can also be used as a mechanism to help communicate some of the assumptions and results of a proliferation assessment at facility level to the designers of a nuclear facility.

In 2008, the IAEA convened a workshop on the 'Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards' [2]. Participants were from Member States, the European Commission, the nuclear industry, and the IAEA. The goals of the workshop were to define the basic principles and fundamental design features deemed critical to the effective and efficient implementation of international safeguards, and to propose a timeline for interactions between the various stakeholders. It was reported that safeguards considerations had often been introduced after a facility's design had been frozen or after construction had reached an advanced stage. In some cases, this had resulted in costly redesign and project delays and had reduced the efficiency and effectiveness of safeguards implementation.

It was determined that the integration of safeguards earlier in the design phases would have reduced the need for modifications and the cost and impact of implementing safeguards. Three main categories of attributes were identified as being crucial to the implementation of safeguards through SBD:

— Those facilitating design information verification;
— Those facilitating nuclear material accounting verification, including item measurements;
— Those facilitating the implementation of containment and surveillance measures.

The workshop stressed the need for a definition of an SBD framework and a process that would produce guidance for designers and operators of nuclear fuel cycle facilities. The guidance should address design features that facilitate the effective and efficient implementation of international safeguards. In order to facilitate the SBD process and address directly the perceived 'weakness in the design community's safeguards culture'[5] [2], the IAEA should also address the cultural, regulatory and legal aspects of SBD. This can be interpreted to mean more effective outreach (presentation of easily understood guidelines and explanations) to all stakeholders in non-safeguards language they can understand and use to take action. The participants recommended that a series of SBD guidelines

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[1] The following stakeholders are discussed in Section 5: Facility owners/operators, designers/constructors, the IAEA, safeguards regulatory authorities, equipment suppliers, and the scientific community.

[2] www.iaea.org/INPRO

[3] http://www.gen-4.org/

[4] http://www.iaea.org/INPRO/inpro_methodology/index.html

[5] Unlike safety culture, which is nowadays strongly supported throughout the nuclear industry, nuclear material safeguards is a little known area for some designers.

be developed to cover all facility types. This would be particularly useful in the design of new facilities and for processes which are currently in a research and development phase.

Subsequent study of the issue has determined that while much of the useful information on SBD is publicly available, it is not well organized and readily accessible by those who need it the most. SBD must facilitate the sharing of useful information through interactions that occur frequently during the facility design and construction process and this should be documented. In order to be effective, the SBD framework should:

— Identify the principal stakeholders and their roles and responsibilities, and outline the potential benefits from SBD;
— Facilitate interactions at key times during the project;
— Define the essential information exchanges which must occur, at a minimum, between the stakeholders.

Each stakeholder identified in the SBD process should have motivation and resources to support the effort, even if they assign (or perceive) different levels of importance to the various aspects. Shared goals could be:

— The reduction of resources needed to implement the requirements;
— The reduction of project risk against schedule delays;
— The avoidance of compensatory measures or 'workarounds';
— The avoidance of extra construction associated with retrofits.

The IAEA and users would benefit from an effective SBD process through cost savings and implementation of more effective safeguards. The same holds true for the safeguards authority[6]. Facility operators will benefit from less intrusive safeguards systems and processes, which will also be less costly over the full lifecycle of the plant. Early discussions on design, constructive dialogue between the stakeholders, and the sharing of lessons learned have the potential to reduce costs, avoid construction delays, and provide for more effective international safeguards.

1.2. OBJECTIVE

This publication is part of a series being prepared to help inform governments, designers and the public about SBD. It will provide information regarding the implementation of international safeguards that States, operators, or other entities can take into consideration when planning new nuclear facilities. Good systems engineering practice includes the inclusion of all relevant requirements early in the design process to optimize the system to perform effectively at lowest cost and minimum risk [3]. One possibility is illustrated in Fig. 1. The experience gained in past efforts to incorporate safeguards systems can be useful in future efforts to build or operate nuclear facilities.

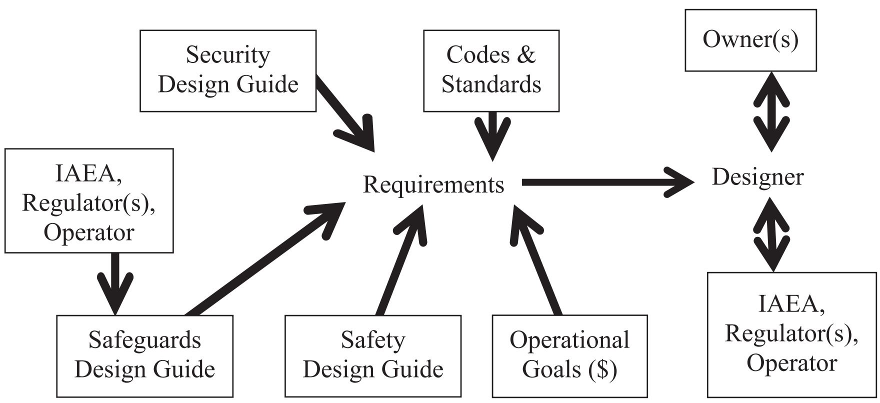

FIG. 1. One possible approach to integrating design requirements.

[6] The safeguards authority or 'regulatory body' terminology encompasses both State and regional regulatory systems as defined in the IAEA Safeguards Glossary [5].

1.3. SCOPE

This guide introduces the basic principles of SBD. It discusses the goals, the cost/rewards, and the stakeholders and places the information into the context of the international safeguards system. It emphasizes the benefits and opportunities to be gained by all stakeholders.

This guide will:

- Introduce general safeguards design principles;
- Identify project stakeholders and define their roles and responsibilities and motivation to facilitate SBD;
- Provide guidance regarding formal integration of safeguards considerations into project management for designing and building new nuclear facilities.

Future guidance, specific to generic facility types, will provide information about the IAEA's safeguards experience, including safeguards measures that have been applied, lessons learned, opportunities missed and opportunities for innovation similar to that published for light water reactors [4].

1.4. STRUCTURE

Section 2 provides a brief introduction to the safeguards by design process. The principles governing SBD are set out in Section 3, while Section 4 describes the roles and responsibilities of stakeholders in the implementation of the SBD process. The conclusion is in Section 5, which is followed by the references and a bibliography for further information.

1.5. OTHER RESOURCES

Other reference material exists that provides States and interested stakeholders with an overview and the background of international safeguards. The IAEA web page (www.iaea.org) has links to:

- The Safeguards System of the International Atomic Energy Agency;
- Guidance for States Implementing Safeguards Agreements and Additional Protocols;
- The Safeguards Glossary [5];
- Other material of general interest.

Additional resources are suggested in the References and the Bibliography at the end of this publication.

2. INTRODUCTION TO SAFEGUARDS BY DESIGN

2.1. DEFINITION

Safeguards by design is defined as an approach whereby international safeguards requirements and objectives are fully integrated into the design process of a nuclear facility, from initial planning through design, construction, operation, and decommissioning [2]. This process is not unique to international safeguards and it represents good project management to include safeguards requirements in the overall design and construction process. By including awareness of all regulatory issues, including international agreements that concern international safeguards [3], project management can schedule consideration at the appropriate time and level of detail and subsequently reduce the project risk.

The SBD process is a multidisciplinary interactive process of optimizing the design features and process parameters of the facility to ensure that safeguards obligations can be reasonably met. When a safeguards specification for the design does not exist a priori, it can be developed as part of the design. It should be noted, however, that detailed information about potential safeguards technical measures do exist in IAEA publications[7] and in the proceedings of professional societies like the Institute of Nuclear Materials Management[8] or the European Safeguards Research and Development Association[9]. Any final safeguards approach[10] is a facility specific combination of safeguards measures and depends on many factors. The designer must understand the interplay between operational and regulatory requirements (e.g. safety[11], safeguards, and security) in order to produce an optimum design. This understanding is best achieved through an iterative dialogue that starts with high level understanding of the objectives and questions regarding how to achieve those objectives. These questions begin at a generic level and then become more detailed as the understanding of the different stakeholders about the different requirements evolves.

2.2. GOALS AND BENEFITS OF THE SBD PROCESS

SBD has several major benefits:

— Minimizing the risk associated with project scope, schedule, budget and licensing;
— Reducing the cost of safeguards implementation to the operator and the IAEA;
— Decreasing costs for State regulators;
— Improving safeguards assurances to the international community and the general public.

An effective and efficient design process is one which clearly defines the functional and performance requirements at the beginning of the project and enables the project to achieve a reasonable balance between competing requirements in a cost effective manner. The most effective option for SBD would be to have international safeguards become a standard part of the design and licensing of nuclear facilities. Ideally, SBD would be taken into consideration as one of the criteria when choosing between final designs for a nuclear facility.

Balanced consideration of all requirements by designers will reduce project risk against delays and cost increments, and facilitate the licensing process. Incorporation of international safeguards into a facility at the design stage can also facilitate improving the effectiveness and efficiency (e.g. costs) of safeguards that are applied by the IAEA and can influence the choice and development of technology options. The objective of SBD is to have facilities that are less expensive to effectively safeguard while minimizing the impact of safeguards on facility design and operations. For successful and effective implementation of SBD, there is a need for a project management framework which identifies key stakeholders, defines their roles and responsibilities, and establishes an interaction timeline. Safeguards agreements are signed with the State, implying that IAEA communication is with the State, not with the designer or facility operator, thereby potentially adding complexity to the project communication process. The State can be proactive in facilitating open communication between the IAEA and the other stakeholders.

Under a comprehensive safeguards agreement, following the strengthening measures regarding design information approved by the IAEA Board of Governors in 1992[12], preliminary design information for a facility should be submitted as soon as a decision to construct, or to authorize construction, has been taken. In practice, sharing preliminary ideas can begin even before such a decision has been taken. In this case, the partial information can facilitate the SBD process, invite questions, and bring stakeholders together on the topic of safeguards. Sharing information for safeguards can precede the legal requirements for provision of information and, furthermore, can facilitate preparation for the formal transfer of the preliminary and final design information from the State to the IAEA. Success is contingent on each stakeholder's understanding of the benefits that can be realized by voluntary participation in the process. Experience has shown that including consideration of safeguards works best (less cost and less impact) when it begins as early as the consideration of safety or security. Thus, project management can be

[7] www.iaea.org

[8] www.inmm.org

[9] http://esarda2.jrc.it/about/index.html

[10] A safeguards approach is a set of measures chosen for the implementation of safeguards in a given situation in order to meet the applicable safeguards objectives [5].

[11] It is understood that safety includes environmental protection.

[12] See documents GC(XXXVI)/1017 and GOV/2554/Attachment 2/Rev.2 (1992).

optimized when explicit safeguards features are integrated into the design. In all cases, a basic understanding of the requirements helps to improve the quality of the project decisions.

Effective safeguards can be challenging to implement efficiently when some stakeholders are not included in the design process. By understanding the goals, needs, requirements and constraints of each other, choices can be made to ensure that the goals of all stakeholders are met. One example of this is that through an understanding of the IAEA requirements, a facility or process could be designed to minimize the time that inspectors would need to be present in the facility. This would benefit the IAEA by allowing it to redirect its resources to other activities. It would benefit the operator by minimizing safeguards intrusiveness at the facility. The State would benefit by reducing the resources necessary to support the activity.

Other areas of benefit can be found in unattended or remote monitoring in bulk handling facilities and in on-load refuelling or continuous flow reactor designs (for example, CANDU, pebble bed, or molten salt designs). For example, if the designer is aware of the types of information used and required for safeguards purposes, it may be possible to design the system enabling real time process information that has been verified as authentic to be collected, the safeguards significance established, and transmitted to the IAEA for evaluation. Ultimately, all parties will benefit if adequate, reliable safeguards information can be provided to the IAEA using equipment designed into the facility. The length of time required for carrying out inspections, and the frequency of inspections, can both be reduced potentially without affecting the ability to meet safeguards objectives. Backup systems or procedures — such as methods to ensure that data collection continues when primary systems fail, or to divert data to on-site secure repositories for subsequent inspector evaluation when remote transmission of data is interrupted — can also be addressed in the design process. Finally, consideration can be given to authentication, measurement facilitation, ease of verification, and continuity of knowledge issues.

SBD should encourage compromise between competing design requirements and also promote innovation to maintain safeguards effectiveness. Furthermore, SBD encourages improved efficiency in the implementation of international safeguards. During the development and planning stage, arrangements between the IAEA and stakeholders can set the framework for joint use of equipment and instrumentation. A clear understanding of the safeguards equipment requirements in a facility allows for the supporting infrastructure to be incorporated into the facility design, thus eliminating the need to retrofit the installation of safeguards related infrastructure at a later stage or the need to work around an unforeseen design conflict.

There are, of course, trade-offs that must be managed by the project between retaining flexibility in the details of the safeguards approach and getting detailed specifications in the design and construction to save resources (i.e. financial or human). In one example, a compromise could be to agree on which rooms or walls require sensors and what type and how many will be placed (thereby specifying the containment penetrations for cabling infrastructure and the supporting equipment cabinets outside controlled areas), but allow for adjustment of the precise sensor locations and selection of any fields of view to be specified later during installation.

3. PRINCIPLES

3.1. GENERAL PRINCIPLES

The IAEA promotes the concept of SBD with the expectation that all stakeholders will realize benefits, particularly reduced costs for installation, equipment, inspection time and labour. These benefits are expected to motivate the stakeholders to participate in the SBD process from an early stage[13]. The benefits may vary from stakeholder to stakeholder, but if safeguards objectives are effectively realized in an efficient manner, all parties will gain. The SBD process assumes that the designer/operator knows the most about the facility and its operation, while the IAEA knows the most about meeting international safeguards objectives. Meanwhile, the formal legally recognized communication channel is to/through the safeguards authority. The authority must be fully engaged in facilitating the necessary and iterative dialogue between the IAEA and other stakeholders if SBD is to succeed. In most cases, the designer, the constructor and the operator of the facility are different entities and the project

[13] Significant motivation occurs once stakeholders understand the safeguards obligations assumed by their State under international treaties and agreements, which are potentially also to be reflected in licensing conditions.

manager must arbitrate between the entities to minimize total project cost and risk. The safeguards authority can take the initiative to include international safeguards considerations in this process.

An important principle of the SBD process is that the more knowledgeable the IAEA is regarding the design, operation, conditions, and constraints of a facility or process, the more likely it is to develop an optimized safeguards approach with reduced resource demands on the operator, the safeguards authority, and the IAEA itself.

Another principle is that the SBD process functions better when information regarding the design of a facility is openly shared with the involved stakeholders. While simple in concept, this may be difficult to realize. In some cases, there is a resistance by stakeholders to providing access to the relevant information. This resistance might be based on concern over the loss of confidential or proprietary information. The IAEA takes the protection of confidential information seriously as it is a requirement specified in safeguards agreements, and supports the principle that the protection of sensitive and proprietary information is of utmost importance. The full scope of security measures will be applied to protect controlled and proprietary information from unauthorized disclosure.

During the development and planning stage, arrangements between the IAEA and stakeholders can set the framework for joint use of equipment and instrumentation. Examples of this would be measurement devices or internationally accepted common systems of identification shared between the IAEA, the State or regional authority and/or the operator. Another possibility would be the sharing of images from surveillance devices utilized for operations, safeguards and safety/security, such as the operator's surveillance of fresh fuel identification. The responsibility for the equipment/instrumentation would have to be agreed upon and arrangements to ensure the authenticity of the data developed, but the resultant reduction in costs would potentially benefit all concerned.

Providing the safeguards equipment requirements for a facility allows for any supporting infrastructure to be incorporated into the design, thus eliminating the need for costly retrofits or workarounds. For example, if locations for surveillance in the facility are identified at the start by the designer, and agreed to by the safeguards authority and the IAEA, the required cabling and mounting mechanisms can be incorporated into the facility design and the design can also take into account the needs for illumination and a clear field of view. Even if the precise equipment locations are not determined early in the process, the necessary infrastructure (e.g. instrument power, adequate lighting, secure data communication lines) can be included in the design and construction without 'change orders' being required.

In some cases, as a facility is being designed, the State where the facility will be located has not been identified. Therefore, the review will be based on the type of facility, its architectural and process related characteristics, and will not depend on the final siting of the facility[14]. Given that nuclear material accounting[15] will remain of fundamental importance to IAEA verification activities, one can consider the IAEA approved measurement, surveillance, and containment technologies a good starting point for beginning a discussion on safeguards considerations with the designers. From a designer perspective, the frequency of inspections might be of less design interest than the possible technologies that could come into play, along with associated infrastructure and personnel access requirements.

The application of process automation at bulk handling facilities[16] can potentially influence the difficulty of diversion. Another important principle of SBD is that transparency of facility operations significantly enhances the possibility of detecting modifications to, or misuse of, a facility as well as diversion of nuclear material. For example, in automated facilities with near-real-time availability of material-process-flow data to inspectors, both the production of undeclared material by a modification of the process or design and the removal of nuclear material can be more easily detected.

It is important to note that regardless of advances in safeguards techniques and technology, nuclear material accountancy and control will remain a safeguards method of fundamental importance for detecting diversion. Once designers and operators understand this fundamental concept and its ramifications, they are better able to accommodate the subsequent needs and to mitigate the corresponding impacts. The implementation of safeguards can be facilitated by such things as:

[14] However, the IAEA will apply State specific factors in developing its approach to safeguards for each State.

[15] Nuclear material accounting is defined as the "activities carried out to establish the quantities of nuclear material present within defined areas and the changes in those quantities within defined periods." [5].

[16] A facility where nuclear material is held, processed, or used in bulk form [5].

— Simplifying the path of nuclear material through the facility and the number of locations where it is stored;
— Understanding the safeguards use of containment, authentication of data, and continuity of knowledge;
— Installing a robust automated accounting system that provides all necessary reports electronically.

Flexibility and project risk must be managed against the possibility of change. From the design perspective, when dealing with a one-step licensing regime that involves design certification at the front of the process, there should be a strong incentive to resolve the safeguards considerations prior to design certification.

Project management should consider assigning the safeguards requirements the same priority as those of other regulatory concerns like safety, including environmental protection, and security. Addressing all requirements simultaneously, and as early as possible, can help to optimize the synergy between them and ensure that they are implemented efficiently. The goals of these disciplines are similar and the parameters which are monitored (dose rate, emissions, nuclear material flows and quantities) are of a similar nature. When each discipline understands the goals of the others, experts should be able to develop innovative, collaborative solutions that reduce implementation costs. An example of this would be the use of an instrument to monitor the number of items in a process[17]. The information from this instrument will be of value to security, safety and safeguards, therefore an instrument can be designed to satisfy the needs of all three.

3.2. INTERACTION/COMMUNICATION

The safeguards system of the IAEA provides the international community with assurance that States are fulfilling their non-proliferation obligations. One of the principles underlying the interaction of stakeholders is that with an understanding of the safeguards system goals and objectives, all stakeholders can contribute to the development of effective and efficient safeguards measures to be applied to a facility. Understanding the basic concepts will facilitate voluntary cooperation. The SBD process relies on the fact that the designers and operators of nuclear facilities are clearly the experts with regard to their facilities.

In some of the early nuclear construction projects, the safeguards authority, designer, and operator had minimal technical interaction. Early collaboration that included safeguards considerations could have helped to build a trusting, open relationship between these stakeholders and helped to develop a greater understanding of the goals, concerns and constraints between the different parties. Stakeholders must document the information they share to improve communications, not only because the information will change, but because the personnel involved will change. Since legal agreements specify the State as part of the communication process, as the intermediary, the safeguards authority must assume responsibility for promoting and documenting voluntary communication. The project lifetimes for designing and constructing large, nuclear facilities are often decades long. The SBD process must plan for, and smoothly accommodate, turnover in personnel among the stakeholders.

For SBD to become as efficient as possible there must be a well structured communication process at both the formal and informal levels. This communication must engage as many stakeholders as possible and must be documented in a widespread, easily accessible, fashion. It must be clear which communications are informative and which are binding commitments. It is important that all stakeholders understand their roles and responsibilities, that essential requirements and regulations are in place, and that there is a project plan that includes the safeguards considerations. In this context ‘considerations’ includes safeguards requirements and also scheduling of when to consider each requirement and at what level of detail. The engagement of all stakeholders in discussions and cooperation from the very early stages of a project is of utmost importance.

As understanding of both safeguards and the design is improved, more detailed and complex questions arise. Besides project management and systems engineering, proliferation assessment methodologies might be useful throughout the project to evaluate the choices between design options. An assessment can quickly help determine whether a fuel cycle facility design has novel safeguards issues [6–8].

Consistent interaction of all stakeholders needs to occur throughout the project in a spirit of transparency, openness and cooperation. This interaction must be thoroughly documented, both for the participants and for others not present during each phase of the project. A project management approach that requires frequent dissemination

[17] Item counting is a “verification activity involving the counting of items … for the purpose of verifying the correctness of the operator’s records …” [5].

of the relevant information to all parties will be productive and beneficial. With this communication, stakeholders will better understand each other's concerns in addition to each other's challenges and constraints. All parties can then better contribute to an optimum balancing of constraints to meet project requirements at the lowest life cycle cost[18].

3.3. OPERATION

A basic SBD principle with regard to the operation of facilities is the expectation that process operations can be designed to facilitate the effective and efficient application of safeguards with little or no impact on operational function or performance. When the designers of a facility understand the information needs/requirements of the national and international authorities to meet safeguards objectives, operational parameters and data flows can be identified for use in the application of safeguards. If needs/requirements are identified early in the design process, modifications can be introduced to ensure that facility data generated to meet safeguards requirements is available, with the proper content and format, and adequately authenticated.

Many of the systems installed at nuclear facilities provide data to the operator which can also help to meet the safeguards objectives. Rather than install monitoring equipment for safeguards purposes which duplicates the information collected by the operator's instrumentation, methods can be developed to ensure that operator generated data are made available to the IAEA[19]. Ideally, satisfying international safeguards may become simply sharing a subset of the operator's knowledge: specifically, sharing a subset of the operator's detailed just-in-time process monitoring information about the nuclear material flows and operations in the facility. A basic principle of SBD is the use of operator equipment and data for process monitoring and safeguards verification activities, to the extent necessary and where practical.

One successful example is the use of facility cameras to verify fresh fuel identification in fuel transfers. Another is the use by inspectors of the operator's data to determine the difference between minimum critical loading and full power at research reactors or critical assemblies. In both cases, the IAEA can take advantage of information readily used by the operator to help meet IAEA needs. For fuel transfers, tracking the fuel items by ID facilitates IAEA item counting during monitored movements of nuclear material. For research reactors, knowing when the reactor is at full or partial power facilitates IAEA monitoring of reactor use periods for comparison to declarations from the State regarding such use.

If, by working closely with designers and operators, the IAEA develops a comprehensive understanding of the attributes, nuclear material flow, and potential for misuse that exist for a facility or process, it opens the door to improved safeguards implementation. For instance, when the IAEA understands that making a measurement in a particular area requires a long counting time due to high background radiation, an alternative location can be sought.

4. STAKEHOLDER ROLES AND RESPONSIBILITIES

4.1. STAKEHOLDERS

Six groups of stakeholders have been identified for the SBD process [2], namely:

- Facility owners/operators;
- Designers/constructors;
- The IAEA;
- Safeguards regulatory authorities;

[18] Life cycle cost could be a useful metric for deciding whether the designer or the operator will be responsible to implement a given safeguards measure.

[19] IAEA consultants meeting on the 'Proliferation Aspects of Process Management and Process monitoring/Operating Data', September 2011, Vienna.

— Equipment suppliers;
— The scientific community and technical service organizations.

4.1.1. Facility owners/operators

The facility owner/operator is responsible for providing the information to the safeguards authority in order to meet the requirements of the relevant safeguards agreements, and to facilitate access for IAEA safeguards inspectors. When a State takes a decision to construct a new nuclear facility, it is responsible for notifying the IAEA. However, in general, the owner/operator is directly involved in the facility design, construction, and project financing. The owner/operator should maintain communication with the various stakeholders, and coordinate interactions with the IAEA through the safeguards authority. As the project moves forward, the operator provides gradually increasing detail to the safeguards authority about the facility design. This information should be promptly passed on to the IAEA, with the understanding that while preliminary information will evolve, it is still useful for IAEA understanding. The IAEA can then respond with relevant safeguards considerations, again with the understanding that they are preliminary. The operator can also look to the safeguards authority for assistance with safeguards expertise, safeguards training, and arranging dialogue with other stakeholders.

The main incentives for the operator to choose a design that best accommodates the safeguards requirements are to: (1) minimize the impact on the overall cost of the facility; and (2) reduce safeguards intrusiveness during operation. In some older bulk handling facilities, IAEA safeguards activities result in a loss of a significant portion of the facilities' operational days. A reduced impact on newer facilities following inclusion of SBD has been reported in those facilities designed or operating, for example, in Canada [9], Finland [10], Japan [11] and the United Kingdom [12, 13].

Provision of the completed as-built design information from the facility owner to the safeguards authority and the IAEA occurs late in the project. However, as stated previously, the design process functions at its best when the provision of design information occurs early and spans a project's lifetime, in part because the safeguards equipment for verification potentially affects the facility operations. Consideration of the impact on operations early in the design process allows the opportunity to reduce such impact. The initial exchanges of information are not definitive, and this flexibility must be clearly understood by all. However, as the design becomes more detailed and complex, it solidifies and change is more difficult to accommodate.

It is the responsibility of the State/operator to provide ancillary facilities and services within the facility to enable safeguards activities to be conducted. The level of effort to implement safeguards will differ depending on the type of facility to be built. It is easier to apply safeguards to simple item facilities than to large, complex bulk processing facilities. Implementing safeguards generally requires more time and effort for new types of facility that do not yet have a model safeguards approach[20]. Plant operational features can have a significant impact on the safeguards approach. Therefore, the preliminary information provided by the owner/operator should include information on operations as well as physical layout.

Although a designer may address elements of safeguards in a basic design, it is the responsibility of the owner/operator and State to ensure that all safeguards considerations are addressed, and of the State to verify that the operator's plans for operating the plant comply with all relevant regulatory requirements. As the project progresses into the construction stage, the discussions between the owner/operator and stakeholders will shift from design issues to design information verification and to ensuring that the IAEA's safeguards equipment is installed, tested, accepted, and commissioned efficiently. Eventually this sort of iterative interaction on safeguards considerations can contribute to the design evaluation process, and also the licensing process.

4.1.2. Designers/constructors

Designers can improve the effectiveness of safeguards in several ways. One way would be to simplify the path nuclear material takes through the facility and to reduce the number of storage locations. Another way would be by reducing the number or size of penetrations and access openings to that path. Designers can reduce operational flexibility to make it more difficult to reconfigure systems for the production of undeclared nuclear material. Some

[20] A model (or generic) safeguards approach is the recommended approach for a specific facility type developed for a postulated reference plant by the IAEA [5].

of these concepts are counter to operational objectives and compromises must be made. Designers can also be charged with making it easier for inspectors to perform design information verification, such as by improving access and illumination, in order to reduce the impact inspections can have on facility operations.

Historically, a facility was designed and constructed, and then safeguards were implemented. Recently, however, this model has changed, especially in the power reactor market sector. The role of the designer/constructor has evolved to the point where the IAEA and the designer can work together more closely than before. However, once a State owner/operator for the nuclear facility becomes clear, the safeguards authority is the main entity responsible for ensuring that safeguards are considered in the design process.

Designers and constructors can justify integrating the SBD process into existing systems engineering processes in order to reduce costs and project risk. This inclusion will help to avoid construction delays and increased costs associated with the addition, changes, or retrofitting of safeguards equipment late in the construction (commissioning phase) of a facility and will also facilitate the licensing process.

Ideally, at the inception and design phase, designers will be made aware of the potential safeguards requirements such as containment considerations, penetrations, camera views, lighting, sealing, locations of potential measurement stations and cabling pre-installation. Inclusion of these features in the design of the plant will lead to substantial benefits in time and costing for the constructors. Otherwise substantial cost increments are possible[21] [9–13].

4.1.3. IAEA safeguards

The objective of IAEA safeguards[22] is the timely detection of diversion of nuclear material from peaceful activities, and the deterrence of such diversion by the risk of early detection. To facilitate the implementation of safeguards, the IAEA establishes high level facility specific safeguards guidelines and communicates these to stakeholders at appropriate times during the design process.[23] In addition to broad guidance, communication from the IAEA about safeguards considerations for specific facilities must include inquiries about the facility-specific safeguards relevant details that are not yet known by the IAEA. It is to be expected that these discussions start at a broad, informal level, and then become more focused and detail oriented as understanding of the design gets more specific. The parallel development of the safeguards approach, as the understanding of the operational details improves, and development of the facility design, as the understanding of the safeguards considerations improves, is similar to the way safety issues are resolved in a construction project. Experience has shown that regular, broad participation including all stakeholders in meetings can be more efficient and effective than passing on the redacted information to other stakeholders through smaller venues.

In order to support implementation of the SBD process, the IAEA can suggest the invitation to meetings of technical experts from stakeholders during the design and construction stages of a facility. More importantly, the safeguards authority must be proactive in bringing all stakeholders into discussions with the IAEA. Once a site within a State has been selected for a facility, the point of contact with the IAEA for safeguards considerations should be the relevant area within the safeguards programme.

For the IAEA, the expected benefits from SBD would be the improvement of inspection conditions and implementation of more effective and efficient safeguards. Additionally, SBD will increase the awareness of safeguards goals and requirements among all stakeholders and will help to develop a ‘safeguards culture’ [2], creating long term benefits to the international community as a whole.

High level IAEA safeguards goals and requirements are publically available and summarized in The Safeguards System of the International Atomic Energy Agency, available on the IAEA web page[24].

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[21] It has been reported that the costs for a ‘change order’ to install infrastructure for a safeguards surveillance system was three times higher than the cost would have been if it had been clearly specified in the original design.

[22] Paragraph 28 of INFCIRC/153. The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).

[23] In addition to communications during meetings between the State and the IAEA, this series of documents on SBD is preliminary guidance. After the site is selected and conceptual design has begun, the IAEA arranges how to share a model safeguards approach with the State.

[24] www.iaea.org.

4.1.4. Safeguards regulatory authorities

The support of the safeguards authority is integral to the SBD concept. The authority is the formal, legally recognized entity responsible for implementation of the State's international safeguards obligations, and serves as the primary interface between the State, including companies within the State, and the IAEA. As such, the safeguards authority is in a position to promote SBD. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) does not confer any obligations directly on the designers of nuclear facilities to interact with the IAEA. Therefore, designers have no direct legal interface with the IAEA. This means that the IAEA safeguards requirements need to be communicated to the designers through intermediaries such as the safeguards authority. The authority can assist safeguards implementation by supporting coordinated interactions between the stakeholders rather than taking a passive approach. The safeguards authority can also facilitate necessary training, such as an introduction to safeguards concepts, the legal basis of safeguards, and even SBD training for the operator.

IAEA safeguards are easier to implement and more effective when they are built on a strong safeguards authority that includes a strong domestic safeguards system[25]. Consideration could be given to developing a nested system, where IAEA verification would rely more heavily on safeguards authority verification while retaining the right to independently verify the authority's findings. And the authority would rely more heavily on facility monitoring and accountancy while retaining the right to independently verify facility declarations. Balancing efficiency against independence and authentication will be challenging. The safeguards authority is responsible for two key interfaces: one with the IAEA and one with the operator/designer. The responsibilities include the management of formal discussions with the IAEA regarding safeguards activities in the State and the transmission of safeguards documentation and data to the IAEA. The safeguards authority should manage and expect interaction with all stakeholders regarding safeguards considerations throughout the design and construction lifecycle.

A State safeguards authority may have a keen interest in clarifying its own requirements for safeguards implementation, based on the applicable legal framework and technical considerations. This can include requiring a safeguards assessment report from the designer addressing safeguards implementation as part of the licensing review process. National and regional[26] legislation (for example, Euratom or ABACC[27]) often stipulate requirements about nuclear activities that must be taken into account from the outset of safeguards design. For example, in the case of the European Union, under the Euratom Treaty the European Commission must approve the techniques to be used for the chemical processing of irradiated material to the extent necessary to attain the safeguards objectives of the Treaty. The European Commission is the collective authority under the Euratom Treaty for ensuring that nuclear material is not diverted from its declared use in European Union Member States and, to this end, requires design information and nuclear material accounting reports to be submitted by operators. This design information and these nuclear material accounting reports are further transmitted to the IAEA under the relevant safeguards agreements. It is crucial for the designer to be made aware of such requirements.

Through the process of early communication, the mechanisms to ensure that the declarations and reports are submitted to the IAEA by the safeguards authority in accordance with obligations can be clarified. The IAEA is working to improve the methods for the electronic transfer of data, which will facilitate the reporting processes. Nevertheless, the safeguards authority retains the primary responsibility for validating and submitting information to the IAEA.

As the IAEA implements 'mailbox declarations'[28], new data transmission techniques and remote data acquisition, the safeguards authority retains the important responsibility for data quality, timeliness, accuracy, and completeness in formal declarations by the State to the IAEA, as well as the responsibility for resolving issues in the declarations. Preparing for improvements in technology and incorporation of these technologies early in the design phase of a new facility should reduce the incidence of human error, communication failure, anomalies, and inconclusive results; thus reducing the State's workload to resolve such issues. An objective of SBD is to

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[25] Experience has shown that States with a strong domestic safeguards system, including reporting to the SRA, generally provide more accurate and timely declarations to the IAEA than States with a less well developed understanding of safeguards.

[26] Some groups of States have regional agreements on activities with nuclear material and nuclear energy.

[27] Brazilian–Argentine Agency for Accounting and Control of Nuclear Materials.

[28] A mailbox declaration is used to accept declarations of activities from operators when an inspector is not present. For example, the operator deposits a signed, dated copy of a declaration (perhaps daily) into a locked box that only the inspectorate can access. The inspectorate then collects the declarations on a regular basis.

eventually have consideration of international safeguards become a standard part of the operating and licensing of nuclear facilities as has begun in Canada, Finland, the United Arab Emirates and the USA [10, 14].

4.1.5. Equipment suppliers

Many stakeholders use subcontractors to provide safeguards equipment and software. Potentially, there can be multiple safeguards equipment suppliers to be included as stakeholders in the SBD process. One type is the supplier of operator equipment to collect and report information to the safeguards authority, to measure nuclear material, and to monitor operational processes. Another type is the supplier of IAEA equipment who provides measurement, containment, and surveillance equipment in both attended and unattended applications.

International safeguards rely on equipment to facilitate the inspector's verification activities; therefore, suppliers can potentially improve their equipment if they have a solid understanding of safeguards. The specification of safeguards equipment can be a complex subject when equipment may be owned by the IAEA, provided by Member State support programmes, owned by the safeguards authority, or owned by the operator of the facility. Important considerations about equipment for the purpose of SBD include performance specifications, interface specifications, supply arrangements, repair and maintenance responsibility, and procurement mechanisms.

In some facilities, there will be a mix of operator and IAEA equipment used for international safeguards, including the monitoring of nuclear material transfer pathways. Design, delivery, installation, and acceptance of equipment requires an interface between the designer/constructor, the equipment supplier and the IAEA to ensure that the necessary safeguards features, such as signal authentication, are incorporated into the equipment being provided. This should largely be covered by specific contractual design specifications. However, where off the shelf equipment is being purchased, there may be a need for early IAEA or operator interface with the suppliers in order to influence its features. Some safeguards applications benefit from adjustments or enhancements to off the shelf equipment, and historically some designers have seen it to their advantage to work closely with the IAEA. Authorization[29], authentication[30] and data security are crucial performance requirements for equipment which generates information used in IAEA safeguards verification activities. Often the responsibility for ensuring that the concerns of all parties are addressed in the requirements falls on the construction project manager, who must be knowledgeable in safeguards (as well as a broad range of other issues) in order to effectively represent the international safeguards interests in the decision process.

4.1.6. The scientific community and technical support organizations

The importance of considering safeguards principles and requirements in the design and construction of nuclear installations should also come to the attention of the scientific and educational community as well as technical support organizations. Safeguards awareness is already becoming conceptualized in academic institutions, research centres, and professional associations like the European Safeguards Research and Development Association, the Association of Southeast Asian Nations and the Institute of Nuclear Materials Management. Graduate level courses are available from several university nuclear engineering departments, e.g. the World Nuclear University, Texas A&M University, Virginia Polytechnic Institute, or the University of Washington.

Apart from safety and security, international safeguards is entering the spotlight of the broader geopolitical stage and the design features of new facilities are often under scrutiny with regard to being 'proliferation resistant[31]' [6–8]. With this in mind, the academic and scientific community has begun to participate in addressing new technological challenges and assisting in informing the public about the issues, risks, and risk reduction with regard to the construction and operating of nuclear facilities. Some methodologies that could be applied to proliferation analysis are in the bibliography of this guide. While some work has occurred, there is a strong need for better, cost effective tools that facilitate decision making, point out gaps in safeguards approaches, and help identify opportunities for innovation. More development work is needed to meet the needs of policy makers and of countries considering embarking on nuclear power programmes. [2, 14].

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[29] Authorization in this context means the equipment is certified by the IAEA for its use.

[30] Authentication in this context means measures providing assurance that genuine information has originated from a known sensor, without modification.

[31] Proliferation resistance is measured by whether safeguards goals can be met effectively and efficiently. Something is more proliferation resistant when it is more difficult to use to make weapons useable nuclear material.

The notion of SBD should find its way into the process of knowledge transfer and dissemination of know-how. Universities, research bodies, and professional associations are becoming more aware of the importance of safeguards. Achieving design features that facilitate the implementation of international safeguards requires an understanding and appreciation in academia so that tomorrow's graduates are knowledgeable about safeguards and become advocates of safeguards friendly designs.

4.2. STAKEHOLDER INTERACTIONS

The potential SBD process and milestones related to stakeholder interactions are summarized in Table 1.

TABLE 1. THE SBD PROCESS *(adapted from Ref. 15)*

Phases	Safeguards authority	IAEA	Operator	Designer
R&D phase (if applicable).	Provision of general information to the IAEA on new facility construction.	Provision of a list of possible safeguards measures for the facility type.	Preparation of pertinent information.	
	Identification of operator.		Call for tenders to designers/suppliers.	Facility pre-concept tenders.
			Tender selection.	
	Tender assessment against safety, security and safeguards.			
Preconceptual design.	Review of list of potential safeguards measures.	List of potential safeguards measures.		Preliminary design concept.
	Approval		Approval.	
	Preliminary design information to the IAEA.	State level safeguards requirements; high level safeguards guidelines.		
Preliminary design.				Preliminary design.
	Approval.		Preliminary design information approval.	
	Design information questionnaire.	Medium level safeguards guidelines.		
		Possible safeguards approaches.		
		Detailed safeguards guidelines.		
		Design information evaluation.		
		Feedback to the relevant safeguards authority.		
	Feedback to operator.		Feedback to designer.	Feedback to safeguards equipment supplier.

TABLE 1. THE SBD PROCESS *(adapted from Ref. 15)* (cont.)

Phases	Safeguards authority	IAEA	Operator	Designer
Final design.	Draft facility attachment.	Detailed safeguards guidelines. Design information evaluation. Feedback to the relevant safeguards authority.		
Construction.		Detailed SG guidelines. Design information evaluation.	Safeguards equipment installation.	
Commissioning.	Final facility attachment.	Feedback to the relevant safeguards authority.	Safeguards testing; Possible feedback to equipment supplier.	Possible feedback to equipment supplier.
Operation.	Accompany inspections; Provide information to the IAEA.	Inspections; design information verification.	Comply with inspections.	

The main point this table emphasizes is the exchange of information over the entire project lifetime, specifically the exchange of the relevant information at the relevant time. The detailed steps will vary from project to project, but early and continuous consideration of safeguards will allow the project to accommodate it smoothly.

One of the issues inhibiting the influence of SBD has been a lack of understanding of why more stakeholders should be involved. Each stakeholder needs to support the inclusion of safeguards considerations. Each stakeholder needs to know a little about the legal requirements and the potential for addressing them in cost effective ways. Instead of having a designer sit in on some of the safeguards discussions, SBD promotes the concept of a safeguards expert sitting in on the discussions of the design and construction team. The safeguards expert must be ready and also available to explain issues of safeguards concern when they come up. Experience has shown that those unfamiliar with safeguards cannot be expected to recognize when they need input from a safeguards expert, nor whom to ask, unless the expert is present and participating in the meeting when the issues come up. Safeguards expertise should be contributed when the project management needs it. In this way, strong systems engineering can influence the project management to ensure that the impacts of safeguards, safety, maintenance, and operations on each other are fully addressed.

5. CONCLUSION

The IAEA has adopted the following as important elements in furthering the SBD process:

— Develop communication channels between all stakeholders;
— Foster the development of a safeguards standard or culture in the design community;
— Publicize the benefits of coordinated safety, safeguards, and security practices in nuclear facilities;
— Develop facility-specific guidance;
— Promote the SBD concept.

The IAEA's emphasis for SBD is on improving communication. In order for the stakeholders to benefit optimally, they must communicate regularly and openly. It is crucial for the safeguards authority to assist in facilitating communication. It is assumed that the facility designers and operators possess the best knowledge of the facility, while the IAEA possesses the best knowledge of the technical objectives of international safeguards. Optimum implementation requires open and voluntary sharing of this knowledge. This encourages information to be shared during the development stage, rather than at the last minute. Furthermore, early, open communication allows concepts or designs to be adjusted more readily and to take each stakeholder's needs and perspectives into consideration in a balanced and positive fashion. It is expected that there are benefits to be realized by coordinating the design requirements and subsequent design across safeguards, security, safety, and environmental protection. Coordination of planning should benefit coordination of response.

The long term objective of SBD is to have international safeguards — along with safety, security, and environmental protection —included in a State's licensing process for nuclear facilities. This approach will require further study and coordination within the IAEA as well as collaboration with States to determine best practices and lessons learned. It is fully recognized that this is the responsibility and authority of the States and the IAEA can only provide guidance on how to achieve this effectively. Nevertheless, a comprehensive process that is codified and regulated as part of facility licences would ensure that safeguards are considered as part of the facility design, construction, and operation.

Even when safeguards costs are less than 0.5 % of total project costs, sometimes even much less, there is no reason not to expend a modest effort to keep those costs minimized. Once designers understand the legal basis and the objectives of safeguards, they can facilitate minimization of the safeguards impact on design and operation. From the designer's perspective, the set of potential safeguards measures is rather limited and while provision of infrastructure to facilitate implementation of this limited set has negligible impact on project scope, schedule, and budget; neglecting to provide for safeguards infrastructure in the early design stages can lead to significant impacts on project schedule and budget at late stages in the project, possibly even delaying the start of operations. Both States and designers considering new nuclear facilities or activities are invited to interact with the IAEA as soon as possible, even before planning is firm or financing is arranged. SBD is about improving the implementation of safeguards by achieving improvements in effectiveness and efficiency and reducing impact on the operators and States.

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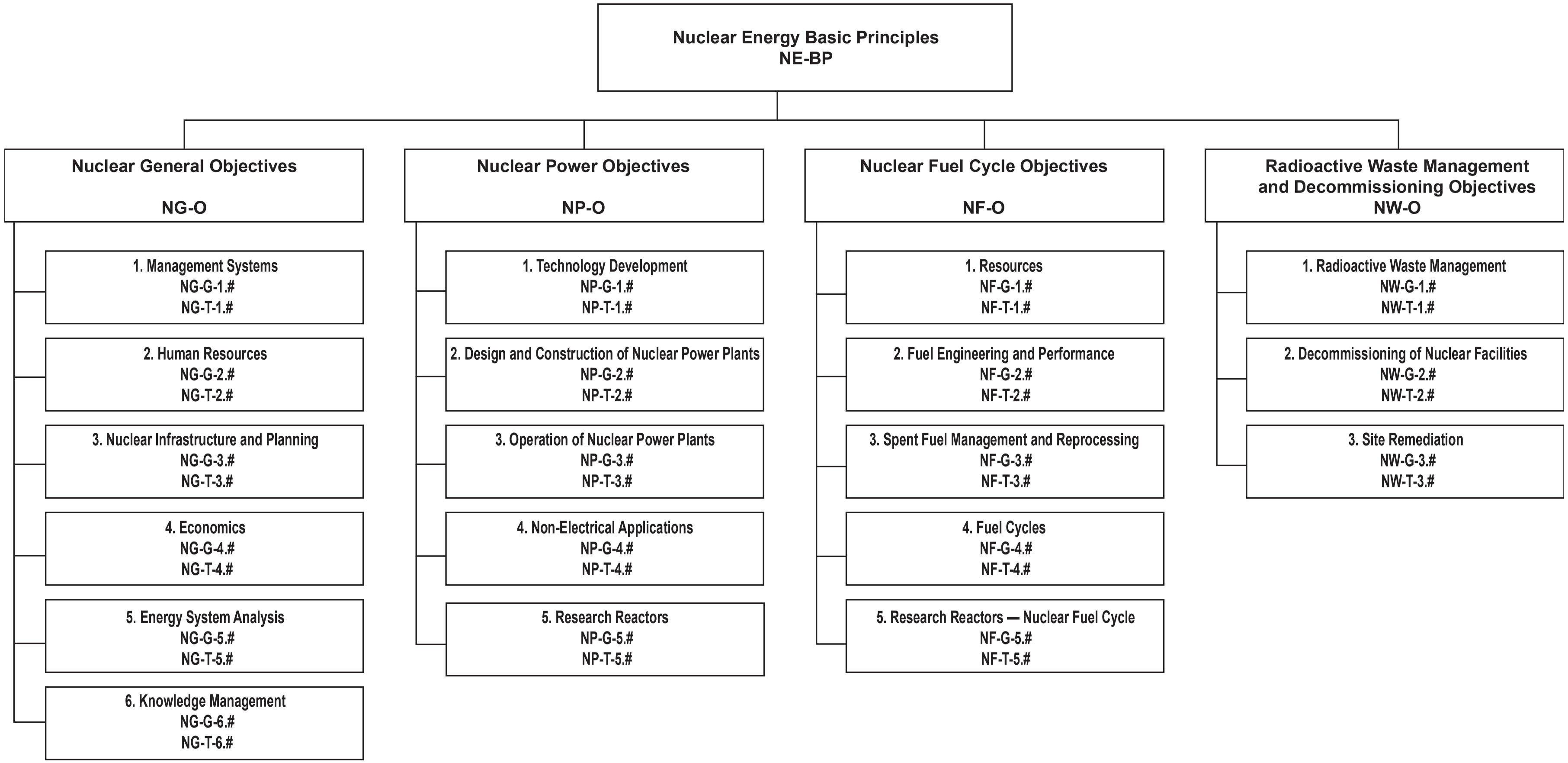

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