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# INPRO Collaborative Project: Proliferation Resistance and Safeguardability Assessment Tools (PROSA)

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# INPRO COLLABORATIVE PROJECT: PROLIFERATION RESISTANCE AND SAFEGUARDABILITY ASSESSMENT TOOLS (PROSA)

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# FOREWORD

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was launched in 2000 on the basis of a resolution of the IAEA General Conference (GC(44)/RES/21). Its objective is to help ensure that nuclear energy is available in the twenty-first century in a sustainable manner. It seeks to bring together all interested Member States — both technology holders and technology users — to jointly consider actions to develop innovative nuclear energy technologies.

In 2012–2013, phase 1 of INPRO focused on developing national long range nuclear energy strategies to assist Member States in making decisions about sustainable nuclear energy development and deployment through nuclear energy system assessments (NESAs). A NESA, which is performed by a Member State using the INPRO methodology, can be used to help determine whether, or to what degree, proposed and planned systems meet national sustainable development goals. The NESA findings can be useful in further developing action plans that seek to address identified areas for improvement.

This publication presents the results of the INPRO Collaborative Project on Proliferation Resistance and Safeguardability Assessment Tools (PROSA). This effort follows and adds to the results of the INPRO Collaborative Project on Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA), which focused on approaches to identifying and analysing high level pathways for the acquisition or diversion of fissile material from a nuclear energy system. PROSA has proposed an approach to assessing proliferation resistance that is simpler and easier to understand than the current INPRO methodology guidance in this area (IAEA-TECDOC-1575 (Rev. 1)), and has further developed the concept of proliferation resistance and safeguardability analysis and assessment tools. The results of this project will also serve as input for the revision of the INPRO methodology guidance.

Initiated in 2012, the PROSA project involves the participation of Canada, China, France, Germany, Italy, Japan, the Republic of Korea, Poland, Romania, the Russian Federation, the United States of America and the European Commission.

The IAEA would like to thank the Korea Atomic Energy Research Institute (KAERI) for performing a case study in support of this effort and for leading the project, and the Japan Atomic Energy Agency and Y. Kuno (Japan) for their valuable contributions. The IAEA officers responsible for this publication are F. Ganda of the Division of Nuclear Power, J. Phillips of the Division of Nuclear Power and J. Sprinkle of the Division of Concepts and Planning.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

This publication presents the results of a collaborative project performed under INPRO Project 1: ‘Proliferation Resistance and Safeguardability Assessment (PROSA) Tools.’ The main objective of the PROSA project is to explore approaches to make the INPRO sustainability assessment of proliferation resistance simpler and easier to understand. This publication also includes the results from applying the PROSA assessment to an illustrative case, demonstrating use of the refined methodology. Additionally, the outcomes of this project may be used to inform the future revision of the INPRO Methodology proliferation resistance assessment approach.

The PROSA assessment process has been developed to address specifically the needs of national (‘self’) assessors performing an INPRO Nuclear Energy System Assessment (NESA) of sustainability. This scope differs somewhat from that of the existing INPRO methodology guidance recorded in IAEA-TECDOC-1575, vol. 5 (2008) [1], which instead takes into consideration potential use also by external stakeholders or interested parties (e.g., equipment/facility vendors or export control authorities of other States). Whereas external stakeholders seek assurances and non-proliferation commitments regarding the absence of undeclared nuclear material and facilities along acquisition paths, NESA self-assessors are primarily concerned with evaluating the proliferation resistance of nuclear energy systems under the sovereign control of a State.

## 1.2. OBJECTIVE

For national self-assessors the main objectives of the proliferation resistance sustainability assessment can be outlined as the following:

- Provide assurance to the international community of compliance with its non-proliferation commitments, and of actual peaceful usage of the country’s nuclear energy system (NES);
- Do so effectively and efficiently, with minimal costs (a) during construction and (b) during operations, and with minimal interference into the operations;
- Minimize future retrofits and changes to facilities and systems, to comply with evolving safeguards requirements, following the principles of Safeguards by Design.

The PROSA process described in this manual is intended to help national self-assessors (from here onwards only ‘assessors’) accomplish those objectives in a systematic and robust way. In particular, PROSA is a methodology for a State to assess whether its NES is in agreement with the basic principle in the area of proliferation resistance, and thus satisfies one of the conditions for its sustainability according to the INPRO assessment. In particular, the PROSA proliferation resistance evaluation is designed to be most applicable in three types of scenarios: (1) a State with an existing NES with proven and/or evolutionary technology, (2) an embarking State acquiring proven and/or evolutionary technology, and (3) an experienced State developing and demonstrating novel/innovative technology. This is based on the reasonable assumption that a State embarking on nuclear power typically will implement proven technology. The assessment team, in its combined capacity, is assumed to have sufficient level of knowledge and expertise to use the IAEA’s methodologies and approaches, as well as on the safeguards implementations.

Specific objectives of PROSA were listed as [2]:

- To make the [INPRO proliferation resistance] assessment methodology simpler and easier to use;
- To allow for different users and depths of analysis;
- To demonstrate the value to the refined assessment methodology to the users.

Moreover, the deliverable of the PROSA Collaborative Project was envisioned as [2]:

> *A report (TECDOC) on the results of the Collaborative Project Proliferation Resistance and Safeguardability Assessment Tools – describing a faster streamlined methodology and providing input to a revision of the INPRO manual in the area of proliferation resistance. The report will include the applicable results, including lessons learned, or applying the coordinated set of tools to the illustrative cases.*

The principal features of this deliverable are descriptions of a potential approach to the INPRO methodology assessment of proliferation resistance that is streamlined, simpler and easier to use, and provides input to a future revision of the INPRO methodology manual in the area of proliferation resistance. A demonstration of the approach on a reference case is also an important feature of this deliverable.

## 1.3. SCOPE

The existing INPRO manual on proliferation resistance [1] outlines an evaluation methodology that provides both a framework for assessing proliferation resistance and guidance to improve the proliferation resistance of a NES under international safeguards. The methodology consists of five user requirements along with relevant criteria, indicators, and evaluation parameters.[1] The proliferation resistance methodology has a basic principle that states [1]:

> *"Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that NESs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme. Both intrinsic features and extrinsic measures are essential, and neither can be considered sufficient by itself."*

Just because a nuclear energy system's proliferation resistance analysis shows it has compliance with the basic principle does not imply the absence of proliferation risk. 'Proliferation resistance' is a qualitative measure of the difficulty to progress along a path independent of the evaluation of the State's intent to follow that path. 'Risk' is typically defined as the product of the probability that a dangerous event will occur and the consequence of that event. As such, proliferation risk should inherently include evaluation of State motivations that are not measured by the INPRO definition of proliferation resistance and can be very subjective. Hence, a State motivation is difficult to assess in a manner that consistently aligns with INPRO principles.

The assessment process developed through PROSA is consistent with the basic principle of the INPRO proliferation resistance methodology but reduces the process from five (in [1]) to three

[1] Those are described in more details in Section 2.3.

simplified user requirements, along with relevant criteria, indicators, acceptance limits, and evaluation parameters[1]. PROSA also intends to be consistent with proliferation resistance principles and objectives promoted through the Generation IV International Forum (GIF) [3], although INPRO and GIF proliferation resistance methodologies target different audiences that have different purposes.

The PROSA project work scope was to be carried out in stages:

- Stage 1: Define multiple user groups and depths of analysis;
- Stage 2: Determine the relevant INPRO Criteria (indicators, acceptance limits, evaluation parameters and evaluation scales) associated with the depths of analysis;
- Stage 3: Determine the relevant INPRO Criteria to assess safeguardability;
- Stage 4: Test evaluation of a reference case.

In accordance with its Terms of Reference [2], PROSA was envisioned as a follow-on project to PRADA (Proliferation Resistance: Acquisition/Diversion Pathway Analysis [4]). PRADA proposed to develop a detailed concept of how to perform an INPRO assessment of user requirement 4, focusing on the development of appropriate methods for the identification and analysis of pathways for the acquisition of weapons-usable material ('special fissionable material'[2] [5]) and on the evaluation of the multiplicity and robustness of barriers against proliferation for each pathway.

Two general conclusions were drawn from the PRADA project that were to be taken into consideration in the PROSA project [4]:

1) "The robustness of barriers is not a function of the number of barriers or of their individual characteristics but is an integrated function of these and is measured by determining whether [IAEA] safeguards objectives can be met;
2) The detailed application of the GIF pathway concept to identify and analyze acquisition/diversion pathways for nuclear material demonstrates the feasibility of merging the methodologies to form a holistic approach."

The first three PROSA consultancy meetings aimed to discuss project stages 1, 2 and 3 in some detail. The final two consultancy meetings took up in detail the issue of what kind of 'input' might be useful to support the revision of the INPRO manual. The fifth and final consultancy meeting reviewed a test evaluation of a reference case.

It turned out to be quite an involved task to develop practically a proper 'input' for future revision of the INPRO proliferation resistance manual [1]. It was necessary to consider the approach and methods used in other INPRO methodology manuals to arrive at an understanding of a consistent format and structure of an INPRO assessment. Furthermore, it was necessary to further develop the key INPRO methodology concept of 'sustainability' as applied to the area of proliferation resistance. In a generic sense, the subject of development of an INPRO proliferation resistance metric had been central to the deliberations underpinning IAEA-TECDOC-1575, vol. 5 [1], and the PRADA [4] and PROSA collaborative projects. However, in the broader context of the INPRO methodology, the INPRO proliferation resistance metric

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[2] Special fissionable material is "plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine; but the term 'special fissionable material' does not include source material" ([5], Article XX.1).

is properly cast as a sustainability measure, not a generic measure of proliferation resistance such as that found in the GIF PR&PP Working Group Methodology [3].

Whereas PROSA did address the issue of 'providing input to a revision' directly, the INPRO methodology definition of sustainability in the area of proliferation resistance remains incomplete and will be addressed in detail during the INPRO manual revision process. Even so, the PROSA project was successful regarding streamlining and simplifying the proliferation resistance INPRO methodology.

Assessing proliferation resistance is a continuous process and requires a good understanding of the underlying nuclear technologies and of the IAEA safeguards policies, concepts and technical approaches. As the size and capacity of an NES increases, and as the relevant technologies develop, the proliferation resistance assessment methodology should be re-evaluated to account for such changes. A proliferation resistance assessment using the PROSA process will provide assessors with a discovery mechanism for potential 'gaps', which may require actions or R&D to improve the proliferation resistance of an NES. The result of the PROSA assessment will summarize strengths, weaknesses, and give recommendations for action, if required, which will improve sustainability of a NES through support of verified peaceful use assurances.

## 1.4. STRUCTURE

The present publication describes the set of information that the assessor needs for the proliferation resistance assessment, the consecutive steps in details and, depending on the technology (proven evolutionary or innovative), the depth of the assessment. Section 2 presents the user requirements and criteria used to verify whether the NES agrees with the basic principle in the area of proliferation resistance, and Section 3 presents an example application of the PROSA methodology to the conceptual design of a sodium fast reactor (SFR) Metal Fuel Manufacturing Facility (SFMF). Appendix I presents a detailed description of the SFMF. Korea Atomic Energy Research Institute (KAERI) performed this case study. It is noted that KAERI did not perform an assessment at the level of the entire NES in the Country, but only a study limited to a single facility. The entire PROSA assessment process is visualized by flowcharts in Annexes II to VI.

# 2. PROSA METHODOLOGY FOR PROLIFERATION RESISTANCE ASSESSMENT

## 2.1. THE PROSA PROLIFERATION RESISTANCE APPROACH

As a follow-up to PRADA [4], the PROSA Collaborative Project seeks to introduce a set of proliferation resistance and safeguardability analysis tools that allow for different depths of analysis according to the information needs of specific users. The assessment methodology accounts for both intrinsic technical features and extrinsic non-proliferation measures with consideration of their relative importance. However, this remains subject to the judgement of the assessor: a quantitative scale in this regard has not been developed and is also not intended under INPRO-PROSA (please see Annex II for a schematic representation of the process).

The assessment process developed through PROSA calls for assessing the NES at the facility level, as well as in aggregate at the State level (please see Annex II).

As a first process step, an assessor will document the intrinsic characteristics of the nuclear material and facilities that comprise the NES.

In the second process step, the assessor will evaluate the States' commitments, obligations, policies, and institutional arrangements regarding non-proliferation. This step is consistent with user requirement 1 of IAEA-TECDOC-1575 [1].

In the third process step, the assessor looks at the facility practices and features that facilitate the implementation of IAEA safeguards, asking whether safeguards can be implemented effectively and efficiently. This step is consistent with user requirement 3 of [1], and it also incorporates the implementation efficiency analysis performed under user requirement 5 in [1]. Additionally, PROSA improved the assessment process for user requirement 3 of [1] through the introduction of more detailed questions which facilitate the assessments of evaluation parameters[3] 3.1 and 3.2.

In the fourth process step, the assessor is asked to evaluate whether all technically-plausible diversion paths can be covered by intrinsic features that maintain compatibility with other design requirements, and by extrinsic measures that suitability reduce the attractiveness for a proliferator to use these diversion paths. This step is consistent with user requirement 4 (i.e. Multiple Barriers) of IAEA-TECDOC-1575 [1].

In a final fifth process step, the assessor is asked to summarize strength, weaknesses and gaps determined in course of the assessment and to make recommendations for improvements and R&D (please see also Annex II, 'Simplified NESA proliferation resistance self-assessment process', for a graphical representation of this step).

It is noted that PROSA eliminated user requirement 2 of IAEA-TECDOC-1575. This reflects an evolution in the INPRO-PROSA assessment towards a more qualitative type of proliferation resistance analysis, based on the fundamental consideration that no intrinsic barrier is sufficient by itself without adequate safeguards.

[3] Evaluation Parameters are described in Section 2.3.

## 2.2. OVERVIEW OF THE PROLIFERATION RESISTANCE ASSESSMENT PROCESS

Reference [6] defines proliferation resistance as "that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other explosive devices."

Consistently with this definition, both the INPRO [1] and the PROSA methodologies address the diversion of nuclear material or misuse of technology from a defined NES that is, or will be, correctly and completely declared to the IAEA. INPRO does not assess States' intents, purposes and objectives to proliferate, though the status of institutional undertakings and legal compliance consider the indicative proxy of intent. In addition, steps associated with the undeclared acquisition of nuclear materials, as well as the acquisition or manufacture of nuclear weapons or other nuclear explosive devices, or materials usable for nuclear weapons, through any means other than those described above, are beyond the scope and purpose of an INPRO assessment.

Reference [6] further states that "the degree of proliferation resistance results from a combination of, inter alia, technical design features, operation modalities, institutional arrangements, and effective safeguards measures. **Extrinsic** proliferation resistance measures are those measures that result from States' decisions and undertakings related to nuclear energy systems". Examples of extrinsic measures include [6]:

- "Commitments, obligations and policies of States, such as the Non-Proliferation Treaty (NPT) and related IAEA safeguards agreements and protocols additional to such agreements;
- Agreements between exporting and importing States on the exclusive use of nuclear energy systems for agreed purposes;
- Commercial, legal or institutional arrangements that control access to nuclear material and technology;
- Verification measures by the IAEA, or regional, bilateral or national measures;
- Legal and institutional measures to address violations of the measures defined above."

"**Intrinsic** proliferation resistance features are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of extrinsic measures" [6]. Intrinsic features consist of technical features that [6]:

- "Reduce the attractiveness of nuclear material for nuclear weapons programmes during production, use, transport, storage and disposal, including material characteristics such as isotopic content, chemical form, bulk and mass, and radiation properties;
- Prevent or inhibit the diversion of nuclear material;
- Prevent or inhibit the undeclared production of direct-use material, including reactors designed to prevent undeclared target materials from being irradiated in or near the core of a reactor, reactor cores with small reactivity margins that would prevent the operation of the reactor with undeclared targets;
- Facilitate the implementation of Safeguards, such as nuclear material accountancy and verification, including of continuity of knowledge through, for example, containment and surveillance or other measures."

As a proliferation-proof NES does not exist (if it consumes or produces any significant amount of special fissionable material), extrinsic proliferation resistance measures – such as institutional measures "will remain essential, whatever the level of effectiveness of intrinsic features" [6]. For example, effective and efficient implementation of international safeguards will remain essential for providing acceptable proliferation resistance and as a legal requirement for the operation of a nuclear energy system in a country with a comprehensive safeguards agreement.

Relating to the Proliferation Resistance Fundamentals [6], the implication is that effective and efficient implementation of safeguards and intrinsic features of an NES are not independent of each other. Ultimately, the robustness of proliferation resistance, built by the combination of intrinsic features and extrinsic measures, is measured by the ability of the IAEA (Statute [5] Article II, and INFCIRC/153 [7] Paragraph I) and other safeguards organizations to reach credible, independent assurance that the system is not used in such a way as to further any proscribed military purpose.

Essential for an INPRO proliferation resistance assessment of an NES is that "State's commitments, obligations and policies provide credible assurance of the exclusive peaceful use of the nuclear energy system (NES)" [1], and especially that the legal framework enables the IAEA to achieve its safeguards objectives. User requirement 1 is focused specifically on assessment of the State's commitments, obligations and policies regarding non-proliferation.

Only if a given State has a Comprehensive Safeguards Agreement (CSA) with the IAEA [7] and the Additional Protocol to the Comprehensive Safeguards Agreement [8] in force, the IAEA will be able to reach its Broader Conclusion: "Based upon the IAEA's finding that there are no indications of diversion of declared nuclear material from peaceful nuclear activities and no indications of undeclared nuclear material or activities in the State as a whole" [8]. Without an Additional Protocol in force the NES would therefore have a significant gap in sustainability, as defined by INPRO [1]. For certain "nuclear embarking States," for example those planning to purchase a single nuclear facility which is identical to a facility built and successfully safeguarded elsewhere, examining compliance with user requirement 1 will suffice. This implies that a more detailed assessment, concluding whether the NES will continue to be an unattractive means to acquire special fissionable material for a nuclear weapons programme may not be required. This situation is represented graphically in the flowchart of Annex II to VI.

Irrespective of the availability of nuclear material and technology in an NES, implementation of effective and efficient safeguards of the NES (as a whole) and at each facility within the NES, is an essential element of proliferation resistance of the NES. This will be examined as the next step in the PROSA assessment process as user requirement 3, calling for 'easy detectability' of diversion of nuclear material and the misuse of nuclear facilities and that the intrinsic features and extrinsic measures implemented and the impact on facility operation should respect a principle of acceptable cost efficiency.

As a final step, the coverage of the NES by multiple and mutually supportive proliferation resistance intrinsic features and extrinsic measures will be examined by user requirement 4. Intrinsic features and extrinsic measures in this context can be relevant at the facility level, as well as at the level of the entire NES and State.

The PROSA assessment process is described in detail and presented as process flowcharts in Annexes II to VI[4]. As PROSA is focused on NESA style self-assessments, it does not deal with any additional information needs of other stakeholders.

## 2.3. INTRODUCTION OF THE BASIC PRINCIPLE, USER REQUIREMENTS AND CRITERIA

The PROSA assessment process follows a similar structure as the INPRO proliferation resistance methodology [1], with a hierarchy of requirements with one basic principle, three user requirements, and the corresponding criteria, indicators, acceptance limits, and evaluation parameters [1].

Those, from [9], are explained below for the convenience of the reader.

"The highest level in the INPRO structure is a Basic Principle (BP), which is a statement of a general goal that is to be achieved in an NES and provides broad guidance for the development of an NES (or a design feature thereof). The wording of an INPRO basic principle always utilizes the verb "shall" or "must"." [9].

"The second level in the INPRO hierarchy is called a *user requirement*. User requirement are the conditions that should be met to achieve users' acceptance of a given NES. I.e., the user requirements define the means of achieving the goal set out in the basic principle. All user requirements of a basic principle should be fulfilled to achieve a sustainable NES. The wording of a user requirement utilizes the verb "should". [9].

"Finally, a *criterion* (or more than one) is required to enable the INPRO assessor to determine whether and how well a given user requirement is being met by a given NES. An INPRO criterion consists of an *indicator* and an *acceptance limit*. Indicators may be based on a single parameter, on an aggregate variable, or on a status statement. Two types of indicators of INPRO criteria are distinguished, numerical and logical. A numerical indicator may be based on a measured or a calculated value that reflects a property of an NES. A logical indicator is usually associated with some necessary feature of an NES and usually is presented in form of a question." [9].

"In addition, some indicators utilize *evaluation parameters*. These parameters were introduced to assist the INPRO assessor in determining whether the acceptance limit for an indicator has been met. In some specific cases these evaluation parameters have their own acceptance limits, in which case they could be called sub-indicators. The acceptance limit of an INPRO criterion is a target, either qualitative or quantitative, against which the value of an indicator can be compared by the INPRO assessor leading to a judgement of acceptability (pass/fail, good /bad, better/poorer.). In correspondence to the two types of indicators there are also two types of acceptance limits, numerical (for quantitative targets) and logical (for qualitative targets).

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[4] Annex II: INPRO-PROSA Proliferation Resistance Self-Assessment Process (simplified).
Annex III: INPRO-PROSA Proliferation Resistance-Assessment by Assessor (2 Pages).
Annex IV: INPRO-PROSA UR3-Assessment Process (Existing NES with proven technology).
Annex V: INPRO-PROSA UR3-Assessment Process (Country embarking on nuclear power with proven technology).
Annex VI: INPRO-PROSA UR3-Assessment Process (Experienced country in nuclear power with novel technology).

Typically, a logical acceptance limit is a positive (yes) or negative (no) answer to a question raised by the indicator." [9].

The process of how to assess each individual criterion, how to provide the data for the assessment, how to decide on the depth of assessment required by different users, and how to document the results, are described for each criterion separately. In many cases, an assessor will require assistance (analysis by technical or institutional specialists) to confirm that the criterion is met. Follow-up action may be required to identify the proper source of expertise in each given instance.

## 2.4. NES PROLIFERATION RESISTANCE INFORMATION CATALOGUE

Before a State assesses the safeguardability and other proliferation resistance issues including trade and export control influences of a NES within the State, it is essential to catalogue the relevant information regarding the nuclear material, facilities and technologies present. An 'NES proliferation resistance information catalogue' is compiled as a preliminary step to collect and organize the information required to support a proliferation resistance assessment under user requirement 3 and user requirement 4 in the PROSA assessment process.

The conceptual process described below aims to collect information in support of the proliferation resistance assessment of existing or planned NES based on the factors outlined above. The main steps in this process include:

1) Determine the facilities, technologies and certain imported equipment in the NES (within the assessing State);
2) Determine the quality, quantity, form and origin of the nuclear material (per IAEA-safeguards standard definitions) and international interdependence;
3) Support evaluation of the approximate IAEA comprehensive safeguards effort as a metric of intrinsic attractiveness and to support safeguardability assessment;
4) Support creation of a trade obligations map of nuclear technologies and materials to evaluate proliferation resistance effects of trade relationships and related export controls (See Annex I).

If these steps are documented correctly and completely, it should then be possible to perform a practical assessment of the safeguardability characteristics of the NES under user requirement 3 and to develop and evaluate trade obligations and export control practices map under user requirement 1 and user requirement 4.

### 2.4.1. Information catalogue step 1

The first information to be collected should be the existing or planned facilities and technologies; and all the especially designed and prepared (EDP) equipment or material[5] within an NES. The nuclear material availability depends on this technical capability and the objectives of the assessing State. If relevant, also the possibility of certain minor actinide partitioning technology may be considered[6]. For embarking countries, this step should be relatively

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[5] Equipment or material especially designed and prepared (EDP) for the processing, use or production of special fissionable material (SFM) is defined in detail in INFCIRC/209/Rev. 4 [9], often referred to as the "Trigger List" in the non-proliferation expert community.

[6] The Secretariat has considered possible options for responding to the proliferation potential of neptunium (Np) and americium (Am). The Board acknowledges that, since there is no basis or other commitments for the Agency

straightforward as many are only interested in introducing reactors for electricity generation. This avoids many complexities associated with assessment of fuel cycle information. For a State with an existing (or planned) NES and fuel cycle facilities, this step will be more complex, but still straightforward. The information can be catalogued at varying levels of detail based on the maturity of the PROSA assessment. In an introductory assessment phase, crude estimates can be used at a facility level. In a detailed assessment, actual data can be used based on existing NES facilities and on detailed estimates based on design information for planned facilities with identified detailed designs.

It is also important to note whether the planned facilities involve technology that is proven, evolutionary, or innovative. For proven technology already deployed in a CSA State, the safeguards approach already exists. For evolutionary technology, some technical detail of the safeguards approach may require definition, and this may require some analysis. In some cases, some instrument development and certification may be required to safeguard an evolutionary technology. For some innovative technologies, the conceptual safeguards approach has not necessarily been developed and it is likely that IAEA verification approaches and equipment may require research and development (R&D) and certification. The absence of a technical safeguards approach and certified verification equipment to support the approach exposes a gap requiring action to ensure sustainability of the NES.

### 2.4.2. Information catalogue step 2

After determining the existing/planned facilities, information regarding the specific nuclear materials being used should be collected (i.e. quality, quantity and form). For most facilities, it is the material information which will determine the basic safeguards effort, to be used in the INPRO PROSA assessment as an indicator of 'intrinsic technical attractiveness' to proliferation[7]. In the case of enrichment, reprocessing and certain other facilities such as uranium-plutonium mixed oxide fuel (MOX) fabrication and handling, the basic safeguards effort is more intensive as these facilities can produce un-irradiated direct use (UDU) material or handle large quantities of UDU material[8]. The material information should be collected at the level known, down to the material balance area (MBA) level if that much technical detail is available. Moreover, the most attractive material within each MBA (or accessible to the operator associated with a unit process within an MBA) should be listed.

The information to be gathered includes:

- Material type: Pu, highly enriched uranium (HEU), U-233, low enriched uranium (LEU), natural uranium, depleted uranium, or thorium and alternative nuclear material[9] if reasonable;

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to legally require the monitoring of materials not defined as source or fissionable material, the Agency's action to apply monitoring should be carried out on a voluntary basis only.

[7] This should not be construed as implying that an increased metric of basic SG effort implies proliferation, but rather that it implies that intrinsic proliferation resistant features, apart from those that accommodate effective and efficient SG verification, have reduced value as part of the balance of intrinsic features and extrinsic measures that convey proliferation resistance in a sustainable system.

[8] In the case of enrichment plants, it is typical that the basic SG effort assumes the potential presence of UDU given the need to verify against the undeclared production of HEU.

[9] NU (natural uranium), DU (depleted uranium). Alternative nuclear material (Np and Am) may be listed if separated and decontaminated or if part of decontaminated mixtures of UDU.

– Material category: UDU, irradiated direct use (IDU), or indirect use;
– Material quantity: Effective kilograms and significant quantities in inventory and annual throughput[10];
– Material form: item, bulk or both.

For a typical embarking State, using proven reactor technology with no fuel cycle facilities beyond storage, this step is simple as this information would have been previously documented in other implementations. In cases of evolutionary reactor technology, satisfactory design information should be available from equipment and facility vendors and this can be used for accurate estimates (in the case of proliferation resistance assessment). For innovative reactor technology, this information can be collected from design authorities, but has uncertainty depending on the maturity of design.

### 2.4.3. Information catalogue step 3

Once all the information from steps 1 and 2 has been compiled, the intensity of safeguards inspection effort is quantified in step 3. The approximate basic safeguards effort can be evaluated from IAEA inspection goals: while the frequency of inspections depends inter alia on the nuclear material category (See 3.20 of IAEA SG Glossary [11]), the intensity of these inspections, measured in person days of inspection (See 11.20 of IAEA SG Glossary [11]), depends on the technology (proven, evolutionary or novel), type, and quantity of nuclear material present at a facility (INFCIRC/153 [7], para. 80), and on the State's capabilities.

While the State level approach may not be shared with the State/operator, the approximate maximum efforts for safeguards implementation for different types of facilities is generally known. This will give an approximate and conservative value that can be used for the purpose of the PROSA assessment.

### 2.4.4. Information catalogue step 4

This step involves cataloguing the nuclear material/technology and associated international non-proliferation-oriented legal obligations, other than safeguards, captured under all bilateral trade and rare regional trade agreements (e.g. EURATOM). The 'Trigger List' (See IAEA Official Documents, Information Circulars, INFCIRC/209 [10]). from the Zangger Committee and the Nuclear Supplier Group Guidelines (See IAEA, Officials Documents, Information Circulars, INFCIRC/254 [12]) might help to identify obligated EDP equipment and materials, but all States engaging in nuclear trade should catalogue and maintain this information pursuant to compliance with their trade agreements in any event. These legal obligations, as required by supplier States, help to ensure the peaceful use of nuclear technology and materials, thus increasing the proliferation resistance of an NES with obligated technology and materials. As such, it is important to compile a complete and accurate catalogue (i.e. to create an 'obligations map' for the NES). This step may be incomplete until later in the design stage (especially for innovative designs), but it is important to update this list as the information becomes available.

For the purpose of the proliferation resistance assessment as proposed by PROSA, the intrinsic (technical) attractiveness of an NES, as a whole or as a facility, to support a nuclear weapons

[10] Inventory is defined as "the amount of nuclear material present at a facility or location outside facilities" (IAEA SG Glossary [11] Section 3.18). Annual throughput is defined as "the amount of nuclear material transferred annually out of a facility working at nominal capacity" (INFCIRC/153 [7], para. 99).

programme depends principally on three factors: material quality, material quantity and material production technology, and whether it is possible within the declared NES to obtain a significant quantity of UDU material (please see TABLE 1).

The technical difficulties associated with different nuclear materials or with the absence of sensitive technologies will continue to exist also under the treaty breakout scenario. However, ‘proliferation resistance’, as defined in the INPRO methodology, does not exist apart from safeguards.

This collection of information into an organized catalogue will allow for an accurate PROSA assessment under user requirement 3 and user requirement 4.

TABLE 1. NES STATUS – ATTRACTIVENESS OF NUCLEAR MATERIAL AND TECHNOLOGY

| Material quality | Material type and category * | UDU | IDU | LEU | Natural uranium | Depleted uranium |
|---|---|---|---|---|---|---|
| | | Y/N | Y/N | Y/N | Y/N | Y/N |
| Material quantity | No. of significant quantities < 1 (material stock or flow/y) | Y/N | | | | |
| Nuclear Technology | Enrichment | Y/N | | | | |
| | Extraction of fissile material | Y/N | | | | |
| | Irradiation capability of undeclared fertile material | Y/N | | | | |

*The Definition of the Material Quality follows the IAEA Safeguards Glossary [11]. The attractiveness of nuclear material and technology impacts safeguards implementation both in a State as a whole (State-level safeguards approach) and at the facility. The three main mechanisms which contribute to proliferation resistance are described as user requirements below.

## 2.5. USER REQUIREMENT 1: THE STATE’S COMMITMENTS

The first user requirement asks the assessor to evaluate the status of its legal framework and institutional arrangements to demonstrate its commitment to non-proliferation obligations. Table 2 shows the basic principle, criteria, indicators and acceptance limits for user requirement 1, while Table 3 provides a list of questions to be answered by the assessor to fully evaluate user requirement 1. An example set of answers for Table 3 is shown in Section 3 for the SFMF.

*Please Note:*

For States with a Voluntary Offer Agreement (VOA) the application of the INPRO proliferation resistance assessment by nature is limited. See for example, Ref. [17] “If the Secretariat found no indication of the diversion of nuclear material to which safeguards had been applied, the Secretariat [only can] conclude[d] that nuclear material to which safeguards had been applied in selected facilities remained in peaceful activities.” Nevertheless, especially the application of user requirement 3 could be helpful also for nuclear weapon States (NWS), since they could test the safeguardability of facilities put under safeguards as well as of those planned and designed for export into a non-nuclear Weapon States with a CSA and an Additional Protocol in force. This is a key concern of both INPRO and GIF.

TABLE 2. BASIC PRINCIPLE, CRITERIA, INDICATORS AND ACCEPTANCE LIMITS FOR USER REQUIREMENT 1 (FROM [1])

**Basic principle [1]: "**Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that NESs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself."

| User requirements | Criteria | |
|---|---|---|
| | **Indicators** | **Acceptance limits** |
| **User requirement 1 State commitments:** State commitments, obligations and policies regarding non-proliferation and its implementation should be adequate to fulfil best practice | **Criterion 1.1** Legal framework | |
| | **Indicator 1.1:** State commitments, obligations and policies regarding non-proliferation | **Acceptance limit 1.1**: Legal Framework is in accordance with best practice and fulfills the qualifications for an effective implementation of IAEA safeguards |
| | **Criterion 1.2** Institutional/structural arrangements | |
| | **Indicator 1.2:** Institutional/ structural arrangements | **Acceptance limit 1.2:** Institutional arrangements support State commitment regarding non-proliferation and facilitate the implementation of IAEA safeguards |

TABLE 3. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 1

| Indicators | Evaluation Parameters | Evaluation results/findings | | | |
|---|---|---|---|---|---|
| | | **YES** | **NO** | **N/A*** | **Comment**** |
| **Indicator 1.1** State commitments, obligations and policies regarding non-proliferation | **Evaluation parameter 1.1.1:** Party to NPT | | | | |
| | **Evaluation parameter 1.1.2:** Party to Nuclear-weapons-free zone (NWFZ) treaty | | | | |

TABLE 3. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 1 (cont.)

| | | |
|---|---|---|
| | **Evaluation parameter 1.1.3**: Party to Comprehensive Test Ban Treaty (CTBT) | |
| | **Evaluation parameter 1.1.4:** Regional system of accountancy and control (RSAC)/safeguards (e.g. Euratom, Brazilian-Argentine Agency for Accounting and Control of Nuclear Material) | |
| | **Evaluation parameter 1.1.5:** Safeguards agreements according to the Non-Proliferation Treaty (NPT) in force | |
| | – CSA in force | |
| | – Participation in the Voluntary Reporting Scheme (or other voluntary mechanisms, e.g., INFCIRC 549) [11] | |
| | – General part of subsidiary arrangements in place | |
| | **Evaluation parameter 1.1.6:** For those who are not party to the NPT, other safeguards agreements (e.g., INFCIRC/66) in force | |
| | **Evaluation parameter 1.1.7:** Additional Protocol | |
| | – Additional Protocol in force | |
| | – Broader Conclusion drawn | |
| | **Evaluation parameter 1.1.8:** Alternative nuclear material | |
| | – Actinide partitioning/partitioning technology | |
| | – Inventories and export of separated Am and Np | |
| | – IAEA has been engaged e.g. ‘flow sheet verification’ | |
| | **Evaluation parameter 1.1.9:** National legislation and regulation on nuclear-related export controls and licensing[12] | |
| | – Develop and enforce appropriate legal and regulatory measures | |

[11] Or Conclusion of Small Quantities Protocols (SQPs) according to the Modified SQP Standardized Text
[12] Including measures to prevent the proliferation of WMD (UN S/RES/1540 [13])

| | | |
|---|---|---|
| | against the proliferation of weapons of mass destruction (WMD) as required by Ref. [13] | |
| | – National reports submitted to the committee established according to Ref. [13] | |
| | – Member of Nuclear Supplier Group | |
| | – Member of Zangger Committee | |
| | **Evaluation parameter 1.1.10:** Member to the IAEA Incident and Trafficking Database | |
| | **Evaluation parameter 1.1.11**[13]**:** State system of accountancy and control (SSAC) in force [14] | |
| | – “Laws, regulations and a system of accounting for and control of nuclear material [have been established] which ensure that the requirements of the safeguards agreements and associated protocols and Subsidiary Arrangements are fully met”, according to Ref. [14] | |
| | – “Provision of timely, correct and complete reports and declarations to the IAEA” [14] | |
| | – “Provision of support and timely access to the IAEA to locations and information necessary to achieve safeguards objectives” [14] | |
| | – IAEA SSAC Advisory Service (ISSAS) Mission has been requested | |
| | **Evaluation parameter 1.1.12:** Partnership approach between IAEA and RSAC/SSAC agreed | |
| | **Evaluation parameter 1.1.13:** Member of the IAEA Support | |

[13] Additional evaluation will be required for evaluation parameter 1.1.11, “State SSAC in force”: Does the SSAC installed by the State satisfy the guidance as specified by the IAEA in the “Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols” [14], and is the Nuclear Material Control and Accounting System in accordance with best practice as described by the IAEA in the “Nuclear Material Accounting Handbook” [15].

TABLE 3. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 1 (cont.)

| | | |
|---|---|---|
| | Programme for Nuclear Verification | |
| **Indicator 1.2:** Institutional structural arrangements | **Evaluation parameter 1.2.1:** Multi-lateral ownership, management or control of a NES (multi-lateral, multi-national) (See [16]) | |
| | **Evaluation parameter 1.2.2:** International dependency regarding fissile materials and nuclear technology (See [7]) | |
| | **Evaluation parameter 1.2.3:** Commercial, legal or institutional arrangements that control access to nuclear material and to the NES (See [16]) | |
| | **Evaluation parameter 1.2.4:** Bilateral cooperation agreements | |
| | **Evaluation parameter 1.2.5:** Export control obligations linked with trade agreements | |

* 'Not Applicable' (N/A), only for evaluation parameter that may not be relevant due to Country-specific conditions.

** Comment: Additional explanations, gaps, weaknesses, proposals for improvement

## 2.6. USER REQUIREMENT 3: DETECTABILITY OF DIVERSION/MISUSE

The third user requirement asks the State, the operators, and the facility/technology designers to assess whether the design and operation of the NES permits timely, efficient and independently verified detection of whether diversion of nuclear material and/or misuse of technology within the NES has occurred. This metric is often referred to as 'safeguardability.' Safeguardability may be enhanced through the process of safeguards by design (SBD) [18]. "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" [18]. Consequentially SBD is a continuous process starting with planning and conceptual design incorporating safeguardability intrinsically into the design and operational features of a nuclear fuel cycle facility. It continues with a stepwise development of a safeguards approach, in interaction with intrinsic design and operational features that attempt to integrate fully safeguards into facility design. Fully integrated means *inter alia,* that safeguards requirements are included in the facility design process, such as locations of potential measurement stations and cabling pre-installation, containment considerations, penetrations, camera views, lighting, and sealing. (Please see Ref. [19]). At the end, the status of a planned NES/facility, evolutionary or innovative, also impacts the SBD process.

Specific guidelines have already been provided in the past by the IAEA to designers of water-cooled power reactors [20]. The IAEA provides general information and guidance on

SBD in its Nuclear Energy Series, "International Safeguards in Nuclear Facility Design and Construction" [18], and further detailed information on specific facility types is provided in Refs. [21, 22, 23, 24, 25, 26]. Information on safeguards techniques and equipment used for nuclear material accountancy, containment and surveillance measures, environmental sampling, and data security [27] is available from the IAEA in one volume of the International Nuclear Verification Series. Explanation of requirements for the State's system of (nuclear material) accounting and controls appears in [14] and [15].

The assessment of user requirement 3 answers the questions [1]: 1) "does design and operation of the NES facilitate the implementation of (IAEA) safeguards?", and 2) "can safeguards objectives be met effectively and efficiently?" (The 'definitions' in the Glossary provide context to these questions). In safeguards terminology [11], effectiveness addresses the completeness and correctness of the safeguards coverage, while efficiency considers the cost of implementation. Efficiency means the accomplishment of, or ability to accomplish, a specified task with a minimum expenditure of time, resources and effort. In the safeguards environment, this means that effective safeguards can be implemented with a minimum expenditure of time, resources and effort which is the goal of SBD [11].

It should be noted that this minimum conceptually, can be achieved most effectively with an Additional Protocol in force, a Broader Conclusion drawn, and State level approach implemented. Under the Additional Protocol, States are required to provide the Agency with an expanded declaration that contains information covering all aspects of their nuclear fuel cycle activities [8] and [14]. Additionally, it provides for certain improved administrative procedures which assist in making the verification effort more effective and efficient. In the end, the assessor is asked to assess whether safeguards can be implemented at an acceptable/minimal cost and burden both for designers/operators and national/international safeguards/verification authorities under the given safeguards regime for that State.

For the evaluation of efficiency, a comparative assessment approach is proposed, since looking at pure monetary values can be misleading. This is because monetary values are generally country and facility-dependent. Furthermore, a complete set of absolute cost values are often not available to the assessor. Therefore, factors other than monetary values need to be considered by the assessor, both during construction and operations, including interference with normal operations, backfitting of facilities, and the requirement to purchase and maintain equipment (at the operator's expenses) to perform the necessary safeguards activities.

The user requirement 3, evaluation parameters 3.1.1–3.1.4, evaluation questionnaire (effectiveness of IAEA safeguards) follows basically the proposed: "System Approach to the Proliferation Resistance Assessment" [28]. The questionnaire asks for fundamental design features that facilitate the implementation of IAEA safeguards (safeguardability), covering the aspects of nuclear material accountancy as well as those, facilitating or enabling the application of containment and surveillance, as well as monitoring. The effectiveness of IAEA safeguards is tested in two ways, depending on the status of development of the NES (Annex III), either 'evolutionary' or 'innovative'. If it is an innovative system, testing safeguards effectiveness follows again the generic "System Approach to the Proliferation Resistance Analysis of a Nuclear Energy System" [28]. If it is more an evolutionary system, the tests follow the "Facility Safeguardability Analysis (FSA) Process" [29], [30]. Screening questions identify aspects of the new design that may create potential issues, when compared to similar existing facilities for which the IAEA has implemented a safeguards approach.

Even if the SBD process is primarily performed for each facility individually, the assessment process developed through PROSA calls for assessment of the NES in totality. This requires an ‘acquisition path analysis’ for a State/NES as a whole, to evaluate and determine suitable safeguards measures in the design of a facility, that would increase the detection probability for each specific acquisition path.

The user requirement 3 assessment process is described in detail here, and presented as process flowcharts in Annexes IV to VI:

- INPRO-PROSA user requirement 3-assessment process – Annex IV
  (Self-) Assessment: Existing NES with proven technology
- INPRO-PROSA user requirement 3-assessment process – Annex V
  (Self-) Assessment: Country embarking on nuclear power with proven technology
- INPRO-PROSA user requirement 3-assessment process – Annex VI
  (Self-) Assessment: Experienced country in nuclear power with novel technology

Table 4 shows the basic principle, criterion, indicators and acceptance limits for user requirement 3.

TABLE 4. BASIC PRINCIPLE, CRITERIA, INDICATORS AND ACCEPTANCE LIMITS FOR USER REQUIREMENT 3 [1].

<table>
<tr><td colspan="3">Basic principle [1]: “Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for NES to help ensure that NESs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.”</td></tr>
<tr><td rowspan="2">User requirement</td><td colspan="2">Criteria</td></tr>
<tr><td>Indicators</td><td>Acceptance limit</td></tr>
<tr><td rowspan="4">User requirement 3<br>Detectability of Diversion/Misuse<br>Diversion* of nuclear material should be easily detectable. Intrinsic features and extrinsic measures implemented on this account and the impact on facility operation respect the principle of acceptability and cost efficiency.</td><td colspan="2">Criterion 3.1 Effectiveness</td></tr>
<tr><td>Indicator 3.1:<br>Effectiveness of IAEA Safeguards</td><td>Acceptance limit 3.1:<br>The IAEA can achieve the technical objectives[14] for safeguards</td></tr>
<tr><td colspan="2">Criterion 3.2 Efficiency</td></tr>
<tr><td>Indicator 3.2:<br>Efficiency[15] of IAEA Safeguards</td><td>Acceptance limit 3.5:<br>IAEA Safeguards can be implemented with acceptable burden[16]</td></tr>
</table>

* **Diversion** includes the “undeclared removal of nuclear material from a safeguarded facility, or the use of a safeguarded facility for the introduction, production and processing of undeclared nuclear material.” [11].

[14] See “Glossary”.

[15] See “Glossary", efficiency applies for both IAEA and operator.

[16] “Satisfactory and able to be agreed to or approved of” (Cambridge English Dictionary) “Acceptable” has both an economical and a political dimension.

TABLE 5. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 3.

| Indicators | Evaluation Parameter | Evaluation Results* | |
|---|---|---|---|
| | | YES | NO |
| Indicator 3.1 Effectiveness of IAEA Safeguards | Evaluation parameter 3.1.1 "The accounting system implemented by the operator provides accurate and complete information on nuclear materials, forms, amounts, flows, locations, transfers and identification of inventory changes" [15] | | |
| | Evaluation parameter 3.1.2 All types of nuclear material flows and inventories can be verified adequately by SSAC/safeguards inspectorates/IAEA methods for the independent verification of operator's declarations | | |
| | Evaluation parameter 3.1.3 Containment and surveillance (C/S) measures and monitoring can be applied to complement nuclear material accountancy verification where appropriate in the safeguards approach | | |
| | Evaluation parameter 3.1.4 The introduction, production and/or processing of undeclared nuclear material in a safeguarded facility is difficult by design and easily detectable (See Ref. [18]) | | |
| Indicator 3.2 Efficiency of IAEA Safeguards | Evaluation parameter 3.2.1 Safeguards can be implemented by the IAEA at equal or lower burden for the IAEA compared to a facility of the same type | | |
| | Evaluation parameter 3.2.2 Safeguards can be implemented at the facility at equal or lower burden for the operator compared to a facility of the same type | | |

*The evaluation results are based on the subsequent Evaluation Questionnaires and Findings below.

TABLE 6. EVALUATION QUESTIONNAIRE: DETAILED QUESTIONS TO ASSESS EACH EVALUATION PARAMETER FOR USER REQUIREMENT 3 [1].

| Evaluation Parameter | Question | Finding [17] | |
|---|---|---|---|
| Evaluation parameter 3.1.1 | Procedures for physical inventory taking (PIT) have been established equal to best practice [15] | Yes | No |

[17] Table 7: Testing "Effectiveness of IAEA Safeguards", Findings

TABLE 6. EVALUATION QUESTIONNAIRE: DETAILED QUESTIONS TO ASSESS EACH EVALUATION PARAMETER FOR USER REQUIREMENT 3 [1] (cont.)

| Evaluation Parameter | Question | Finding [17] | |
|---|---|---|---|
| The accounting system implemented by the operator provides accurate and complete information on nuclear materials, forms, amounts, flows, locations, transfers and identification of inventory changes [15] | Nuclear material (on) inventory is properly tagged and identifiable | Yes | No |
| | International standards of accounting [11] are met | Yes | No |
| | International target values [11] are met for destructive analyses (DA) and for non-destructive analyses (NDA) | Yes | No |
| Evaluation parameter 3.1.2<br>All types of nuclear material flows and inventories can be verified adequately by SSAC/safeguards inspectorates/IAEA methods for the independent verification of operator's declarations | Nuclear material can be identified and verified by adequate methods with sufficient accuracy to enable SSAC/safeguards inspectorates/IAEA to draw independent conclusion on the non-diversion of nuclear material | Yes | No |
| | On-site IAEA equipment can be installed and used for verification purposes as required | Yes | No |
| | Authentication of operator's data is feasible and properly implemented, if used for verification | Yes | No |
| Evaluation parameter 3.1.3<br>C/S measures and monitoring can be applied to complement nuclear material accountancy verification as appropriate | C/S measures can be applied to "verify information on movements of nuclear material or other material, equipment, and samples, or preservation of the integrity of safeguards relevant data, as applicable" [11] | Yes | No |
| | C/S measures can be applied to ensure the continuity of knowledge on inventories previously verified, as applicable | Yes | No |
| | C/S measures can be applied "to ensure that SSAC/safeguards inspectorates/IAEA equipment, working papers and supplies have not been tampered with." [11]. | Yes | No |
| | Sealing systems are easily verifiable (e.g. sealing systems easily accessible and replaceable) | Yes | No |
| | Process monitoring[18] can be applied as complementary measure to enable the SSAC/safeguards inspectorates/IAEA to give | Yes | No |

[18] Please see the Glossary for a definition of Process Monitoring.

TABLE 6. EVALUATION QUESTIONNAIRE: DETAILED QUESTIONS TO ASSESS EACH EVALUATION PARAMETER FOR USER REQUIREMENT 3 [1] (cont.)

| Evaluation Parameter | Question | Finding [17] | |
|---|---|---|---|
| | credible assurance of non-diversion, if accountancy verification and C/S are not sufficient to meet Safeguards objectives | | |
| Evaluation parameter 3.1.4<br>The use of a (safeguarded) facility "for the introduction, production and processing of undeclared nuclear material" [7] is difficult by design and/or detectable | Design of facility and facility-owned equipment impedes misuse | Yes | No |
| | Access, availability and implementation of equipment and collection of data by the inspectorate that indicates all credible misuse scenarios (see also evaluation parameter 3.1.2 and evaluation parameter 3.1.3) | Yes | No |
| | Verifiability of design information regarding facility layout, flow of nuclear material, and containment features | Yes | No |
| Evaluation parameter 3.2.1<br>For the IAEA, safeguards can be implemented by the IAEA at equal or lower burden compared to a facility of the same type | Have safeguards requirements been considered during design and construction agreed upon between IAEA, State authorities, and the operator, and has the result been documented?<br>If NO[19], continue. | Yes | No |
| | Are the (projected) 'person-days of verification work in the field'[20] equal or lower than at a facility of the same type and comparable safeguards regime?[21] | Yes | No |
| | Is the number of installed (projected) safeguards equipment equal or less than at a facility of the same type and comparable safeguards regime? [21] | Yes | No |
| Evaluation parameter 3.2.2 | Have safeguards requirements been considered during design and construction agreed upon between IAEA, State authorities, | Yes | No |

[19] If YES, it is assumed that SG can be implemented efficiently, otherwise the IAEA would not have agreed to the facility attachment.

[20] This Question can be answered only in close coordination/consultation with the IAEA, and the accuracy will evolve with progress and status in the project. 'Person-days of verification work in the field' is the only enumerable measure, which is also strongly related to 'inspection related working-days at the headquarter'. Additional effort due to an Additional Protocol in force is State specific without distinct arithmetic function. E.g. regarding 'complementary access': "The implementation of complementary access shall not be mechanistically or systematically seek to verify the information referred to in Article II" ([8], Article 4). A 'quantification' therefore is not reasonable in the context of evaluation parameter 3.2.1.

[21] This information has to be based on approximate data obtained from various sources available to the SG community.

TABLE 6. EVALUATION QUESTIONNAIRE: DETAILED QUESTIONS TO ASSESS EACH EVALUATION PARAMETER FOR USER REQUIREMENT 3 [1] (cont.)

| Evaluation Parameter | Question | Finding [17] | |
|---|---|---|---|
| For the operator, safeguards can be implemented at the facility at acceptable burden compared to a facility of the same type | and the operator, and has the result been documented? If NO, continue. | | |
| | Will additional wiring be needed for the installation of safeguards equipment and data transfer? | Yes | No |
| | Will back-fitting be required regarding C/S and/or measurement equipment to enable the implementation of required safeguards measures? | Yes | No |
| | Does Physical Inventory Taking/Interim Inventory Verification (PIV/IIV) require additional outage beyond operational requirements (and national law and regulations)? | Yes | No |
| | If YES: Is the outage time equal or lower than at a facility of the same type? | Yes | No |
| | Does the implementation of safeguards impact the operational capacity? | Yes | No |
| | If YES: Does the impact on the operational capacity compensate otherwise required down time? | Yes | No |
| | Does the implementation of IAEA safeguards require additional equipment by the operator enabling verification at PIV/IIV? | Yes | No |
| | If YES, is this equal or less than at a facility of the same type? | Yes | No |
| | Does the implementation of IAEA safeguards require additional, expensive radiation protection measures? | Yes | No |

### 2.6.1. Simplified assessment for NES with only proven or evolutionary technology

A detailed review of evaluation parameters will not be required in cases of already proven technology and a design with IAEA safeguards already implemented, while assessing evolutionary or novel technology requires a more detailed examination of evaluation parameters (see Annexes IV to VI). In the case of evolutionary technology, a ‘comparative assessment’ may be adequate, checking the differences between proven technology and a further evolved one, with regard to their impact on safeguards implementation [29], [30].

On the other hand, in the case of innovative technology, an in-depth analysis is essential for evaluating the safeguardability [28] based on an ‘acquisition/diversion path analysis’ identifying potential diversion, misuse and concealment strategies, as part of the SBD process, and identifying safeguards tools and measures required.

Table 7 shows a set of questions which enable a comparative approach for proven or evolutionary technology, vis-à-vis corresponding questions for a generic safeguardability test. It is noted, however, that the comparative approach described in Table 7 has not been demonstrated in this publication, since the SFMF test case is based on innovative technology.

The multiplicity of intrinsic features and extrinsic measures including safeguards will be tested in detail for each acquisition path under user requirement 4 in Section 2.7.

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES.

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| Evaluation parameter 3.1.1 | Procedures for PIT have been established equal to best practice [15] | Evaluation parameter 3.1.1 | Procedures for PIT have been established equal to best practice [15] |
| Test | The foreseen PIT procedures can consider all relevant needs | Question | Does this design lessen the efficiency of PIT by the operator or the effectiveness of PIV by the IAEA |
| | The nuclear material accountancy and control (NMAC) system has follow-up/tracking functions that provide timely information about the locations and characteristics of all nuclear material in the system | | Does this design impair the ability of the operator to produce timely and accurate interim inventory declarations |
| | Nuclear material (on) inventory is properly tagged and identifiable | | Nuclear material (on) inventory is properly tagged and identifiable |
| Test | The NES foresees a scheme of identification of nuclear material | Question | |
| | Operator’s inventory control can ensure | | |

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| | matching between records and physical reality | | |
| | Items serial numbers and identifier tags can be checked without moving the item | | |
| | International standards of accounting [11] are met | | International standards of accounting [11] are met |
| Test | It is possible to carry out measurement activities with accurate and precise quantification of the material that will be referred to in accounting declarations | Question | Does the design/process employ nuclear material types, categories, or forms that are more difficult to measure accurately at 'inventory key measurement points'. If so, can the plant accountancy measurement system meet 'international target values' for the PIT |
| | The amount of hidden inventory is as low as reasonably achievable | | |
| | International Target Values [11] are met for DA and NDA | | International Target Values [11] are met for DA and NDA |
| Test | It is possible at Key Measurement Points (KMPs) to meet relevant criteria for accuracy and precision | Question | Does the design increase measurement uncertainties at 'flow key measurement points'? If so, can the plant accounting system meet 'international target values' for inventory changes |
| Evaluation parameter 3.1.2 | Nuclear material can be identified and verified by adequate methods with sufficient accuracy to | Evaluation parameter 3.1.2 | Nuclear material can be identified and verified by adequate methods with |

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| | enable SSAC/Safeguards inspectorates/IAEA to draw independent conclusion on the non-diversion of nuclear material | | sufficient accuracy to enable SSAC/safeguards inspectorates/IAEA to draw independent conclusion on the non-diversion of nuclear material |
| Test | It is possible to apply validated methods and approved procedures | Question | Does the plant/process design reduce the measurement accuracy or otherwise impede the use of 'inventory key measurement points' |
| | It is possible to use passive[22] NDA techniques for detecting gross and partial defects | | Does the design preclude PIT/PIV verification activities on some inventory? |
| | On-site equipment can be installed and used for verification purposes as required | | On-site equipment can be installed and used for verification purposes as required |
| Test | The system design permits dedicated areas for inspectors' monitoring, collecting and reviewing activities | Question | Would the design limit or preclude IAEA ability to authenticate plant physical measurement systems or introduce independent systems? |
| | Authentication of operator's data is feasible and properly implemented, if used for verification | | Authentication of operator's data is feasible and properly implemented, if used for verification |
| Test | | Question | Would the design limit or preclude IAEA ability to authenticate plant |

[22] This does not exclude active methods, if so required.

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| | | | physical measurement systems or introduce independent systems? |
| Evaluation parameter 3.1.3 | Containment/Surveillance (C/S) measures can be applied to verify information on movements of nuclear material or other material, equipment, and samples, or preservation of the integrity of safeguards relevant data, as applicable | Evaluation parameter 3.1.3 | C/S measures can be applied to verify information on movements of nuclear material or other material, equipment, and samples, or preservation of the integrity of safeguards relevant data, as applicable |
| Test | The system facilitates the application of optical surveillance | Question | Does this design obscure process areas or MBA boundaries making C/S or installation of verification measurement and monitoring equipment more difficult |
| | The system's routine operations facilitate the application of surveillance | | |
| | C/S measures can be applied to ensure the continuity of knowledge on inventories previously verified, as applicable | | C/S measures can be applied to ensure the continuity of knowledge on inventories previously verified, as applicable |
| Test | Sealable areas are easy to be sealed | Question | Does the design preclude verification activities on some inventory? If so, does the new design include features to permit Continuity of Knowledge (CoK) to be maintained from a previous |
| | Surveillance systems can have a clear and unobstructed view | | |

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| | | | measurement and verification? |
| | C/S measures can be applied to ensure that SSAC/safeguards inspectorates/IAEA equipment, working papers and supplies have not been tampered with | | C/S measures can be applied to ensure that SSAC/safeguards inspectorates/IAEA equipment, working papers and supplies have not been tampered with |
| | Sealing systems are easily verifiable | | Sealing systems are easily verifiable |
| Test | Sealable areas are easy to be sealed | | |
| | Accessibility to seals for verification purposes, possibility to applying remote surveillance to sealing points | | |
| | Process monitoring can be applied as complementary measure to enable the SSAC/safeguards inspectorates/IAEA to give credible assurance of non-diversion, if accountancy verification and C/S is not sufficient to meet safeguards objectives | | Process monitoring can be applied as complementary measure to enable the SSAC/safeguards inspectorates/IAEA to give credible assurance of non-diversion, if accountancy verification and C/S are not sufficient to meet safeguards objectives |
| Test | | Question | Would ‘other strategic points’ be less effective in providing additional assurance for high uncertainty verifications done at KMPs (e.g. reduce the scope or accuracy of Process Monitoring, or limit |

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | | Comparative approach [29], [30] | |
|---|---|---|---|
| | | | or preclude IAEA ability to authenticate plant physical measurement systems or introduce independent systems)? |
| Evaluation parameter 3.1.4 | Design of facility and equipment impedes misuse | Evaluation parameter 3.1.4 | Design of facility and equipment impedes misuse |
| Test | Available processes and equipment cannot be easily modified for producing weapon-grade fissile material | Question | Does this design differ from the comparison design in ways that create new or alter existing opportunities for facility misuse or make detection of misuse more difficult? |
| | Available processes and equipment are difficult to modify for separating pure weapons usable material | | |
| | Any modification would severely alter the routine operation of the nuclear system | | |
| | Access, availability and implementation of equipment and collection of data by the inspectorate that indicates all credible misuse scenarios (see also evaluation parameter 3.1.2 and evaluation parameter 3.1.3) | | Access, availability and implementation of equipment and collection of data by the inspectorate that indicates all credible misuse scenarios (see also evaluation parameter 3.1.2 and evaluation parameter 3.1.3) |
| | Verifiability of design information regarding facility lay out, flow of nuclear material, and containment features | | Verifiability of design information regarding facility lay out, flow of nuclear material, and containment features |
| Test | All process lines are clearly distinguishable and identifiable | Question | Does this design differ from the comparison design in |

TABLE 7. ILLUSTRATIVE TESTS [28] AND SCREENING QUESTIONS [29], [30] FOR THE ASSESSMENT OF THE SAFEGUARDABILITY OF A NES (cont.)

| Generic safeguardability test [28] | Comparative approach [29], [30] |
|---|---|
| | a way that increases the difficulty of design information examination and verification by IAEA inspectors? |
| Process lines' unobservable parts are reduced to the bare minimum | Are there aspects of the design that would preclude or limit IAEA maintenance of CoK associated with design verification during the life of the facility? |
| Process lines' visually unobservable parts are inspectable | |

## 2.7. USER REQUIREMENT 4: MULTIPLE BARRIERS

User requirement 4, as a final and summarizing step in the assessment, asks the user to assess the effectiveness of 'multiplicity' of barriers for safeguardability at all levels of the assessment, including at the entire 'State level'. The coarse pathway analysis already performed in order to answer user requirement 3 at the facility level, can be utilized as a starting point for the analyses necessary for user requirement 4. Similarly, the set of answers provided for user requirement 1, can be utilized as a starting point for the 'State level' analyses performed under user requirement 4.

The analysis at the 'entire State level' is a challenging task, and it has not been tested before. However, INPRO requires a comprehensive and holistic analysis at the State level to support a sustainability claim. It is noted that the example provided in this publication for the SFMF, does not attempt to assess the safeguardability at the State level, since the SFMF is a single facility.

Table 8 shows the basic principle, criteria, indicators and acceptance limits for user requirement 4, while Table 9 provides the list of the evaluation parameters for user requirement 4. An example set of answers for Table 9 is shown in Section 3 for the SFMF.

As a measure enhancing proliferation resistance, in addition to international safeguards, each plausible acquisition/diversion path should be covered:

- By technical features that are suitable for reducing the attractiveness of using this specific nuclear material, and that "prevent or inhibit the diversion of nuclear material and the undeclared production of direct use material" [6] (see also user requirement 3);
- By extrinsic measures (see also user requirement 1).

TABLE 8. BASIC PRINCIPLE, CRITERIA, INDICATORS AND ACCEPTANCE LIMITS FOR USER REQUIREMENT 4, FROM [1].

| Basic principle [1]: "Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for nuclear energy systems (NES) to help ensure that NESs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself" | | |
|---|---|---|
| User requirements | Criteria | |
| | Indicator | Acceptance limit |
| User requirement 4 Multiple barriers: Nuclear energy systems (NES) should incorporate multiple proliferation resistance features and measures | Criterion 4.1 Defence in depth | |
| | Indicator 4.1: Coverage of the NES by multiple intrinsic features and extrinsic measures | Acceptance limit 4.1: All plausible acquisition paths are (can be) covered by intrinsic features, which are compatible with other design requirements, and by extrinsic measures on the facility or State level |

TABLE 9. INDICATOR AND EVALUATION PARAMETER FOR USER REQUIREMENT 4, REF. [1].

| User requirement 4: Nuclear energy systems should incorporate multiple proliferation resistance features and measures | | | |
|---|---|---|---|
| Indicators | Evaluation Parameter | Evaluation Results | |
| | | YES | NO |
| Indicator 4.1: Coverage of the NES by multiple intrinsic features and extrinsic measures | Evaluation parameter 4.1: All plausible diversion paths are (can be) covered by intrinsic features and by extrinsic measures on the facility- or State- level that reduce the attractiveness of or inhibit/impede a diversion path | Yes | No |

Intrinsic features and extrinsic measures that are relevant for a specific acquisition/diversion path should be documented by the designers and by an assessor knowledgeable in safeguards and in the State's commitments and obligations. Examples of such intrinsic features at the facility and NES-level include [6]:

- Technical features of a nuclear energy system that **reduce the attractiveness** for nuclear weapons programmes of nuclear material during production, use, transport, storage and disposal (e.g. a nuclear energy system that eliminates the need for enrichment facilities in the fuel cycle; reactors that produce spent fuel with relatively low percentages of fissile plutonium; a large number of process steps needed to obtain weapons-usable materials; complexity of chemical processes required to separate nuclear material from accompanying diluents and contaminants);

- Technical features of a nuclear energy system that **prevent or inhibit the diversion of nuclear material** (e.g. reactors that use large, difficult-to-dismantle fuel assemblies or reactors that use fuel from which it is difficult to extract fissile material);
- Technical features of a nuclear energy system that **prevent or inhibit the undeclared production of direct-use material**. (e.g. facilities that are difficult to modify for undeclared production of nuclear, cores that are not accessible during reactor operation only allowing 'target' materials to be introduced during refuelling operations);
- Technical features of a nuclear energy system that **facilitate verification, including of continuity of knowledge** (e.g. nuclear energy systems in which nuclear materials remain accessible for verification, to the greatest extent practical or a NES with inventories and flows of nuclear material that can be specified and accounted for in the clearest possible manner);
- Complexity and cost of modifying a facility process to obtain weapons-usable materials;
- Items that are difficult to transport without detection to another (clandestine) facility (e.g. size, weight, amount, or radiation level);
- Attractiveness of nuclear material for a nuclear weapons programme (see TABLE 1) (i.e. material quality, material quantity and material production technology).

Examples of extrinsic measures include [6]:

- **State's commitments, obligations and policies** related to nuclear non-proliferation and disarmament;
- Agreements between exporting and importing States that nuclear energy systems will be used only for agreed purposes and subject to agreed limitations. This sort of measure could be supported by an **agreement between exporting and importing States** that guarantees supplies of nuclear fuel or services;
- **Commercial, legal or institutional arrangements** that control access to nuclear material and nuclear energy systems;
- The **application of IAEA verification** and, as appropriate, regional, bilateral and national measures, to ensure that States and facility operators comply with non-proliferation or peaceful-use undertakings;
- **Legal and institutional arrangements to address violations of nuclear non-proliferation** or peaceful-use undertakings (e.g. sanctions in case of non-compliance with bilateral agreements regarding the use of nuclear material, non-nuclear materials, and facilities/specified equipment).

Further examples of intrinsic features and extrinsic measures are given in "Proliferation Resistance Fundamentals for Future Nuclear Energy Systems" [6].

An example for the evaluation of plausible acquisition/diversion paths regarding their coverage by multiple intrinsic features and extrinsic measures has been given in the PROSA Case Study: "Demonstration of the INPRO PROSA Methodology Taking the Conceptual Design of the Korean SFR Metal Fuel Manufacturing Facility (SFMF) As Example" (Section 3). It shows for each acquisition/diversion path and activity the applicable intrinsic features and extrinsic measures and their relevance for the Facility/NES and the State.

It is noted that a generic set of questions and tables for user requirement 4, of the type that was substituted in Table 3 for user requirement 1 and in Table 5 for user requirement 3, is not provided here: the structure of such table would be strongly dependent on the particular NES/facility analyzed. Therefore, the structure of the presentation of the assessment of user requirement 4 needs to be developed individually by a knowledgeable assessor for each individual diversion/acquisition path. Example tables relevant for the SFMF are provided in Section 3.

It is noted that for a non-nuclear weapons State with a CSA in force, as a basic principle, all plausible acquisition/diversion paths should be covered already by safeguards measures in the framework of the State-level safeguards approach (see also user requirement 3). The conclusion in the 'safeguards statement' for a State with a CSA alone "relates only to the non-diversion of declared nuclear material from peaceful activities." [17]

## 2.8. SUMMARY OF THE PROSA PROCESS STEPS

Table 10 provides a summary of the process steps as described in this Section, including the relevant question and the relevant information to be collected for each process step. The overall process is also summarized in Annex III.

TABLE 10. SUMMARY OF THE PROSA PROCESS STEPS.

| Process Step | Relevant Question | Activities/Evaluation/Analysis |
|---|---|---|
| Step 1 | Could the NES provide unirradiated direct use material (by diversion or misuse) that can be used for a nuclear weapon? | – Collection of information on the NES;<br>– Material quantity;<br>– Material quality (material type & category, material form);<br>– Nuclear technology;<br>– Timeliness goal. |
| Step 2 | Do the State's commitments, obligations and policies provide credible assurance on the exclusive peaceful use of the NES, and the legal basis for required verification activities by the IAEA? | – Collecting information on State's commitments, legal obligations and institutional arrangements;<br>– Assessment of user requirement 1 at the State level. |
| Step 3 | Does design and operation of the NES facilitate the implementation of IAEA safeguards? | – Coarse diversion path analysis for the NES. Identification of plausible diversion paths, diversion and concealment strategies;<br>– Testing whether the technology facilitates the effectiveness of the IAEA safeguards findings according to Annexes IV to VI and Table 7 (Illustrative tests [28] and screening questions [29], [30] for the assessment of the safeguardability of a NES).<br>– Evaluate whether the technology facilitates efficient safeguarding for both, the IAEA and the operator. |
| Step 4 | Can all technically plausible acquisition paths be covered by intrinsic features, compatible with other design requirements, and extrinsic measures that are suitable to reduce the attractiveness for a proliferator to use these acquisition paths? | For each plausible diversion path, identification of:<br>– Intrinsic features, applicable to that acquisition path;<br>– Extrinsic measures, applicable to that acquisition path. |
| Step 5 | Summary of findings | – Strengths/weaknesses/gaps;<br>– Recommendations for improvements/R&D. |

# 3. DEMONSTRATION OF THE INPRO PROSA METHODOLOGY TAKING THE CONCEPTUAL DESIGN OF THE KOREAN SFR METAL FUEL MANUFACTURING FACILITY (SFMF) AS EXAMPLE [23]

## 3.1. INTRODUCTION

The main purpose of the case study provided in this section, is to validate the proposed PROSA assessment process and the structure of the revised user requirements and criteria in the area of proliferation resistance [1], to demonstrate its usefulness, and to provide input to a revision of the INPRO manual in the area of proliferation resistance.

The Korea Atomic Energy Research Institute selected the *sodium-cooled fast reactor (SFR) Metal Fuel Fabrication Facility (SFMF)* case representing novel technology that is not fully developed yet, but still in the conceptual design phase. This allows a testing of all the elements of the proposed assessment process, from the early stage of design, and it also shows the interrelationship of the proliferation resistance assessment to the safeguards-by-design process, identifying potential R&D gaps.

In this context, the coarse acquisition path analysis done does not claim to be complete, but it identifies plausible acquisition paths already detailed enough for demonstrating the assessment process. It is also not intended to develop a ‘complete’ safeguards approach, but to show that the assessment can provide reasonable insights regarding safeguardability, the availability of safeguards tools and measures required for the implementation of effective and efficient safeguards, and the coverage of the NES by multiple extrinsic measures and intrinsic features.

Furthermore, as result of the assessment process, strengths, weaknesses and gaps of a system should be identified and represented in a generally understandable form.

The SFMF itself is a part of the conceptually designed Korean, Innovative, Environment-friendly, and Proliferation Resistant[24] System for the 21st Century (KIEP-21) [31]. The concept of the KIEP-21 is to recycle spent fuel from pressurized water reactors (PWRs) to Generation IV SFR using pyroprocessing as shown in FIG. 1, thereby recovering more energy and minimizing long-term radioactive wastes by burning long-lived and high-heat-producing minor actinides, and to reduce proliferation using new proliferation-resistant pyroprocessing technology. The three main objectives of the KIEP-21 are: (1) to develop technologies with nuclear material that is unattractive for the use in a nuclear weapons programme, (2) to minimize radiological impacts, and (3) to increase back-end of the fuel cycle management flexibility.

The pyroprocessing technology being developed in the Republic of Korea is under examination by a joint United States of America-Republic of Korea collaboration project on pyroprocessing known as the Joint Fuel Cycle Study. The Joint Fuel Cycle Study will determine mutually whether the introduction of pyroprocessing technology in the Republic of Korea is technologically and economically feasible as well as acceptable under the aspect of proliferation

[23] This Section was prepared by Hong Lae Chang, Won-Il Ko (of the Korea Atomic Energy Research Institute, and by Eckhard Haas, consultant) as an integral part of the Korean Case study of the same name. Some of the content of this Section was published before as conference proceedings [32] and in Ref. [33].

[24] KIEP-21 evaluates materials and processes as unattractive for the use in a nuclear weapons program.

resistance, including international safeguards standard. For simplicity, only the SFMF is considered in the case study of the INPRO PROSA Project.

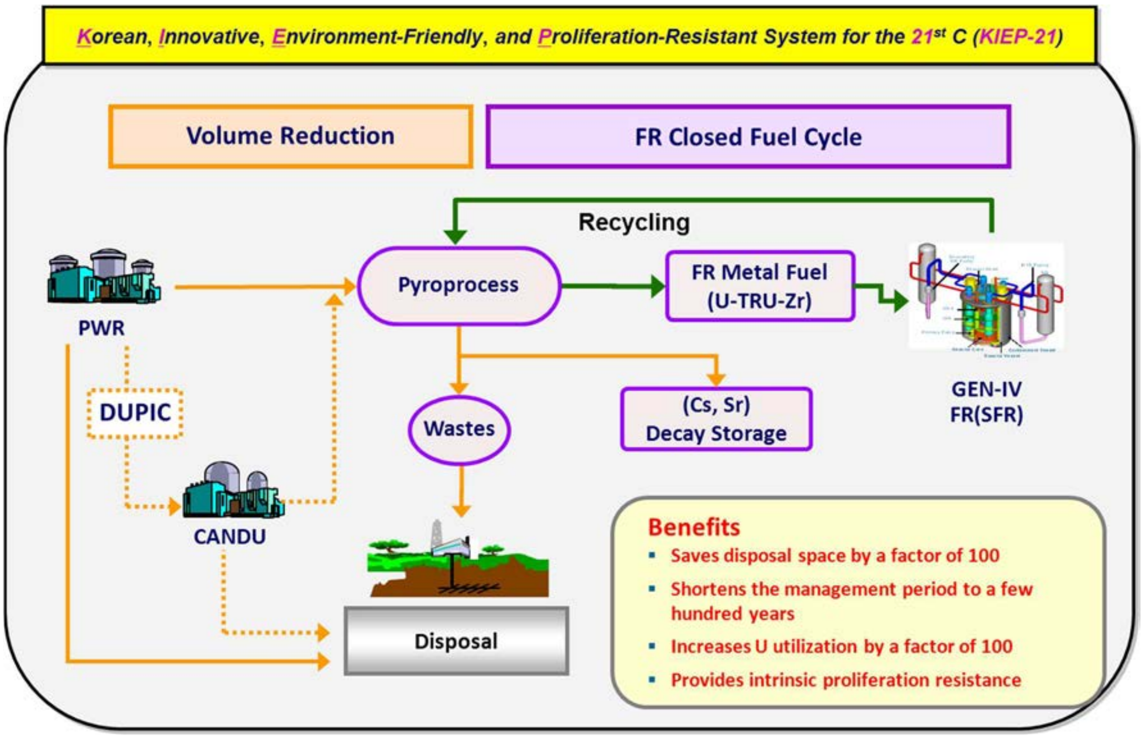


*FIG. 1. Conceptual diagram of the Korean Innovative Environment-friendly and Proliferation Resistant System for the 21st Century (KIEP-21).*

### 3.2. NUCLEAR MATERIAL ACCOUNTANCY AND CONTROL (NMAC) AND SAFEGUARDS ELEMENTS APPROACH FOR THE SFR FUEL MANUFACTURING FACILITY

The plutonium content in the metallic uranium/transuranic/rare-earths (U/TRU/RE) ingots from the pyroprocessing module would be verified using chemical analysis and by weighing the ingots done by the shipper, as well as NDA at the SFMF by the receiver. This constitutes the plutonium input into the facility. The NMAC system monitors and records all movements within the process by container identifier, batch identifier, weights, and locations in real time. Nuclear material data are carried forward by the accounting system with the materials in process. NDA will determine the amount of materials out of the product stream, like wastes.

Once the SFR fuel assemblies are fabricated, each assembly is verified again using NDA for determination of the active fuel length and weight at the end of the process. Together with the TRU bearing waste materials, this constitutes the facility plutonium 'output'. Most of the NDA systems used for verifying plutonium content of TRU materials use neutron and neutron coincidence counting together with high resolution gamma spectroscopy. Gamma spectroscopy is used to determine the presence and relative fractions of isotopes of Pu, U, Am, etc., while the coincident neutron counters are used to determine the effective mass of Pu-240 present in the material assayed. Passive neutron albedo reactivity and the advanced spent fuel conditioning facility's Safeguards Neutron Coincidence Counter (ASNC) with 2–5% measurement uncertainty are under development at the Korea Atomic Energy Research Institute (KAERI).

FIG. 2 shows a preliminary conceptual design of MBA and KMPs of the SFMF. The MBA for the SFMF is defined to cover the whole SFR fuel rod manufacturing module and fuel assembly assembling module. The design minimized the number of entrance and exit portals into the facility to simplify the verification of all material additions and removals as consistent with operator and State declarations. These transfer ports will require systematic monitoring to ensure no material is diverted at these points in the system. The most important details with respect to safeguards for the fuel manufacturing process are the primary mass flow and inventory, the waste streams, and hold up and residual materials that can be released as fines. Most fuel items generated as waste are released to the waste form fabrication process and recycled to process units. However, significant amounts of used crucible, breached moulds and dross go to be disposed of in the waste form fabrication without further recovering of TRU. All these materials will be measured using NDA to the extent possible and monitored by NRTA systems.

The Korea Atomic Energy Research Institute assumed that passive neutron albedo reactivity and ASNC will be the two main instruments to account for plutonium contents of the fuel material in the process.

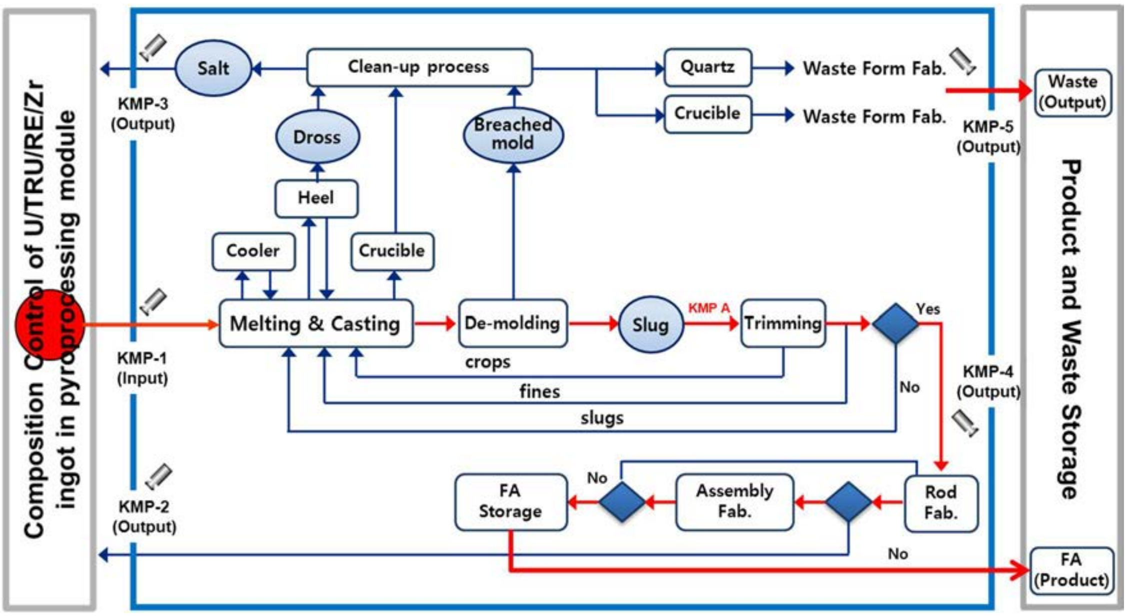


*FIG. 2. Conceptual design of MBA and KMPs of the SFMF.*

The safeguards approach is in general based on the accountancy system of the operator. Whether for safeguards purpose the data from process control will be shared with the IAEA or whether the NMAC systems are to be duplicated needs further analysis and agreement with the IAEA in the course of the SBD process. Basic principles of NMAC and safeguards will be:

- The facility is designed for remote operation, no human access to process areas except for maintenance due to safety issues (inert gas and high temperatures);
- All SFR fuel materials to be measured and monitored in process;
- Extensive use of unattended weighing and NDA and surveillance systems to verify 100% of the SFR fuel material flows in the process;
- More extensive use of video surveillance to monitor and maintain the continuity of knowledge of SFR fuel materials (amounts and locations), including scrap recovery and product/waste storage areas;
- All NMAC/safeguards systems to accommodate automated facility operation, i.e. it is not necessary for the operator to shut down the process to accommodate the activities performed for interim verification;
- Additional equipment for each NDA instrument such as video cameras to confirm identifier numbers of the object, or independent load cells to confirm the gross weight of the container being assayed;
- All unattended NDA and surveillance systems to be amenable to 'remote monitoring.'

## 3.3. INPRO ASSESSMENT OF THE SFMF USING THE PROSA METHODOLOGY

The following provides a complete example of an assessment process for the SFMF, according to the steps described in Section 2.8 and Table 10.

### 3.3.1. Assessment process, step 1: collection of information on the NES

**Question**: Could the NES provide unirradiated direct use material (by diversion or misuse) that can be used for a nuclear weapon?

**Material Quantity**

- o Capacity: 38.6 t HM/y
- o Maximum inventory: 2 240 kg heavy metal (HM)
- Main interim storage positions: fuel rod fabrication
  - o TRU metal storage {2}*: 112 ingots → 2240 kg HM
  - o Heel/scrap storage {13}*: 250 kg HM
  - o Fuel slug temporary storage {17}*: 22 000 fuel slugs → 1870 kg HM
  - o Fuel slug storage[25] {19}*: 22 000 fuel slugs → 1870 kg HM
- Main interim storage positions: fuel assembly module
  - o Fuel rod magazine {5}*: 22 764 fuel rods → 1935 kg HM
  - o Fuel assembly temporary storage vault {17}*: 84 assemblies 1935 kg HM

**Material Quality**

- o Feed, intermediate products, final product
  Metal fuel: 65% U / 20% TRU / 5% RE / 10% Zr
- o TRU composition (27.72% TRU, vs 72.28% U):
  24.74% Pu, 0.43% Np, 1.55% Am, 1.00% Cm, 0.00% Bk, 0.00% Cf
- o Plutonium fissile (Pu-239+Pu-241) isotopic ratio (Pu fissile/total Pu): 51.05%
- o Feed material has been determined/verified by DA and weighing.

[25] The fuel slug storage has a capacity of one-week-production of quality controlled fuel slugs

- The homogeneity of an ingot and with this the representativeness of DA results is questionable, however the impact on the material balance of SFMF will be little, because once the input data have been determined, it will not be re-assessed by DA during the process and will be used also for the accounting of the output masses.

**Waste Production**[26].

- Breached quartz from the moulds: 10.4 tons/year with 3.9 kg TRU/year.

**Measurement Capabilities/Accuracy of nuclear material in the hot cells by NDA:**

- 2 – 5% [27][34][35][36][37] (except waste in waste containers).

**Removal of Material from the SFMF:**

- Due to its high radiation field, removal of nuclear material is reasonable only in heavily shielded waste containers, or as fuel element.

**Misuse:**

- Discrete separation of TRU or un-irradiated plutonium inside SFMF is not possible without changing the design of the facility (Please see also user requirement 3).

**Actinide Partitioning / Partitioning Technology**

- Not applicable/not considered. (Please see also evaluation parameter1.1.8).

**Conclusion:**

- The NES (SFMF) does not provide UDU by diversion or misuse.
- The technical difficulty for the acquisition of weapon usable material by means of the NES is relatively high. Diversion and subsequent processing in a clandestine facility would require plenty of time[27] and the detection probability under an Additional Protocol in force would be also relatively high (see Annex VII: "PROSA SFMF case study: detection probability along the acquisition path").

### 3.3.2. Assessment process, step 2: collection of information on the State's commitments, legal obligations and institutional arrangements

**Question:** Does the State's commitments, obligations and policies provide credible assurance on the exclusive peaceful use of the nuclear energy system (NES), and the legal basis for required verification activities by the IAEA?

List of Treaties and Arrangements:

1) United States/Republic of Korea Peaceful Nuclear Cooperation Agreement, 1956:

---

[26] The main waste generated from the SFMF includes breached mould (quartz) and crucibles. The amount of breached mould is assumed to be 0.5 tons/yr and will be stored in the universal container for vitrified waste (CSD-V) containers (1388mm H x 430 mm inner Ø), which are used at the La Hague plant as a standardized container for vitrified waste.

*Equipment No

[27] Conservatively a timeliness goal of one month will be assumed

2) Bi-lateral nuclear cooperation agreements with 26 other countries (as of August 2013)
3) Commercial arrangements with seven nuclear supplier countries, including the United States (uranium ore, conversion, and enrichment)
4) Membership to the IAEA, 1957
5) Treaty on the Nonproliferation of Nuclear Weapons (NPT), 1975
6) Comprehensive Safeguards Agreement (CSA) with the IAEA (INFCIRC/254), 1975
7) Subsidiary Arrangements to the Safeguards Agreement, 1976
8) SSAC in place since 1956 and further developed and adopted to the requirements of the Safeguards Agreement with the IAEA.in 1976
9) Joint declaration on the denuclearization of the Korean Peninsula, 1992
10) Nuclear Suppliers Group, 1995
11) Zangger Committee, 1995
12) Wassenaar Arrangement, 1996
13) Comprehensive Nuclear-Test-Ban Treaty, 1996 (ratified in 1999)
14) Additional Protocol (according to INFCIRC/540), 2004
15) 'Broader Conclusion' drawn by the IAEA, June 2008
16) Member to the IAEA Incident and Trafficking Data Base, since 1998
17) All nuclear material is 'US obligated'
(except minor quantities extracted from mineral residues and from sea water)

A specific 'trade obligation map' (information catalogue step 4) has not been developed and is also not reasonable for the SFMF:

- All nuclear material is United States of America obligated;
- Technology and equipment have been developed in Republic of Korea;
- The development of the pyro-processing is subject to a Republic of Korea- United States of America cooperation agreement;
- As member of the Nuclear Supplier Group and the Zangger Committee trade rules are accordingly applied, and a rigid export/import control regime established [38].

*3.3.2.1. Assessment of user requirement 1*

Table 11 presents the results of the evaluation questionnaire for user requirement 1 for the SFMF.

TABLE 11. EVALUATION QUESTIONNAIRE FOR ADEQUACY OF STATES' COMMITMENTS, OBLIGATIONS AND POLICIES

| Indicators | Evaluation Parameter | Evaluation Results/Findings | | | |
|---|---|---|---|---|---|
| | | YES | NO | N/A* | Comment** |
| Indicator 1.1 States' commitments, obligations and policies | Evaluation parameter 1.1.1: Party to NPT. | O | | | |
| | Evaluation parameter 1.1.2: Party to Nuclear-weapons-free zone (NWFZ) treaty. | | | O | |

TABLE 11. EVALUATION QUESTIONNAIRE FOR ADEQUACY OF STATES' COMMITMENTS, OBLIGATIONS AND POLICIES (cont.)

| Indicators | Evaluation Parameter | Evaluation Results/Findings | | | |
|---|---|---|---|---|---|
| | | YES | NO | N/A* | Comment** |
| regarding non-proliferation | Evaluation parameter 1.1.3: Party to CTBT | O | | | |
| | Evaluation parameter 1.1.4 Regional RSAC/Safeguards (e.g. Euratom, Brazilian-Argentine Agency for Accounting and Control of Nuclear Material) | | | O | |
| | Evaluation parameter 1.1.5: Safeguards agreements according to the NPT in force. | | | | |
| | – CSA in force | O | | | |
| | – Participation in the 'voluntary reporting scheme' (or other voluntary mechanisms, e.g. INFCIRC 549) [28] | | | O | |
| | – General part of subsidiary arrangements in place | O | | | |
| | Evaluation parameter 1.1.6: For those who are not party to the NPT other safeguards agreements (e.g., INFCIRC/66) in force. | | | | N/A |
| | Evaluation parameter 1.1.7: Additional Protocol: | O | | | |
| | – Additional Protocol in force | O | | | |
| | – Broader Conclusion drawn | O | | | |
| | Evaluation parameter 1.1.8: Alternative nuclear materials | | | | |
| | – - Actinide partitioning/partitioning technology | | | O | |
| | – - Inventories and export of -separated Am and Np | | | O | |
| | – IAEA has been engaged, e.g. -'flow sheet verification' | | | | |
| | Evaluation parameter 1.1.9: National legislation and | | | | |

[28] Or Conclusion of Small Quantities Protocols (SQPs) according to the Modified SQP Standardized Text

TABLE 11. EVALUATION QUESTIONNAIRE FOR ADEQUACY OF STATES' COMMITMENTS, OBLIGATIONS AND POLICIES (cont.)

| Indicators | Evaluation Parameter | Evaluation Results/Findings YES | NO | N/A* | Comment** |
|---|---|---|---|---|---|
| | regulations on nuclear related export controls and licensing[29] | | | | |
| | – Develop and enforce appropriate legal and regulatory measures against the proliferation of WMD as required by Ref. [13]. | O | | | |
| | – National reports submitted to the committee established according to Ref. [13]. | O | | | |
| | – Member of Nuclear Supplier Group | O | | | |
| | – Member of Zangger Committee | O | | | |
| | Evaluation parameter 1.1.10: Member to the IAEA Incident and Trafficking Data Base | O | | | |
| | Evaluation parameter 1.1.11: SSAC in force [14] | | | | |
| | – "Laws, regulations and a system of accounting for and control of nuclear material [have been established] which ensure that the requirements of the safeguards agreements and associated protocols and Subsidiary Arrangements are fully met", according to Ref. [14] | O | | | |
| | – "Provision of timely, correct and complete reports and declarations to the IAEA" [14]. | O | | | |
| | – "Provision of support and timely access to the IAEA to locations and information necessary to achieve safeguards objectives" [14]. | O | | | |
| | – IAEA SSAC Advisory Service Mission has been requested | O | | | |
| | Evaluation parameter 1.1.12: Partnership approach between | O | | | |

[29] Including measures to prevent the proliferation of WMD (UN S/RES/1549 [13])

TABLE 11. EVALUATION QUESTIONNAIRE FOR ADEQUACY OF STATES' COMMITMENTS, OBLIGATIONS AND POLICIES (cont.)

| Indicators | Evaluation Parameter | Evaluation Results/Findings YES | NO | N/A* | Comment** |
|---|---|---|---|---|---|
| | IAEA and RSAC/SSAC agreed | | | | |
| | Evaluation parameter 1.1.13: Member of the IAEA Support Programme for Nuclear Verification | O | | | |
| Indicator 1.2 Institutional structural arrangements | Evaluation parameter 1.2.1: Multi-lateral ownership, management or control of a NES (multi-lateral, multi-national) (See [16]). | | | O | |
| | Evaluation parameter 1.2.2: International dependency with regard to fissile materials and nuclear technology (See [7]). | O | | | |
| | Evaluation parameter 1.2.3: Commercial, legal or institutional arrangements that control access to nuclear material and to the NES. (See [16]). | O | | | Commercial arrangements with seven nuclear supplier countries. |
| | Evaluation parameter 1.2.4: Bilateral cooperation agreements. | O | | | Nuclear cooperation agreements with the United States of America and 26 other Countries. |
| | Evaluation parameter 1.2.5: Export control obligations linked with trade agreements. | | | | See the remarks on a 'Trade Obligation Map' under Process Step 2. |

* 'Not Applicable' (N/A), only for evaluation parameter that may not be relevant due to Country specific conditions.

** Comment: additional explanations, gaps, weaknesses, proposals for improvement

*3.3.2.2. Summary of findings*

| | |
|---|---|
| Indicator 1.1<br>States' commitments, obligations and policies regarding non-proliferation to fulfil best practice | Fully satisfied, as far as applicable. |
| Indicator 1.2<br>Institutional structural arrangements | Fully satisfied, as far as applicable. |

*3.3.2.3.Conclusions of assessment process, step 2*

State's commitments, obligations and policies provide credible assurance on the exclusive peaceful use of the nuclear energy system (NES), and the legal basis for required verification activities by the IAEA according to the IAEA "Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols" [14].

### 3.3.3. Assessment process, step 3: assessment of user requirement 3

**Question:** Does design and operation of the NES facilitate the implementation of IAEA safeguards?

*3.3.3.1.Timeliness goal, frequency of IAEA inspections*

The timeliness goal will be one or three months. However, this might involve State specific factors such as whether the Additional Protocol is implemented and the possible opportunities for further separation (including the size and technical difficulty of potential undeclared activities and State's technical maturity).

Conservatively, a timeliness goal of one month will be assumed, since it is a single facility and a possible State level approach is not considered in the case study.

*3.3.3.2.(Coarse) diversion path analysis*

A (coarse) diversion path analysis is performed here with 4 alternative diversion strategies.

1) Exemplified, selected diversion and concealment strategy 1:
   (ca. 60 fuel slugs are needed for 1 significant quantities);
   - Diversion of fuel slugs from the fuel slug temporary storage {17}* and loading of fuel slugs into a waste container;
   - Removal of fuel slugs in waste containers via the waste airlock {34}* into the lower waste storage, removal from the facility;
   - Replacement of diverted fuel slugs in {17}* by fuel slug dummies, brought in from the upper maintenance floor.
2) Exemplified, selected diversion and concealment strategy 2:
   (2 ingots are needed for 1 significant quantity);
   - Replacing of an TRU ingot by a uranium ingot, in a crucible, and further processing of 'dummy' material, loading of the TRU.
3) Exemplified, selected diversion and concealment strategy 3:
   (Capacity of the Heel/Scrap Storage: 250 kg HM, equivalent to about 6 significant quantities);
   - Removal of TRU-ingots in waste container(s) via the waste airlock {34}* into the lower waste storage floor, removal from the facility;
   - Removal of scrap from the Heel/Scrap Storage {13}* and loading of heel/scrap into a waste container;
   - Removal of scrap in waste containers via the waste airlock {34}* into the lower waste storage floor;
   - No replacement in the Heel/Scrap Storage, falsification of inventory data {13}* Recycling process can be maintained after some 'overproduction' of scrap.

4) Exemplified, selected diversion and concealment strategy 4:
(160–240 Fuel Assemblies are to be manipulated, equivalent to about 14 – 20 % of the annual production);
- o Replacement of fuel rods in a fuel assembly by 2–3 dummy fuel rods (Removal of diverted fuel rods via the Waste Transfer Airlock {21}* in the SFR fuel assembly assembling cell is not possible due to the limited size of the airlock);
- o Removal of diverted fuel rods as 'excess' fuel assembly and transfer to fuel assembly product store;
- o Opening of 'excess' fuel rods as 'out of specification' for retransfer to a pyroprocessing facility, diversion of the obtained fuel slugs as in diversion path 1.

5) Misuse:
- o Discrete separation of TRU or un-irradiated plutonium inside SFMF is not possible without changing the design of the facility.

*{} Equipment No - Appendix I, FIG. 9 and FIG. 10

The user requirements, criteria, indicators and acceptance limits for user requirement 3 are provided in Table 12, 13 and 14 as detailed answers to the questionnaires for user requirements 3.1 and 3.2, respectively.

TABLE 12. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 3.

| Indicators | Evaluation parameter | Evaluation Results* | |
|---|---|---|---|
| | | YES | NO |
| Indicator 3.1<br>Effectiveness of IAEA Safeguards | Evaluation parameter 3.1.1<br>"The accounting system implemented by the operator provides accurate and complete information on nuclear materials, forms, amounts, flows, locations, transfers and identification of inventory changes" [15]. | X | |
| | Evaluation parameter 3.1.2<br>All types of nuclear material flows and inventories can be verified adequately by SSAC/safeguards inspectorates/IAEA methods for the independent verification of operator's declarations. | X | |
| | Evaluation parameter 3.1.3<br>Containment and Surveillance measures and monitoring can be applied to complement nuclear material accountancy verification where appropriate in the safeguards approach. | X | |
| | Evaluation parameter 3.1.4<br>The introduction, production and/or processing of undeclared nuclear material in a safeguarded facility is difficult by design and easily detectable (See Ref. [18]). | X | |

TABLE 12. LIST OF EVALUATION PARAMETERS FOR USER REQUIREMENT 3 (cont.)

| Indicators | Evaluation parameter | Evaluation Results* | |
|---|---|---|---|
| | | YES | NO |
| Indicator 3.2<br>Efficiency of IAEA Safeguards | Evaluation parameter 3.2.1<br>Safeguards can be implemented by the IAEA at equal or lower burden for the IAEA compared to a facility of the same type. | Probably Yes | |
| | Evaluation parameter 3.2.2<br>Safeguards can be implemented at the facility at equal or lower burden for the operator compared to a facility of the same type. | Probably Yes | |

*The Findings and Evaluation Results below for Indicator 3.1 are based on the subsequent evaluation questionnaires asking for fundamental design features that facilitate the implementation of safeguards (safeguardability), with tests following the 'generic approach' (Generic Approach, Generic Safeguardability Test)

TABLE 13. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETERS 3.1 FOR USER REQUIREMENT 3

| Evaluation Parameter | Question | | Finding |
|---|---|---|---|
| Evaluation parameter 3.1.1<br>The accounting system implemented by the operator provides accurate and complete information on nuclear material, forms, amounts, flows, locations, transfers and identification of inventory changes [15]. | Procedures for PIT have been established equal to best practice [15] | | YES |
| | Test | The foreseen PIT procedures can consider all relevant needs. | YES |
| | | The NMAC system has follow-up / tracking functions that provide timely information about the locations and characteristics of all nuclear material in the system. | YES |
| | Comment: For PIT all process positions will be cleaned. The accounting system is batch wise organized, with one 'feed ingot' as starting batch, all production losses will be associated with the batch of origin. | | |
| | Nuclear material (on) inventory is properly tagged and identifiable | | YES |
| | Test | The NES foresees a scheme of identification of nuclear material. | YES |
| | | Operator's inventory control can ensure matching between records and physical reality. | YES |
| | | Items serial numbers and identifier tags can be checked without moving the item. | ? |
| | Comment: The item is the container and identified by the container in which it is kept. However, system design should assure that the identifier number of all storage containers in all storage positions can be read / checked without moving the storage container. | | |

TABLE 13. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETERS 3.1 FOR USER REQUIREMENT 3 (cont.)

| Evaluation Parameter | Question | | Finding |
|---|---|---|---|
| | International Standards of Accounting [11] are met | | Not defined for novel technology |
| | Test | It is possible to carry out measurement activities with accurate and precise quantification of the material that will be referred to in accounting declarations. | TBD[30] |
| | | The amount of hidden inventory is as low as reasonably achievable. | YES |
| | Comment: The amount of nuclear material in heel/scrap is determined by weighing and by assigning the amount to their batch of origin. Destructive analysis is not required, since the material remains unchanged by the process, and is also not applicable due to the inhomogeneity of heel/scrap collected in a container. | | |
| | International target values [15] and [39] are met for DA and NDA | | Not defined for novel technology |
| | Test | It is possible at KMPs to meet relevant criteria for accuracy and precision. | DA:<br>Procedure for sample taking does not exist yet<br>NDA:<br>Not defined |
| | Comment: For heel/scrap in containers an ASNC-type counter<br>[34] and [36] developed by KAERI in collaboration with Los Alamos National Laboratory, can be used. Expected accuracy: 2–3% [39].<br>Oxide dross and waste will be measured by the same system. | | |
| Evaluation parameter 3.1.2<br>All types of nuclear material flows and inventories can be verified adequately by SSAC/safeguards inspectorates/IAEA methods for the independent verification of operator's declarations | Nuclear material can be identified and verified by adequate methods with sufficient accuracy to enable SSAC/safeguards inspectorates/IAEA to draw independent conclusion on the non-diversion of nuclear material | | Partially |
| | Test | It is possible to apply validated methods and approved procedures. | NOT YET |
| | | It is possible to use passive NDA techniques for detecting gross and partial defects. | YES |
| | Comment: NDA equipment (like ASNC or passive neutron albedo reactivity [37]) is still to be validated and approved for use by the IAEA. Partial defect in fuel elements will be difficult to detect. | | |
| | On-site equipment can be installed and used for verification purposes as required | | YES |

[30] See Section 3.3.5.1: "*Recommendations for improvements / R&D*"

TABLE 13. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETERS 3.1 FOR USER REQUIREMENT 3 (cont.)

| Evaluation Parameter | Question | | Finding |
|---|---|---|---|
| | Test | The system design permits dedicated areas for inspectors' monitoring, collecting and reviewing activities. | YES |
| | Authentication of operator's data is feasible and properly implemented, if used for verification | | YES |
| Evaluation parameter 3.1.3 C/S measures and monitoring can be applied to complement nuclear material accountancy verification as appropriate | C/S measures can be applied to "verify information on movements of nuclear material or other material, equipment, and samples, or preservation of the integrity of safeguards relevant data, as applicable" [11]. | | YES[31] |
| | Test | The system facilitates the application of optical surveillance. | YES |
| | | The system's routine operations facilitate the application of surveillance. | YES |
| | C/S measures can be applied to ensure the continuity of knowledge on inventories previously verified, as applicable | | YES |
| | Test | Sealable areas are easy to be sealed. | YES |
| | | Surveillance systems can have a clear and unobstructed view. | YES |
| | Comment: Seals are not foreseen in the hot cell environment, only for waste containers in the waste storage. | | |
| | C/S measures can be applied "to ensure that SSAC/safeguards inspectorates/IAEA equipment, working papers and supplies have not been tampered with" [11] | | YES |
| | Sealing systems are easily verifiable | | YES |
| | Comment: see comment above. | | |
| | Process monitoring can be applied as complementary measure to enable the SSAC/safeguards inspectorates/IAEA to give credible assurance of non-diversion, if accountancy verification and C/S are not sufficient to meet safeguards objectives | | NO |
| | Comment: Process monitoring is not currently planned or in the baseline. | | |
| Evaluation parameter 3.1.4 The use of a (safeguarded) facility "for the introduction, production and processing of | Design of facility and equipment impedes misuse | | YES |
| | Test | Available processes and equipment cannot be easily modified for producing weapon-grade fissile material. | YES |
| | | Available processes and equipment are difficult to modify for separating pure weapons usable material. | YES |

[31] This needs to be verified during the design process and after the design is completed

TABLE 13. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETERS 3.1 FOR USER REQUIREMENT 3 (cont.)

| Evaluation Parameter | Question | | Finding |
|---|---|---|---|
| undeclared nuclear material" [7] is difficult by design and/or detectable | | Any modification would severely alter the routine operation of the nuclear system. | YES |
| | Comment: Separation of TRU or un-irradiated plutonium inside SFMF is not possible. | | |
| | Access, availability and implementation of equipment and collection of data by the inspectorate that indicates all credible misuse scenarios (see also evaluation parameter 3.1.2 and evaluation parameter 3.1.3) | | Not relevant |
| | Comment: see above. | | |
| | Verifiability of design information regarding facility lay out, flow of nuclear material, and containment features | | YES |
| | Test | Design Information Questionnaire has been submitted to the IAEA. | |
| | | All process lines (and units) are clearly distinguishable and identifiable. | YES |
| | | Process lines' unobservable parts are reduced to the bare minimum. | YES |
| | | Process lines' visually unobservable parts are inspectable. | N/A |
| | Comment: All inspections can/have to be performed remotely using video monitors and/or radiation monitors. | | |

TABLE 14. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETER 3.2 FOR USER REQUIREMENT 3

| Evaluation Parameter | Question | Finding |
|---|---|---|
| Evaluation parameter 3.2.1<br>For the IAEA, safeguards can be implemented by the IAEA at equal or lower burden compared to a facility of the same type | Have safeguards requirements been considered during design and construction agreed upon between IAEA, State authorities, and the operator, and has the result been documented?<br><br>If NO, continue. | TBD |
| | Comment: Safeguards requirements been taken into account in the design; however, the project is still in a conceptual design phase. | |
| | Are the (projected) 'person-days of verification work in the field' equal or lower than at a facility of the same type and comparable safeguards regime? | Still to be determined |

TABLE 14. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETER 3.2 FOR USER REQUIREMENT 3 (cont.)

| Evaluation Parameter | Question | Finding |
|---|---|---|
| | Comment: A comparable facility does not exist (novel technology). It might be compared best with a fully automated MOX facility without direct access to nuclear material. 'Person Days of Verification Work in the field' will strongly depend on the automation of safeguards equipment and its reliability. | |
| | Is the number of installed (projected) safeguards equipment equal or less than at a facility of the same type and comparable safeguards regime? | YES |
| | Comment: Since the process is much simpler than in a comparable MOX fuel fabrication facility, the intermediate products much less, and safeguards measures are based primarily on C/S (remote video monitoring and/or radiation monitors.), it can be assumed that the safeguards equipment needed will be in fact equal or less. | |
| Evaluation parameter 3.2.2<br>For the Operator, safeguards can be implemented at the facility at equal or lower burden compared to a facility of the same type | Have safeguards requirements been considered during design and construction agreed upon between IAEA, State authorities, and the operator, and has the result been documented?<br><br>If NO, continue. | TBD |
| | Comment: Safeguards requirements been considered in the design, however, the project is still in a conceptual design phase. | |
| | Will additional wiring be needed for the installation of safeguards equipment and data transfer? | N/A |
| | Comment: Wiring will be determined as part of the SBD process. | |
| | Will backfitting be required regarding C/S and/or measurement equipment to enable the implementation of required safeguards measures? | N/A |
| | Does PIV/IIV require additional outage beyond operational requirements (and national law and regulations)? | YES |
| | If YES: Is the outage time equal or lower than at a facility of the same type? | Probably YES |
| | Does the implementation of safeguards impact the operational capacity? | NO |
| | If YES: Does the impact on the operational capacity compensate otherwise required down time? | ---- |
| | Does the implementation of IAEA safeguards require additional equipment by the operator enabling verification at PIV/IIV? | NO |

TABLE 14. EVALUATION QUESTIONNAIRE. DETAILED QUESTIONS TO ASSESS EVALUATION PARAMETER 3.2 FOR USER REQUIREMENT 3 (cont.)

| Evaluation Parameter | Question | Finding |
|---|---|---|
| | Comment: All equipment needed to determine the inventory will be fixed installed, and will be specified as part of the SBD process. | |
| | If YES, is this equal or less than at a facility of the same type? | ---- |
| | Does the implementation of IAEA safeguards require additional, expensive radiation protection measures? | NO |

### 3.3.4. Assessment process, step 4: assessment of user requirement 4

The user requirements, criteria, indicators and acceptance limits for user requirement 4 are provided in Table 15, together with the summary of the evaluation results.

Evaluation of plausible acquisition paths with regard to their coverage by multiple intrinsic features and extrinsic measures are shown in Table 16 to Table 19 for four example 'diversion paths'.

TABLE 15. CRITERION, INDICATOR AND EVALUATION PARAMETER FOR USER REQUIREMENT 4 [1].

| User requirement 4: Nuclear energy systems should incorporate multiple proliferation resistance features and measures. | | | |
|---|---|---|---|
| Indicators | Evaluation Parameter | Evaluation Results* | |
| | | Yes | NO |
| Indicator 4.1: Coverage of the NES by multiple intrinsic features and extrinsic measures. | Evaluation parameter4.1: All plausible acquisition[32] paths are (can be) covered by intrinsic features or by extrinsic measures on the facility or State level – that reduce the attractiveness or inhibit/impede a diversion path. | X | |

*The evaluation result is based on the subsequent evaluation of plausible acquisition paths

[32] The term 'acquisition' is consistent with IAEA-TECDOC 1575 [1] for user requirement 4, evaluation parameter 4.1: however, it is understood that in the case study, a full acquisition path analysis is reduced to a 'diversion' path analysis, since only facility levels analysis is performed.

TABLE 16. DIVERSION PATH ANALYSIS FOR EXAMPLE ‘DIVERSION PATH 1’ (cont.)

TABLE 16. DIVERSION PATH ANALYSIS FOR EXAMPLE ‘DIVERSION PATH 1’

| Diversion Path 1: | | Facility/NES level | Country-level |
|---|---|---|---|
| Step 1: Diversion of fuel slugs from the Fuel Slug Temporary Storage {17}* and loading of fuel slugs into a waste container | Extrinsic measure (safeguards) | | |
| | All fuel containers are registered (identification number, tare, gross, net), continuous monitoring of all movements, balancing of inventories and reconciliation with operating records with Near Real-Time Accountancy (NRTA), maintaining CoK | X | |
| | Transfer routes for TRU fuel and heel/scrap (product stream) should be strictly separated from transfer routes for waste, to make the transfer of TRU fuel and heel/scrap into waste containers impossible | Resultant design requirement | |
| | Other Extrinsic measure | | |
| | All nuclear material is United States of America-obligated | X | X |
| | Comment: This extrinsic measure imposes additional obligations to the operator and to the State and increases the consequences in case of misuse and detection. | | |
| | Intrinsic features | | |
| | High radiation, nuclear material can be handled only remotely. | X | X |
| | Has the IAEA determined that the material is UDU or IDU?[33] | | X |
| | Discrete separation of special fissionable inside SFMF is not possible. | X | |

[33] This classification has an impact on the frequency of inspections.

TABLE 16. DIVERSION PATH ANALYSIS FOR EXAMPLE 'DIVERSION PATH 1' (cont.)

| Diversion Path 1: | | Facility/NES level | Country-level |
|---|---|---|---|
| | SFMF is highly automated, interference will be possible only for maintenance and at an emergency | X | |
| | Points of access are kept to a minimum and can be controlled by surveillance and radiation monitoring devices. | X | |
| | Comment: The intrinsic features above apply to all diversion paths at SFMF | | |
| Step 2:<br>Removal of fuel slugs in waste containers via the waste airlock {34} into the lower waste storage, removal from the facility. | Extrinsic measure (safeguards) | | |
| | Proposal: Radiation limit signalling device at the waste airlock | X | |
| | Discrimination capabilities between waste containers loaded with waste or with TRU fuel and heel/scrap is still to be determined | Comment Recommendation | |
| | Other Extrinsic measure | | |
| | See Step 1 | X | X |
| | Intrinsic features | | |
| | High number of fuel slugs (ca. 500) to be diverted for 1 significant quantity | X | |
| Step 3:<br>Replacement of diverted fuel slugs in {17} by fuel slug dummies, brought in from the upper maintenance floor. | Extrinsic measure (safeguards) | | |
| | See Step 1 | X | |
| | Other Extrinsic measure | | |
| | See Step 1 | X | X |
| | Intrinsic features | | |
| | High number of fuel slugs (ca. 500) to be diverted for 1 significant quantity | X | |

TABLE 17. DIVERSION PATH ANALYSIS FOR EXAMPLE 'DIVERSION PATH 2'.

| Diversion Path 2: | | Facility / NES level | Country-level |
|---|---|---|---|
| Step 1:<br>Replacing of an TRU ingot by a Uranium ingot, brought in from the upper maintenance floor, in a crucible, and further processing of 'dummy' material. | Extrinsic measure (safeguards) | | |
| | All fuel containers are registered (identification number, tare, gross, net), continuous monitoring of all movements, balancing of inventories and reconciliation with operating records (NRTA), maintaining CoK | X | |
| Loading of the TRU-ingot into a waste container | Transfer routes for TRU fuel and heel/scrap should be strictly separated from transfer routes for waste, to make the transfer of fuel TRU fuel and heel/scrap into waste containers impossible | Resultant design requirement<br>Same as diversion path 1, Step 1 | |
| | Input control of each ingot before storage and at transfer into a crucible, discriminating between TRU-ingots and uranium ingot. | X | |
| | Other extrinsic measure | | |
| | Same as diversion path 1, step 1 | X | X |
| | Intrinsic features | | |
| | Same as diversion path 1, step 1 | X | X |
| Step 2:<br>Removal of TRU-ingots in waste container(s) via the waste airlock {34*} into the lower waste storage floor, removal from the facility. | Extrinsic measure (safeguards) | | |
| | Proposal: Radiation limit signalling device at the waste airlock | X | |
| | Discrimination capabilities between waste containers loaded with waste or with TRU fuel and heel/scrap is still to be determined | Comment | |
| | Other Extrinsic measure | | |
| | Same as diversion path 1, step 1 | X | X |

TABLE 18. DIVERSION PATH ANALYSIS FOR EXAMPLE ‘DIVERSION PATH 3’.

| Diversion Path 3: | | Facility / NES level | Country-level |
|---|---|---|---|
| Removal of scrap from the Heel/Scrap Storage {13}* and loading of heel/scrap into a waste container.<br><br>Removal of scrap in waste containers via the waste airlock {34}* into the lower waste storage floor.<br><br>No replacement in the Heel/Scrap Storage, falsification of inventory data {13}* | Extrinsic measures and intrinsic features:<br><br>Same as for diversion path 1 | X | X |

### 3.3.5. Assessment process, step 5: analysis of strengths, weaknesses and gaps

**All Acceptance Limits, in principle, are met.**

However, it should be noted that acceptance limit 3.2 “IAEA Safeguards can be implemented with acceptable cost and effort” can be answered only at the end of the safeguards-by-design process, including interactions with the IAEA Department of Safeguards.

Procedures for DA sampling for the verification by the IAEA are not defined/developed; target values for NDA [39] for this type of nuclear material are also not defined. Demonstrations of NDA measurements on novel material types and material flows need to be completed. Nevertheless, gross and partial defect will be detectable with the NDA equipment already available

*3.3.5.1.Recommendations for improvements / R&D*

- System design has to assure that the identifier number of all storage containers in all storage positions can be read / checked without moving the storage container;
- Transfer routes for TRU fuel and heel/scrap (product stream) should be strictly separated from transfer routes for waste, to make the transfer of TRU fuel and heel/scrap into waste containers impossible;
- NDA equipment (like ASNC or passive neutron albedo reactivity) is still to be validated and approved for use by the IAEA;
- Safeguards measures and/or surveillance system to make sure that held-up material in the equipment module (i.e. heel) cannot be removed from the process cell without detection by safeguards;
- Development of appropriate waste form for graphite;
- Discrimination capabilities between waste containers loaded with waste or with TRU fuel and heel/scrap is still to be determined.

TABLE 19. DIVERSION PATH ANALYSIS FOR EXAMPLE ‘DIVERSION PATH 4’.

| Diversion path 4: | | Facility / NES level | Country-level |
|---|---|---|---|
| Step 1<br><br>Replacement of fuel rods in a fuel assembly by three[34] dummy fuel rods | Extrinsic measure (safeguards) | | |
| | ---- | | |
| | Intrinsic Feature | | |
| | About 500 dummy fuel rods are needed for the replacement of 1 significant quantity in form of fuel rods or fuel slugs | X | |
| Step 2<br><br>Removal of diverted fuel rods as ‘Excess’ fuel assembly and transfer to fuel assembly product store. | Extrinsic measure (safeguards) | | |
| | The ‘excess’ fuel assembly will be identified by the NRTA systems and become part of the balance. The ‘mismatch’ between fuel slug production and fuel element production would be detected at the latest at PIV.<br><br>Fuel elements identified by the book-keeping system as shipment will remain under safeguards also elsewhere in the country | X | X |
| | Intrinsic feature | | |
| | Only one ‘point of access’ exists for the removal of a fuel assembly, being monitored by the NRTA system | X | |
| Opening of ‘excess’ fuel rods as ‘out of specification’ for retransfer to a pyroprocessing facility, diversion of the obtained fuel slugs as in diversion path 1 | Extrinsic measures and intrinsic features:<br><br>Same as for diversion path 1 | X | X |

[34] The DA detection capability cannot detect less than 3 fuel rods.

## APPENDIX I.
## GENERAL DESCRIPTION AND DESIGN INFORMATION OF THE SFMF UTILIZED IN SECTION 3 AS EXAMPLE DEMONSTRATION OF THE PROSA METHOLOGY [35]

The conceptually designed SFR fuel cycle facility (SFCF) involves (1) receipt of composition controlled TRU feedstock from the pyroprocessing to make metallic fuel slugs using an injection casting process, (2) fabrication of SFR fuel pin, fuel rods, and fuel assemblies, (3) inspection of SFR fuel, wrapping, temporary storage, (4) collection, treatment, wrapping, temporary storage and shipping of process wastes, (5) quality control and assurance, (6) accounting and control of nuclear material, and (7) others such as power supply, maintenance, safety measures. The main components of TRU are Np, Pu, Am, Cm, Bk, and Cf, where all the TRU except Pu are called minor actinides.

FIG. 3 shows technical specification of fresh SFR fuel [32, 33].

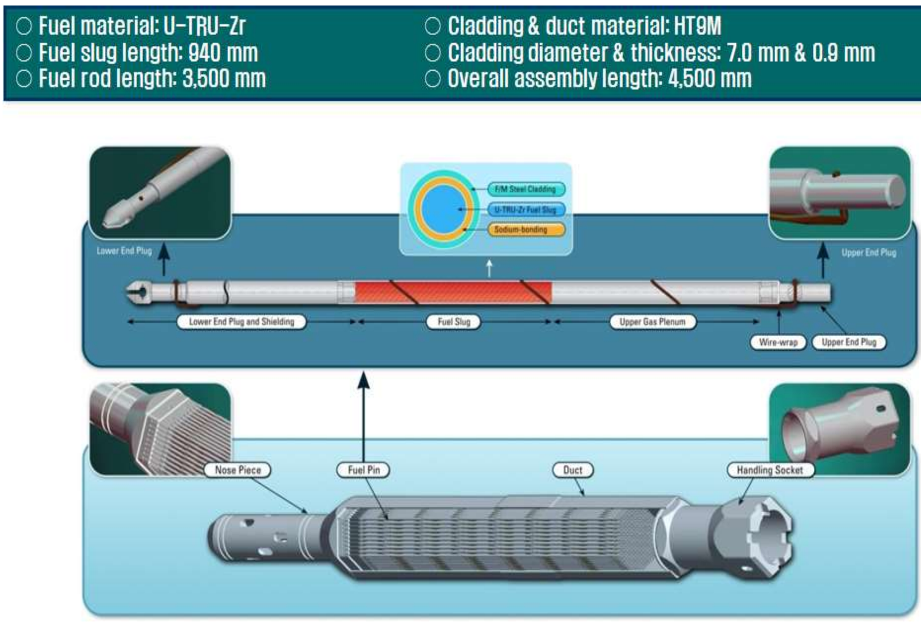


*FIG. 3. SFR fuel specifications.*

The SFMF process consists of four main elements: (1) fuel metal feedstock meting and fuel slugs casting, (2) fuel pin fabrication, (3) fuel rod fabrication, and (4) assembly fabrication. The fuel metal feedstock will be composition controlled TRU metal ingots containing rare earth elements (RE) (65U-20TRU-5RE-10Zr, numbers in weight %) from the pyroprocessing module of SFCF which also includes U-TRU-RE-Zr containing process materials recycled from the SFMF (casting heels, fuel slugs end crops, out of specification fuel slugs, etc.). RE elements

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[35] This Section was prepared by Hong Lae Chang, Won-Il Ko (of the Korea Atomic Energy Research Institute, and by Eckhard Haas, consultant) as an integral part of the Korean Case study of the same name. Some of the content of this Appendix was published before as conference proceedings [32] and in Ref. [33].

include Y and lanthanides from La to Lu. Table 20 shows the major design requirements of the SFMF.

TABLE 20. MAJOR DESIGN REQUIREMENTS OF SFMF[36]

| | | | |
|---|---|---|---|
| 1) | Capacity | Fresh SFR fuel fabrication | 38.619 ton of HM/year (11.4 ton of TRU/year);<br><br>Fuel rods: 327 139/year;<br><br>SFR fuel assemblies: 1207/year |
| 2) | Location of Plant | | Co-located with 6 SFR units |
| 3) | Net operation time | | 200 days/yr (55% operation in consideration of O&M) |
| 4) | Plant Life Time | | 60 years |
| 5) | Feed material | | U/TRU/RE/Zr metal ingot |
| 6) | Products | | – SFR fuel assemblies<br>– Wastes (ceramic, vitrified, metal) |
| 7) | Feed composition | | – Fuel Material: 65wt% uranium-20wt.% TRU-5wt% RE-10wt.% Zr<br>– Minor actinide content: <5wt.%<br>– Rare Earth content: <5wt. %<br>– Fuel Bonding: Na |
| 8) | Main Functions of SFMF | Fuel rod fabrication module | – SFR Fuel slug/rod/assembly fabrication<br>– Wastes treatment and recycling<br>– Temporary storage of TRU ingots and fuel pins |
| | | Fuel assembly fabrication module | – Fabrication of SFR fuel assembly<br>– Temporary storage of SFR fuel assembly |
| | | Product and waste storage cell | – Storage<br>o Vitrified waste<br>o compact waste<br>o SFR fuel assemblies |

In the SFMF, the U-TRU-RE-Zr ingots from pyroprocessing is induction-melted and injection-cast into moulds, cooled, removed from the mould and sheared to length. The atmosphere of the hot cells is maintained inert through the use of Ar gas to (a) prevent

[36] A prototype SFR of 130 $MW_e$ is planned to be in operation with U-Zr fuel (19.75% LEU) from 2028, while the SFMF is planned to be in operation from 2038 for 6 units of commercial scale SFR reactors of 1200 $MW_e$ each.

pyrophoric reactions, and (b) to maintain purity of the sodium and fuel inside the fuel rod. A general flow diagram for metallic fuel manufacturing process currently considered of the KIEP-21 concept at KAERI is shown in FIG. 4. Table 21 and 22 show design requirements and assumptions made for the operation of the SFMF, respectively.

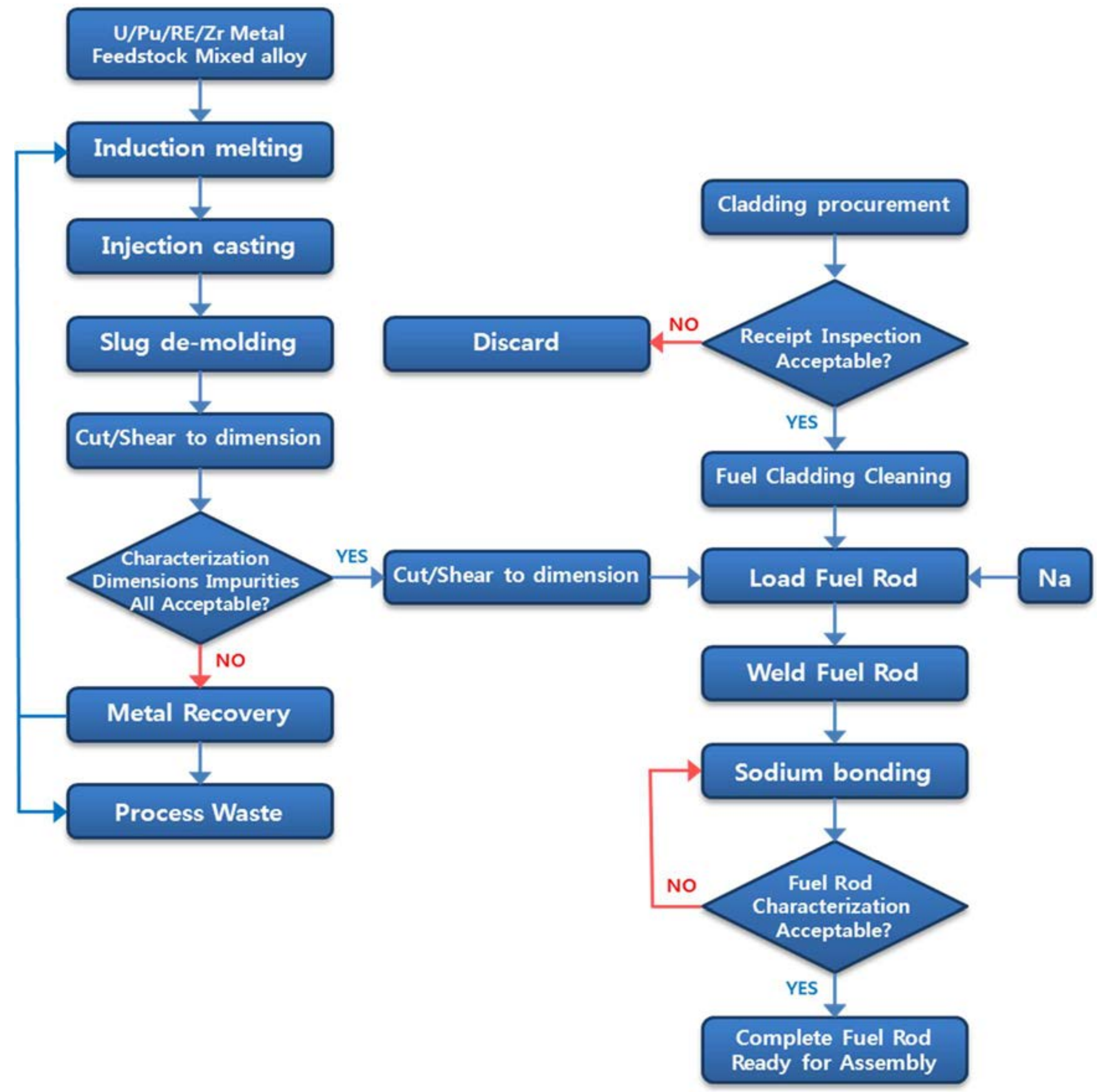



*FIG. 4. General flow diagram for metallic fuel fabrication.*

TABLE 21. DESIGN REQUIREMENTS OF THE SFMF [32, 33]

| Item | Unit | Per SFR unit | For 6 SFR units | Remarks |
|---|---|---|---|---|
| Number of fuel assemblies | | 155 | 930 | |
| Annual input | kg | 6437 | 38 620 | |
| Annual TRU input | kg | 1907 | 11 440 | Pu+MA |
| Mass of slug | g | 85 | 85 | |
| TRU contents of a fuel slug | g | 17 | 17 | 65U-20TRU-5RE-10Zr |
| Batch size | kg | 20 | 20 | <Pu 4.5kg |
| Number of fuel slug production/batch | | 236 | 236 | |
| Annual treatment of batches | | 463 | 2777 | (ca. 2800) |
| Annual production of qualified slugs | | 109 046 | 654 277 | |
| Annual production of fuel slugs | | 54 323 | 327 139 | |
| Number of fuel rods per fuel assembly | | 271 | 271 | |
| Annual production of fuel assemblies | | 201 | 1207 | 1.6 |

TABLE 22. ASSUMPTIONS FOR THE SFMF OPERATION [32, 33]

| Process | Assumptions for the SFMF Operation |
|---|---|
| Batch | – 20kg ingot for 1 batch<br>– 50 batches/yr (5 batches/month with 10 months operation)<br>– Operation time of 1 Batch= 4 days<br>– Weight of a slug = 85g |
| Recycling | 100% recycling of the following to the melting and casting unit<br>– Heel after casting<br>– Butt and finds after trimming<br>– Unqualified fuel slug |
| Slug Casting | – Amount of heel remaining in the crucible after casting is 10% of initially charged amount of ingot |
| Crucible Waste | – Metal content of the crucible waste = 0.5% of the initially charged amount of ingot |
| De-moulding | – Crash, measurement, cut, receipt, measurement |
| Mould Waste | – Metal content in the mould waste = 0.5% of the initial charged amount of ingot |
| Slug inspection | – Weight, length, diameter, straightness, appearance |
| Slug trimming | – Butts (both ends) of slug is recycled to the melting casting system<br>– Amount of butts and fines is assumed to be 10% of a slug |
| Pin Inspection | – Fraction of defective fuel pins = 5% |
| Fuel rod Inspection | – He/scintillation leak test, smear surface contamination test<br>– Fraction of defective fuel rods = 10% |

## I.1. DESIGN INFORMATION OF THE SFR FUEL MANUFACTURING FACILITY (SFMF)

The SFCF is a facility to recycle spent SFR fuel and consists of three main modules of a pyroprocess module (pyroprocessing of recycled spent SFR fuel), fuel pin and rod fabrication module, and a fuel assembly assembling module. Six SFR units of 1200 $MW_e$ each are also part of the SFCF. The SFMF is a facility to manufacture fresh SFR fuel of 38.62 tHM/yr (1207 fuel assemblies) for 6 SFR units. The site area with double fences would be about 70 200 $m^2$ of 270 m width by 260 m length. A simplified conceptual layout of the SFMF is shown in FIG. 5.

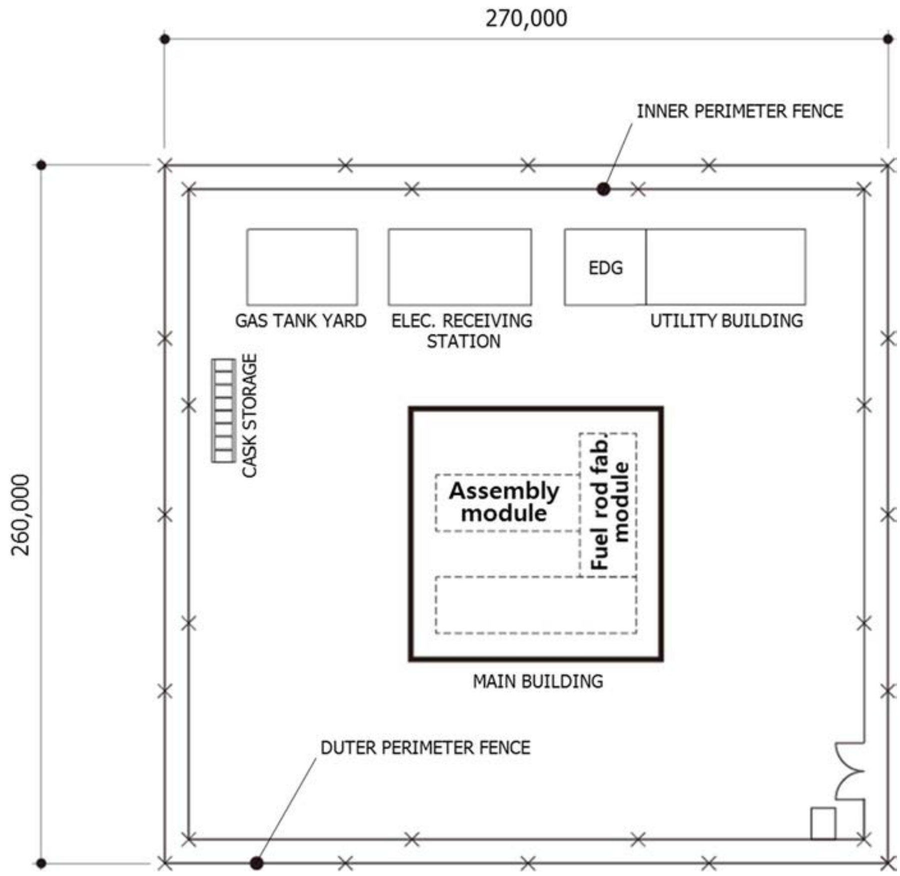



*FIG. 5. Layout of the SFR Fuel Cycle Facility.*

### I.1.1. Layout of the SFR fuel manufacturing facility (SFMF)

For the case study of the INPRO PROSA methodology, the SFR fuel manufacturing facility (SFMF) has been defined to consist of the fuel rod fabrication module and fuel assembly assembling module and excludes the pyroprocessing module for simplicity. Therefore, the feed material for SFMF is U/TRU/RE ingots produced from spent SFR fuel at the pyroprocessing module plus additional make-up U/TRU/RE ingot produced using spent PWR fuel.

The main building with three main processing modules also includes the waste storage, maintenance cells (located below each module), laboratories and utilities, and was designed as a three-floor building with a basement floor, overall 95.5 meters length, 87.0 meters wide and 37.2 meters high. The layout of the first floor of the main building is shown in FIG. 6 [32, 33].

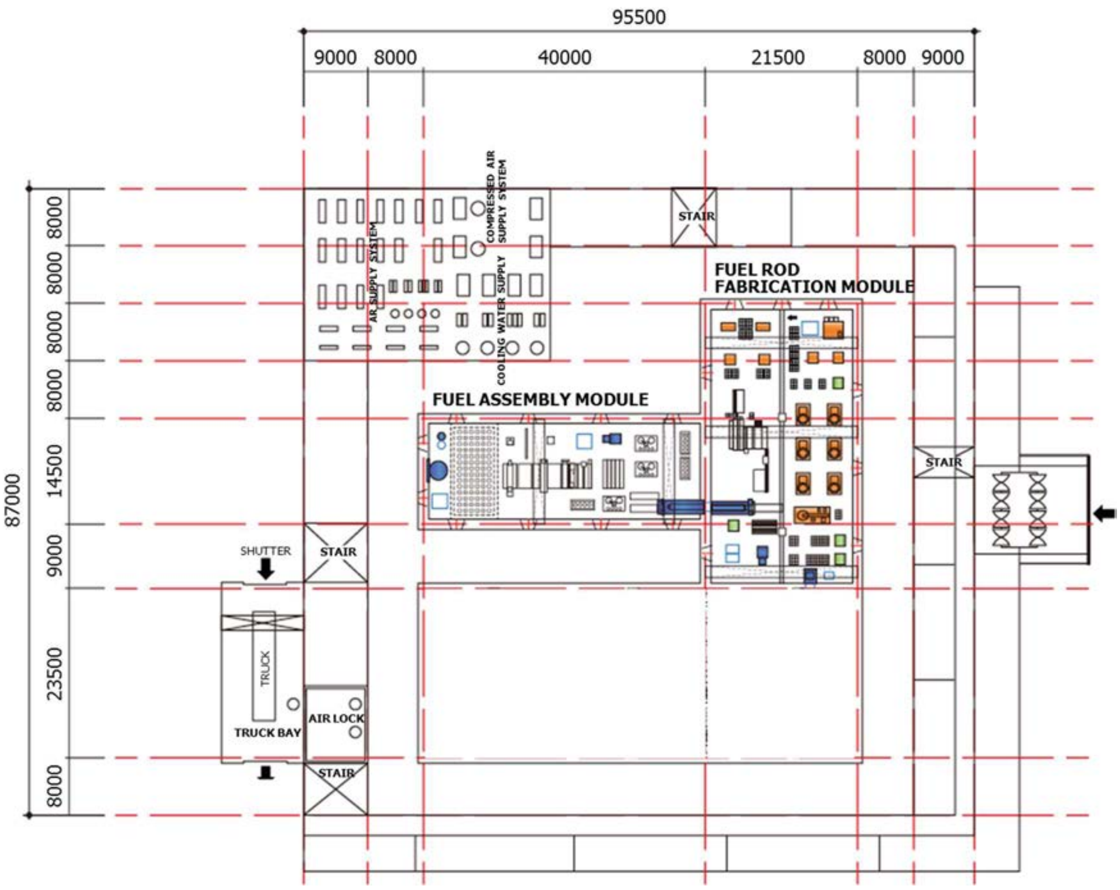



*FIG. 6. Layout of the First floor of Main Building.*

### *I.1.1.1. Metal feedstock elements from pyroprocessing of spent SFR fuel*

The spent SFR fuel from six SFR reactor units, after cooling, is treated in the pyroprocessing module of SFCF to recover uranium, actinides mixture, and a little amount of rare earth elements in the form of ingot. This ingot product from pyroprocessing of spent SFR fuel in the pyroprocessing module of SFCF, U-TRU-RE, plus additional U-TRU-RE ingots to make-up for the shortage of fuel material are metal feedstock to metallic SFR fuel fabrication in the SFMF. The metal feedstock is controlled to have a weight composition of 65U-20TRU-5RE-10Zr (numbers are weight fractions) in the pyroprocessing module before it is transferred to the SFMF. The content of rare earth is intentionally controlled to be around 5% to keep the radiation level high for self-protection, which is also a supporting measure to proliferation resistance. The isotopic composition of the TRU content is commensurate with that of the spent SFR fuel.

## I.1.2. Preliminary conceptual design of the SFR fuel manufacturing facility

### *I.1.2.1. Fuel metal slug preparation and slug casting*

The casting process currently planned at KAERI is the counter-gravity process and employs integrated casting technology, as descried in Ref. [40]. The homogenization of the alloy melt and the injection casting will be performed in the furnace in one operation.

- The ingots of composition-controlled feedstock elements from pyroprocessing module of the SFCF are transferred through inlet portal of SFMF and loaded into yttria-coated graphite crucibles and melted in a high-frequency-powered pressure/vacuum induction furnace at approximately 1500°C for U-TRU-RE-Zr alloy.
- The furnace will heat the melt under vacuum to facilitate injection casting as well as to preclude any reactions with the atmosphere. Melting temperature for complete alloying entirely depends on the elements and its composition to be alloyed. A small portion of the melt that contains the undesirable fission products will oxidize in the crucible, forming the dross which floats on the upper part of heel after casting [40]. Each crucible will be used for 10 times before sent to the waste storage.
- The mould pallet within the induction furnace is capable of holding up to 162 precision, bore-glass tubes used as moulds, made of quartz used for the 10 wt% Zr alloy (U-Pu-RE-Zr) due to the high temperature of these alloys and the higher softening temperature of 1667°C for quartz.
- The moulds are placed in a flanged opening directly above the melt crucible with vertical travel controlled by an air-actuated cylinder. Each glass mould is internally coated with zirconia-alcohol slurry and pre-heated prior to injection with a tubular heater in the furnace top hat.
- The furnace is evacuated before each injection casting run. Following evacuation, the mould pallet is lowered, placing the lower portion of the moulds below the surface of the melt. The moulds are held below the melt surface for several seconds to allow the moulds to pre-heat, after which the furnace was rapidly pressurized with argon gas. The increased pressure rapidly forces the molten fuel alloy into the moulds [40]. FIG. 7 shows the outline of metal fuel manufacturing process by injection casting planned at KAERI.
- After filling molten alloy into the glass moulds, the furnace cools to below 300°C before the castings are moved to a hood where the glass mould is broken, and the cast fuel slugs are removed [40]. The alloy left as a holdup in the crucible is defined as ‘heel’. The heel occurs from each batch and recycled to the melter. Residues arising from casting are the oxides generated from melt and moulds. Oxide cannot be recycled directly to the melter or caster. They can be converted into metal or dissolved in salt for reuse at the head end pyroprocess module. The casting ends that are sheared off are called the ‘scrap’ and are also reused as starting materials in the subsequent casting batches.

With the injection casting, the casting moulds present the most problems. The quartz moulds need treatment as contaminated waste because they are destroyed (not reusable) upon removing the cast metal fuel slugs, increasing the fabrication waste stream volume and cost [40]. After slug removal, the glass shards and residual fuel scrap will be separated with the larger pieces physically separated and the fines electromagnetically separated. This process step minimizes amounts of actinide elements transferred to waste. In the casting process several streams of potential transuranic loss can also be identified. For example, americium is easily vaporized during melting and casting of Am containing alloy because of its high vapor pressure. It was also experimentally confirmed that about 40% of initial charged Am could be evaporated during melting and casting process. However, the vaporized americium should be solidified at the cold part and recovered to the feed stock unit so that any americium will not be released to environment or waste stream. It is also possible that a leak takes place due to a defect of connection status of pipe or welding status of equipment during the process. Occurrence of leak results in the outflow of molten melt from equipment and as soon as the melt is spilt over on the floor, the melt will be shortly solidified by cooling down. Accordingly, the leaked melt will be easily recovered and recycled because there is no possibility the solidified melt will be extensively spread. At present, it is difficult to exactly estimate leakage frequency and amounts.

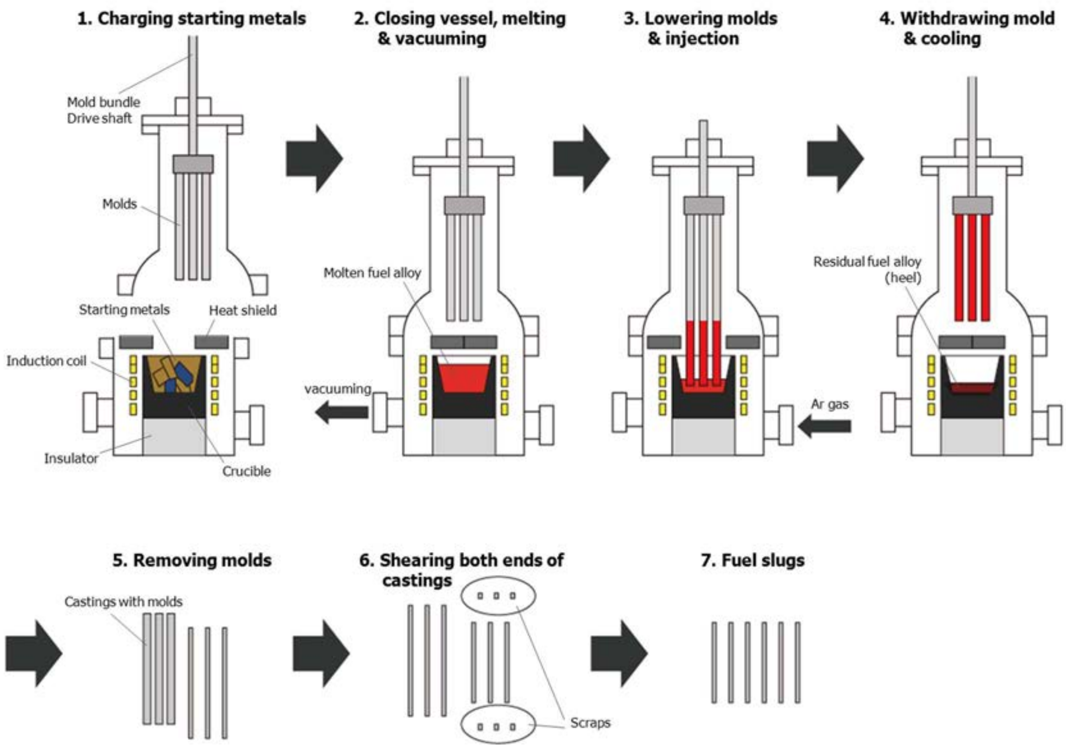



*FIG. 7. Outline of metal fuel manufacturing process by injection casting.*

### *I.1.2.2. Fuel rod fabrication system*

FIG. 8 shows the detailed flowsheet for the metallic fuel rod fabrication system, as described in Ref. [40]. The gap between the fuel and cladding is to be filled with a substance with a high thermal conductivity, i.e. sodium, to increase heat transfer from the fuel to the cladding A fuel jacket was fabricated, loaded with sodium under argon environment to facilitate bonding, followed by the insertion of the fuel slugs and finally closure welded. It is critical to keep the jacket welding surfaces free of sodium so that sodium needs to be placed in the jacket in solid form before the slugs are loaded. Sodium bonding is the process of wetting sodium to the fuel slugs and cladding and removing any voids present in the annulus, each of which ensures adequate heat transfer between the fuel and cladding [40]. FIG. 9 show the layout of the SFR fuel rod fabrication module which has fuel rod fabrication system inside.

### *I.1.2.3. Fuel assembly fabrication module*

FIG. 10 shows the layout of the fuel assembly assembling module. Fuel assemblies for the SFR, each of which contains fuel rods, are constructed remotely in a hot cell using a single pair of manipulators. The temperature of the fuel rod containing fuel processed using melt refining and containing high concentrations of fission products is above the melting point of sodium as a result of radioactive heating [40]. Therefore, fuel assembly construction occurs in a vertical position.

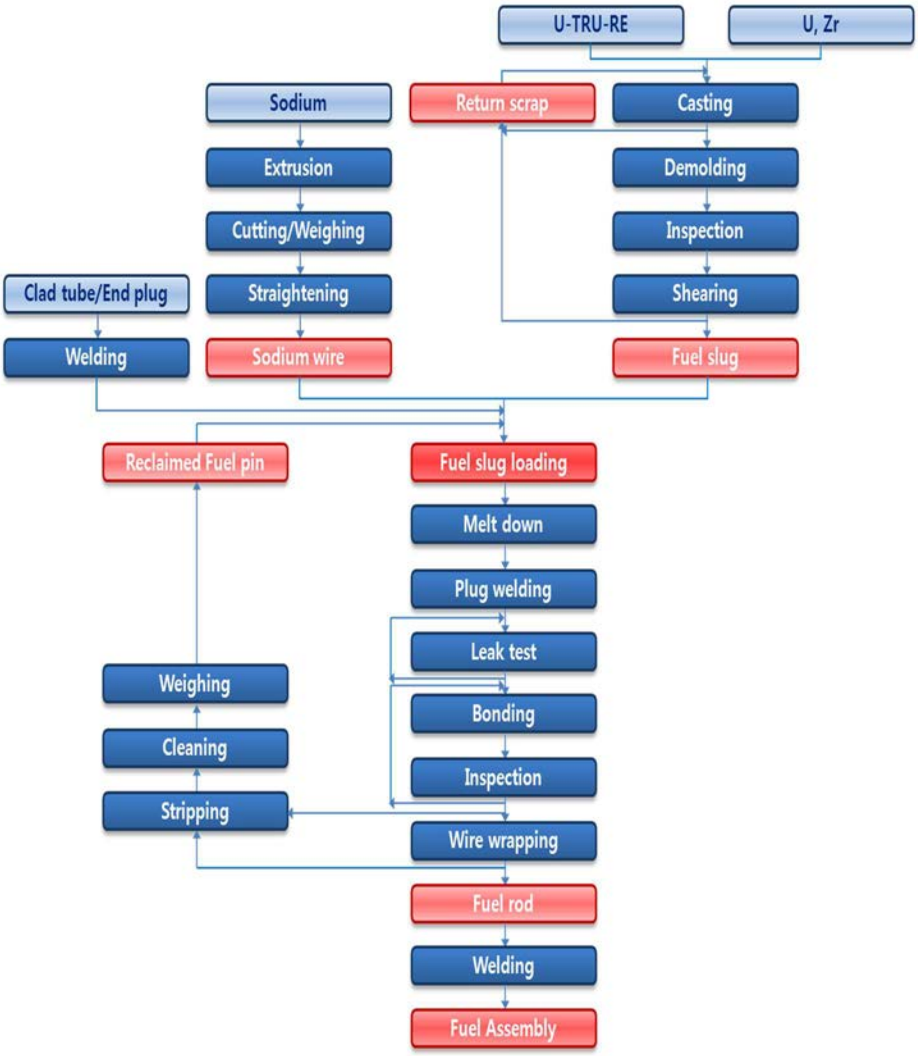
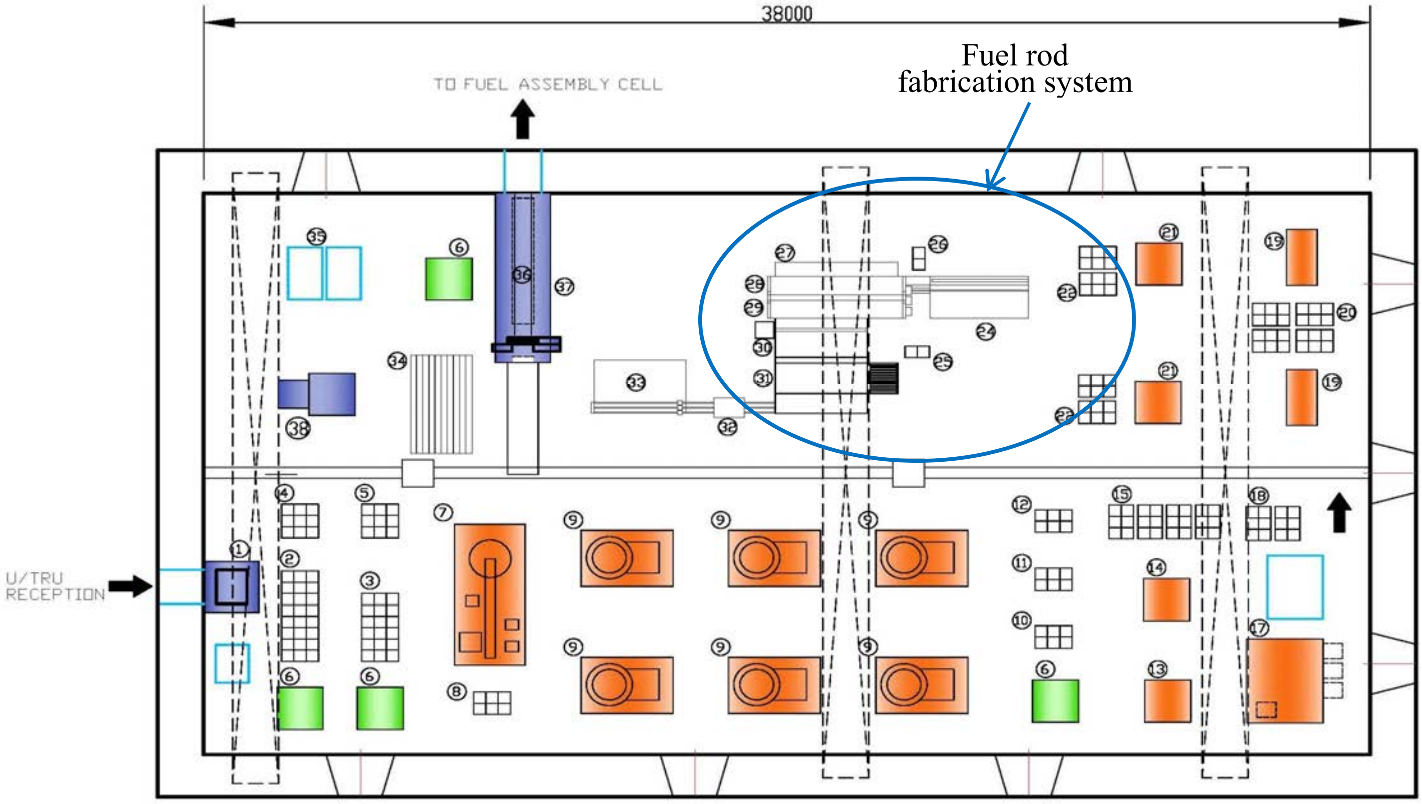



*FIG. 8. Detailed flowsheet for metallic fuel rod fabrication.*

This arrangement would also allow a high modularity and flexibility to the remote handling equipment in the process cells with specifically limited functions. Process equipment can be designed in a modular approach to maximize the simplicity of transfer process between process cell and maintenance cell because most complex manipulations of equipment would be performed by removing an equipment module from the process cell to the maintenance cell and replacing the module with a spare equipment while maintenance is done.

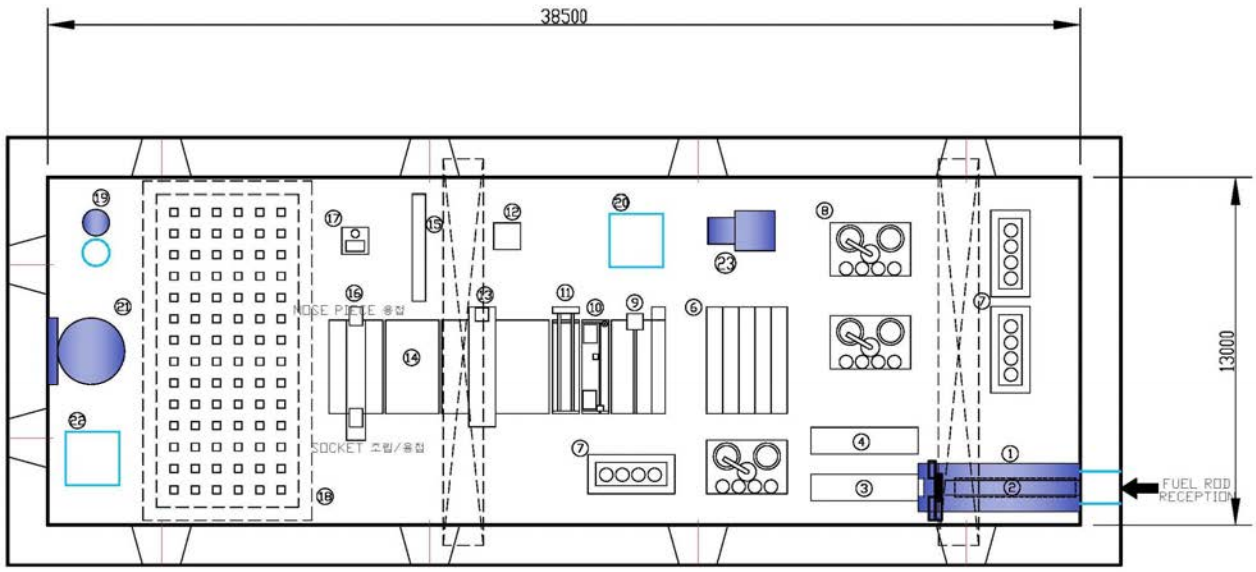



| No | Name | No | Name | No | Name | No | Name |
|---|---|---|---|---|---|---|---|
| 1 | TRU ingot transfer portal | 2 | TRU metal storage | 3 | TRU metal storage | 4 | Scale for receiving material |
| 5 | Scale for receiving material (backup) | 6 | Mould storage | 7 | Injection casting apparatus | 8 | Crucible storage |
| 9 | Coating material storage | 10 | Dross storage | 11 | Dross removal unit | 12 | Heel removal unit |
| 13 | Heel/scrap storage | 14 | Mould removal unit | 15 | Storage for breached mould and dross dust collection | 16 | Sample collection and transfer unit |
| 17 | fuel slug temporary storage | 18 | Fuel slug inspection device | 19 | Fuel slug storage | 20 | Slug tray and supply table |
| 21 | Rod end fitting storage | 22 | Bond Na storage | 23 | Cladding tray and supply table | 24 | Na/slug charging device |
| 25 | Fuel rod welding and inspection | 26 | Ultrasonic test device | 27 | He leakage test unit | 28 | Surface decontamination device |
| 29 | Contamination inspection unit and fuel rod loading table | 30 | Fuel rod tray and loading table | 31 | Temporary storage space for replacing equipment parts | 32 | Transfer device |
| 33 | Fuel rod transfer air lock | 34 | Waste transfer air lock | 35 | Fuel material transfer airlock | 36 | Shielding windows |

*FIG. 9. Layout of the SFR fuel rod fabrication module.*

### I.1.3. Additional design approach for proliferation resistance purpose

Safeguards by design (SBD) 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 [31] and [19]. In this regard, one of the design goals of the process cells is to minimize the number of ways that materials can be transferred and the possibilities for equipment to be manipulated. These design actions simplify the monitoring of the transfer processes. In addition, to improve the overall facility availability, maintenance cells are located on the second floor, as shown in FIG. 11. These cells are directly over the first floor shown previously in FIG. 6. This construction allows maintenance and refurbishment to be done off-line. The product and waste storage areas are located in the basement below the first floor.




| No. | Name | No. | Name | No | Name | No | Name |
|---|---|---|---|---|---|---|---|
| 1 | Fuel rod transfer airlock | 2 | Transfer device between cells | 3 | Fuel rod tray replacing equipment | 4 | Empty tray buffer |
| 5 | Fuel rod magazine | 6 | Fuel rod transport cart | 7 | Na bonder | 8 | Fuel rod horizontal transfer and bond tester |
| 9 | Wire wrapping device | 10 | Fuel pin inspection device | 11 | Wire storage | 12 | Fuel pin loading and assembling machine |
| 13 | DUCT assembly table | 14 | DUCT support | 15 | Final assembling machine | 16 | Fuel assembly inspection device |
| 17 | Fuel assembly temporary storage vault | 18 | Fuel assembly exit | 19 | Maintenance area | 20 | Equipment air lock |
| 21 | Waste transfer airlock | 22 | Shielding windows | | | | |

*FIG. 10. Conceptual layout of the SFR fuel assembly assembling module.*

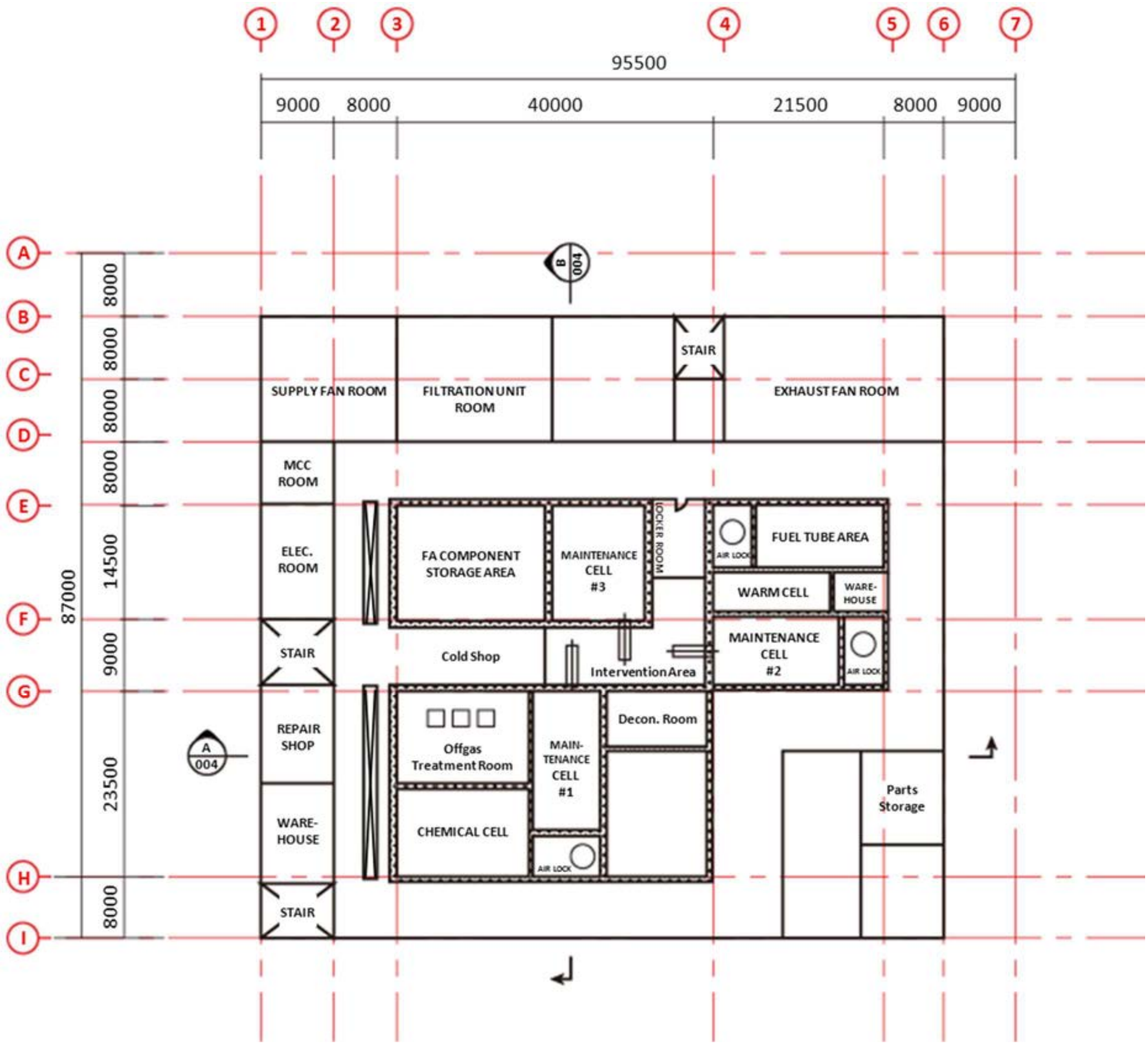



*FIG. 11. Layout of the second floor of the main building.*

Overall facility availability may be improved because maintenance and refurbishment can be done off-line. A key issue with separating process and maintenance operations will be the need to reliably remove TRU-bearing material from equipment modules — except for residual contamination — before they are transferred out of a process cell. It is therefore important to have safeguards instrumentation that can assay the residual transuranic material remaining in an equipment module to verify that its complete removal and consistency with declared values. Likewise, if the number of entry and exit portals into the process cells is minimized, verifications of the consistency of all material additions and removals with declared operation can be reduced.

However, the separation of process and maintenance functions is only required for processes that handle TRU. Processes that handle non-TRU streams (off-gas, separated uranium, cladding hulls, fission products) do not need the same safeguards intensity if transfers into those processes are monitored to confirm that they are consistent with declared operation (e.g., residual transuranic inventories consistent with declared operation). Table 23 shows the list of major equipment in the SFMF facility.

TABLE 23. A LIST OF MAJOR EQUIPMENT IN THE SFMF

| Equipment of Major Processing | Processing capacity | | Equip. Capacity | Equipment Size (meters) | Quantity |
|---|---|---|---|---|---|
| | Annual | Daily | | | |
| Raw material temporary storage | 45.1 tHM | 225.2 kgHM | 2250 kgHM | 3.0Lx3.0Wx2.0 H | 1 |
| Scale for receiving material | 45.1 tHM | 225.2 kgHM | 250 kgHM/day | | 3 |
| Mould, pellet assembling device | 45.1 tHM | 225.2 kgHM | 250 kgHM/day | | 1 |
| Injection casting apparatus | 45.1 tHM | 225.2 kgHM | 40 kgHM/day | 5.0Lx4.0Wx3.0 H | 6 |
| Scale for Crucible | | | | | 1 |
| Mould removal unit | | | | 2.5Lx2.0Wx2.0 H | 1 |
| slug inspection device | 654 277 ea | 3271 ea | 3300 ea/day | 1.5Lx1.5Wx1.5 H | 1 |
| Fuel rod welding and inspection | 327 139 rods | 1635 rods | 1650 rods/day | 4.5Lx3.0Wx3.0 H | 1 |
| He leakage test unit | 327 139 rods | 1635 rods | 1650 rods/day | 8.0Lx4.0Wx1.5 H | 1 |
| Surface decontamination Device | 327 139 rods | 1635 rods | 1650 rods/day | 3.5Lx2.0Wx1.5 H | 1 |
| Contamination inspection Unit | 327 139 rods | 1635 rods | 1650 rods/day | | 1 |
| Ultrasonic test device | 327 139 rods | 1635 rods | 1650 rods/day | | 1 |
| Na bonding device | 327 139 rods | 1635 rods | 1650 rods/day | 1.0ØWx4.0H | 3 |
| Bonding inspection device | 327 139 rods | 635 rods | 1650 rods/day | 8.0Lx2.0Wx1.5 H | 1 |
| Wire wrapping device | 327 139 rods | 1635 rods | 1650 rods/day | 5.0Lx6.0Wx1.5 H | 1 |
| Fuel rod inspection device | 327 139 rods | 1635 rods | 1650 rods/day | 8.5Lx2.0Wx2.0 H | 1 |
| Final assembling machine | 1207 assemb | 6 assemb. | 1207 assemb /day | 5.0Lx2.0Wx1.5 H | 1 |
| Fuel assembly inspection device | 1207 assemb | 6 assemb. | 1207 assemb /day | 1.0Lx5.0H | 1 |
| Rework device | | | | | 4 |

### I.1.4. Process Materials

The current SFMF is designed for a throughput of 38.62 tHM/year and metal fuel consists of an alloy including about 20% TRU (65U-20TRU-5RE-10Zr: 11.4 ton TRU/year; 327 139 fuel rods/year; 1207 fuel assemblies/year). The TRU feedstock consists of Pu, Am, Np and Cm, as well as recycled U-TRU-RE-Zr process materials (casting heels, fuel slug end crops, out of specification fuel slugs, etc.).

In general, the fuel rod fabrication process generates a significant amount of process residues during processing. However, most are recycled back to the process units for reuse, and just small amounts are released to the waste-form fabrication process as final waste. For example, excessive waste is produced during de-moulding, due to shards of broken quartz. The heel is partially covered with oxide dross that is created by the reaction between the alloy and oxygen. Likewise, it is intended to recover the TRU contained in these wastes, in order to send TRU-free waste to the waste form fabrication process.

*I.1.4.1. Process residues*

For injection casting, the bottom ends of quartz moulds, the top ends of which are closed, are immersed in the molten alloy. As there is a certain clearance between the bottom of the crucible and the bottom ends of the moulds, following the casting, a small quantity of the melted slugs remains as a hold up. This is known as 'heel'. The heel occurs from each batch, and is recycled to the melter after removing dross, which is in oxide form. Typically, the heel is about 10% of the initial charged amount. Therefore, in the case of 1 ton/year throughput, about 0.1 ton will occur as heel. However, the amounts generated is fully recycled to the metal fuel preparation unit for reuse, not released as waste.

Fuel slug trimming used for identification of alloy microstructure and chemical characterization will be recycled into the casting process or metal alloy preparation unit. Rejected slugs will also be recycled to process units in order to minimize waste amounts.

Two types of waste forms will be discharged: graphite and quartz composing. Quartz waste can be incorporated into a borosilicate form. However, an appropriate form for graphite has not been identified yet.

*I.1.4.2. Oxide wastes*

As the residues arising from the metal fuel fabrication, the oxide dross is generated from melts and moulds, respectively. They each come from a result of an oxidation of alloy. For example, $Y_2O_3$ coated on graphite crucible can oxidize all elements in alloy as follows:

$$3Zr \text{ (in alloy)} + 2\ Y_2O_3 \text{ (on graphite)} \rightarrow 3ZrO_2 + 4Y$$

On the other hand, it is possible that the outer of mould reacts with melt to generate alloy oxides that can occur as follows:

$$Zr \text{ (in melt)} + SiO_2 \text{ (in quartz)} \rightarrow ZrO_2 + Si$$

Oxide cannot be recycled direct to melter or caster. That can be converted into metal or dissolved in salt for reuse at the pyroprocess units. Dross adhered to outer surface of moulds is dissolved with $ZrCl_4$ and recycled to the electrorefiner to recover actinides, leaving just quartz as waste. Also, dross from heel can go to the electro-reducer to convert oxide into metal, but it is also possible to be dissolved with $ZrCl_4$ to produce a salt including actinides. In that case, the dross from heel can go to the electrorefiner. Accordingly, all oxides generated are dissolved in the salt and then the salt including TRU is recycled to the electro-refiner.

During the metal fuel fabrication, 0.6% of initial charged amounts take place as the dross, but 0.55% is dissolved in LiCl-KCl eutectic salt and the salt is recycled to the electro-refiner. Only 0.05% of the whole dross indicates TRU amounts included in the breached quartz following clean-up of moulds. Eventually, this will be disposed of as final waste after a waste form fabrication. Based on 1 ton/yr throughput of metal fuel, 500 g TRU/year will be incorporated into a waste form.

### *I.1.4.3. Crucible and breached moulds*

The used crucible and breached moulds will be classified as waste. As they include small amounts of TRU, they should go to the cleanup process in order to dissolve TRU in the LiCl-KCl salt before disposing of them. In the case of used crucible, we do not expect many amounts of used crucible to be generated as waste during metal fuel fabrication. The crucible can be continuously used until coated material ($Y_2O_3$) is peeled off from graphite crucible. KAERI estimates a generation rate of used crucible to be 0.5% which means that the used crucible including 5kg alloy (for 1ton/yr throughput) will be generated as waste. Following clean-up process, about 0.5kg alloy will be annually incorporated into a waste form together with crucible material of graphite. This is identical with about 100g TRU.

In the case of breached moulds, as a mould contains about 85g alloy, about 11 800 moulds are required based on a 1 ton/yr throughput. Accordingly, the used quartz amounts are calculated to be about 270kg annually.

- Outer diameter: 6 mm
- Inner diameter: 5 mm
- Length: 1200 mm
- Quartz density: 2.20 g/cm$^3$
- Number of moulds: 11 800

Only 0.5% of initially charged alloy amounts will be generated as waste and 90% of them will be dissolved in the salt during clean-up process, leaving about 500g alloy in breached quartz. This corresponds to 100g of TRU in 270kg quartz.

### *I.1.4.4. Process feed and products*

Feed ingots, fuel rods and assemblies will need regular inspection to ensure that they comply with metal fuel standards. Acceptance conditions would be:

- Ingots: non-destructive assay. If it should be rejected and recycled, it goes to melter or metal alloy preparation unit.
- Rod: straightness, Na bonding status and welding status are checked and if needed to be recycled, it goes to electrorefiner due to treatment of sodium.
- Assembly: straightness will be confirmed, and if need to be recycled, it goes to fuel rod fabrication process.

Table 24 shows generation ratios of by-products and waste during metal fuel fabrication. KAERI plans to trim about 10% of initial charged amount. Table 24 also shows that the reject ratios of ingots, rod and fuel assembly are about 3.5%, 5.0% and 0.05%, respectively. However, all materials to be rejected will be recycled to process units for reuse, not releasing them for waste fabrication. At any event, annual generation amounts will be 35 kg for ingots, 50 kg for rod, and 0.5 kg for fuel assembly, respectively, based on a 1 ton/year throughput.

TABLE 24. GENERATION RATIOS OF RESIDUES AND WASTE DURING METAL FUEL FABRICATION

| | Generation Ratio * | Recovery Status | Waste Amounts |
|---|---|---|---|
| Heel | 0.1 | recycled | - |
| Crop | 0.098 | recycled | - |
| Heel Dross | 0.003 | recycled | - |
| Used Crucible | 0.005 | Recycled/waste | 0.0005 |
| Mould Dross | 0.005 | recycled | - |
| Mould | - | waste | 0.0005 |
| Ingots | 0.035 | recycled | - |
| Pin | 0.050 | recycled | - |
| Assembly | 0.0005 | recycled | - |
| Am | TBD | recycled | TBD |
| Fines | TBD | recycled | TBD |
| Total | 0.251 | | 0.001 |

* on the basis of initial charged amounts

### *I.1.4.5. Final waste inventories and form*

Although most parts generated as waste are recycled to process units and not released to waste form fabrication process, used crucibles, breached moulds composing of $SiO_2$ are supposed to be disposed of for waste form fabrication without further recovering TRU material of which waste streams also need to meet IAEA safeguards requirement of ‘practically-irrecoverable’ for safeguards to be terminated. The amount of heavy metal contained in the breached moulds is assumed to be 0.5 tons/year and can be incorporated into borosilicate glass form together. Graphite crucible waste is also assumed to contain 0.5 tons/year, and that a high-temperature, corrosion-resistant ceramics needs to be considered as crucible of melting and casting. The breached moulds and used crucibles will be stored in the universal container for vitrified waste (Universal Container-V: 1338 mm H x 430 mm Ø) which are used at the La Hague reprocessing plant as a standardized container for vitrified waste.

## REFERENCES


[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Proliferation Resistance, Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1575, IAEA Vienna (2007).

[2] IAEA/INPRO, Terms of Reference of the INPRO Collaborative Project on Proliferation Resistance and Safeguardability Assessment Tools (PROSA), Rev.9 Final 05 June 2012.

[3] THE PROLIFERATION RESISTANCE AND PHYSICAL PROTECTION WORKING GROUP OF THE GENERATION IV INTERNATIONAL FORUM, Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Rev. 6, September 15, (2011).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA), IAEA-TECDOC-1684, IAEA Vienna (2012).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Statute, As Amended up to 28 December 1989, IAEA (1989).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Proliferation Resistance Fundamentals for Future Nuclear Energy Systems, IAEA STR-332, IAEA, Vienna (2002).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, 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).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected), IAEA, Vienna (1998).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Overview of the Methodology, Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1575, IAEA Vienna (2008).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Communications Received from Members Regarding the Export of Nuclear Material and of Certain Categories of Equipment and Other Material, INFCIRC/209, IAEA, Vienna (1974).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary 2001 Edition, International Nuclear Verification Series No.3, IAEA, Vienna (2002).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Communications Received from Certain Member States Regarding Guidelines for the Export of Nuclear Material, Equipment or Technology, INFCIRC/254, IAEA Vienna (1978).

[13] UNITED NATIONS, Security Council Resolution 1540, S/RES/1540 (2004).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for States Implementing Comprehensive Safeguards Agreements and Additional Protocols, IAEA Services Series 21, (2016).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Material Accounting Handbook, IAEA Services Series No. 15, (2008).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Multilateral Approaches to the Nuclear Fuel Cycle, Expert Group Report to the Director General of the IAEA, IAEA, Vienna (2005).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards statement for 2019, IAEA, Vienna (2019).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in Nuclear Facility Design and Construction, NE Series Document NP-T-2.8, Vienna (2012).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards, IAEA-STR-360, IAEA, Vienna (2009).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Design Measures to Facilitate Implementation of Safeguards at Future Water Cooled Nuclear Power Plants, Technical Reports Series No. 392, Vienna, (1998).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Nuclear Reactors, IAEA Nuclear Energy Series No. NP-T-2.9, IAEA, Vienna, (2014).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Uranium Conversion Plants, IAEA Nuclear Energy Series No. NF-T-4.8, IAEA, Vienna, (2017).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Fuel Fabrication Plants, IAEA Nuclear Energy Series No. NF-T-4.7, IAEA, Vienna, (2017).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Facilities for Long Term Spent Fuel Management, (2018).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Reprocessing Plants, (2019).
[26] INTERNATIONAL ATOMIC ENERGY AGENCY, International Safeguards in the Design of Enrichment Plants, (2019).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Safeguards Techniques and Equipment: 2011 Edition, International Nuclear Verification Series No. 1 (Rev. 2) (2011).
[28] RENDA G., Resisting Nuclear Proliferation Through Design, A System Approach to Nuclear Proliferation Resistance Assessment, A dissertation submitted to the University of Bristol, (2008).
[29] UNITED STATES DEPARTMENT OF ENERGY, Overview of the Facility Safeguardability Analysis (FSA) Process, PNNL-21698, (2012).
[30] UNITED STATES DEPARTMENT OF ENERGY, Trial Application of the Facility Safeguardability Assessment Process to the NuScale SMR Design, PNNL-22000 Rev.1, (2013).
[31] PARK, S.W., Why South Korea Needs Pyroprocessing, Bull. Atom. Scientists, (Oct.26, 2009).
[32] CHANG L. et al., A Case Study for the INPRO Collaborative Project, Proliferation Resistance and Safeguardability Assessment Tools (PROSA), Institute for Nuclear Material Management — 55th Annual Mtg., Atlanta, GA, 20–24 July (2014).
[33] KIM S. K., KO W. I., LEE Y. H., Economic Viability of Metallic Sodium-Cooled Fast Reactor Fuel in Korea, Science and Technology of Nuclear Installations, Volume 2013, Article ID 412349, (2013).
[34] LEE, T-H., et al, Development of a Neutron Coincidence Counter for advanced Spent Fuel Conditioning Process, Journal of the Korean Physical Society, **48**, 2, 218 (2006).

[35] LEE, T-H., et al, A Direct Non-Destructive Assay for the Pu of U/TRU Ingot in Pyroprocessing Using 244Cm Neutron Albedo Reactivity Technique and Its Error, Nuclear Technology, (2012).
[36] LEE, T-H., et al, Hot-Test Results of the Advanced Spent Fuel Conditioning Process Safeguards Neutron Counter for PWR Spent Fuel, Nuclear Technology, Nucl. Technol., 176, 147 (2011).
[37] TOBIN, S., et al, Determining Plutonium Mass in Spent Fuel with Non-Destructive Assay Techniques / NGSI Research Overview and Update on NDA Techniques, Part 1, IAEA-CN-184/130, IAEA Safeguards Symposium, Vienna (2010).
[38] LEE, J., South Korea’s Export Control System, Stockholm International Peace Research Institute, (2013).
[39] INTERNATIONAL ATOMIC ENERGY AGENCY, International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials, STR-368, Vienna (2010).
[40] BURKES D. E. et al., A US perspective on fast reactor fuel fabrication technology and experience part I: metal fuels and assembly design, Journal of Nuclear Materials, 389, pp. 458–469, (2009).
[41] UNITED STATES OF AMERICA, U.S. Atomic Energy Act, Section 123 (1954).
[42] INTERNATIONAL ATOMIC ENERGY AGENCY, Introduction to the Use of the INPRO methodology in a Nuclear Energy System Assessment, NP-T-1.12, IAEA, Vienna (2010).
[43] INTERNATIONAL ATOMIC ENERGY AGENCY, Terms for Describing New, Advanced Nuclear Power Plants, IAEA, TECDOC-936, Vienna (1997).
[44] BATHKE, C., et al., Implications for Advanced Safeguards Derived from a Proliferation Resistance and Physical Protection Case Study for a Generation IV Nuclear Energy System, Nucl. Technol., 179, 5 (2012).
[45] PELLAUD, B., Proliferation Aspects of Plutonium Recycling, J. Nucl. Mater. Management, 31, 30 (2002).
[46] KESSLER, G., Plutonium Denaturing by $^{238}$Pu, Nucl. Sci. Eng., 155, 53 (2007).
[47] SAGARA, H., et al., Denaturing of Plutonium by Transmutation of Minor-Actinides for Enhancement of Proliferation Resistance, J. Nucl. Sci. Technol., 42, 161 (2005).
[48] SAITO, M., et al., Development of Methodology for Plutonium Categorization (II) - Improvement of Evaluation Function ‘Attractiveness’, American Nuclear Society Transactions, 98, 1, 669 (2008).
[49] INTERNATIONAL ATOMIC ENERGY AGENCY, Supplementary Document to the Report on The Conceptualization and Development of Safeguards Implementation at the State Level (GOV/2013/38), Report by the Director General, GOV/2014/41, IAEA, Vienna (2014).

## ANNEX I.
## NUCLEAR TRADE AND EXPORT CONTROL

An important factor in assessing the proliferation resistance of a State is nuclear trade agreements and subsequent arrangements concluded between trading partners when peaceful use nuclear materials and/or technologies are transferred between them.[37] These agreements and arrangements define the terms of trade and legal obligations between the parties[38]. Some of the legal obligations stipulated in these agreements and arrangements make significant contributions to the non-proliferation regime. Examples of legal obligations on transferred nuclear materials and especially designed and prepared (EDP) equipment that may confer proliferation resistance advantages include:

- Assurance of peaceful use: no nuclear explosive, no military end use, or both.
- Safeguards required in perpetuity with comprehensive IAEA Safeguards applied in non-nuclear weapons States. Though rare, this may include an Additional Protocol in force.
- Right of the supplier to suspend trade and to repatriate obligated nuclear materials and EDP equipment in the event a trading partner detonates a nuclear explosive device or terminates/abrogates an IAEA Safeguards agreement [41].
- No retransfer of material, equipment and/or related sensitive data without prior consent of the supplier.
- No change in form or content of nuclear material supplied or otherwise obligated through contact with obligated EDP equipment without prior consent of the supplier.
- Though rare, specific restrictions on front and back end approaches and related fuel cycle service providers/suppliers.

As a first step in assessment of the effect of trade agreements on proliferation resistance, it is necessary for the assessor to associate nuclear materials and facilities/technology/EDP equipment with specific trading partners in the case that items are imported from a supplier. It is also important to realize that obligations may be conferred on nuclear material through contact with facilities/technologies/EDP equipment in addition to the original obligation associated with origin and procured fuel services (e.g., imported conversion, enrichment and fabrication services).

Although National nuclear export control laws and regulations are not part of the IAEA Safeguards verification regime, they are a critically important part of the broader non-proliferation regime. These laws and regulations are applied prior to nuclear material and EDP equipment transfers under a given trade agreement/arrangement. Identification of the trade

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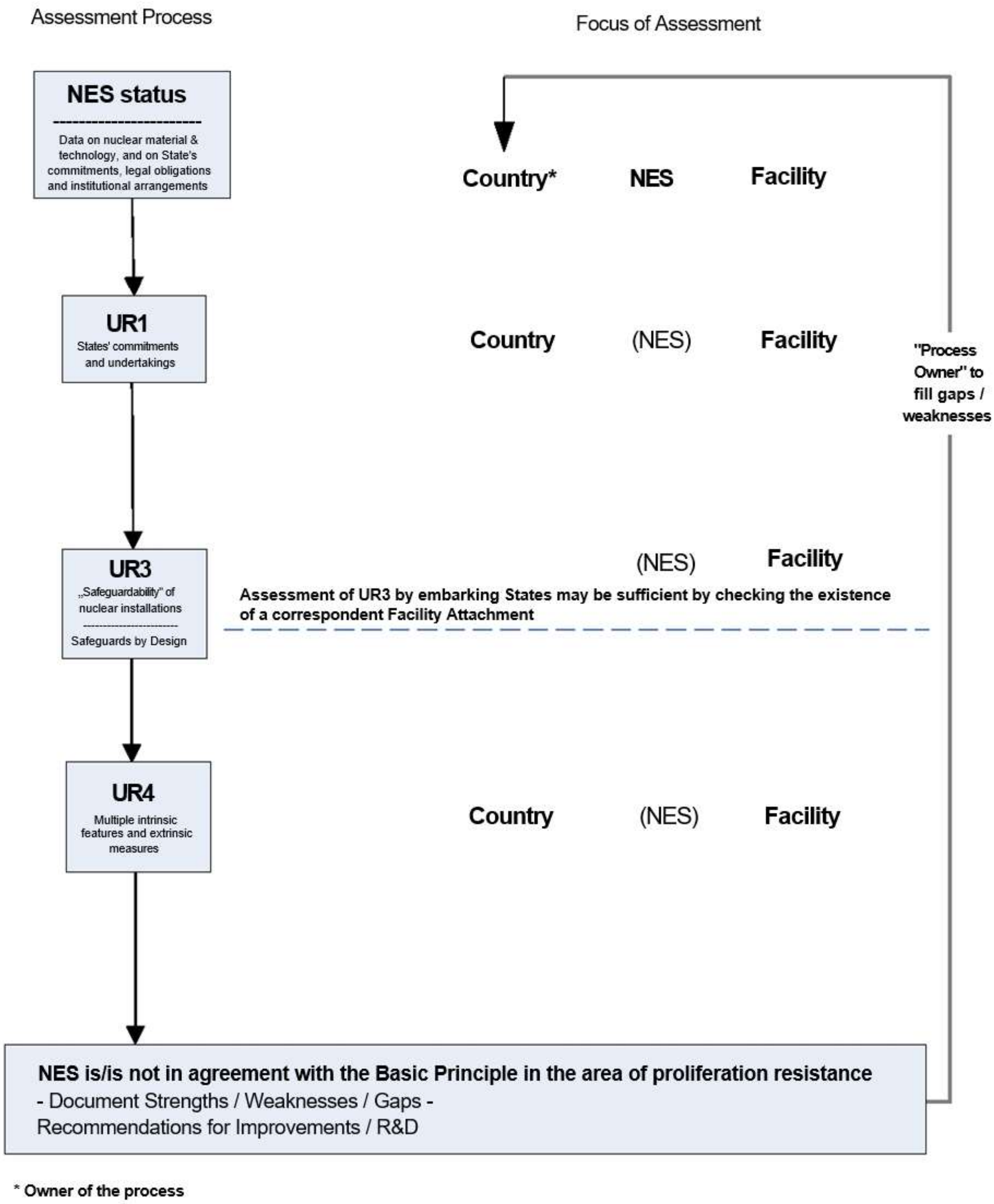
[37] It is possible that such agreements and arrangements may involve common markets as a single trading entity or partner as in the case of Euratom. However, it is most common that trade agreements and arrangements are concluded bilaterally between two countries.

[38] These trade obligations are not included within the legal framework and scope of the IAEA and are not required as part of a State's IAEA Safeguards declaration and related undertakings.

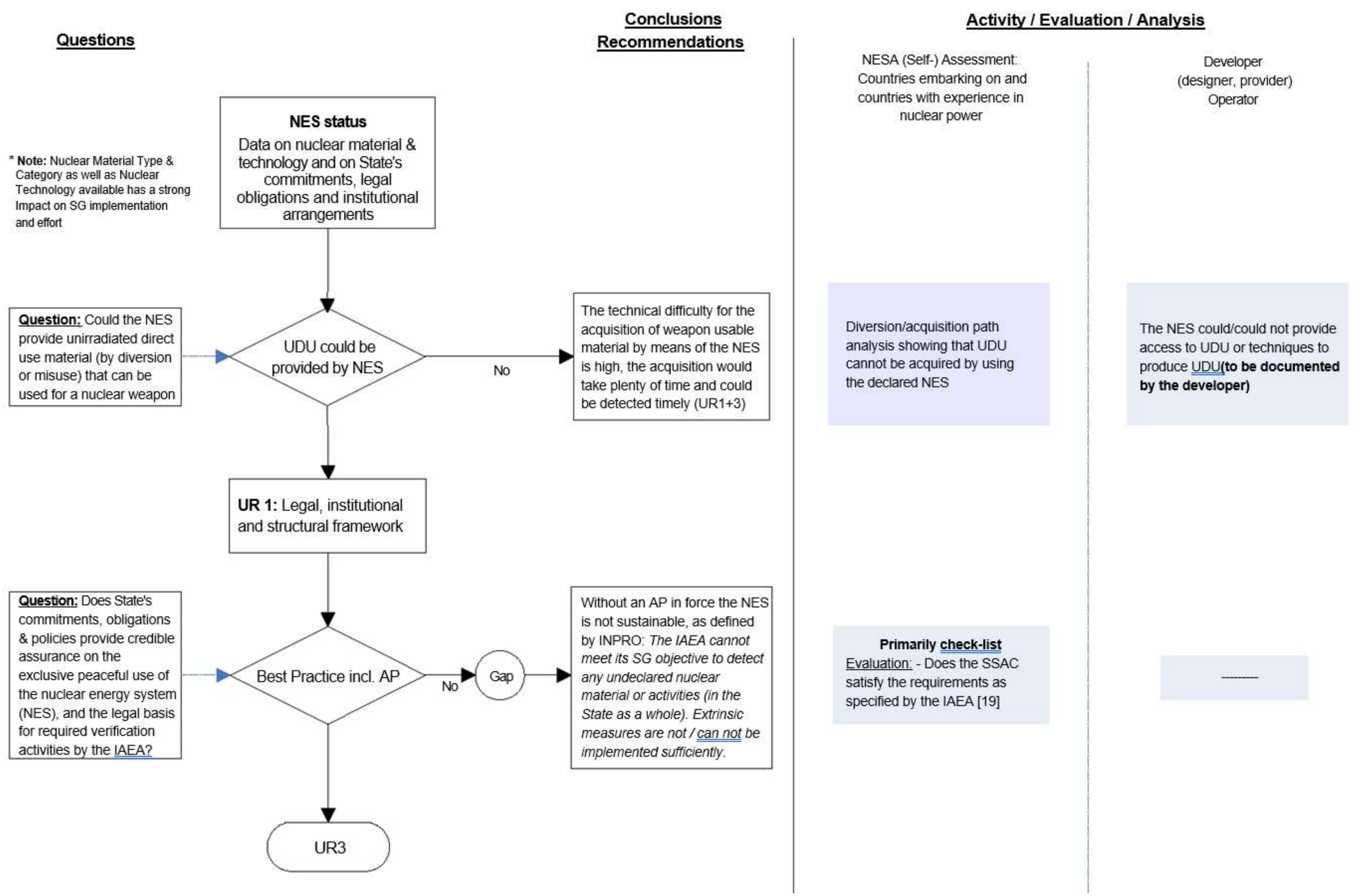
obligations also points to a set of exercised National export control laws and regulations. In this case, the assessor will indicate whether and if the exporting trade partner exercises best practices on export control, such as participation in the Nuclear Suppliers Group or other best practices. Participation of exporters in best legal and regulatory practice results in a more sustainable, proliferation resistant NES in importing trade partners.

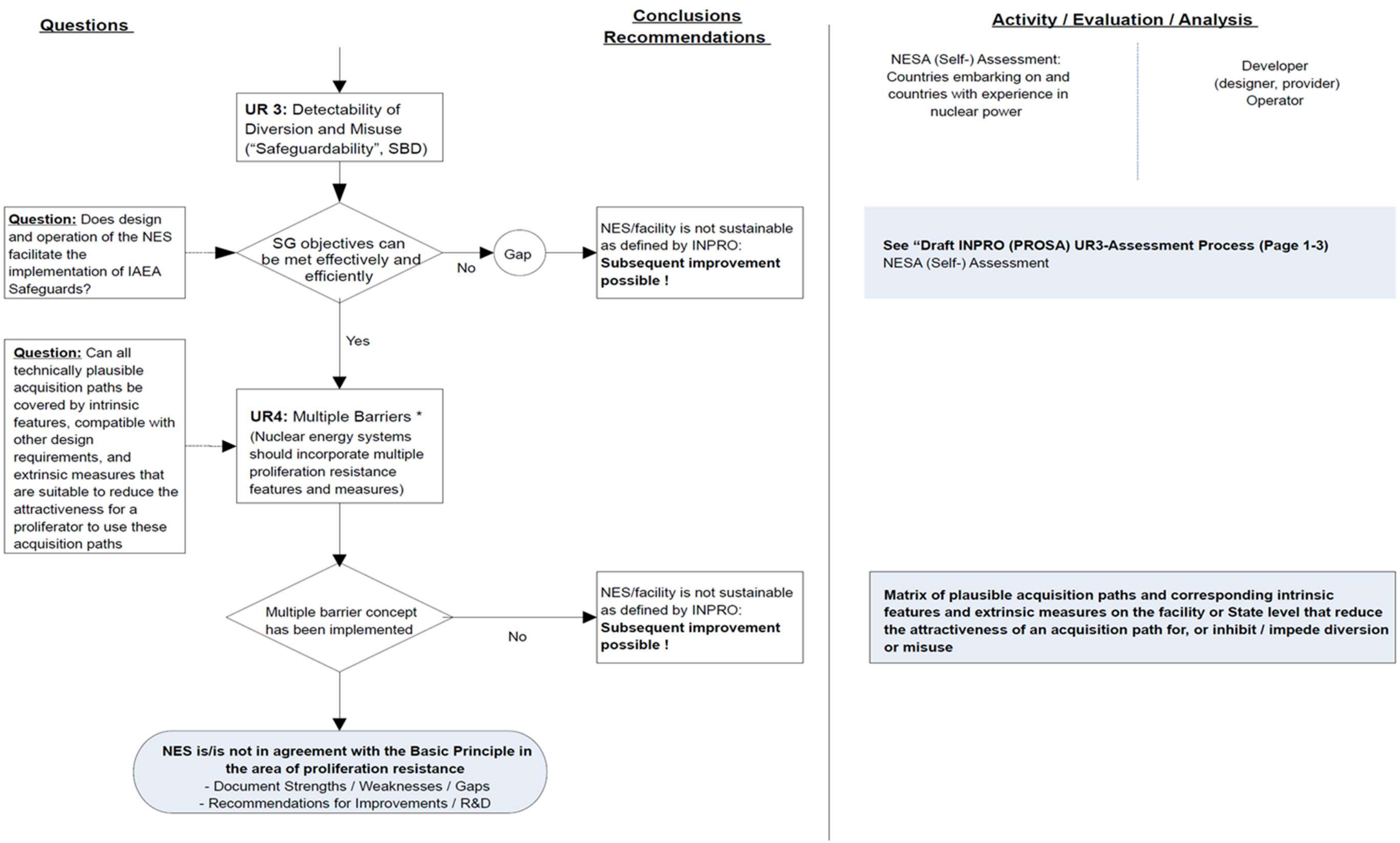
# ANNEX II.
# INPRO-PROSA PROLIFERATION RESISTANCE SELF-ASSESSMENT PROCESS (SIMPLIFIED)

How to perform the INPRO-PROSA proliferation resistance self-assessment is illustrated in flow charts in Annexes II to VI. Annex II provides a simplified overview of the process sequence according to the INPRO-PROSA methodology, followed by a detailed view of the process steps with questions to be answered by the assessor, and conclusions to be drawn as the result of the analysis (Annex III). In addition, the assessment process is further detailed for User Requirement 3, "Detectability of diversion and misuse", in Annex IV to VI.

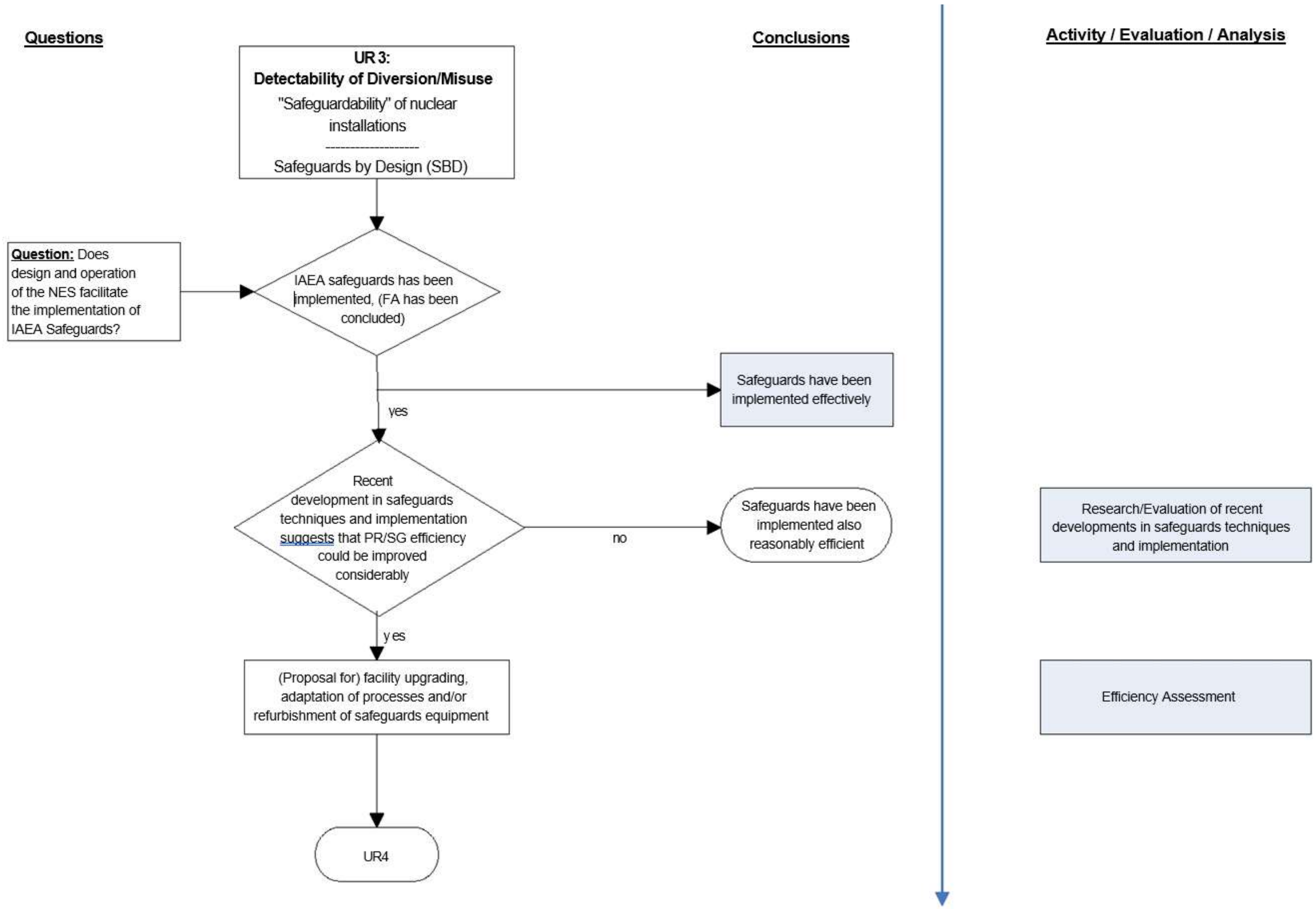


# ANNEX III.
# INPRO-PROSA PROLIFERATION RESISTANCE-ASSESSMENT ANALYSIS PROCESS BY ASSESSOR

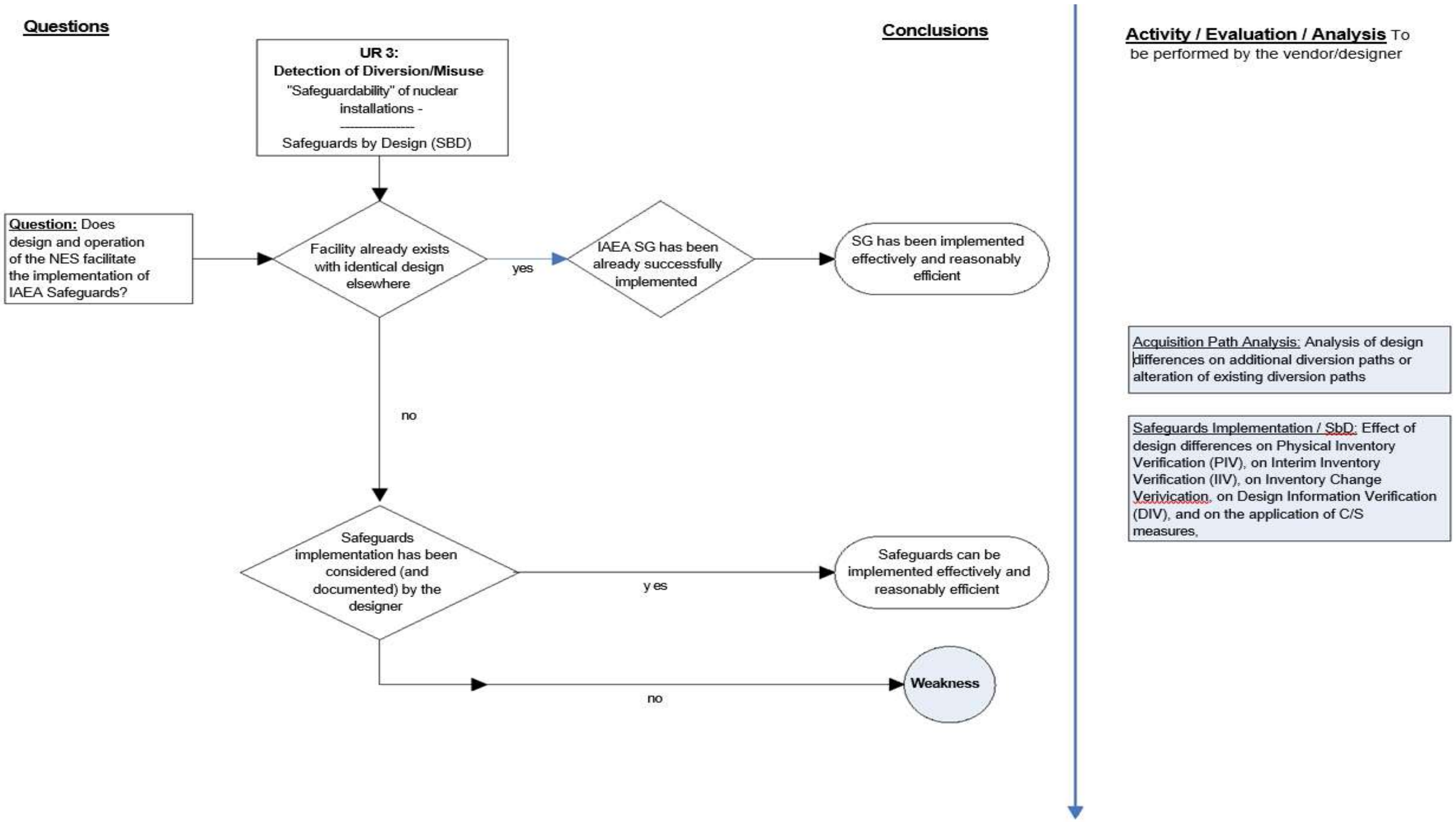



Questions
Conclusions
Recommendations
Activity / Evaluation / Analysis
NESA (Self-) Assessment: Countries embarking on and countries with experience in nuclear power
Developer (designer, provider) Operator
UR 3: Detectability of Diversion and Misuse ("Safeguardability", SBD)
Question: Does design and operation of the NES facilitate the implementation of IAEA Safeguards?
SG objectives can be met effectively and efficiently
No
Gap
NES/facility is not sustainable as defined by INPRO: Subsequent improvement possible !
See "Draft INPRO (PROSA) UR3-Assessment Process (Page 1-3)
NESA (Self-) Assessment
Yes
Question: Can all technically plausible acquisition paths be covered by intrinsic features, compatible with other design requirements, and extrinsic measures that are suitable to reduce the attractiveness for a proliferator to use these acquisition paths
UR4: Multiple Barriers * (Nuclear energy systems should incorporate multiple proliferation resistance features and measures)
Multiple barrier concept has been implemented
No
NES/facility is not sustainable as defined by INPRO: Subsequent improvement possible !
Matrix of plausible acquisition paths and corresponding intrinsic features and extrinsic measures on the facility or State level that reduce the attractiveness of an acquisition path for, or inhibit / impede diversion or misuse
NES is/is not in agreement with the Basic Principle in the area of proliferation resistance
- Document Strengths / Weaknesses / Gaps
- Recommendations for Improvements / R&D

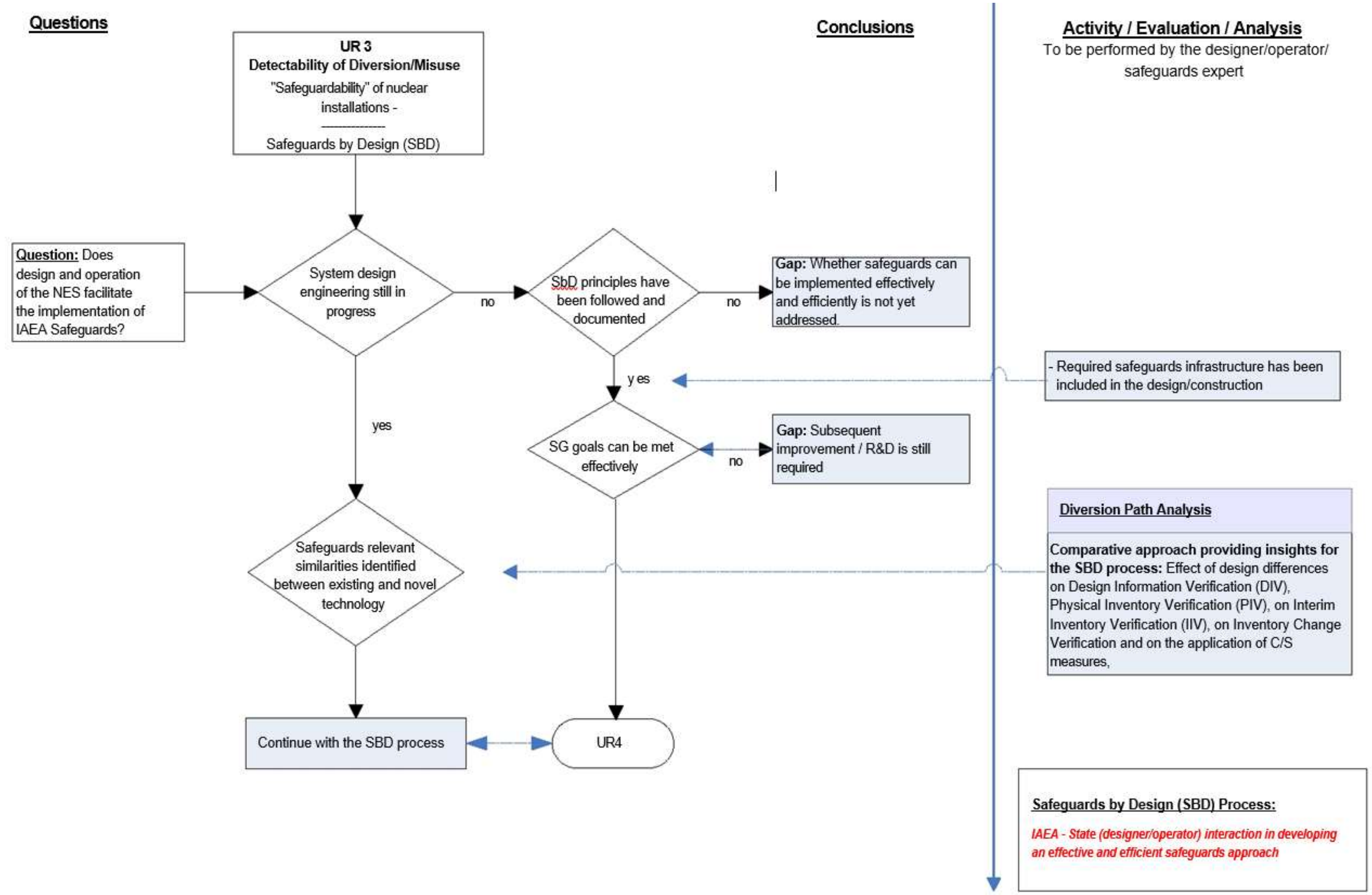
# ANNEX IV.
# INPRO-PROSA USER REQUIREMENT 3 -ASSESSMENT PROCESS (SELF-) ASSESSMENT: EXISTING NES WITH PROVEN TECHNOLOGY



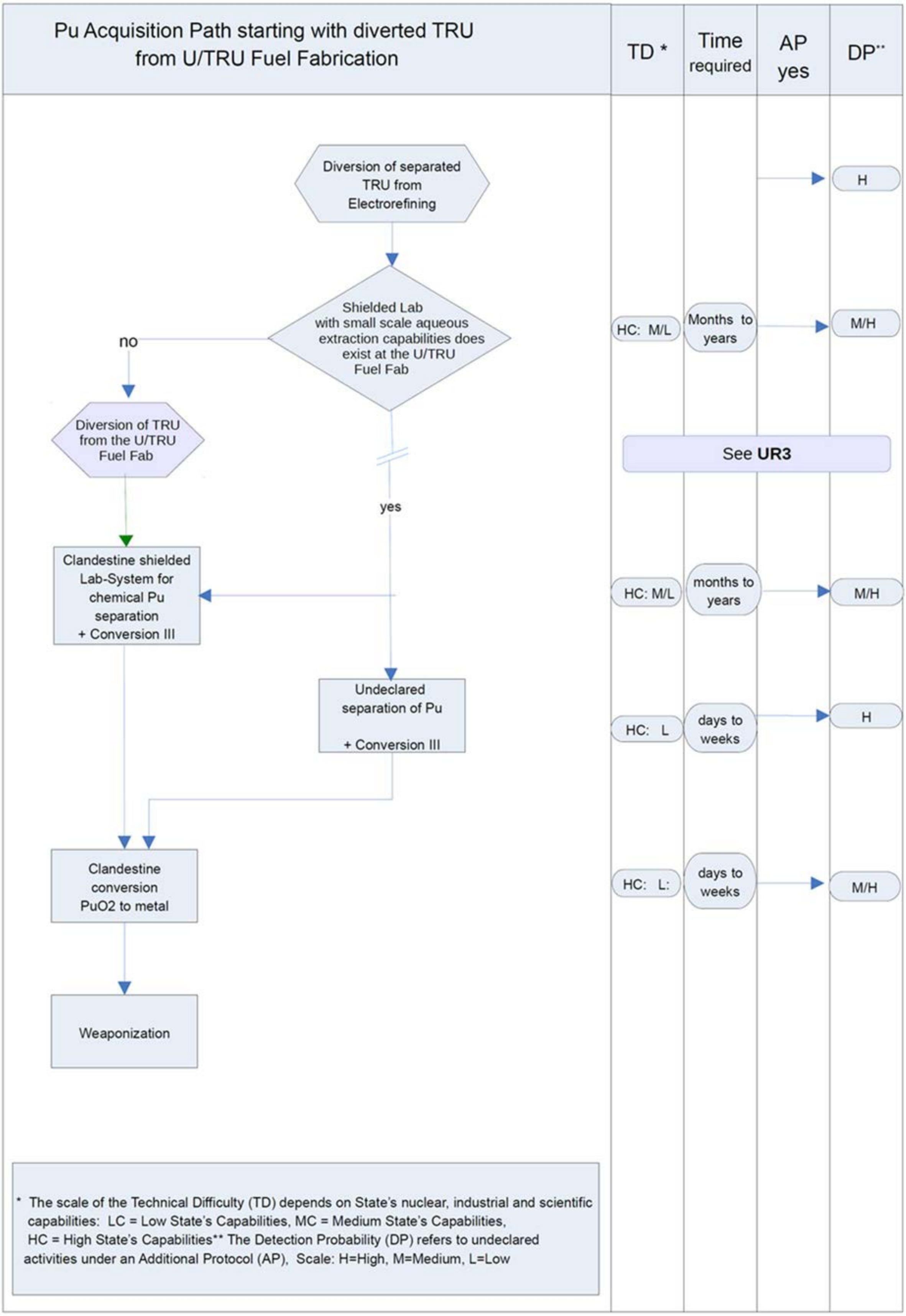
# ANNEX V.
# INPRO-PROSA USER REQUIREMENT 3 – ASSESSMENT PROCESS (SELF-) ASSESSMENT: COUNTRY EMBARKING ON NUCLEAR POWER WITH PROVEN TECHNOLOGY



# ANNEX VI.
# INPRO-PROSA USER REQUIREMENT 3 - ASSESSMENT PROCESS (SELF-) ASSESSMENT: EXPERIENCED COUNTRY IN NUCLEAR POWER WITH NOVEL TECHNOLOGY



## ANNEX VII. PROSA SFMF CASE STUDY: DETECTION PROBABILITY ALONG THE ACQUISITION PATH



## GLOSSARY

**acquisition path analysis**. The analysis of all plausible acquisition paths or acquisition strategies for a State to acquire nuclear material usable for the manufacture of a nuclear explosive device. An acquisition path analysis may be part of the development of a State level safeguards approach. The purpose of an acquisition path analysis is to determine whether a proposed set of safeguards measures would provide a sufficient detection capability with respect to a specific acquisition path or acquisition strategy [11].

**basic principle.** A statement of a general goal that is to be achieved in an NES and provides broad guidance for the development of an NES (or a design feature thereof) [42].

**criterion.** A metric that enables the assessor to check whether the addressee of the corresponding user requirement has met or exceeded a limit that indicates sustainability. It consists of an indicator (indicator) and an acceptance limit (acceptance limit) [42].

**diversion path analysis.** The analysis of all possible diversion paths or diversion strategies for nuclear material at a facility. A diversion path analysis may be part of the development of a model safeguards approach for a common facility type and may also be carried out for a specific facility. The purpose of a diversion path analysis is to determine whether a proposed set of safeguards measures would provide a sufficient detection capability with respect to a specific diversion path or diversion strategy [11].

**efficiency.** Accomplishment of or ability to accomplish a job with a minimum expenditure of time and effort (Dictionary.com). In the context of safeguards, it means that effective safeguards can be implemented with a minimum expenditure of time and effort. [18]. The minimum can be achieved only with an additional protocol in force and a Broader Conclusion already drawn.

**evaluation parameter.** Parameters used to assist the assessor in determining whether the acceptance limit for an indicator has been met [42].

**evolutionary design.** An advanced design that achieves improvements over existing designs through small to moderate modifications, with a strong emphasis on maintaining design 'provableness' to minimize technological risks [IAEA-TECDOC-936] [43]. With respect to proliferation resistance, an evolutionary design should be able to implement IAEA Safeguards with limited modifications in accepted model approaches. Safeguards equipment and instrumentation used should not require significant R&D to certify for use.

**extended process monitoring.** Makes full use of this (process monitoring) data, providing a higher level of operational transparency.

**indicator and acceptance limit.** The acceptance limit is a target against which an indicator is to be evaluated by an assessor, leading to a judgement of sustainability within the current century (gap or no gap) [42].

**innovative design.** An advanced design which incorporates radical conceptual changes in design approaches or system configuration in comparison with existing practice as defined in Ref. [43]. With respect to proliferation resistance, an innovative design implies that implementation of IAEA Safeguards may require significant modifications in accepted model approaches – or wholly new concepts yet undeveloped. Safeguards equipment, instrumentation and conceptual approaches may require significant R&D to certify for use in innovative designs.

**INPRO methodology.** The INPRO methodology defines itself as an assessment approach performed on the Criteria level of the hierarchy of INPRO methodology requirements. The INPRO assessor should retrieve/collect information from existing documents (possibly describing results of analyses or existing agreements) to define the value of an INPRO Indicator and of a corresponding Acceptance Limit. The INPRO assessment process consists of comparing the Indicator with the Acceptance Limit of the Criteria. In many cases, an analysis by specialists is needed to confirm that the criterion has been met [42].

**INPRO NESA Assessor**. The current INPRO methodology distinguishes between three different types of 'users of the INPRO methodology' called the 'assessor': 1) a country embarking on nuclear power, 2) a country with experience in nuclear power (adding nuclear power plants or other nuclear facilities), and 3) a developer (designer, supplier) of new (innovative) nuclear facilities. The assessor of the first two types of users (embarking or experienced user) is part of a Nuclear Energy System Assessment (NESA) team covering all areas of the INPRO methodology and typically comes from a scientific/academic organization such as a research centre in a country. The third type of assessor is typically from a supplier organization or research centre involved in development of nuclear facilities. These three types of users and how they could use the INPRO methodology in a NESA are described in IAEA Nuclear Energy series publication [42].

**material production technology.** The technologies capable of producing nuclear material for direct use in nuclear explosives are reprocessing, enrichment, and reactors.

**material quality**. Depending on the material type (classification of nuclear material according to the element contained and, for uranium the degree of enrichment [11]) and material category (categorization of nuclear material according to its irradiation status and suitability for conversion into components of nuclear explosive devices [11]), several process steps may be required to get material that can be used in a nuclear weapon. Each of these process steps, done either in clandestine facilities or by misuse of declared facilities, might be technically difficult for the potential proliferator, may take time, and the probability of early detection will increase as more steps are required. In addition, the radiation field and the chemical/physical form may have an impact on the effort needed to process and convert nuclear material into a form that can be used in a nuclear weapon. Regarding the isotopic composition of plutonium, as a basic principle and according to IAEA definitions, plutonium containing less than 80% Pu-238 is direct use nuclear material and can be used for a nuclear explosive device. Different analytical approaches, for in-depth theoretical analysis of Pu quality, based on differing assumptions, have been proposed inter alia by Bathke [44], Pellaud [45], Kessler[46], Sagara[47] and Saito[48].[39]

[39] Many of these material quality models are influenced by physical protection design basis threat assumptions that are quite different than see above State level proliferation threat considerations. Direct applicability to proliferation resistance may be unclear.

Nonetheless, the ‘attractiveness’ or ‘convenience’ for the use in a nuclear weapon may be different for potential proliferant states, depending on each State’s capabilities.

**material quantity.** The more nuclear material that must be diverted and processed to get sufficient quantity required to produce a weapon, the higher the effort and time for processing the nuclear material will be. This also increases the probability of early detection [11].

**nuclear energy system**. According to INPRO, a nuclear energy system (NES) consists of all the declared nuclear facilities of the front end and back end of the fuel cycle, such as mining and milling, conversion, enrichment, fuel fabrication, reactor, waste management facilities, reprocessing and final depositories of nuclear waste. [42]. Research reactors can be included in the above definition, together with any other nuclear installation that is or will become subject to IAEA safeguards.

**process monitoring.** An element of a safeguards approach that monitors material, processes, and equipment (nuclear and non-nuclear) in all types of nuclear facilities, through independent and/or shared safeguards-relevant operator measurements.

**proven design.** A design that incorporates technology with significant and successful operational history, including successful implementation of IAEA Safeguards.

**State-level approach to safeguards.** A customized approach to implementing safeguards for an individual State. A state level approach is detailed in internal publications developed by the Secretariat. It consists of safeguards objectives for a State as well as applicable safeguards measures, to be implemented by the Agency in the field and at Headquarters, to address those objectives. [49].

**technical objectives.** Objectives established for a State, through the conduct of acquisition or diversion path analysis, to guide the planning, conduct and evaluation of safeguards activities. The Agency seeks to attain the technical objectives in order to detect proscribed activities along a plausible acquisition or diversion path. The technical objectives support the Secretariat in addressing the generic objectives. [49]

**unattended monitoring.** A special mode of application of non-destructive assay or C/S measures, or a combination of these, that operates for extended periods without inspector intervention [11].

**user requirement.** Defines what a specific nuclear programme stakeholder (or user), such as a designer, operator’s government or national industry must do to achieve sustainability of the programme. The fulfilment of user requirements is evaluated by an assessor via the evaluation of corresponding criteria [42].

## ABBREVIATIONS

| | |
|---|---|
| ASNC | Advanced Safeguards Neutron Coincidence Counter |
| CoK | Continuity of Knowledge |
| CSA | Comprehensive Safeguards Agreement |
| C/S | Containment and Surveillance |
| CTBT | Comprehensive Test Ban Treaty |
| DA | Destructive Analysis |
| EDP | Especially Designed and Prepared |
| FP | Fission Product |
| FSA | Facility Safeguardability Analysis |
| GIF | Generation IV International Forum |
| HEU | Highly Enriched Uranium |
| HM | Heavy Metal |
| IAEA | International Atomic Energy Agency |
| IDU | Irradiated Direct Use [nuclear material] |
| IIV | Interim Inventory Verification |
| INPRO | Innovative Nuclear Reactors and Fuel Cycles |
| ISSAS | IAEA SSAC Advisory Service |
| KAERI | Korea Atomic Energy Research Institute |
| kgHM | Kilograms of Heavy Metal |
| KIEP | Korean, Innovative, Environment-friendly, and Proliferation Resistant System |
| KMP | Key Measurement Point |
| LEU | Low Enriched Uranium |
| MA | Minor Actinides |
| MBA | Material Balance Area |
| MOX | Mixed Oxide Fuel |
| $MW_e$ | MegaWatt Electric |
| NDA | Non-Destructive Analysis |
| NES | Nuclear Energy System |
| NESA | Nuclear Energy System Assessment |
| NMAC | Nuclear Material Accountancy and Control |
| NPT | Non-Proliferation Treaty |
| NRTA | Near Real-Time Accountancy |
| NWFZ | Nuclear-Weapon-Free Zone |
| NWS | Nuclear Weapon State |
| OSP | Other Strategic Points |
| PIV | Physical Inventory Verification |
| PIT | Physical Inventory Taking |
| PR&PP | Proliferation Resistance & Physical Protection |
| PWR | Pressurized water reactor |
| R&D | Research and Development |
| RE | Rare Earth |
| RSAC | Regional System of Accountancy and Control |
| SBD | Safeguards by Design |
| SFCF | SFR fuel cycle facility |
| SFM | Special Fissionable Material |

| | |
|---|---|
| SFMF | SFR metal Fuel Manufacturing Facility |
| SFR | Sodium Fast Reactor |
| SSAC | State System of Accountancy and Control |
| TBD | To Be Decided |
| tHM | Tons of Heavy Metal |
| TRU | Transuranic |
| UDU | Un-irradiated Direct Use [nuclear material] |
| VOA | Voluntary Offer Agreement |
| WMD | Weapons of Mass Destruction |

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Vienna, Austria: 1–3 February 2012
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