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Nuclear Reactor Technology Assessment for Near Term Deployment

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NUCLEAR REACTOR TECHNOLOGY ASSESSMENT FOR NEAR TERM DEPLOYMENT

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NUCLEAR REACTOR TECHNOLOGY ASSESSMENT FOR NEAR TERM DEPLOYMENT

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FOREWORD

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

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

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

Several IAEA Member States have embarked recently on initiatives to establish or reinvigorate nuclear power programmes. In response, the IAEA has developed several guidance and technical publications to identify with Member States the complex tasks associated with such an undertaking and to recommend the processes that can be used in the performance of this work. A major challenge in this undertaking, especially for newcomer Member States, is the process associated with reactor technology assessment (RTA) for near term deployment. RTA permits the evaluation, selection and deployment of the best technology to meet the objectives of the nuclear power programme. Documenting and defending the basis for this RTA decision making requires and deserves technical approaches that are developed on the basis of best practices.

In the infrastructure development programme to support nuclear power in newcomer Member States, several major tasks interface directly with RTA. The initial stage of the RTA programme requires principal objectives to be defined by the policy development decision makers. The programme then develops and delivers the core technical evaluations for the project feasibility study, the bid invitation, the bid evaluation and contracting, and the reactor deployment phases. The same approach may also be applied for Member States seeking to expand their nuclear energy programme.

This report demonstrates how RTA is performed and how the process and results of this work enable decision making for nuclear power planning and implementation for each of the above tasks. The approach provides decision makers with the documentation necessary to support their conclusions. Further, the preparation for and application of the RTA approach and process creates an additional vehicle for capacity building in Member States through IAEA technology training.

The IAEA officer responsible for this report was M. Harper of the Division of Nuclear Power.

EDITORIAL NOTE

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SUMMARY

The development or expansion of a nuclear programme requires successful execution of several important and interrelated tasks. The IAEA infrastructure milestone process identifies these major elements to provide guidance and technical advice to Member States in their work. Nuclear reactor technology assessment (RTA) is the evaluation and selection process which enables Member States to accomplish these tasks.

This report:

- Establishes RTA as the decision making process for the evaluation of nuclear power plant technologies for selection and deployment;
- Identifies the need to establish clear and prioritized policy objectives for the nuclear power programme as the prerequisite to initiate the RTA;
- Describes the RTA for near term deployment within the context of the adjoining major tasks of nuclear programme implementation, delivering the core technical evaluations for the project feasibility study, the bid invitation, the bid evaluation and contracting, and the reactor deployment phases;
- Focuses the process for performing RTA by gathering and refining expert opinion to identify the most important features and components for the evaluation;
- Augments decision making processes for application in RTA, including the Kepner–Tregoe analysis and the multi-attribute utility theory (MAUT) techniques, and describes in detail how these approaches can be employed to improve current practices in selecting the best technology for application;
- Recommends and demonstrates the application of decision making processes to perform RTA in a manner that integrates with the IAEA technical approach for the evaluation of bids for nuclear power plants;
- Describes the use of quantitative measures and metrics to evaluate the worth of design features (the value function or utility function) so that the assessment team can develop a consistent approach for assigning the benefit derived from each required element;
- Describes the relationship between the feasibility study and RTA;
- Defines the relationship between RTA and the invitation and evaluation of bids for nuclear power plants;
- Presents approaches to enhance the use of RTA results and lessons learned to improve construction, operation and maintenance for the nuclear power plant.

1. INTRODUCTION

1.1. BACKGROUND

Given the increasing interest in the near term deployment of new nuclear power plants both among newcomer countries and in those countries with expanding programmes, IAEA Member States have requested advice in the process of evaluating and selecting available technology options. Reactor technology assessment (RTA) permits the evaluation, selection and deployment of the best technology to meet the objectives of the nuclear power programme. These goals and objectives, which describe the rationale for initiating a nuclear power programme or a particular nuclear project, should be clearly understood and specified at the outset. Key technical elements and features are linked to each policy objective. This ensures that the technical and economic comparison of the candidate nuclear power plant designs and associated technologies will be objectively assessed against the conditions, the constraints and the needs of the country, so that the most suitable design for a particular application can be selected.

The RTA process is the evaluation approach that enables the decision maker to choose the reactor technology or the nuclear power plant type that will fulfil the policy objectives. This process is established with respect to the other major elements of nuclear programme development. There are several applications where Member States will perform and apply the RTA process and, although the detail of the evaluation and the scope of the selection will vary between phases, there should be a common approach and the issues raised at each phase should be carried through to the next phase. These applications are:

- Technology assessment during the feasibility study (National Infrastructure Milestones 1 and 2) [1];
- Technology assessment in preparation of the bid invitation specifications and for the process of evaluation of bids (National Infrastructure Milestone 2);
- Technology assessment as a decision making tool in preparation for contract negotiations (National Infrastructure Milestone 2);
- Technology asessment as an ongoing evaluation tool during nuclear power plant construction and operation (National Infrastructure Milestone 3).

At each subsequent stage of the milestone process, the detail of the RTA would increase, with the initial stage being used to determine what technologies would be feasible, and later stages allowing differentiation between design options.

The development of this report was recommended by the IAEA Technical Working Group on Water Cooled Reactors. In addition, in 2007, 2008 and 2011 the IAEA organized Technology Assessment Workshops to identify and discuss approaches and results developed from the current practice of technology assessment. In feedback from these meetings, the Member States emphasized their desire for the IAEA to capture and formalize through a specific document an RTA process for their use based upon their particular needs.

1.2. OBJECTIVE

The objective of this publication is to provide Member States with advice to support informed decision making when choosing among various available reactor designs in order to determine the nuclear power plant that best will meet the needs of the Member State. This report provides a design-neutral systematic approach to evaluate the technical merits of the various nuclear power plant technologies already available on the market or expected to be commercialized in the near future (indicatively by 2020) based on each user’s objectives and requirements.

The aim is to document and demonstrate the basic elements of the approach and methodology that is recommended for use in performing the RTA. In addition, this report clarifies the variety of definitions and applications of technology assessment in the Agency, as well as in industry applications. It provides both basic and detailed descriptions of the way in which a technology assessment is planned, executed, evaluated, documented and reported.

The objective is to provide a clear, high level view of the process steps and sufficient description to build and conduct an RTA.

1.3. SCOPE

This report focuses on the description and application of RTA for near term deployment, and the processes, criteria, data and evaluations are defined and described accordingly. The approach for the introduction of a nuclear power programme is described in the IAEA document Milestones in the Development of a National Infrastructure for Nuclear Power [1]. RTA combines activities for the feasibility study, the invitation and evaluation of bids and the nuclear power plant deployment programme.

The application processes and examples are prepared to demonstrate key features of the approach. Actual implementation in practice will be more elaborate and complex. The framework of the presentation is designed with this in mind.

The scope of this report includes description of the RTA approach, which could be carried out to integrate technical and economic considerations with Member State objectives, to support discussions and decisions on selecting reactor technology options appropriate for a Member State specific nuclear power programme.

The scope of this report does not involve presentation of a ranking of available reactor technology options on the basis of perceived technical pros and cons and projected costs.

1.4. USERS

The primary users of this report are utilities/operator organizations, governing organizations, or others who are or will be responsible for the process of selecting a nuclear power plant technology. Technical experts of Member States, regulators, and others actively involved in planning and developing a nuclear power plant project, and technical experts involved in advising government or utility officials should also understand this report with regard to impacts on planning and infrastructure development.

The decision makers for reactor technology selection and implementation are the ultimate users of the output from the work described in this report. Accordingly, it is expected that reactor suppliers, architect engineers and constructors, and equipment manufacturers will also benefit from an understanding of how their reactor designs and technical proposals will be evaluated, judged and selected. IAEA Member States need to obtain reliable information that can be used to make these relevant comparisons between different nuclear power plant designs. The best source of data should be that provided by the technology holder.[1] The IAEA expects that technology holders may follow the approach given and develop a standard technical description of their product with an emphasis on addressing the key topics and questions that are identified in this report. These data, when provided for use by multiple countries, would support the performance of RTAs in IAEA Member States.

1.5. STRUCTURE

This report is structured in order to provide Member States with the appropriate framework for performing RTAs in the context of evaluation, development and deployment of a specific technology within a nuclear power programme. This report briefly describes applications of RTAs at a variety of stages throughout this process, including the policy formulation and feasibility study, the development of bid invitation specifications, the evaluation of bids and deployment. Wherever practical, these descriptions are only summarized here and incorporated by reference to avoid duplication of material that has been presented in other IAEA publications.

Section 2 presents the objectives and scope of the processes in general terms to provide a clear view of the critical elements necessary to conduct an RTA. The applications affected directly by this work are identified. The key organizational and human resources to perform the assessment process and to document the results are discussed. This section also presents an integrated technology assessment analysis approach for each of the major applications, identifying the challenges and opportunities which will be presented to the assessment team. For example, for the bid specification, the technology assessment process specifies the key information that should be provided by each technology holder to ensure that the input to the assessment and the corresponding results

[1] In this report, the technology holder refers to the company/consortium/organization responsible for the design, manufacture, construction and commissioning of the nuclear power plant.

are consistent and accurate. Sample questions are developed to facilitate this process. This section also describes the further applications of the results of the RTA in subsequent infrastructure and operational activities, including construction, operation and maintenance.

Section 3 describes the purpose of, and approaches to, the development of policy inputs to the RTA. Approaches to derive and assign importance to the elements of the policy for the purpose of initiating the assessment are suggested.

Section 4 demonstrates how the key technology features of the RTA process are derived. This section identifies key elements for decision making which should be included in the RTA. For each element, key topics are listed and example questions are provided with the aim of obtaining consistent responses from the technology holders so that the key elements can be assessed in a balanced way.

Section 4 also identifies several topical elements regarding project or programme uncertainty or risk assessment that may affect the decision making process. These may include, for example, a Member State's policy, direction or regulatory practice that could emerge as the deciding factor. These factors should be incorporated into the decision making process in an appropriate fashion. Annex II provides additional features that should be considered in the application of the process.

Section 5 presents the development and application of the integrated RTA approaches that are recommended in this report. The basic concept of rational decision making is introduced and then a series of approaches that can be used to perform applications in a qualitative or quantitative manner are described. These applications are designed to be matched to the particular tasks that the Member State and/or owner are performing. An example application of RTA using these approaches is provided in the Appendix.

The three annexes capture valuable RTA features derived in the development of this work.

1.6. USING THIS PUBLICATION

RTA is a decision making process that contributes to several evaluations in the integrated nuclear infrastructure programme. It follows and is dependent upon the nuclear programme policy formulation. It is one focus of the feasibility study process, identifying the type of technology that should be used to determine the feasibility of the nuclear programme or project. If a Member State then determines that the nuclear power programme is feasible, or if a nuclear programme already exists in the Member State, RTA provides the input to, and the technology related evaluation process for, the bid specification and the evaluation of bids.

The report develops and demonstrates a comprehensive description of the RTA approach and requisite inputs and outputs. The RTA is performed and managed as an integrated process to provide benefits in several types of applications. These applications extend from the initial definition of programme objectives to power plant operation. Several support services and capabilities within the IAEA are related to RTA. This report identifies these programmes and their linkages. Member States are encouraged to utilize the complement of IAEA resources best suited to assist in each stage of their nuclear power programme development, reactor technology identification and assessment, technology selection and deployment.

2. REACTOR TECHNOLOGY ASSESSMENT TO SUPPORT NUCLEAR POWER PROGRAMME DEVELOPMENT

This section describes the objectives, process and practical arrangements of the RTA. Key expectations that must be understood to commence, and achieved to deliver, a successful RTA are identified. The relationships between the RTA and other activities in a nuclear power plant programme or project development, including purpose, process and timing, are discussed. Finally, types of organizational approaches, human resource allocations, and deliverable content and quality are presented.

2.1. REACTOR TECHNOLOGY ASSESSMENT PURPOSE AND PROCESS

RTA for near term deployment is designed to determine the most appropriate nuclear power plant technology option available to fulfil energy delivery requirements and the policy objectives of a Member State. For a newcomer country working in the early stages of the infrastructure development programme, preparation for RTA may assist in refining the infrastructure building process or identifying capacity building requirements. The process must be linked directly with the programme policy formulation and early evaluations, in which the Member State determines whether the nuclear power option is the most viable for a particular energy deployment project. Once these policy objectives are determined and validated, the RTA process structure and evaluation approach can be established. This should be completed before the end of Phase 1 in the infrastructure development programme. For an expanding nuclear programme, these policy objectives are expected at the initiation of the reactor technology programme expansion or the facility addition/expansion project.

At this stage the RTA may become linked with a feasibility study for a specific project. In the next major phase the work will expand to develop the technical input and evaluations required for both the invitation to bid and the evaluation of bids. In these stages the assessment will aid in the development of technical requirements for the bid evaluation, identify specific technical questions for obtaining consistent information from the selected technology holders and serve as the technical core for the evaluation of bids tendered. The products delivered by these technical evaluations will document the decision making rationale for the choice of technology and serve the operating organization through construction, operation and maintenance of the facility.

This section introduces the major steps of the RTA process. The coarse level of detail shown here may be used to frame assessments to be used within early applications such as the policy formulation and the feasibility study. In Sections 3–5, this approach is expanded and refined to meet the overall multiple objectives required for reactor technology selection for near term deployment. Table 1 delineates and Fig. 1 displays the general steps in this process.

As introduced in Table 1 and shown in Fig. 1, the general methodology to be employed for the RTA follows the practice of a basic decision making evaluation of available technical options that have the potential to satisfy the needs of a particular power production application. In addition to these technical features to be considered, other characteristics and influences present in any technology considered need to be incorporated in the process. These features are captured by the category of uncertainty and risk assessment factors as shown in Table 1. These are discussed in detail in Sections 3.3 and 5.4.

2.2. KEY EXPECTATIONS FOR SUCCESSFUL RTA

This section establishes key expectations that must be understood in the design, performance and use of the RTA. These reflect common experience of practitioners in the application of technical decision making for these types of major, capital intensive projects.

2.2.1. Setting the policy goals for reactor technology assessment

To initiate the RTA, it is first necessary to define, understand and quantify the policy objectives of the nuclear energy programme or project under consideration. Without a comprehensive understanding of what is desired, it is not possible to establish the model and metrics to enable the assessment and selection process to be successful. These may be national policy goals for a Member State’s programme or project or corporate goals for an owner/operator project.

The national policy or project goals are expected to be the key output of the first phase of the infrastructure programme for newcomer Member States. For nuclear power expansion projects, the policy goals and issues may be either revived or amended from previous projects. In either case, for the RTA to be most successful, these high level goals should be as specific as possible so that the technology features that affect them can be readily identified. Secondly, the policy makers should rank-order and weight the importance of each of the policy goals. This is the information that the assessment team requires to structure and perform the most effective assessment.

TABLE 1. RTA AND SELECTION PROCESS

Item	Basic steps
1	Establish a competent assessment team/group — Organization and human resources
2	Develop general criteria and requirements based on relevant policy goals and objectives, such as: — National energy plan — National infrastructure: the grid, site and environmental characteristics — Local conditions: industry, economy, workforce and demography — Regulatory and safety requirements; emergency planning — Plant costs and financing options — Cost of plant operation and electricity generation — Security, physical protection and safeguard requirements — Performance requirements
3	Ensure that the relative importance of each of the selected policy goals and objectives has been established
4	Identify nuclear power plant designs and technologies that are commercially available and have the potential to meet the general criteria[a]
5	Identify and evaluate key nuclear power plant technical features and requirements
6	Develop specific input and questions for technology holders to obtain consistent information required to perform the assessment
7	Determine factors and importance weighting associated with the assessment elements
8	Evaluate influences or quantify uncertainty and risk assessment factors
9	Perform assessment and derive rankings using decision making process approaches
10	Integrate and validate the results and recommendations of the combined assessments

Note: If at any point in the process the initially selected criteria clearly cannot be met, the process should reset to the appropriate step which allows the criteria to be reviewed and modified.

[a] The designs identified for consideration should be those adequately defined and available within the foreseen timeline. For the process to succeed, this list should not be altered during the RTA process.

The national policy or project goals are expected to vary from country to country and may also vary project by project. It is the work of the policy team to provide clear, unambiguous direction explicit expectations regarding these goals. Also, the policy team approves criteria and assigns weighting factors to their relative importance. This direction is to be provided up front, and should not be amended in the subsequent course of the RTA work. These goals provide the structure that allows the assessment team to initiate and conduct its technology assessment work. The technology features that are determined to affect these goals will also vary on these same bases, and the importance values that are established for these technology features will also vary by programme and project.

2.2.2. Reactor technology assessment: Implementing policy in decision making throughout the infrastructure programme

Establishment of the national policy or project goals and initiation of the RTA can contribute to and affect all features of the decision making and implementation programme on a continuous basis. During the different phases

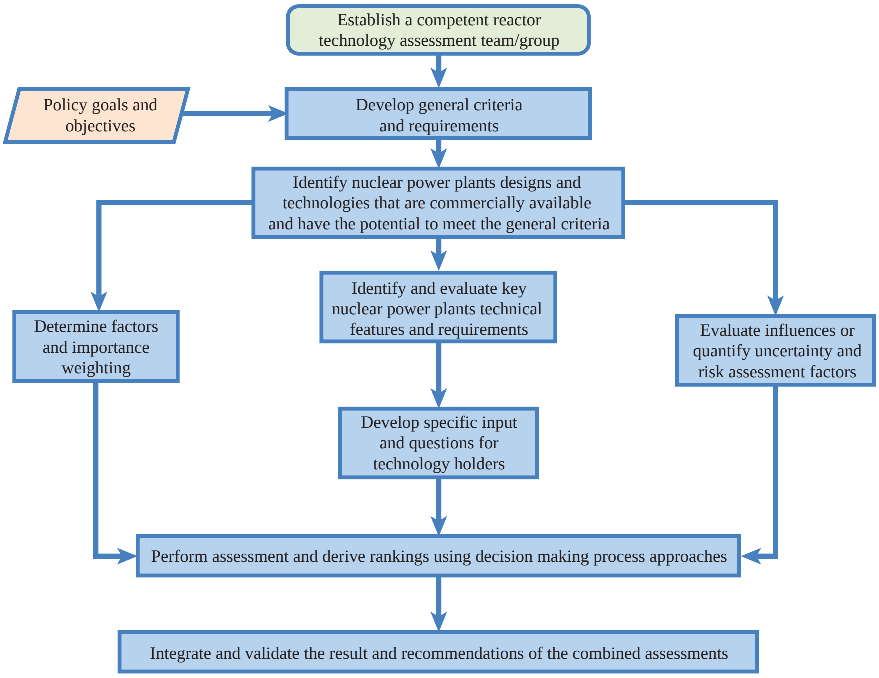

FIG. 1. RTA process.

of decision making, the assessment team is gathering, evaluating and refining the information and evaluation through an iterative process with the technology holders and the stakeholders. Once the technology is selected, the assessment becomes a valuable resource which has documented the adequacies and shortfalls of the selected technology against the policy goals and the evaluation features and criteria. Expectations or commitments made by the technology holder in the evaluation and contracting process can also be incorporated into the final evaluation and documentation for use in the reactor deployment process.

2.2.3. Understanding and balancing conflicting demands and criteria

It is important that the assessment team, as well as the decision makers and policy makers, understand that the results of a technology assessment will never be a ‘perfect answer’. Especially in the case of a complex technology evaluation, it is clear that the solution cannot fully satisfy all objectives. The recommendation for selection is based upon the best fit to these objectives, not upon a perfect fit.

This recognition should enable the assessment team, the decision makers and the policy makers to understand that the technology assessment exercise is generally not conducted at a high level of numerical accuracy. The importance that individual factors have on the final decision generally becomes evident in the course of the technical evaluation. As necessary, sensitivity studies are conducted to determine the effect of variability in modelling or input data on the overall assessment results.

2.2.4. Using the reactor technology assessment process productively

The assessment team uses the process to gather credible and consistent information from the technology holders, using the importance weighting structure of the policy objectives, and the technology feature identification and associated importance weightings to focus that effort.

The assessment team understands the technology and the technology assessment process components and structure sufficiently well to ask the right questions of the technology holders to derive the necessary comparative data.

The assessment team gathers or develops methods to evaluate the technology holders’ critical data and responses to key questions, such that the technology holder responses can be ensured to be fully applicable to the reactor technology application under evaluation.

2.3. THE ROLE OF REACTOR TECHNOLOGY ASSESSMENT IN THE INTEGRATED NUCLEAR INFRASTRUCTURE PROGRAMME

This section presents how RTA fits to the features of the integrated nuclear infrastructure phases and milestones, and defines the interrelationships and roles that RTA fulfils with each of the primary tasks in the overall programme. Figure 2 displays major roles of RTA and selection in Phases 1 and 2 of the programme, thereby stretching across and connecting with the major tasks of the feasibility study and the full bidding process.

The activity labelled "Reactor Technology Assessment" shown at the bottom of the figure is initiated during Phase 1, prior to and then as a part of the feasibility study. Prior to the feasibility study, Member States are expected to include in their programme the necessary capacity building to ensure understanding of the available reactor technology choices, as well as the RTA process. The major work in RTA then continues from the end of Phase 1, where the policy objectives for the programme are defined, up to the selection of the reactor technology for the given application. Additionally, as demonstrated by the broad-line block and described further in this section, the contributions that RTA can provide to the owner/operator continue into the activities required to construct and successfully operate the chosen facility. Ideally, the lessons learned in this process should be carried forward to additional programmatic decision making in future operation and expansion of the Member State's nuclear programme.

As described in the following sections, the RTA is a contributor to the feasibility study and its results; key information developed in the feasibility study is then used to transition into RTA to perform and support the decision making process prior to and into the invitation and evaluation of bids. As will be seen in the development descriptions for this methodology, the diagram of the overall process visually demonstrates that the level of detail and level of effort of the RTA varies as a function of the programme phase, as well as the process that is being performed. As shown in Fig. 2, the RTA may be conducted as a part of the preparation for the feasibility study in Phase 1. Once the feasibility study is completed, the RTA moves to the detailed technology evaluations performed in Phase 2, where the candidate technology and reactor types are determined for the selection process for bid evaluation, then in the preparation for the bid specification and finally in the bid evaluation. Descriptions follow for each of these applications.

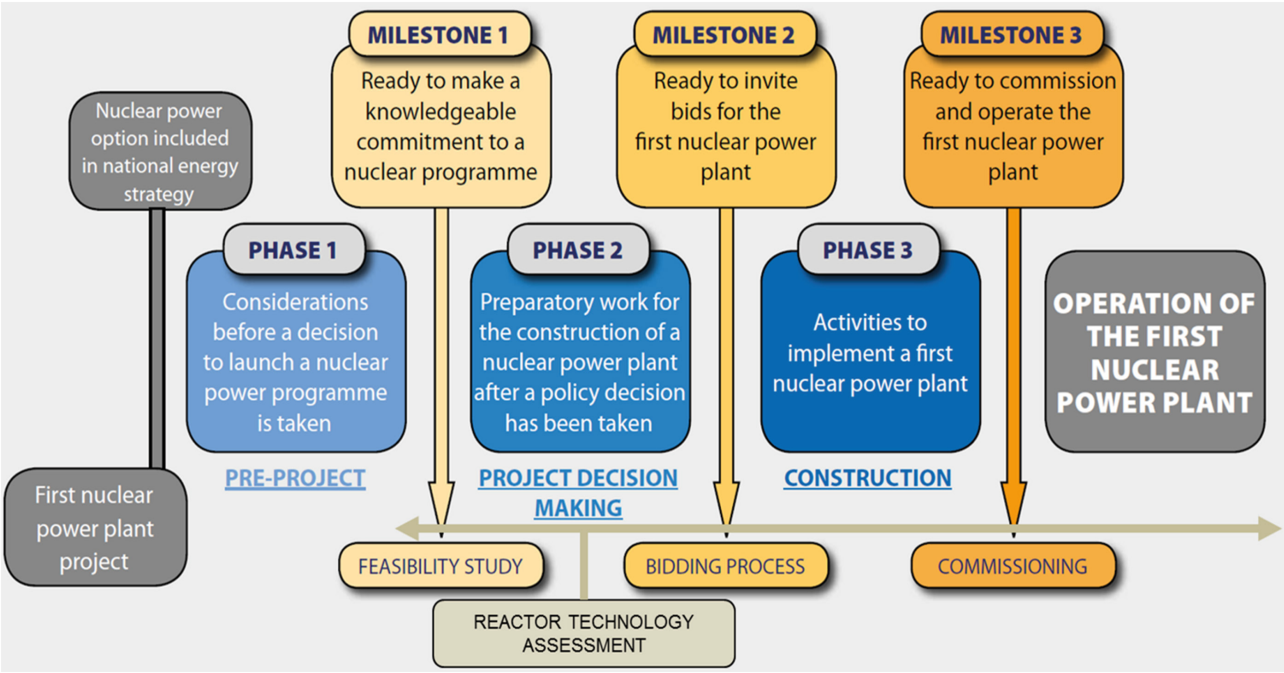

FIG. 2. RTA for near term deployment within the nuclear infrastructure development programme [1].

2.3.1. Policy setting and programme feasibility studies

The outcome of Phase 1 for a newcomer Member State is the conclusion as to whether a nuclear energy programme will be of benefit and should be achievable, as well as the assumptions under which this conclusion was reached (e.g. costs less than $*x*/kW(e), construction schedule less than *y* months). In most cases this decision will have been reached in part using some generic evaluations related to RTA. No specific reactor type or technology holder would be chosen. Rather the work would have supported the determination of whether the technology of nuclear power is an appropriate technical and economic option to achieve a given set of policy objectives and priorities, such as power production (e.g. electricity production, non-electric applications or both), national economic and technical development, or energy independence. RTA is a part of the feasibility study, because it is necessary to describe and categorize the available and suitable technologies sufficiently to make the decision to proceed with a specific nuclear power application.

For a newcomer Member State, the evaluation through Phase 1 will target the full evaluation and results needed to determine if a nuclear power programme should be pursued as a part of the Member State's energy portfolio. For a Member State considering augmenting its existing nuclear power programme, it will target the decision of whether expansion of its nuclear power programme is the proper choice.

A feasibility study typically incorporates several general evaluations, which will include the performance of a preliminary RTA regarding the choice of technology. This is a high level assessment, which can be performed using the principles of data gathering and decision making as developed in this report. The assessment will identify as a minimum the class of reactors suitable to meet the national policy or corporate goals and objectives of the Member State programme or the project and will provide sufficient information to perform the economic, technical, environmental and societal evaluations in the feasibility study.

2.3.1.1. Feasibility study application

The feasibility study (FS) is performed to implement Phase 1 of the nuclear power programme to determine whether the technology of nuclear power is an appropriate technical and economic option for a specific application. The RTA role is to first describe and then categorize the available and suitable technologies sufficiently to support the decision to proceed. The FS thereby documents the choice for the nuclear power plant technology or range of technologies that are to be utilized for the given project as a part of the nuclear power programme. This will ensure sufficient definition and description of the reactor technology to promote meaningful evaluations required to achieve appropriate conclusions and recommendations resulting from the FS. The degree to which the details of the selected nuclear power plant technology may be developed at this stage in the nuclear power programme will depend upon the focus and specificity of the policy objectives that have been prescribed for the programme, as well as the goals and expectations that have been developed for the specific nuclear power plant project.

For the FS or the initiation of the RTA, the review of the nuclear power reactor technology should be put together in the form of a market survey. The basics of this survey can be obtained from documentation and evaluations available through the IAEA and augmented by information obtained directly from technology holders. In the FS, the RTA will examine the nuclear power plant technology in combination with the associated components of the fuel cycle for the given design. The results from the FS that will be brought forward to the next stage of the RTA will include additional detail on achievable metrics and ranges for the utility functions that will describe both the nuclear power plant and fuel cycle technologies.

The FS market survey examines the spectrum of those reactor types that may be capable of attaining the policy objectives that have been established for the nuclear power programme. A matrix of these objectives should assist in identifying the types of reactor systems that could be acceptable in terms of design, availability, constructability and record of performance. A further survey and evaluation would be expected to focus on the additional purposes and goals developed for the specific nuclear power plant project that is being evaluated in this FS.

The IAEA Advanced Reactors Information System database for reactor technology options is available for building the appropriate sets of reactor types and parameter listing for the first-cut evaluations [2]. Numerous additional references are available to first examine the possibilities and refine the possible technology approaches to the first levels of consideration, based on the programme objectives and nuclear power plant project goals [3, 4]. Therefore, it is appropriate to identify those objectives and goals in this section, or to summarize them from earlier sections of the FS report. Once this is completed, subsets of the nuclear power reactor technology appropriate for the national programme are expected to be evident.

2.3.1.2. Nuclear power plant technology assessment process approach

For the FS, the RTA process to review available technologies against the programme policy objectives and project goals will be a screening evaluation. This can be performed by developing a subset of the elements in the approach developed in Section 5.1. The appropriate subset will match the policy objectives as the key elements and features relate to them at the time the work is performed.

The evaluation process performed in the FS is expected to define those conditions or constraints that cause the nuclear power plant to be financially and technically attractive compared with alternative approaches (e.g. gas, coal, hydro and renewables). These conditions are then applied in the detailed nuclear power plant RTA process to further prepare the nuclear power plant project team for a bid invitation and evaluation [5].

The specific focus areas for use in the performance of the feasibility study are identified for the purposes of the screening evaluation. For example:

(1) Programme or project specific requirements:
  - (a) Country specific needs, conditions;
  - (b) Size and stability of the national electric grid;
  - (c) Seismicity of the selected site;
  - (d) Availability of water resources for ultimate cooling;
  - (e) Accessibility to waterways for the transportation of large components or modules;
  - (f) Performance considerations including power level, operability, manoeuvrability, inspectability, maintainability, availability factor and reliability;
  - (g) Fuel procurement for long term supply;
  - (h) Nuclear safety elements, such as safety margins, defence in depth, passive versus active safety systems, and probabilistic and deterministic safety evaluation comparisons.

(2) Considerations with respect to the assumption of programme or project risks:
  - (a) Desired level of technology maturity or innovation;
  - (b) Technology maturity risk the country is willing to assume;
  - (c) Level of completion of a design and its licensability;
  - (d) Use of advanced construction techniques and cost–benefit analysis;
  - (e) Extent of use of reactor designs.

(3) Technology holder or other programme or project relationship considerations:
  - (a) Technology transfer arrangements;
  - (b) Regional partnerships;
  - (c) Fuel supply and/or procurement options;
  - (d) Technology holder fuel supply arrangements/opportunities, including fabrication and enrichment services;
  - (e) Spent fuel management options, including spent fuel take-back.

2.3.1.3. Fuel cycle technology evaluation and impact assessment

For each reactor technology or specific nuclear power plant design under consideration for the FS, the corresponding fuel cycle implications should be identified for evaluation:

(1) The key features that have the potential to differentiate between reactor technologies or reactor types should be identified and elaborated, such as:
  - — Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience;
  - — Fuel performance experience — extent and quality of experience;
  - — Impact of fuel cycle on the plant operation — including refuelling operations;
  - — Long term assurance of fuel supply and availability of component and replacement parts.

(2) The nuclear power plant technology assessment approach should be applied to assess the extent to which these features have the potential to differentiate between reactor technologies or reactor types.
(3) The results of the fuel cycle technology evaluation should be examined together with the general FS technology assessment results to develop the final nuclear power plant technology recommendations.

2.3.2. Programme and project decision making through bid evaluation

In parallel to supporting input for the feasibility study, the RTA in Phase 2 provides the more detailed decision making process for the programme or project and determines the reactor type(s) and technology holders to be specified for the bid invitation[2]. This, in turn, supports the preparation of the bid specification documentation and process.

The purpose of RTA in the invitation and evaluation of bids [5] is: (1) to obtain high quality and fully responsive bids from qualified technology holders for the application required; and (2) to evaluate those design options presented in competitive bids against one another to contribute to the final decision of the technology to be constructed. A high level description of the features of the RTA process is included in Ref. [5], which assimilates recent bid evaluation experience in Member States. The specific details of how the process can be performed are provided in Sections 3–5 of the present publication, where the objective is to ensure through examples an understanding of how the general descriptions of key RTA features and methodology may be applied.

2.3.3. Reactor technology assessment in facility deployment

Once completed for the purposes of selection, the RTA products and results may be applied for the benefit of plant construction, using, for example, the documentation established with the technology holder regarding technology selection requirements or desired features during the bid specification and evaluation process. The documentation packages will detail the characteristics of the design and the rationale that influences the decision making process. These tools may be used to ensure that the selected technology holder is held accountable to the committed plant features, including commitments pertaining to construction, procurement, construction practices and other construction related deliverables.

Adhering to and documenting a formal RTA process should ensure the owner/operator’s comprehensive understanding of the bases for the decisions made in technology selection. These results will, by definition, identify certain trade-offs that were required to be made in selecting the chosen technology. In the detailed contract negotiations and final specification of the selected plant, the results of the RTA may be used to specify design improvements, for example, additional design features required for licensing or modifications necessary to better match site specific conditions, normally in the balance of plant (BOP) such as ultimate heat sink (UHS).

2.4. ORGANIZATIONAL APPROACHES AND HUMAN RESOURCE EXPECTATIONS

In the ideal process, the organizational and human resource requirements would always be matched to the stage in the nuclear power programme infrastructure development of the Member State. As described in Section 2.1, it is understood that the process of RTA is one which develops hand-in-hand within the phases of the nuclear power programme. Therefore, both the organizational structure to support the technology assessment process and the size and qualifications of the assessment team will be determined with the organizational development in the infrastructure capacity building programmes.

Ownership and membership within the RTA process are critical success factors. It is imperative that the owner organization take full responsibility for the conduct and results of each phase of the work. Reporting within the organization should be established such that the technical and managerial assessment team is assembled and directed to perform the mission by top management. Accordingly, the assessment team’s results and recommendations will be reported directly to the top-level decision maker(s) in the owner organization. The use of consultants is recommended to augment or supplement the assessment team with specific expertise. Consultants

[2] In some cases an open bid process (rather than an invitation to specified technology holders) may be used, in which case the RTA would be used to screen the bids.

should report their input to the assessment team management, so that it becomes a part of the team’s analysis and results. Generally, consultant reports should not be used as the sole basis for major decisions by the assessment team.

2.4.1. Organizational approaches

The previous sections demonstrate that the RTA process will apply to a variety of applications throughout the phases of infrastructure development or the reactor development project. The performance of these several tasks and linked opportunities may be optimized by assembling and maintaining the assessment team with a strategic plan. In general planning terms it is desirable and strongly recommended that a core assessment team be formally established for the purposes of performing the RTA tasks associated with the feasibility study. Assuming that the final results of the study support the initiation of a nuclear power programme, this assessment team will carry the RTA programme forward into the subsequent steps of preparing the technical elements of the invitation to bid, performing the first stage of the bid review and formulation of requests for additional information (RFI) from the bidders, and evaluation of the bids, through to the selection of the technology and successful suppliers.

In the case where a Member State is investing in major nuclear infrastructure development and deployment, it will be likely that additional near term RTA projects will require new assessment teams. Prudent organizational development practices would then recommend that certain key players on the first successful team form the core of the new team. New members of the team will benefit from their experience in completing the technical and programmatic tasks required to determine the best technology.

Member States should not underestimate the value of the RTA programme and its elements in capacity building for human resource development. This programme will expose engineers and project managers to all technical aspects of the nuclear power development programme for the operator, including financial, political, environmental and public policy elements. There are several core programmes within the integrated infrastructure programme that combine to create these opportunities. Because the RTA process is central to key programmes required in Phase 2, these individuals must work closely with all constituencies in the process, especially with technology holders and contractors, to develop a full understanding and finalize the recommendation of the best outcome. This prepares members of the team with fundamental, hands-on design, engineering and implementation work experience that will be invaluable in the construction, operation and maintenance of the facilities.

2.4.2. Human resources expectations

The team size and characteristics, in terms of the types of disciplines that should be represented by organization or consultant participants, will also vary as a function of the phase of the RTA. In addition, the results of the RTA work in the nuclear energy programme implementing organization (NEPIO) policy studies or in the early phases of the FS programme will determine the nature of the detailed technical evaluations necessary over the course of the RTA. Decision making may be strongly affected by the uncertainty and risk assessment factors that are described in Section 3.3. The influence of these factors will determine what general type of RTA programme will be best suited for the organization to meet its development objectives. In turn, this may also affect the decisions on the scope and staffing required for the performance of this RTA in Phase 2, specifically the development of technical elements of the invitation to bid, and involvement in the bid evaluation.

The RTA is first performed as a part of the FS, and the recommendations of the FS support the Phase 2 steps of invitation and evaluation of bids. A range of personnel and disciplines, as well as organization personnel and consultant breakdowns, is required to represent various levels of infrastructure development. In general the assessment team will possess full expertise in design, engineering, construction and operation of the facility and its environs.

The baseline description shows that a newcomer Member State may require higher levels of external resources (advisory or contributing consultancy) in the early stages of the technical assessment for the feasibility study. As described previously, this approach should also be an important component of capacity building for the newcomer Member State. A Member State with an existing nuclear power programme, which is preparing the feasibility study for expansion, should use consultants only for specialized tasks that the organization has not performed routinely. Given the organizational rationale discussed in Section 2.3.1, it is desirable to use in-house personnel for the primary RTA tasks in the feasibility study.

2.5. PERFORMANCE QUALITY AND DOCUMENTATION INTENTIONS

This section describes the quality expectations of the RTA process and the documentation that is recommended in the performance of this work. It is important that quality and documentation expectations be established early in the process of RTA and that they be designed to be applied consistently throughout. The benefit of proper documentation associated with RTA development and determination relates to the role that such assessment will play in highlighting the key issues that must be examined for the chosen technology design, construction and commissioning. As described in Sections 2.1 and 2.2, this process may be active over a long period within the integrated infrastructure development. Therefore, as soon as the Member State begins the capacity building and feasibility study, it is recommended that the proceedings and findings be documented and a quality assurance programme support be adopted.

Since the assumptions and analyses in the RTA for the feasibility study will support key decisions by the organization, it is important that such information be appropriately documented and that the analyses, assumptions and input to decision making be subjected to document preparation, review and approval practices, as specified by the quality assurance programme. In this process it will be important for the organization originating the documents to clearly state the purposes for which each document is to be applied. Methods for augmentation and revision of these documents should be defined to ensure that the programme follows formal document change processes.

As with other elements of the RTA work scope, there are dual purposes here. Firstly, the documents associated with these decisions are important corporate records and should be assembled in a formal way. Secondly, the use of a formal documentation and quality programme can be a strong component of capacity building within the organization, especially for a newcomer Member State. Again, as stated earlier, the results of the RTA process at one stage will build upon the previous work and will support ongoing and future decision making. If the work upon which these decisions are based is not itself based on a quality programme, but upon faulty data, assumptions or analyses, then future decision making will become unsupportable. The undertaking to build quality documentation produced using a quality programme should be established early. It is difficult and expensive to backfit quality.

3. SETTING THE STAGE FOR SUCCESSFUL REACTOR TECHNOLOGY ASSESSMENT: IDENTIFYING THE NUCLEAR PROGRAMME POLICY GOALS AND OBJECTIVES

The RTA process is initiated with the following major elements:

— Development of clear and prioritized policy objectives for the nuclear energy system (NES) and/or nuclear power plant project and establishment of the policy objectives based upon:
  - National energy plan;
  - Relevant national strategies;
  - Economic and financial goals and constraints;
  - National infrastructure — current status and future expectation;
  - Local demographics and infrastructure;
  - Regulatory and safety design requirements;
  - Security, physical protection and safeguards requirements;
  - Site and environs conditions.

— Survey and selection of nuclear power plant designs and associated NES technologies that are commercially available and may potentially meet the policy objectives[3].

[3] National policy on safety design requirements should be clearly defined, and plants which would not meet these requirements should not be considered.

— Sharpening of the general requirements with additional details and finalizing the policy objective for turnover to the assessment team.
— Assessment of the selected nuclear power plant designs against the combined requirements and appropriate subsets of technology elements and features.

RTA begins with the definition of the NES [6] developed by the IAEA INPRO programme and includes the nuclear power plant, as well as the fuel cycle and other technical systems that are required to support it. This section describes the resources needed and the processes used to formulate and to select the criteria to be used in the RTA process. There are numerous resources that may be applied, and each may contain a vast amount of technical considerations, specifying hundreds of technical criteria. Therefore a key challenge for Member States is to develop a manageable and meaningful set of criteria for their applications. The approach derived for the RTA is developed in this section.

3.1. IDENTIFICATION OF POLICY OBJECTIVES AND BASES

To develop user criteria and their bases for the purposes of RTA, it is necessary to establish overall project objectives. The goal of this assessment process is to differentiate one reactor technology and/or design from another, in order to determine the technology or design that best achieves the goals of the owner/operator. Following five decades of reactor design and operational experience, in the past two decades several organizations have developed user requirement documents that specify in detail how key and specific technical objectives need be met for a licensable, successful nuclear power plant design [7–10]. These documents provide clear considerations to the designer to achieve user requirements. However, this generally creates a matrix of detailed design information and data too unwieldy to use in differentiating between technologies or designs.

As a result, the user criteria and bases for RTA must be derived by the programme or project developer, potentially with user requirement documents as considerations [7–10]. The first stage in technology assessment is the identification of national or corporate policy objectives that describe in a specific manner what the nuclear power programme or project intends to achieve. One approach a newcomer Member State may use to assemble the policy objectives for its programme would be to review the outcome of the national policy document where the following questions have been answered: Under what conditions does this programme or project make sense? Why have we chosen to take this course of action for this endeavour? What are those specific outcomes that will create the expected success?

These policy objectives must be developed to the point where they are documented clearly in writing for the benefit of the stakeholders and for use by the assessment team. In addition to ensuring that these policy objectives are identified with clear descriptions, for the decision making process to begin, the policy maker must prioritize these policy objectives by assigning a relative importance weighting to each one. The ranges of conditions that lead to (or allow) project success should facilitate these weightings.

Once these policy objectives and their respective importance are defined for the project, the assessment team should be prepared to identify those technology features which can best be used to demonstrate how each of these policy objectives will be evaluated or measured. Depending on the working relationship between the assessment team and the policy maker(s), this process may be iterative. However, at some defined milestone the policy maker(s) should fix the set of prioritized policy objectives and allow the assessment team to perform the detailed process to derive the results and recommendations from the RTA. This involves creating the subsets of key elements and features that affect the policy objectives and evaluating their respective importance and performance for the candidate reactor designs.

3.2. SOURCE DOCUMENTS FOR SETTING POLICY OBJECTIVES FOR THE PROGRAMME OR PROJECT

The organization setting the policy objectives should be familiar with resource documents such as the IAEA common user considerations (CUCs) [7]. The assessment team should also be familiar with the details set forth in several other sets of guidance documents that explain user requirements and criteria. These other documents [8–10] detail several different approaches, which can be evaluated and incorporated as desired into the objectives and technical components for the Member State's RTA process.

Reference [7], Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy Systems, was produced by the IAEA in 2009. The work identifies the needs as expressed by newcomer Member States in terms of development and deployment of new nuclear energy systems. These needs were derived on the basis of the input of a large number of experts, acting as 'technology users' and representing 35 developing countries. The report also incorporates the recommendations of experts from 'technology holder' countries, as well as lessons learned from a number of international and IAEA activities, including user requirements programmes in technology holder countries.

The CUC publication covers the general technical and economic characteristics of nuclear power plants and fuel cycle options (including waste management facilities), as well as associated support services requested by potential users of future nuclear energy systems in developing countries.

The three publications described below are controlled by the originating organization and may not be readily accessible to Member States. They are described in summary form by way of comparison with the CUC publication to provide a perspective on the approaches these sets of publications have taken in establishing policy objectives and the technical elements and features useful for assessment.

The European Utility Requirements (EUR) document [8] was developed by several European utilities beginning in 1995 with the goal of establishing a common consensus related to the design expectations and requirements for future LWR nuclear power plants in Europe. The resulting base document of four volumes covers major policies and objectives, as well as the generic and specific nuclear and conventional system designs. Several additional volumes cover a variety of design and technology types. The document is also applicable to nuclear power plant installations in other markets.

The EPRI Advanced Light Water Reactor Utility Requirements Document (ALWR URD) [9] and the EPRI Utilities Requirement Document for Small Modular Reactors [10] present clear and comprehensive utility requirements for advanced LWR nuclear power plants in the USA. The ALWR URD was developed with the management and coordination of the Electric Power Research Institute (EPRI) and under the leadership of EPRI member utilities. The focus of the development and application of the document was on both reactor and facility design and licensing, such that the URD has been referenced heavily in the US Nuclear Regulatory Commission licensing proceedings for these reactor types. The Utility Requirements Document for Small Modular Reactors [10] is the latest initiative currently in development by EPRI in response to the recent technology development expansion in this field. Although this report is in the first stages of development, the intent is to establish a format, content and approach that will parallel the previous work that was built to support the development and licensing of the ALWR designs.

In addition to the above, detailed technical information on design elements and features for designs under review by the US Nuclear Regulatory Commission is available in the design control documents (DCDs) submitted by technology holders for design certification review and licensing [11].

3.3. FORMULATION OF POLICY OBJECTIVES AND TECHNOLOGY ELEMENTS FOR TECHNOLOGY ASSESSMENT

Policy objectives as well as technology elements and features are drawn from a compilation prepared from IAEA infrastructure, CUC, and bid specification and evaluation documents. In the course of preparing this report and from previous IAEA work, as well as through other industry programmes, these have received substantial attention. Therefore, this report provides the reference material and links to the IAEA publications in which these elements have been identified and described. As described in the previous subsection for policy objectives, the approach in RTA is to classify those technology elements and features that support each policy objective. Then these key elements and features are characterized using two critical factors for evaluation and analysis: (1) the importance (weight) that each technology feature or topical element holds for the decision maker for the reactor technology application under evaluation and (2) the comparative value (score) the assessment team determines and assigns to each feature or element .

The general criteria identification process will identify listings of criteria that may be classified into either policy objectives or those elements or features that support them. The hierarchy for these is not known until the policy objectives are established. One approach is for the Member State to establish its full listing of the general criteria that is designed to encompass all those criteria from which each policy objective will be selected.

The listings of general criteria by category are separated into two subsets, although there is some overlap between them. The first subset includes those criteria that are identified as candidate policy objectives that can be readily treated in a direct and open manner in the assessment process. Sets of these criteria for direct application are described in Section 3.3.1.

The second subset includes criteria that are considerations for risk and uncertainty in the programme or project. These are described in Section 3.3.2. Some of these criteria descriptions may also overlap. In most cases this is because in defining the assessment process, experts have found these criteria to be important and have included them whenever either subset is developed. What is important here is that these considerations of risk and uncertainty are included in the process of criteria selection for determining policy objectives and their elements, since they can have a prominent impact on, if not a determining role in, the decision making process.

3.3.1. General user criteria for primary application

The general listing of the criteria of interest in the RTA process is given in Table 2. Depending upon the Member State's programme or the nuclear project under consideration, these criteria may be selected as policy objectives, technology elements or technology features. The primary listing of general criteria for the nuclear energy system is shown in the first column of the table. The remainder of the table provides an approximate cross-reference of topics that are included in the three completed reference document sets described above. In addition, Table 3 expands the listing to include key technical features of interest.

The listings of general user criteria and general technical criteria given in Tables 2 and 3 are taken from some of the IAEA publications that have previously described RTA processes. The notes to Table 3 show several other factors that may be worthy of consideration based on these publications. The entries in the tables tend to broaden the topics as well.

Common user considerations [7]:

— Reactor type: Preference is for light water reactors (LWRs) or heavy water reactors (HWRs).
— Unit capacity: Generally the CUC surveys demonstrated a preference for large units. This also relates to the experience base for small and medium sized reactors (SMRs)[4].
— Applications: The user considerations focus generally on baseload electricity production versus non-electrical applications for those Member States participating in the study and which were preparing for their first application.
— Simplicity with large design margin; decommissioning considered in design.
— Cycle length of 18–24 months.
— Fuel flexibility: MOX (mixed oxide fuel) or thoria are desired long term possibilities.
— Human–machine interfaces: Low or no interest in first-of-a-kind applications.
Level of automation regarding operation.

European utility requirements document [8]:

— Quantitative safety objectives: Probabilistic targets.
— Off-site release limits: Normal operation.
— Off-site release targets for accidents.
— MOX fuel to 50%.
— Stretch-out (coastdown) capability to 60 days.
— Low leakage fuel management is recommended to address materials design considerations.
— Component and systems functional requirements are specified.

[4] The IAEA defines a small size reactor as having a power generating capability less than 300 MW(e) and a medium sized reactor as having a power generating capability between 300 and 700 MW(e).

TABLE 2. GENERAL USER CRITERIA AREAS FOR THE NUCLEAR ENERGY SYSTEM

General user criteria	Common user considerations (CUCs) [7]	European utility requirements (EUR) [8]	Utility requirements document (EPRI ALWR-URD) [9]
Sustainability	Sustainable lifetime operation is expected	Sustainable lifetime operation is expected	Programme policy statement
Power generation demand	To be owner specified	Plant size focus: 600 to 1800 MW(e)	To be owner specified
Electrical grid characteristics	To be owner specified (determine effects)	Specific planning capacity provided	To be owner specified (determine effects)
Site characteristics	Expect remote locations (design to accommodate local external events)	To be owner specified (determine effects)	To be owner specified (determine effects)
Environmental impact	Off-site release limits (operations and incidents)	Off-site release limits (operations and incidents)	Off-site release limits (operations and incidents)
Nuclear safety	Policy statement for safety programme requiring analysis of design, quantification of margin and consideration of beyond design basis events (severe accident risk)		
Regulation and licensing	Compliance with regulations and standards	Compliance with codes and standards	Major focus of overall URD effort
Radiation protection	Occupational radiation exposure compliance	Occupational radiation exposure targets	Occupational radiation exposure compliance
Nuclear fuel cycle policy	Assurance of fuel supply	Fuel cycle cost targets and guidance on policy	Expected assurance of fuel supply
Nuclear waste management	Spent fuel, waste and decommissioning services	Spent fuel and radioactive waste disposal targets	Spent fuel, waste and decommissioning services
Safeguards	Intrinsic proliferation resistance	To be incorporated in design	Programme policy statement
Security and physical protection	Intrinsic physical protection	To be incorporated in design	Programme policy statement on sabotage protection
Emergency planning	Plan and implementing process derived in concert with nuclear safety requirements		
National participation	User involvement, technology transfer	User considerations	User considerations
Industrial development	Cost reduction through local content	User considerations	User considerations
Human resource development	Technical and project management development	Programmatic component	Programmatic component
Overall economics of NES	Generation costs Construction schedule	Construction and generation cost targets	Programme policy statement Economics
Project financing	Type of contracts Supplier support	User considerations	Programme policy statement Economics
Other important criteria	Public perception Assurance of component and spare parts supply Supplier qualification	Additional key technical features described	Additional key technical features described

TABLE 3. GENERAL TECHNICAL CRITERIA AREAS FOR THE NUCLEAR ENERGY SYSTEM

General technical criteria [5]	Common user considerations (CUCs) [7]	European utility requirements (EUR) [8]	Utility requirements document (EPRI ALWR-URD) [9]
Proven technology	High maturity level (most important)	Licensable Standardized	Programme policy statement
Standardization	Cost and component/spare parts replacement	Main policy statement	Programme policy statement
Simplification	Simplified design while assuring performance	Policy statement	Programme policy statement
Plant lifetime	50–60 years	40 years without refurbishment 60 years extension	60 years
Availability	Equal to or greater than 90%	Capacity factor >90% Refuelling <20 days	Top-tier requirements: plant performance
Operability and manoeuvrability	Safe shutdown on load rejection; base load is expected	Detailed requirements provided	Top-tier requirements: plant performance
Inspectability and maintainability	Accept current practice and demonstrated improvements	Performance assessment methodology is specified	Programme policy statement
Refuelling schedules	18–24 months	Flexible between 12 and 24 months	18–24 months
Nuclear island	Level of detail not developed	Provides generic and European preferences	All details provided
Conventional island	Level of detail not developed	All details provided	All details provided
Electrical systems and components	Level of detail not developed	All details provided	All details provided
Instrumentation and control systems	Level of detail not developed	All details provided	All details provided
Balance of plant	Level of detail not developed	All details provided	All details provided
Civil works and structures	Level of detail not developed	All details provided	All details provided
Plant simulator	Level of detail not developed	All details provided	All details provided
Mechanical, I&C (instrumentation and control), electrical equipment	Level of detail not developed	All details provided	All details provided
Architectural finish	Level of detail not developed	All details provided	All details provided

— Layout and design process and documentation rules are provided.
— Constructability guidelines are specified.
— Quality assurance programme is specified.
— Probabilistic safety assessment methodology is specified.
— Performance assessment methodology is specified.

EPRI utility requirements document [9]:

— Additional policy statements on:
  - Human factors;
  - Design basis versus design margins;
  - Regulatory stabilization;
  - Constructability;
  - Quality assurance;
  - Economics;
  - Good neighbour policy.
— Top-tier requirements covering:
  - General design requirements;
  - Safety and investment protection;
  - Design process.

3.3.2. General criteria listing in consideration of programme or project risk

There are a variety of factors that increase the risk of a major technological project; likewise, there are factors or decisions that may reduce this risk. The risk impacts due to these factors may be actual or perceived. These are termed 'non-technical' factors because they are generally not associated directly with the reactor technology under consideration. Examples of such factors may relate to the long term consequences of technology selection, technology holder historical construction performance, reactor technology transfer history or opportunities, political considerations, national resource constraints or opportunities, or human resources availability. These non-technical considerations or factors can have a prominent impact, if not a determining role, on the decision.

Criteria that may be selected to capture programme or project risk are provided with associated risk factors in Table 4. In the same way as those criteria categorized for the technical application, these may be used as policy objectives or goals, or may be an element or feature as a component of a higher level objective. For example, some may be grouped as elements under a policy objective such as national economic development, public involvement and support, or even programmatic risk minimization.

3.4. EXAMPLE SELECTION AND APPLICATION OF POLICY OBJECTIVES FOR REACTOR TECHNOLOGY ASSESSMENT

Sections 3.1 through 3.3 define the policy objectives, describe their use, and review sources of information for their formulation. Table 5 provides a listing that recasts the criteria from Tables 2–4 into what might be considered by a Member State or owner/operator as the candidate listing for their policy objectives. This listing is not intended to be complete; rather it is an example drawn from findings related to the CUCs, combined with the other cited references. A Member State or owner/operator using the RTA approach should establish its own candidate listing based upon its own objective assessment, and then should continue with the steps that follow in this demonstration exercise section to finalize and prioritize its own listing of policy objectives.

In this example the candidate list is shown in Table 5. In the next step, the policy makers must identify those candidate policy objectives that would be of highest importance. Those objectives that are rearranged in rank order for this example are shown in Table 6. The number of objectives to be selected from this set will vary and will generally depend on the breadth of scope for the individual objectives and on the process approach being used for the assessment. For a typical process approach four to eight policy objectives or goals might be chosen. This number may depend upon the breadth of the selected objectives.

Next, the relative importance or weighting of each of these objectives must be assigned to be consistent with policy. This is accomplished by reviewing the rank-ordered list and then assigning the weights such that the total point value matches the typical scoring for the RTA process approach being applied. The recommended weighting will sum to 100%. This example is carried forward in the demonstration applications for the process approaches displayed in the Appendix.

TABLE 4. CRITERIA REPRESENTING PROGRAMME OR PROJECT RISK FACTORS

Criteria	Factors
Relationship with the reactor designer and suppliers	The relationship with the reactor designer and supplier can be based upon: past experience with the technology holder; reputation of the technology holder promoted by other customers; nationalization (within the country); longevity of the technology holder — going back and reaching forward; experience of the technology holder (independent of technological considerations)
Strength of the relationship of the technology holder with its suppliers	Certainty of quality and timely supply; long term assurance of supply for current design; R&D for required product improvement for the future (e.g. analogue to digital system transitions)
National participation	National participation for this project: capacity of the project to promote industrial growth within the project; capacity building within the human resource base of the country may be incorporated; second order effects on the national economy based upon one technology holder’s proposal versus those of others
Technology transfer	Technology transfer offerings of one technology holder versus those of others. The RTA team should strive to develop quantitative benefits for each technology holder. Then these results could be incorporated in the bid evaluation. However, the benefits for a given technology proposal may only qualify for use as qualitative input values in the evaluation process
Technical support: Technology holder organization	Technical support provided by the technology holder organization (including suppliers, technology holder personnel and consultants). See ‘Technology transfer’ regarding quantification features for this criterion
Technical support: Assistance provided by other customers, industry groups or consultants	Sister utilities using and enabling the reactor type/technology holder under consideration User/utility groups Owner groups; EPRI; consortiums, including university support
Long term fuel supply assurance	Provisions by governmental, corporate or contracted supply networks with the objective of long term availability, capability and related support
Spent fuel	Spent fuel take-back under governmental or commercial terms and conditions: the spectrum spans from Member States who want to internalize the full scope fuel supply and disposal capability to those who want the fuel supplied and waste removed
Project financing assistance opportunity	Financing capability for the programme or project may be critical if not a major factor in decision making. Support from the technology holder’s governmental or commercial resource base could be required or desirable
Project schedule risk	Project schedule risk is intertwined with both project cost and financing and is therefore a factor in the risk/uncertainty profile. This can be quantified by uncertainty factor analysis; however, at some level of uncertainty for a programme or project, this risk may be unacceptable

TABLE 5. EXAMPLE CANDIDATE POLICY OBJECTIVES FOR A NUCLEAR POWER PROGRAMME

Candidate policy objectives for Member State:

Member State nuclear programme to achieve: electricity production for energy independence and national industrial development

The candidate policy objectives of this programme may include:

- Maintain and enhance nuclear safety performance;
- Achieve nuclear electricity production at competitive cost;
- Meet the national energy plan for on-line production with a capacity and time frame specified by the plan;
- Develop national participation through acquisition of nuclear technology;
- Use proven technology (such that the design concepts and plant components have been demonstrated in application);
- Ensure that substantial long term technical support is available from the technology holder organization or from other industry relationships;
- Ensure sustainability through assurance of components supply over facility lifetime;
- Ensure fuel supply through assurance of materials supply, proven fuel design and performance and diversity of suppliers;
- Promote industrial development to support plant construction and long term component production related to fuel supply;
- Minimize the impact of the programme on the local environment;
- Achieve long term closure option for the nuclear fuel cycle;
- Minimize construction and financing costs by ensuring that the proposed construction schedule is met;
- Maximize the value this first project contributes to the long term nuclear energy programme;
- Ensure that this project builds and sustains national and local human resource development.

TABLE 6. EXAMPLE OF POLICY OBJECTIVES AND ASSIGNED RANGE OF IMPORTANCE FOR ELECTRICITY PRODUCTION, ENERGY INDEPENDENCE AND NATIONAL INDUSTRIAL DEVELOPMENT

Importance	Policy objective
High	Meet the national energy plan with on-line production with an electric power capacity and timing specified by the plan
High	Achieve nuclear electricity production at competitive cost in Member State
High	Establish and maintain nuclear safety
High	Develop national participation through acquisition of nuclear technology
Medium	Ensure substantial long term technical support is available from the technology holder organization and/or from other industry relationships
Medium	Use proven technology (such that the design concepts and plant components are demonstrated in application)
Medium	Minimize construction and financing costs by ensuring that the proposed construction schedule is met
Medium	Ensure fuel supply through assurance of materials supply, proven fuel design and performance, and diversity of suppliers
Low	Promote industrial development to support plant construction and long term component production related to fuel supply
Low	Ensure that the project builds and sustains national and local human resource development
Low	Minimize the impact of the programme on the local environment
Low	Maximize the value this first project contributes to the long term nuclear energy programme
Low	Ensure sustainability through assurance of components supply over facility lifetime
Low	Achieve long term closure option for the nuclear fuel cycle

4. KEY ELEMENTS AND DETAILED FEATURES IN THE REACTOR TECHNOLOGY ASSESSMENT APPROACH AND PROCESS

This section identifies the key elements of reactor design, construction and performance that should be considered in the RTA decision making. The previous section described the approach to establish the policy objectives for the programme or project. The next step is to identify key elements and features of the candidate technologies that will contribute to the success or failure of these objectives. These design, analysis, operational performance, and economic elements and features for each of the candidates are assembled to perform the comparative assessment.

The first part of this section describes these elements derived from reviews of the guidance documents as discussed in Section 3. The purpose is to develop and define a common structure for the elements that have been determined to be the most important in RTA. The key elements and features assembled here are derived from a combination of the reference documents described in previous sections, as well as from the expert opinion and review of the IAEA. In the performance of the RTA, it is the responsibility of the assessment team to identify those sets of elements and features that support the policy objectives. This is one of the major tasks necessary for performing the RTA. Since every set of objectives and goals will be different and every set of candidate technologies is distinct, the assessment team performs the tasks of reviewing and selecting the appropriate elements and features, assigning weights to those parameters, and determining the metrics and ranges that will be used to score the performance in the assessment process.

The second part of this section introduces additional decision making elements that must be considered in the RTA process. They are grouped into a category of features associated with policy, protocol, and uncertainty or risk factors. These elements may have a major impact on the process of technology assessment as well as on the final decisions that are made in technology selection. Treatment of these elements is described further in the subsequent sections on methodologies and assessment.

4.1. TECHNICAL, PROGRAMMATIC AND ECONOMIC ELEMENTS FOR DECISION MAKING

Table 7 lists the key elements that have been chosen as the base categories for the RTA. As described in Section 2.2, the emphasis applied to these elements in the assessment will vary as a function of the application. The table identifies the typical focus for the applications for the RTA in the Phase 1 feasibility study, and then those supporting the invitation to bid and the evaluation of bids in Phase 2, and the further applications of the assessment in construction, operation and maintenance.

For example, the key elements for decision making that are most likely to influence the process of evaluation associated with the feasibility study are the relevant column indicated. Some will be a major focus for the feasibility study: namely, the site and grid specific characteristics, the unit size, the environmental impact and those other parameters that will affect the preliminary economic evaluations. The RTA that provides input for the feasibility study will include each of the elements marked on the table. The extent of the evaluation is suggested by minor (“O”) and major (“X”) entries in the table.

Significant design information on many water cooled reactors is available in the IAEA Advanced Reactors Information System [2]. To obtain more detailed design and economic performance information from the technology holders in response to certain questions given in this section, it is expected that the potential buyer will be requested to sign a non-disclosure agreement with the technology holder.

As the table shows, the large majority of the elements should be understood and considered through the process of the RTA to provide proper input to the invitation to bid. The NEPIO or owner/operator is expected to actively engage the technology holders in the invitation to bid process, and to provide directions or expectations with regard to the decision making elements. A summary description related to this process is provided in the IAEA guidance publication on “Invitation and Evaluation of Bids for Nuclear Power Plants” [5]. The selection of candidates for the invitation to bid results from the work of this stage.

The RTA process completes its final evaluation when all the information associated with the bidding process has been received. Here the candidate designs will be evaluated with the methodology to determine how well each has met the expectations of the Member State. This process will engage each of the elements selected for decision making. The table completes the review of each stage by showing the selected elements that may be followed and evaluated during the construction, operation and maintenance of the facility. As discussed in Section 2.2, the Member State should continue to use the RTA process to achieve the fullest potential in project construction and facility deployment.

Table 7 also indicates in general the responsibilities of the NEPIO or the owner/operator and the technology holder. The table indicates the extent to which the owner/operator will express requirements or desired features to the technology holder. As a responder to or initiator of a request for information, the technology holder will for the most part always have direct or shared responsibility. Therefore, the value added here is to show those items specified most directly by the owner/operator.

Table 8 expands the elements for decision making to incorporate those elements related to programme or project risk and uncertainty areas. These represent non-technical considerations that may impact the decision. As such, these should be considered in the RTA and included as appropriate.

Examples of ranking considerations for elements of decision making are displayed in Tables 9 and 10. These are derived from a compilation of expert opinion, but are intended to be a demonstration of the ranking process and potential results. The policy team determines the ranges, values and the rationale for the weighting factors in the RTA.

TABLE 7. ELEMENTS FOR DECISION MAKING AND DIVISION OF RESPONSIBILITY

Elements for decision making	Typical elements of focus for:				Responsibility	
	Feasibility study	Invitation to bid	Bid evaluation	Construction operation maintenance	Owner/ operator	Technology holder
Site considerations	X	X	X	X	X	X
Grid integration	X	X	X	X	X	X
Nuclear plant safety	X	X	X	X	X	X
Technical characteristics and performance:						
Unit size	X	X	X		X	X
Plant lifetime	X	X	X		X	X
Proven technology	X	X	X			X
Standardization		X	X	X		X
Simplification		X	X	C		X
Constructability		X	X	C		X
Operability, inspectability, maintainability, reliability	X	X	X	X	O	X
Plant availability and capacity factors	X	X	X	X	O	X
Manoeuvrability	X	X	X	X		X
Major systems and components			X	X		X
Nuclear fuel and fuel cycle performance	X	X	X	X		X
Radiation protection		X	X	X	X	X

TABLE 7. ELEMENTS FOR DECISION MAKING AND DIVISION OF RESPONSIBILITY (cont.)

Elements for decision making	Typical elements of focus for:				Responsibility	
	Feasibility study	Invitation to bid	Bid evaluation	Construction operation maintenance	Owner/ operator	Technology holder
Environmental impact	X	X	X	X	X	X
Safeguards	X	X	X	X	X	X
Plant and site security		X	X	X	X	X
Owner scope of supply		X	X	X	X	
Supplier/technology holder issues		X	X	C		X
Project schedule capability	X	X	X	C	O	X
Technology transfer and technical support		X	X			X
Project contracting options	X	X	X	X	X	X
Economics:						
Capital costs	O	X	X	X	X	X
Operation and maintenance costs	O	O	X	X	X	X
Fuel costs	O	O	X	X	X	X
Decommissioning costs			O	O	X	X

Note: X — Major contribution; O — Minor contribution; C — In construction.

TABLE 8. RISK AND UNCERTAINTY AREAS AND SHARE OF RESPONSIBILITY

Elements for decision making	Typical elements of focus for:				Responsibility	
	Feasibility study	Invitation to bid	Bid evaluation	Construction operation maintenance	Owner/ operator	Technology holder
Relationship considerations:						
Relationship with designer/technology holder	X	X	X	X	X	
Relationship with suppliers	X	X	X	X	X	
Strength of technology holder/supplier relationship	X	X	X	X		X
Technical support available:						
Technology holder long term technical support	X	X	X	X		X

TABLE 8. RISK AND UNCERTAINTY AREAS AND SHARE OF RESPONSIBILITY (cont.)

Elements for decision making	Typical elements of focus for:				Responsibility	
	Feasibility study	Invitation to bid	Bid evaluation	Construction operation maintenance	Owner/ operator	Technology holder
Experienced utilities willing to help		X	X	X	X	X
User/utility/owners groups			O	O	X	X
WANO, EPRI, INPO, consortiums			O	O	X	
Potential risk contributors:						
Regulatory/licensing Issues	X	X	X	X	X	X
Project schedule risk	X	X	X	C	O	X
Long term fuel supply security	X	X	X	X	X	X
Project financing assistance/assurance	X	X	X	X	O	X
Decommissioning issues			O		X	X
National issues:	Country specific elements					
Country to country relationships	X	X	X		O	O
Political stability — supplier		X	X			O
Political stability — owner/operator	O	O	O		X	
Infrastructure development relationships	X	X	X		O	X
Government programmes or commitments	Country specific				O	O
National energy policy	X	X	X	X	X	
National participation — human resources		X	X	X	O	X
National participation — industrial growth	Country specific				O	X
National participation — economy	Country specific				X	X
Localization (owners scope of supply)	X	O	X	C		X
Nuclear fuel cycle — front and back end	X	O	X	X	X	O
Spent fuel return	Country specific					X
Technology holder/constructor Physical presence, availability (call-in time), language	X	X	X	X		X

Note: X — Major contribution; O — Minor contribution; C — In construction.

TABLE 9. EXAMPLE WEIGHTING FACTORS RANGES

Elements for decision making	Weighting factor range				Comments
	High	Medium	Low	Not a differentiator	
Site considerations	X				
Grid integration	X				
Nuclear safety	X				
Technical characteristics and performance:					
Unit size	X				
Plant lifetime			X		
Proven technology	X				
Standardization		X			
Simplification		X			
Constructability			X		Schedule risk ($$$)
Operability, inspectability, maintainability, reliability		X			
Plant availability and capacity factor	X				Technology holder analysis consistency
Manoeuvrability					Locale dependent
Major systems and components					Function of level of detail
Nuclear fuel and fuel cycle performance		X			
Radiation protection		X			
Environmental impact			X		
Safeguards				X	Expect compliance
Plant and site security			X		
Owners scope of supply		X			
Supplier/technology holder issues	X				
Project schedule capability		X			Impact of unplanned delay
Technology transfer and technical support	X				
Project contracting options	X				
Economics:					
Capital costs	X				
Operation and maintenance costs		X			
Fuel costs		X	X		
Decommissioning costs				X	

TABLE 10. EXAMPLE RISK AND UNCERTAINTY AREAS

Elements for decision making	Weighting factor range				Comments
	High	Medium	Low	Not a differentiator	
Relationship considerations:					
Relationship with designer/technology holder	X				
Relationship with suppliers	X				
Strength of technology holder/supplier relationship	X				
Technical support available:					
Technology holder long term technical support	X				
Experienced utilities willing to help	X				
User/utility groups			X		
Owners groups			X		
WANO, EPRI, INPO, consortiums				X	
Potential risk contributors:					
Regulatory/licensing issues					Function of issues and their status
Project schedule risk	X				High potential cost impact
Long term fuel supply security	X				“Long term”— case specific
Project financing assistance/assurance	X				
Decommissioning issues			X		
National issues:					Country specific elements
Country to country relationships					TBD[a]
Political stability — supplier					TBD
Political stability — owner/operator					TBD
Infrastructure development relationships					TBD
Government programmes or commitments					TBD
National energy policy					TBD
National participation — human resource		X			Training and procedures provisions
National participation — industrial growth					TBD
National participation — economy					TBD
Localization (owner’s scope of supply)	X				Request in the offer up-front
Nuclear fuel cycle — front and back end	X				Reactor design differentiator
Spent fuel return					Technology holder. or country specific
Technology holder/constructor physical presence, availability (call-in time), language					TBD

[a] TBD — Importance weighting to be determined (country specific elements).

The tabulated elements for decision making are now characterized by their expanded description to introduce those types of considerations that should be important to the RTA. The summaries here are provided for three purposes:

(1) The descriptions of these elements are needed to build the understanding of the RTA process that is presented in Section 5.
(2) This level of detail is intended to provide the chief characteristics, which may be sufficient to perform the RTA for the feasibility study work.
(3) These descriptions set the stage for the development of more detailed information required to perform a detailed, quantitative RTA, as developed in Section 5 and amplified by example in the Appendix.

In particular these items described for each element include:

— Description: Summary statement to define the element.
— Importance factor range: Designation of importance as derived for Table 9 (recommended range).
— Importance factor rationale: Explanation of why the importance factor has been rated in the range as shown.
— Key topics: Topics which require consideration for the element. These topics may be features or sub-features which will be used to evaluate or to quantify the element.
— Key questions: Using the RFI process with technology holders is a standard process required to evaluate the key elements or features that are identified for the RTA process. It is necessary to gather specific information from each candidate technology holder that is fully consistent and that can then be quantified comparatively using a rational analysis process and set of metrics.
— Evaluation expectations and relative comparisons: Considerations that are important to incorporate in the assessment of the candidate nuclear power plants.

4.1.1. Site specific considerations

Description: Site specific parameters affecting the plant design.

Importance factor range: High

Importance factor rationale: Interaction between site characteristics and the features of the proposed design may be strong differentiators; for example, design features that have been included in the standard nuclear power plant for external events.

Key topics:

— Ambient site environmental conditions and ecology, including seismic, flooding, wetlands, population density;
— Heat sink temperature, condenser cooling water source and extent of water resources;
— Predicted magnitude and frequency of all external events (design and safety considerations);
— Site size requirements, boundary conditions, population, neighbours and environs;
— Transportation routes/facilities and access to required infrastructure for construction and operation;
— Site development and preparation requirements;
— Site structure plan; single- or multi-unit site requirements.

Site parameters compared with the site parameters envelope offered by the technology holder for the proposed (standard) plant, for example:

— Soil conditions (soft, medium, rock);
— Site seismic level ground acceleration (e.g. safe shutdown earthquake ground motion, operating basis earthquake ground motion);

— Wind velocity;
— Snow load;
— Environmental conditions (barometric pressure, temperature, relative humidity, etc.);
— Cooling water temperatures (for non-safety related cooling systems and safety related cooling systems, and ultimate heat sink considerations);
— Site ambient temperatures and relative humidity for HVAC (heating, ventilation, air conditioning) system design (non-safety and safety related HVAC systems);
— Condenser cooling water source;
— Heat sink temperature (note: this impacts the design of heat exchangers, pumps and the safety analyses. The resultant designs of the heat exchangers and pumps impact the plant electrical output);
— Condenser temperature rise (note: this is determined by the circulating water and service water flows, which in turn affect plant performance);
— Seismic design basis and site differences, including impact on structures and embedment given soil interaction analysis for the site spectra; seismic requirements for the turbine island;
— Water resources required for plant make-up, blowdown and margin required for operation.

Key questions:

Question for the owner/operator:

(1) What is the range of acceptable plant ratings for this procurement? For this plant site?

Questions for the technology holders:

(1) What is the size and weight of your largest component, and how do you propose to transport it to the site?
(2) What site specific issues could affect the site preparation schedule and costs?
(3) What is the footprint of the major facilities on the site?
(4) What is the impact of local temperature variation on plant performance and MW(e) output?

Evaluation expectations and relative comparisons: Ensure that each technology holder’s plant design and site configuration and characteristics are consistent with the site specific characteristics.

4.1.2. Grid integration

Description: The interface between the facility design and the grid system in which it is to operate, including normal operation, off-normal operation at the plant, upset conditions on the grid and combinations thereof.

Importance factor range: High

Importance factor rationale: Unique or challenging features of the grid arrangement for the facility interface in both initial and lifetime operation is critical to the facility’s safe, economic and reliable operation.

Key topics:

— Grid stability, size, existing and future capacity, plant connectivity;
— Plant operation under normal grid, disturbed grid and isolated grid conditions;
— Off-site power requirements for the plant;
— Ability to house load the power station;
— Grid code restrictions applicable to plant;
— Grid breaker switching capability under blackout transitions.

Key questions:

(1) What are the grid interface requirements and expectations for the proposed facility?
(2) What are the requirements for the emergency power systems on the grid?
(3) What are the abilities of the power station to operate on house load?
(4) What are the grid code restrictions applicable to the power station?

Evaluation expectations and relative comparisons: Evaluate the technology holder proposals and analyses associated with the grid–plant interface. This must consider the necessary scenarios to ensure safe and reliable operation of the plant under normal, off-normal, accident and severe accident conditions.

4.1.3. Nuclear plant safety

Description: The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards [12].

According to INSAG-10 [13] and INSAG-12 [14] the defence in depth concept is a fundamental safety principle that provides an overall strategy for safety measures and features of nuclear power plants. When properly implemented in the design, this concept ensures the fulfilment of all three fundamental safety functions as defined in Ref. [15]:

- — Control of reactivity;
- — Removal of heat from the reactor and from the fuel in storage;
- — Confinement of radioactive materials, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.

Also addressed here is characterization of the design with respect to the facility response in the event of a severe accident involving core melt. The intent is to evaluate the spectrum of accident release events that are considered in design, and the technical and programmatic response plans and facilities that have been developed as part of the facility design.

Importance factor range: High

Importance factor rationale: Nuclear safety is expected to be included at the policy objectives level or the highest element contribution level. It has the potential to be a strong differentiator. Gathering consistent and accurate information from technology holders for appropriated comparisons will be required. A wide variety of metrics is available, yet the approach should be to select a reasonable number that will appropriately represent the capability of the facility with respect to nuclear safety.

Key topics:

- — Regulatory requirements in the Member State and the standards applied by the technology holder for the design, including:
  - Licensing process and issues, recent or ongoing, both in country of origin and on other export sites;
  - Language of original licensing material.
- — Regulations in the Member State on radiation and safety for nuclear power plant siting.
- — Safety approach (e.g. fully active, fully passive, combination).
- — Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage, including:
  - Assurance that the technology holder has sufficient technically qualified and appropriately trained staff at all levels;
  - Adequate quality management of the design process;

- Key safety features to limit plant transients;
- Key safety features to avoid core damage;
- Key safety features to contain core damage;
- Key safety features to reduce offsite release.

— Degree of diversity and redundancy in providing the above key safety features:
- Redundant safety related trains and major components segregated in different rooms with controlled access;
- Main safety related structures, systems and equipment designed against human caused and natural external events, including internal and external flooding;
- Separate emergency control facility with capabilities to control safe shutdown in emergency or security events;
- Features such as separation of redundant trains, major components, and compartmentalization of safety and non-safety systems;
- Loads and load combinations, including large missiles and jet impingement.

— Spent fuel pool safety:
- Building location and integrity;
- Alternative means for cooling and inventory control.

— Defence against external events (Fig. II-1 in Annex II):
- Margins in design basis calculations;
- Affected margins for best estimate calculations, e.g. siesmic events;
- Determination of ultimate failure conditions.

— Severe accident releases and response:
- Severe accident management programmes, processes;
- Containment design (e.g. double containment with liner);
- Containment and penetrations design pressure failure point;
- Post–core damage management (e.g. core catcher, in-vessel retention);
- Hydrogen management (e.g. recombiners);
- Filtered containment vent;
- Emergency technical support centre:
  - ■ Communications;
  - ■ Habitability;
  - ■ Power supply.

— Safety equipment testing and survelliance requirements.
— Classification of components and related quality requirements.
— Reliance on off-site power.
— Probabilistic safety assessment (PSA) scope, maturity and results:
- Comparisons of initiating events;
- Internal events;
- Fire evaluations;
- External events analyses;
- Extent to which risk is dominated by single issue or event (e.g. loss of off-site power).

— Safety margins against deterministic requirements.
— Plant control and protection logic architecture.
— Provisions to ensure a high level of safety:
- Human–machine interface and instrumentation and control (I&C) design;
- Plant design life and replacement provisions for safety systems, and components with foreseen shorter life;
- Design provisions for safety systems and components testability and maintainability, in particular during power operation;
- Safety systems and components qualification requirements.

— Due consideration of human factors engineering (including equipment accessibility post-accident).
— Fuel and water supply for diesel generator, emergency feedwater and primary system make-up.
— Integration of technical specifications with safety analysis report (SAR) and PSA.
— Completeness of operating technical specifications (OTS), SAR and PSA.

Key questions:

(1) Which regulatory requirements and standards are the basis for the nuclear power plant design? Does the design include exceptions to any IAEA safety standards? What other design requirements and standards are met?
(2) What regulatory agencies have approved/are approving (and/or have certified) this design? What are the ongoing or recent major licensing issues being addressed?
(3) What are the approach and philosophy followed to achieve defence in depth in the design, including assurance of containment integrity?
(4) Does the design comply with regulations on radiation and safety related to nuclear power plant siting in the Member State?
(5) What is the programme carried out by the technology holder to incorporate lessons learned from the accident at the Fukushima Daiichi nuclear power plant? What nuclear safety and operational reliability improvements have been made to the design as a result of the Fukushima accident?
(6) What other improvements have been made to the design as a result of regulatory or internal/external design reviews in the past five years?
(7) Which external events are considered in the design and what are the associated design criteria and margins? How have severe external events or multiple external/internal events been considered in the design and operating procedures?
(8) What are the severe accident mitigation systems and how are they redundant to and different from other safety and operating systems?
(9) What systems are included in the design specifically to minimize the consequence of potential severe accidents?
(10) What are the safety performance advantages of the primary reactor coolant system loop (conventional or integrated) adopted in the nuclear power plant design?
(11) What requirements are incorporated into the design of the UHS? What assumptions are made with regard to assurance of UHS availability? What systems are required to function to ensure heat transfer to the UHS? Under what conditions can core and fuel pool damage with sustained loss of UHS be avoided?
(12) What are the general safety design criteria with regard to emergency core cooling system capacity, single failure/redundancy, diversity, separation and independence as it relates to reactor trip and emergency cooling?
(13) What has been the approach to optimize the incorporation of inherent features, passive and/or active safety systems into the design?
(14) What is the design approach (including conceptual and engineering design, operational procedure and training) to reduce or alleviate human errors?
(15) What is the capability of safety systems in terms of the grace period for operator action and available off-site power during a station blackout (loss of all AC power and emergency diesel generators)? For other major events?
(16) How long can the plant sustain a loss of all AC and DC power before core damage occurs?
(17) What are the capabilities of steam driven safety systems (if any), emergency power supplies (including DC power), and diverse or redundant safety systems (including electric and non-electric cooling systems) in the event of loss of AC power?
(18) How is control room habitability ensured in the event of an accident? What is the capability of and pathway to the alternate shutdown facility/panel?
(19) Are there any conditions under which the plant could have a positive coefficient of reactivity (e.g. moderator temperature)? If so, what is the justification and control of this condition?
(20) What are the core damage frequencies (CDFs) and the large early release frequencies (LERFs) associated with internal, shutdown and external events (with external event assumption bases)?
(21) What regulatory or peer reviews have been conducted on your PSA methodology, analyses and results?
(22) What improvements have been made in the safety design based on the insights from PSA and from operational experiences of the same or similar designs?
(23) Given the Member State regulatory basis, what emergency plan does this design require?
(24) What are the features for physical protection of plant systems?
(25) What systems and equipment are needed for severe accident on-site and off-site response?
(26) What emergency response facilities and capabilities are in the offer?

(27) What regulatory review and approval has been performed for the emergency plan and severe accident management programme?
(28) Is there alternate cooling in the spent fuel pool in the case of a loss of integrity?
(29) Is boric acid required to ensure subcriticality in the spent fuel pool?
(30) What safety features are developed specifically to support automatic or manual load following capability?
(31) In the event of severe core damage, what measures are available to prevent containment failure?
(32) Does the safety of the design rely on the vanishly low probability that certain components will fail (e.g. reactor pressure vessel)?
(33) What provisions are taken to protect the switchyard and its supplies from external events?
(34) How is redundancy, train separation and diversity of sensors for initiating safety functions (e.g. reactor trip, emergency cooling) incorporated into the plant's design?
(35) How long can the site operate without external supply of water or diesel fuel under loss of off-site power?
(36) What systems are required to function to maintain the in-vessel retention or core catcher integrity?

Evaluation expectations and relative comparisons: The challenge is to examine those elements and features that will best differentiate the safety of different designs. This will be dependent on the spectrum of reactor designs under consideration. Since nuclear safety is a policy objective, it is necessary to conduct the evaluation so that the approach and the results can be clearly explained to policy makers. The evaluation should include plant systems, as well programmes and procedures for emergency and severe accident responses for the plant and its surroundings.

4.1.4. Technical characteristics and performance

4.1.4.1. Unit size

Description: The total heat and electrical generating capacity of the nuclear reactor.

Importance factor range: High

Importance factor rationale: Substantial differences exist among large reactors, as well as SMRs, and these affect a number of additional elements under consideration in the assessment. The purpose here should be to avoid duplication with any other chosen evaluation element. Note that the key questions also examine the advertised versus the actual expected plant output. Since calculation assumptions and approaches may vary among technology holders, it is important to develop an approach to ensure consistent results related to plant output.

Key topics:

— Plant net rated output (MW(e));
— Plant efficiency (kW(e)/kW(th));
— Auxiliary power consumption (MW(e));
— Expected capacity factor.

The owner/operator provides:

— Projected grid size and characteristics during plant life;
— Transmission access;
— Availability of cooling and process water resources and requirements.

Key questions:

Questions for the owner/operator:

(1) What is the desired unit size?
(2) What is the range of acceptable unit sizes for this procurement? For this facility site?

Questions for the technology holders:

(1) What is the proposed unit size?
(2) What is the range of available unit sizes for this procurement? For this facility site?
(3) What is the plant net rated electrical output and plant efficiency for the environmental condition profile specified for the site ($T_{heat\ sink}$, T_{air}, humidity…)?
(4) What is the gross electrical output on this site and what are the major contributors to the auxiliary power consumption?
(5) What is the expected capacity factor for the proposed plant?

Evaluation expectations and relative comparisons: Ensure that there is common understanding regarding the output for each proposed plant as a function of site environmental conditions.

4.1.4.2. Plant lifetime

Description: The length of time that the nuclear power plant is designed to operate.

Importance factor range: Low

Importance factor rationale: The plant designed operational lifetime is typically 60 years or more, and technology holders maintain margins associated with this determination. Extra consideration of this key element would be warranted for the assessment if the plant design has features that are known to have limited useful lifetimes.

Key topics:

— Economic design life and physical life specification (years).
— Limiting equipment or components and their design lifetimes.
— Replaceability of components intended to be changed during plant lifetime (including impact on plant lifetime availability).
— Major component design margins (e.g. vessel fluence, containment and physical structures).
— Materials assessment and availability including spare parts and capability of common suppliers.
— List of components and structures that meet the design life requirements without refurbishment.
— Design margin analyses to assure plant lifetime optimization for major components and structures.
— Long term assurance for component and replacement parts availability.
— Design lifetime refurbishment plan:
  - Definition of the main scenarios and economic estimates involving component replacement and outages for refurbishment;
  - Identification and estimate of specific maintenance, surveillance and condition monitoring results that are crucial for determining schedules and periodicities for refurbishment;
  - Design lifetime assessment report analysing the industrial experience on ageing mechanisms and justifying the material selection;
  - Commercial and contractual treatment of described commitments.

Key questions:

(1) What is the programme for replacement of components and structures to attain the design lifetime? Describe the component replacement plan required to achieve design lifetime in terms of ten year intervals, including cost experience or cost estimates.
(2) What are the lifetime design margins for the reactor vessel, the containment or other major replacement cost items? What are the estimated replacement costs?
(3) What are the assumptions regarding regulatory factors that influence achieving the design lifetime?

(4) What are the assumptions regarding availability of replacement components, materials, equipment and parts? What assurance is provided regarding availability of suppliers or commonality of replacement supply?

Evaluation expectations and relative comparisons: Structure the economic comparison for the component and system replacement programme and the life-of-plant reliability and availability predictions. Combine with best estimates of lifetime achievement based upon comparative design margins for major life-limiting features and including potential for life-limiting regulatory issues.

4.1.4.3. Proven technology

Description: The level of experience through operation of a certain component or a certain nuclear power plant design for a certain length of time demonstrating the capabilities of those technologies.

Importance factor range: High

Importance factor rationale: Verification of proven technology is important for a complex system for long term safe, economical and reliable operation.

Key topics:

— Operating experience of the plant design and components;
— Characteristics of the design: proven, evolutionary or innovative;
— Completeness of design: percentage of detailed design completed;
— Completeness of the procurement specification process;
— Licensing and/or certification status for the design, including past, current and anticipated licensing issues and resolutions;
— Comparison with utility requirements;
— Compliance with regulatory requirements;
— Status of regulatory approval in various countries;
— Compliance with local rules, if different.

Key questions:

(1) What operational experience and/or experimental validations do you have on the proposed design or on a similar design?
(2) What is the licensing history of the design in the country of origin?
(3) What licensing has been completed for construction and operation in other countries?
(4) What are the plans and status for certification and licensing for this application?
(5) How many years of reactor operating experience have you had in this region?

Evaluation expectations and relative comparisons: Determine in a consistent fashion what the expectations should be regarding the demonstration of proven technology. Expectations will differ if the project objectives include technological advances. In this case the expectations with regard to the testing and demonstration programme should be described in detail for the benefit of both the technology holder and the assessment team.

4.1.4.4. Standardization

Description: The extent to which a nuclear power plant design or the major components can be made to an established standard.

Importance factor range: Medium

Importance factor rationale: Standardization has become a general expectation within the industry for current plants under construction. It will be more important for SMR and other advanced reactor types to commit to this practice. Standardization can be especially important to the Member State or owner/operator with a new programme or only a few units, to ensure the opportunity to share and apply lessons learned from and with the standardized fleet.

Key topics:

— Standardized plant design description with site envelope parameters;
— Current and planned deployments, including schedule;
— Standardized design elements, components, materials (and suppliers);
— Changes that can be made to suit local conditions;
— Completeness of design standardization;
— Other similar plants being built in the region or in the world;
— Opportunities for common material and spare parts inventory, suppliers and procurement specifications.

Key questions:

(1) To what extent are the major components standardized?
(2) What is your experience of availability of replacements of standard material, components and equipment?
(3) What long term assurance of supply can be given for standardized equipment which needs to be replaced?
(4) How many similar plants are in service, under construction and committed to construction?
(5) What is the level of experience in information sharing between users of the standardized plants?
(6) To what extent has standardization of equipment and components of the nuclear power plant been addressed in the licensing process?

Evaluation expectations and relative comparisons: Technology holders should provide a comprehensive description of their standardization practices and related history that can be used along with the key topics to evaluate this element and develop meaningful comparisons commensurate with the importance factor and potential connections of this element to the policy objectives.

4.1.4.5. Simplification

Description: The minimization of the number of types of systems and components, without adverse impacts on the plant economics, performance and safety, while improving ease of operation and maintenance.

Importance factor range: Medium

Importance factor rationale: Whereas simplification is considered very important, especially with respect to new technology and for SMRs, it is expected to be a common approach for all technology holders. Therefore, it is not expected that simplification will be a strong differentiator, or that it will be a major contributor to the policy objectives. It could have a significant effect on economics of construction, operation costs for replacement parts, and labour requirements for operation and maintenance support. Simplification should have a positive impact on plant safety. Economics and safety categories are expected to be included as high level elements or policy objectives in most assessments.

Key topics:

— Comparative design simplification for nuclear steam supply systems (NSSS), components, operations and safety systems;
— Human–machine interface systems to simplify plant operation and facilitate maintenance;
— Plant construction simplification with design to facilitate on-line maintenance;
— Systems and equipment design and control room design to minimize demands on plant operators during normal and emergency conditions;

— Simplified control logics;
— Use of a minimum number of systems and components (e.g. pumps, valves, instruments or electrical equipment) to meet essential functional requirements;
— Design that facilitates plant construction;
— Buildings arrangement, equipment design and layout to simplify and facilitate maintenance;
— System redundancy to support on-line maintenance;
— Operator actions for transients/accidents (available/required response time).

Key questions:

(1) What changes have been made in this design to reduce operator actions during normal and transient operations? To what extent have operator actions been reduced?
(2) What is your experience with the proposed human–machine interface in the plant design?
(3) What improvements have been achieved in the maintenance conduct and procedures due to simplification of the design?
(4) What is the minimum number of reactor operators required considering the regulatory requirements?

Evaluation expectations and relative comparisons: Technology holders should provide a comprehensive description of their simplification practices and related history that can be used along with the key topics to develop meaningful comparisons commensurate with the importance factor and potential connections to the policy objectives. Caution should be used to ensure that benefits related to simplification are not double counted.

4.1.4.6. Constructability

Description: The technologies and methods that will be used during the construction of the nuclear power plant.

Importance factor range: Low

Importance factor rationale: Although constructability is considered quite important as a feature, it is not expected to be a key differentiator on its own. Rather the benefits will be seen in lower capital cost estimates, lower construction time periods (financing costs) and lower construction schedule risk factors.

Key topics:

— Detailed construction plan, management, schedule, resources and interfaces;
— Use and completeness of construction work packages;
— Size of laydown area;
— Planned construction housing facilities;
— Extent of modular construction, demonstrated capability, manufacturing, management, transportation and installation support requirements;
— Construction quality assurance (QA) programme and demonstrated site construction quality;
— Construction safety and health programmes during and after construction;
— Civil site preparation and earthwork requirements and schedule;
— Use of smart construction techniques.

Key questions:

(1) What is your proposed construction schedule, including major milestones, and what is your experience record with intended partners?
(2) What advanced construction techniques [16] have you included in your plan?
(3) Have you executed the proposed construction plan or a similar plan? If so, describe your actual versus expected performance.
(4) What is your modular construction plan and what modular construction techniques are you proposing to use?

(5) What are the transportation challenges expected for executing the modular construction plan? What are the size and weight transport requirements and what are the infrastructure expectations needed to support their effective delivery?
(6) What are the transportation challenges expected for the reactor vessel and other major components?
(7) What has been your experience in the use of modular construction techniques — actual versus planned? What issues were identified, how were they resolved, and what was their impact on cost and schedule?
(8) What are the construction challenges expected in delivering the proposed design for operation on schedule, given the available site, environs and workforce?
(9) What are the bulk material quantities for construction (e.g. concrete and steels)?
(10) What land area and water source and supply are required for construction, including all layout and temporary use land areas?
(11) Have you used consistent systems of measurement units throughout your design documents?

Evaluation expectations and relative comparisons: Technology holders should provide a comprehensive description of their constructability features and proven construction practices as history that can be used along with the key topics to develop meaningful comparisons commensurate with the importance factor. The evaluation should review for the technology holders: (1) their actual versus planned experience with the construction plans for comparable designs, site and environs, workforce and locale considerations; (2) proposed construction schedules compared with their experience base with plant type and construction plan. Caution should be used to ensure that any benefits related to constructability are not double counted, given the tight coupling to capital costs.

4.1.4.7. Operability, inspectability, maintainability and reliability

Descriptions: The methods, technologies and experience involved in maintaining the nuclear power plant for safe and reliable operation.

Importance factor range: Medium

Importance factor rationale: These are all important features associated with operational considerations for facilities under consideration. All these areas of performance are a function of the capabilities of the owner/operator as well as the design features of the facility. To the extent that these areas also appear in other key factors — availability and capacity factors, for example — there can be overlap in the elements. This should be considered in the overall evaluation.

Key topics:

— Operational and design margins in normal operating modes;
— On-line and off-line maintenance expectations versus experience;
— Fuel transfer system capability and refuelling outage duration versus experience;
— Remote technology options for inspection, monitoring and maintenance;
— Plant trip response (design versus experience), including trips of the reactor, turbine, feedwater and main condensate pump;
— System redundancy and logic switchover systems to avoid trips;
— Mean time between failure (MTBF) and mean time between maintenance (MTBM) for key components;
— Design margins (design, technical specification limits, and operational margins), including equipment redundancy;
— Reactor normal shutdown and cooldown process descriptions;
— Emergency remote shutdown requirements versus capabilities;
— Critical path comparisons;
— Major maintenance comparisons;
— Major component and reactor internals replacement comparisons;
— Ability to remove and transport major components (on-line/off-line);

— Replaceability/reparability of control and instrumentation systems;
— Containment accessibility during plant operation.

Key questions:

(1) What plant commissioning support (e.g. startup support) will be provided?
(2) What support is available after plant commissioning, including plant operation and maintenance?
(3) What reactor simulators are provided and what is the proposed operator training programme and schedule?
(4) What experience base exists for this simulator facility and for the operator training programme offer?
(5) What is the on-line and off-line maintenance programme plan and what is the experience base that supports its design?
(6) What are the MTBF and MTBM for key components which affect overall plant availability?
(7) How have adequate space and access requirements for efficient maintenance been assured in this design?

Evaluation expectations and relative comparisons: To the extent that these key topics also appear in other key elements — availability and capacity factors, for example — there can be overlap in the elements. This should be considered in the assignment of importance factors as well as evaluation techniques.

4.1.4.8. Plant availability and capacity factors

Description: The plant availability is the fraction of time that the plant is capable of fulfilling its intended purpose [12], and the capacity factor is the actual energy output of an electricity generating device divided by the energy output that would be produced if it operated at its rated power output for the entire year [17].

Importance factor range: High

Importance factor rationale: Plant availability and capacity factor have a strong influence on the power generation costs. These are classified as a high importance factor because they can be directly related to superior operational success. Caution must be used in assessments and economic evaluations as described below.

Key topics:

— Expectations and experience in plant availability and capacity factor for similar installed units (from the IAEA Power Reactor Information System);
— Materials assessment and life expectancy;
— Design margins.

Key questions:

(1) What is the plant availability of existing plants of this type?
(2) What average plant availability and capacity factors will you achieve for the local conditions for this project facility, considering both technical capability and local regulations?
(3) What changes have been made to address past limitations to improve plant availability and capacity factors?
(4) What are the principal contributors to planned and unplanned capacity loss factors?

Evaluation expectations and relative comparisons: It is critical to ensure that a careful assessment be done to accurately predict the availability and capacity factors. Issues which should be accounted for are: (1) local conditions of operation to capture variations in plant thermal output (a site specific versus a generic calculation will give considerably more accurate information); (2) historical factors that depend upon local regulations and maintenance practices, so that a detailed review of the reasons for unavailability can be performed based appropriately on historical data from a country, region or company. Historical datasets may need to be adjusted based upon the reporting organization’s definitions of capacity and availability factors, which depend on a variety of plant capability conditions, including plant modifications over time, such as power up-rates or other operational considerations or changes.

4.1.4.9. Manoeuvrability

Description: The capability of the nuclear power plant to cope with varying demands from the grid.

Importance factor range: Dependent on locale

Importance factor rationale: The importance factor could be in the range of low to high. A grid with a high demand fluctuation will need manoeuvrability capability, so that the design features that support such operation could become critical to success. The evaluation needs to be done taking into consideration changes in demand across plant lifetime.

Key topics:

- Operational margins, design margins in normal operating modes;
- Load follow and related operational manoeuvrability versus specifications;
- Emergency remote shutdown requirements and capabilities;
- Waste generation;
- Fuel power and ramp rate limit constraints;
- Heat-up and startup, power ascension;
- Reactor normal shutdown and cooldown;
- Load rejection requirements versus capability;
- Steam bypass system requirements versus capacity;
- Impact of power generation by renewables on manoeuvrability needs.

Key questions:

(1) What are the load following capabilities of the plant and what is the experience of load following operation?
(2) What is the load rejection capability of the plant without shutdown?
(3) What are the operational margins of the design during normal full power and load follow operation?
(4) What are the capabilities for remote shutdown?
(5) How much increase in waste generation will be caused by load following (e.g. boron inventory management considerations)?
(6) Are there any concerns on fuel mechanical conditioning and capability during load following (e.g. pellet–cladding interaction)?

Evaluation expectations and relative comparisons: The experience base of the technology holder for this element needs to be established through reviews of technology holder information, historical experience and discussions with other operators of the equipment (or similar equipment) whenever possible. Evaluating the technical features and the key features of load follow without data from experience will be difficult. Careful consideration should be given to claims and historical data regarding fuel reliability in load following situations, ensuring that the experience is applicable to the proposed fuel design and operational modes.

4.1.4.10. Major systems and component evaluations

Description: Identification of major systems and components that deserve special attention and evaluation in comparison of the technology holder options under consideration.

Importance factor range: Function of level of detail in the treatment of specific design features in the evaluation process approach. Some assessments have used these evaluations as the groundwork for performing the assessment on a system by system and component by component level. This type of evaluation examines performance, reliability, constructability, nuclear safety, maintenance and other features based upon the presentation of these detailed design features. Importance factors should be assigned accordingly.

Importance factor rationale: The detailed evaluation described above will incorporate multiple importance factors across the spectrum of evaluations. A high level evaluation of systems and components, coupled to the broader set of technical element evaluations, would be assigned an importance factor range of medium.

Key topics: Key systems are identified for detailed system comparisons, and to provide key input to the detailed technology assessment process:

- NSSS;
- Conventional island;
- BOP;
- Instrumentation and control systems;
- Electrical systems;
- Containment and reactor building structures and layout.

Sample listings are provided in Annex I.

Key questions:

(1) What is the demonstrated in-plant operational experience for major systems and components? For components and systems that are newly designed, what are the rationale and pedigrees that support the design decisions?
(2) For the I&C systems, what are the architecture and the nuclear licensing basis?

Evaluation expectations and relative comparisons: These will depend upon the level of detail in the design evaluation approach as described above for the determination of the importance factor range.

4.1.5. Nuclear fuel and fuel cycle performance

Description: All operations associated with the production of nuclear energy, including: mining and processing of uranium or thorium ores; enrichment of uranium; manufacture of nuclear fuel; operation of nuclear reactors (including research reactors); reprocessing of spent fuel; all waste management activities (including decommissioning) relating to operations associated with the production of nuclear energy; and any related research and development activities [12].

Importance factor range: Medium

Importance factor rationale: The importance factor recognizes that fuel costs are small in comparison to capital costs for the facility. Once the facility is in operation, however, the performance of the fuel and the fuel cycle, and the in-plant management of fuel can have a major impact on plant operation and operating costs. Therefore, the comparative offerings and technology holder experience with regard to fuel and fuel cycle performance is important.

Key topics:

- Considerations related to the design, procurement and operating experience for the nuclear fuel — materials, fabrication, operational expectations and experience;
- Flexibility of plant operation with respect to different fuels, including higher enrichment levels or mixed oxide (MOX) fuels;
- Services offered for the front end and back end supply;
- Availability and competitiveness of different fuel materials and components for the facility design;
- Assurance for fuel supply and for availability of related component and replacement parts;

— Agreements with UF_6 and associated fuel product suppliers;
— Demonstrated ability to manufacture fuel bundles;
— Characteristics of primary and alternate fuel and materials suppliers;
— Experience with similar fuel;
— Length of refuelling cycle and economic evaluation;
— Special nuclear materials management;
— Impact of the fuel cycle on the facility operation, including refuelling outage frequency and duration, fuel storage throughput requirements, spent fuel pool storage capacity, dry fuel storage requirements;
— Potential for increasing the spent fuel pool storage capacity in the future;
— Dry fuel storage experience base.

Key questions:

(1) What is the proposed fuel cycle length? What is the potential for fuel cycle length extension?
(2) What are the expected refuelling batch sizes and enrichments to achieve the proposed fuel cycle length? What assumptions about capacity factor during operation are made in this calculation?
(3) What is the expected fuel cycle outage duration? What assumptions are made for fuel movement and manoeuvrability in the fuel outage? Is full-core discharge assumed in the refuelling plan? What is the industry experience base for refuelling cycle lengths and refuelling outages for this facility design?
(4) What is the fuel design type and what is the industry experience with this proposed fuel design? Are there any fuel design changes that are being proposed for this reactor design that have not been demonstrated through industry experience?
(5) What are the assembly-average and peak-rod fuel burnup values?
(6) What are the design and licensing features that limit fuel burnup?
(7) Which fuel suppliers have fabricated fuel that has operated successfully in this reactor design type?
(8) Describe the supply chain for fuel product material supply and manufacture, including the duration and stability of the supply chain relationships.

Evaluation expectations and relative comparisons: The evaluation should address:

— Availability of fuel supply;
— The technology holder’s experience: (i) in fabricating fuel; (ii) with in-reactor fuel performance with similar fuel; and (iii) with the fuel shuffle plans necessary to achieve the proposed cycle length;
— Support in dealing with spent fuel.

4.1.6. Radiation protection

Description: The protection of people from the effects of exposure to ionizing radiation, and the means for achieving this [12].

Importance factor range: Medium

Importance factor rationale: Individual characteristics of the radiation protection design and planning may show important variance among designs; however, in the general radiation protection programme, it is expected that radiation protection in the work environment will be maintained. Therefore, the differentiation is expected to be in the medium range.

Key topics:

— Separation of clean and radiation areas; radiation area zoning in the design plan;
— ALARA (“as low as reasobaly achievable”) and radiation protection procedures, shielding and radiation monitoring implementation in design, including rationale for ALARA improvements via design;
— Procedures and shielding required for exposure reduction during operation, refuelling and maintenance;

— Remote maintenance equipment design and usage;
— Access control and layout design criteria;
— Estimated total annual site personnel dose exposure;
— Personnel exposure estimates during operation, refuelling and maintenance activities;
— Available projections versus actual exposure and exposure reduction comparisons during operation, refuelling and maintenance activities;
— Post-accident vital areas accessibility and shielding.

Key questions:

(1) What information is available for each of the key topics, and demonstrates clear benefits with regard to comparative dose reduction and ALARA application?
(2) Under which ICRP (International Commission on Radiological Protection) standard was the plant designed?

Evaluation expectations and relative comparisons: Examine carefully dose evaluation bases with the goal of validating estimates versus actual experience from radiation protection programmes and personnel exposure.

4.1.7. Environmental impact

Description: The adverse effects of the nuclear power plant on its surrounding environment during the plant lifetime.

Importance factor range: Low

Importance factor rationale: Individual components within the environmental impact evaluations may show important variance among designs; however, in the general environmental assessment, the differentiation is expected to be in the low to moderate range.

Key topics:

— Water usage, impact on aquatic life, birds, plants and animals;
— Visual impact expectations versus projections;
— Impacts on wetland and natural terrain;
— Radiological releases to the environment (normal operation and accident);
— Effect on local industry and economy;
— Archaeological impact assessment (owner/operator responsibility).

Key questions:

(1) Provide impact projections related to the topics above, as appropriate for the facility design, including:
   (a) What are the off-site release limits during normal operation?
   (b) What are the effects on the site and its environs during construction?
   (c) What are the environmental effects during operation, including radiological and thermal discharge?

Evaluation expectations and relative comparisons: Compare and contrast the features provided for each of the key topics.

4.1.8. Safeguards

Description: An extensive set of technical measures by which the IAEA independently verifies the correctness and the completeness of the declarations made by States about their nuclear material and activities [18].

Importance factor range: Not a strong differentiator

Importance factor rationale: IAEA safeguards will be applied to materials and facilities placed under Agency safeguards by a State or States [18]. Therefore, this feature should not be a differentiator.

Key topic:

— Design features incorporated to facilitate the implementation of IAEA safeguards.

Key question:

(1) What specific features are included in the design to facilitate implementation of IAEA safeguards? (see Ref. [19]).

Evaluation expectations and relative comparisons: This element should not be a differentiator, unless there are factors which would hinder application of IAEA safeguards.

4.1.9. Plant and site security

Description: The prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities [12].

Importance factor range: Low

Importance factor rationale: Although there may be differences in the details of the security plan and systems, it is expected that site security will be achieved by the responsible authorities.

Key topics:

— Security plans (note: the evaluation of all physical security systems should be performed under a confidential process, independent of the rest of the technology evaluation process).
— Integrated plant access control system to include in the general plant design, for example:
  - Perimeter fences and roads;
  - Perimeter detection systems;
  - Closed circuit television (CCTV) control and recording system;
  - Security dedicated lighting system;
  - Supervisory security system;
  - Plant access detection.
— Diversity and redundancy of security facilities.
— A dedicated security communication system with external support services:
  - Police;
  - Fire;
  - Emergency medical;
  - Regulatory and government agencies.
— The security access building and related security facilities design against security related threats.

Key question:

(1) What programmes and facilities for site security are provided?

Evaluation expectations and relative comparisons: This element should not be a differentiator, unless the security provisions are significantly deficient or will not be amended to conform.

4.1.10. Owner's scope of supply

Description: The responsibilities of the owner/operator are defined to ensure understanding of the obligations and opportunities associated with the successful progress and completion of the facility. This includes the owner/operator requirements for design, construction and operational startup testing.

Importance factor range: Medium

Importance factor rationale: This will determine the degree of involvement of the owner. The lack of clear definition of interfaces can lead to significant issues.

Key topics:

— General level of owner/operator involvement;
— Owner/operator options related to site infrastructure;
— Owner scope for BOP;
— Simulator and training facilities;
— Owner oversight of engineering, procurement, construction facilities and construction labour;
— Division of responsibility on major tasks of construction and operational startup testing.

Key questions:

(1) What are the technology holder expectations regarding owner/operator scope?
(2) What activities must the technology holder manage? What activities does the technology holder not plan to manage?
(3) What programme is proposed for interface and integration between the owner/operator and the technology holder?
(4) What owner/operator tasks would the technology holder prefer to assume and what are the proposed cost estimates?
(5) How does the technology holder propose to limit project risks due to the owner/operator programmes and interface?

Evaluation expectations and relative comparisons:

— Owner requirements in design and construction for BOP, site preparation, infrastructure and site facilities, including for training and the simulator and training facilities;
— Impact of different designs on owner/operator responsibility;
— Owner oversight of engineering, procurement and construction.

4.1.11. Supplier/technology holder issues

Description: Strength of the relationship between the technology holder and its suppliers, including an assessment of the capabilities and history of the suppliers, the duration of the relationship, and any quality or schedule issues or advantages based upon current data or relevant experience record.

Importance factor range: High

Importance factor rationale: This speaks directly to the ability of the technology holder to deliver the plant as specified.

Key topics:

- — Clear delineation of responsibilities related to the technology holder's scope of supply, to include programmes on quality, subcontractor relationships and key personnel assignments.
- — Contract model acceptable to technology holder: turnkey, supply package, multi-package, direct open book negotiation, build–own–operate, build–operate–transfer.
- — Risk sharing and means of dispute resolution.
- — Plant contractor: reactor technology holder as the only contractor, consortium/joint venture (JV) between reactor technology holder and turbine island (TI) manufacturer; other consortium/JV arrangements (e.g. including construction companies).
- — One-step bidding process (commercial and technical bids to be submitted and evaluated at the same time) or two-step bidding process (technical bid submission and evaluation (step 1) followed by the commercial bid submission and evaluation (step 2)).
- — Recent experience of technology holder and main subcontractors.
- — Experience of key personnel.
- — International political impacts.
- — QA oversight and review of suppliers.
- — Prioritized near and long term suppliers for key components and parts.
- — Long term supply chain assurance.
- — Warranties:
  - • Corrective action programme;
  - • Equipment commercial grade dedication;
  - • Industrial safety programmes and achievement record.
- — Nuclear safety programmes.
- — Corrective action programme.
- — Safety conscious work environment (SCWE) programme.
- — Employee concerns programme.
- — Construction QC programmes.
- — Subcontractor quality, safety, SCWE, concerns and corrective action programmes.

Key questions:

(1) What kind of delivery contracts would you require/offer?
(2) What supply chain arrangements have you used/will you use in the project?
(3) What partnerships have been established or will be established to support this project?
(4) Who takes the risk with regard to the assurance of supply of components and parts?
(5) How will the architect/engineer/technology holder handle QA for lower level/domestic components?
(6) How will export control issues of sensitive technology be addressed?

Evaluation expectations and relative comparisons: Compare the technology holder scope of supply, including programmes on quality, subcontractor relationships, personnel assignments, employee programmes, safety practices and record, and process and schedule controls.

4.1.12. Project schedule capability

Description: Ability for all aspects of the facility project including design, construction and operation to be delivered on the committed schedule.

Importance factor range: Medium

Importance factor rationale: This speaks directly to the ability of the technology holder to deliver the plant as specified for schedule and cost.

Key topics:

— Schedule for procurement of long lead time items;
— Site preparation schedule;
— Critical path identification and contingency plan development;
— Impact of local conditions — for example, accommodation for labour laws, weather or transportation infrastructure;
— Integrated project schedule, including engineering, procurement, construction, startup;
— Scheduling tools and software for scheduling and analyses.

Key questions:

(1) What are your methods for project scheduling and what is the corporate experience in their application?
(2) What is the historical and recent experience in project planning and actual schedule conformance for projects of this type? For other projects of similar size and duration?
(3) What project management methods are used for ensuring contractor performance with respect to schedule and quality?
(4) What is the historical and recent experience in contract project management for projects of this type? For projects of similar size and duration?

Evaluation expectations and relative comparisons: Evaluate the schedule for procurement of long lead time items and site preparation, with critical path and contingency. Examine the integrated project schedule and experience base, including engineering, licensing, procurement, construction and startup.

4.1.13. Technology transfer and technical support

Description: Technology holder technology transfer of design features for related design, construction, and facility operating and refurbishment requirements. Technical support available from comparable plant operators, including industry groups enabling standardized plant cooperation or shared operational and support experiences.

Importance factor range: High

Importance factor rationale: In terms of technology transfer, this is a direct function of the national policy of the Member State. The technical support is a key requirement to confirm long term reliable operation of the plant.

Key topics:

— Technical support capability provided by or transferred from the technology holder.
— Transfer of the tools and the technology that developed, comprise and support the design bases.
— Technical or operational support programmes available through owner/operator contacts, especially those which can or will be provided through other owner/operators.
— Technical or operational support programmes available through technology holder contacts:
  • Experienced utility or owners groups available for technical support;
  • Other regulatory or operational affinity support groups;
  • Industry support group programmes specific to the design — through WANO, INPO, EUR, EPRI.
— Facilities or assets that can be used for technical support organizations.
— Ease of technical support, such as local language, regional presence and programme resources.

Key questions:

(1) What are the technology transfer opportunities to be offered with this project and design?
(2) What constitutes the extent of the design basis and in what form will the design basis be transferred to the owner/operator?

(3) What technologies (software, design documents, design tools) will be provided to support the facility's design?
(4) What technical or operational support programmes will be available through owner/operator contacts?
(5) What support and technology is offered to support future required modifications to the design basis?
(6) What technical or operational support programmes will be available through technology holder contacts with partner suppliers?

Evaluation expectations and relative comparisons: The evaluation should examine the effectiveness of the technology holder's programmes to share technology and to support capacity building related to design, construction, manufacturing and technology details. The scope and interest of technology transfer should be requested and assessed, considering the vision for the future nuclear programme.

4.1.14. Project contracting options

Description: Capital payment structure and project financing opportunities.

Importance factor range: High

Importance factor rationale: This factor relates directly to the project affordability and the related financial closure.

Key topics:

— Technology holder's available financing options for project development and construction;
— Related financing or participation proposals or opportunities;
— Country of origin of financial support.

Key questions:

(1) What financing arrangements and terms are available from the technology holder?
(2) Are any government guarantees or undertakings required?
(3) Does the technology holder's government offer any guarantees or undertakings?
(4) What types of construction contracts are required/offered (e.g. turnkey with fixed price and dates, guarantees and penalty for time, budget and quality)?

Evaluation expectations and relative comparisons: This evaluation should address the contract options offered by the technology holder, and the country of the technology holder, with regard to financing, project participation, guarantees and type of construction contract offered, and technical support during commissioning, startup and operation.

4.1.15. Economics

Key economic considerations:

— Calculated levelized costs;
— Capital costs;
— O&M costs;
— Fuel costs;
— Decommissioning costs.

4.1.15.1. Capital costs

Description: Site specific facility capital costs.

Importance factor range: High

Key topics:

— Capital component of levelized cost of power;
— Comparison of material quantities;
— Impact of local labour and productivity;
— Cost of licensing;
— Plant design and costs include Fukushima related safety improvements;
— Ensuring that all necessary equipment is included in the cost estimate, or that there is no ‘missing equipment’ (e.g. hydrogen recombiners);
— Assurance of reliable estimates of technology holder equipment prices.

Key questions: What are the expected capital costs for the proposed facility (cost/kW(e))? (Note: To understand what the technology holder has included in this cost information, it could be helpful to ask for this information according to a standard account system. One such system is the IAEA account system for nuclear power plants that is given in Ref. [20].)

(1) What are the major material quantities and do they align with the projection of expected capital costs?
(2) What are the labour cost estimates used in projecting the capital costs, and the supporting rationale?
(3) What is the expected capital cost of the *n*th of a kind (NOAK) unit versus the cost of the first of a kind (FOAK) unit?

Some background information on means of achieving good economic performance while meeting stringent safety standards is provided in Ref. [21].

Evaluation expectations and relative comparisons: Identification of capital costs and cost impact factors, including material quantities, labour and equipment.

4.1.15.2. Operation and maintenance (O&M) costs

Description: Site specific facility O&M costs.

Importance factor range: Medium

Importance factor rationale: O&M cost impact is secondary to facility capital costs.

Key topics:

— Evaluation of projected O&M with comparisons to experience;
— Staffing;
— Plant design features to reduce O&M cost;
— Impact of localization versus O&M contract;
— Opportunities and costs for shared spare parts pool;
— Reliance on passive design and redundant system trains to optimize operation and maintenance on-line;
— Optimized outage schedules based on equipment performance and trending data, real and historic.

Cost factors:

— Annualized O&M cost (cost/kW·h);
— Operations, maintenance, security, engineering, management, staff costs;
— Operations chemicals (feedstocks) and maintenance materials;
— Replacement equipment and spare parts;

— Utilities, supplies, miscellaneous consumables;
— Capital plant upgrades (not including financing costs);
— Taxes, insurance, regulatory costs;
— Contingency on annualized O&M costs.

Key question:

— What is the technology holder's estimate of the O&M cost advantage or penalty for the proposed facility (cost/kW·h) versus the O&M costs reported for today's fleet?

Evaluation expectations and relative comparisons: The evaluation should examine the technology holder's prediction of the O&M cost, and also identify the basis for the prediction.

— Evaluation of projected O&M with comparisons to experience.

4.1.15.3. Fuel costs

Description: Facility nuclear fuel cycle costs.

Importance factor range: Medium to low

Importance factor rationale: Fuel cost impact is secondary to facility capital costs.

Key topics:

— Fuel costs projected with comparisons to applicable current experience;
— Fuel burnup and plant efficiency;
— Impact of raw material price variations;
— Trade-off between cycle length and outage times;
— Spent fuel capacity;
— Contractual opportunities for fuel supply and spent fuel disposal;
— Competitive advantage between original equipment manufacturers and other suppliers/fabricators.

Key questions: In addition to fuel cost analysis preparation:

(1) What fuel supply arrangements would you offer/require?
(2) Would you take back spent fuel?

Evaluation expectations and relative comparisons: Fuel costs are a key benefit to the selection of nuclear power plants. When the plant is in operation, fuel costs account for a high fraction of the variable operating costs. Therefore, the evaluation should identify those technical or contractual arrangements that can lower fuel costs for each technology option. Economic evaluation of fuel costs may be performed by:

(1) Comparisons of fuel cost estimates provided by each technology holder;
(2) Comparisons of fuel costs provided in contract, if fuel supply contracts are to be requested in the offerings;
(3) Fuel cost analyses, derived from prospective materials costs as developed in the technology holder proposals to meet the specifications in the request for proposal;
(4) Fuel cost evaluations as developed by consultants or the assessment team.

Contractual opportunities between options should be differentiated, including the use of alternative fuel technology holders.

Security of fuel supply for the reactor technology should be evaluated.

Other factors to consider are:

- — Fuel costs projected with comparisons to applicable experience;
- — Contractual opportunities for fuel supply and spent fuel disposal;
- — Competitive advantage between original equipment manufacturers and other suppliers/fabricators.

4.1.15.4. Decommissioning costs

Description: Facility decommissioning costs.

Importance factor range: Not a strong differentiator

Importance factor rationale: Decommissioning costs are long term, a small component of overall costs, and should not differ greatly between designs and offerings.

Key topics:

- — Major decommissioning expenditures start near the end of the facility lifetime, but the funds for covering the expenses are generally accumulated during operation;
- — The national policies, industrial strategies and cost estimation models adopted or assumed for decommissioning projects vary widely.

Key question:

(1) What is the projected decommissioning and decontamination funding requirement at the end of the facility lifetime? As a percentage of the total direct capital cost?

Evaluation expectations and relative comparisons: Economics estimates of decommissioning costs can be developed. Good practice in design should incorporate features to minimize decommissioning costs and burdens. Since decommissioning costs are collected during, but expended following, a 60 year plant lifetime, this implies a relatively small impact on levelized energy generation costs.

5. INTEGRATED TECHNOLOGY ASSESSMENT METHODS

This section describes the types of methods that may be utilized to perform quantitative analysis in the RTA. A general discussion of the rational decision making process is presented. The features of the process that are recommended for RTA are then described. Example applications developed for this type of work are provided in Annex III.

5.1. EVALUATION APPROACHES FOR THE INTEGRATED TECHNOLOGY ASSESSMENT

5.1.1. Rational decision making process

The following comprises the basic steps in a rational decision making process [22]:

- — Define the situation/decision to be made;
- — Identify the important criteria for the process and the likely (or desired) range of outcomes;
- — Assign scores in a consistent fashion and normalize appropriately to avoid introducing bias;
- — Consider all possible solutions;

— Calculate the consequences of these solutions with respect to their likelihood of satisfying the criteria;
— Choose the best option.

This process generally employs a decision matrix or selection matrix which displays each evaluation criterion (or elements/features) for each of the options to be assessed. The simple approaches assign numerical scores or rankings to each criterion and add the results to derive an overall score or ranking.

In most decision making approaches, a relative importance is assigned to each criterion to be considered. Next, each of the options (in the case of RTA, the options are nuclear power plant designs) are evaluated on a comparative or absolute performance basis and scored for each of the criteria and these scores are presented in the first matrix. A second matrix is developed to incorporate the importance weighting of each criterion or set of criteria. The option that scores the highest weighted summation becomes the selection recommendation.

A rational decision making process presupposes that there is one best outcome. Because of this assumption, it is often classified as an optimizing decision making process. Such a process also assumes that it is possible to consider each of the criteria for every option and also to know or predict the future consequences of each. Certain criteria may be difficult to quantify or even compare. These processes may become very complex, require a large resource commitment of personnel and time, and generate a great deal of information. And finally, a rational decision making process is meant to negate the role of emotions in decision making.

The work here is aimed at recognizing these potential issues and developing appropriate assumptions, methods and constructs to simplify the complexities where possible. The decision making process for an RTA can be summarized in the eight-step model shown in Table 11.

5.1.2. Decision making processes best suited for reactor technology assessment

A number of processes have been reviewed which may be applied to RTA [23, 24]. Each follows the basic steps outlined above. The processes for this application may be differentiated on the basis of:

— Degree of quantification versus qualitative evaluation (qualitative approach);
— Decision making using common metric (cost–benefit, net present value evaluations);
— Complexity of model building (analytic hierarchal process);
— Kepner–Tregoe expert scoring and evaluation approach — scoring and weighting is ‘simple’, but is generally completed with the assistance of experts (e.g. what is the basis of 8 versus 10?);
— Detail and complexity of criterion or measures (multi-attribute utility theory).

TABLE 11. DECISION MAKING PROCESS: AN EIGHT-STEP PROCESS [23]

Step	Action
1	Define the problem
2	Determine the requirements that the solution to the problem must meet
3	Establish goals that solving the problem should accomplish
4	Identify alternatives that will solve the problem
5	Develop evaluation criteria based on the goals
6	Select a decision making tool
7	Apply the tool to select a preferred alternative (evaluate the alternatives against criteria)
8	Check the answer to make sure it solves the problem (validate solution(s) against the problem statement)

5.2. USING THE KEPNER–TREGOE METHOD

In the Kepner–Tregoe method the selection is done first by defining decision categories for each criterion using the following considerations. For certain strategic requirements or criteria, it may be established that the technology holder ‘must have’ them as a prerequisite to further consideration of the technology option (also called ‘rejection criteria’). For the next tier of criteria, which are termed operational objectives, the technology holder will strive to provide them as close to the ‘want to have’ requirements as possible; however, if the match is not perfect, the technology could still cover the risk. In this case the level of satisfaction of fulfilling each requirement or criterion is defined by a set of numerical scores. The Kepner–Tregoe methodology recommends deriving the measure of the level of satisfaction using numerical values from 1 to 10.

The next step is to score each set of criteria or requirements for each technology option against the level of satisfaction measures. In performing this task, it is first necessary and recommended that any alternative that does not meet the ‘must have’ or ‘rejection’ criteria be eliminated. Then, for the remaining technical options the analysts examine each suitable requirement or criterion one by one, rating them using the level of satisfaction measures within a scale of 1 to 10 to derive the satisfaction level score. Finally, the overall decision analysis ranking is derived by multiplying the weighting factors chosen for each requirement or criterion by the satisfaction level score to derive the composite weighted score for each technology option.

The methodology is intended to incorporate one additional feature: once the top candidate options are selected, these options are further evaluated in terms of downside risk potential. The assessment team would be charged with determining these risk factors and evaluating the downside risk versus the comparative upside potential that has been determined for each option. In most applications the consideration of downside risk is used only as a confirmation check of the final rank order of the options. Sensitivity studies can also be done to evaluate risk factors that may be assigned to the selection of the weighting factors or to the scoring values of the basic requirements or technology elements. This methodology has been applied in the selection process for new reactor design technology by one US utility company. Although the details of the work and its results are proprietary, the Kepner–Tregoe techniques were used to perform the quantitative evaluation of several technology options [25, 26]. This is discussed further in Annex III.

5.3. USING THE MULTI-ATTRIBUTE UTILITY THEORY METHOD

Multi-attribute utility theory (MAUT) is a quantitative comparison method used to combine dissimilar measures of costs, risks and benefits, along with individual and stakeholder preferences, into high level, aggregated preferences.

The foundation of MAUT is the use of utility functions. Utility functions transform diverse criteria to one common, dimensionless scale (0 to 1) known as the multi-attribute ‘utility’. Once utility functions are created, an alternative’s raw data (quantitative) or the analyst’s beliefs (qualitative) can be converted to a utility score that ranges between zero (bad) and unity (perfect). As with the other methods, each of these criteria is weighted according to importance. To identify the preferred, multiply each alternative’s utility score results for all of the criteria that were assessed, and then sum these products. The preferred alternative will have the highest summation score.

Utility functions (and MAUT) are typically used when quantitative information is known about each alternative, which can result in firmer estimates of the alternative performance. Utility graphs are created on the basis of the data for each criterion. Every decision criterion has a utility function created for it. The utility functions transform an alternative’s raw score (i.e. dimensioned — feet, kilograms, litres per minute, dollars, etc.) to a dimensionless utility score that may range between 0 and 1. The utility scores are weighted by multiplying the utility score by the weight of the decision criterion, which reflects the decision making support staff’s and decision maker’s values, and totalled for each alternative. The total scores indicate the ranking for the alternatives.

The MAUT evaluation method is suitable for complex decisions with multiple criteria and many alternatives. Additional alternatives can be readily added to a MAUT analysis, provided that data are available to determine the utility from the utility graphs. Once the utility functions have been developed, any number of alternatives can be scored against them.

The simple multi-attribute rating technique (SMART) can be a useful variant of the MAUT method. This method utilizes simple utility relationships. Data normalization to define the MAUT/SMART utility functions can be performed using any convenient scale. Five, seven and ten point scales are the most commonly used. In a classic MAUT the full range of the scoring scale would be used even when there was no real difference between alternative scores. The SMART methodology allows for use of less of the scale range if the data do not discriminate adequately, so that, for example, alternatives which are not significantly different for a particular criterion can be scored equally. This is particularly important when confidence in the differences in data is low.

In these cases, less of the range is used to ensure that low confidence data differences do not present unwarranted large discriminations between the alternatives. When actual numerical data are unavailable, subjective reasoning, opinions and/or consensus scoring can be substituted and documented in the final report instead. Research has demonstrated that simplified MAUT decision analysis methods are robust and replicate decisions made from more complex MAUT analysis with a high degree of confidence.

5.3.1. Developing utility functions for MAUT: Averting biases and establishing good practices

5.3.1.1. Selecting the scoring approach

The objective is to establish a consistent scoring approach that will be used for assigning the achievement score for each feature. The rating or grading scoring system for the selected elements should be consistent across all elements, so that no bias is inadvertently introduced in the evaluation.

The importance or weighting values are to be established separately from the evaluation or scoring of merit, elements or features. Modifying the scoring approach from one feature to another is a way in which bias may be introduced and should be avoided. Examples of poor practices that will cause an error in constructing the evaluation process are:

- Setting the scoring value range differently for the elements that are perceived to have lesser or higher importance:
    - Choosing a lower and narrower range to apply for less important features (say, 1–5) and a broader range (say, 1–10) for more important features. The numerical scoring ranges that are assigned (lower and upper bounds) should always the same.
- Setting the range differently for the elements that may be quantified more easily or lend themselves to an analytical evaluation approach and then choosing a lower or narrower range to apply for qualitative features:
    - For example, since qualitative evaluation is a coarse process, selecting generally a narrower band (say, 1–5), but for features that are quantified with greater precision or through more complex formulae, selecting a broader range (say, 1–10) to be certain to capture the detailed results. Again, the numerical scoring ranges that are assigned (lower and upper bounds) should remain the same for both these types of features.

5.3.1.2. Common acceptable approaches for evaluation of merit or scoring

Typical ranges may be 1–5 or 1–9. These ranges are convenient because they have an integer midpoint, they have well accepted verbal designations and they relate easily to a qualitative scoring approach: the quartile system. A ten point scoring system can be set both in integers (0 being unacceptable, 5 as average and 10 being superior) and as a percentage based scoring system (0, 50 and 100%). Figure 3 provides visualizations of five point and nine point scoring systems.

5.3.1.3. Identifying consistent scoring of features across the selected range

Once the scoring approach for the evaluation of merit is chosen and the range for the scoring system is selected, it is important to carefully establish the figures of merit for the lower and upper boundaries of the range. These should be consistent with either the acceptable or the expected range of values for the elements.

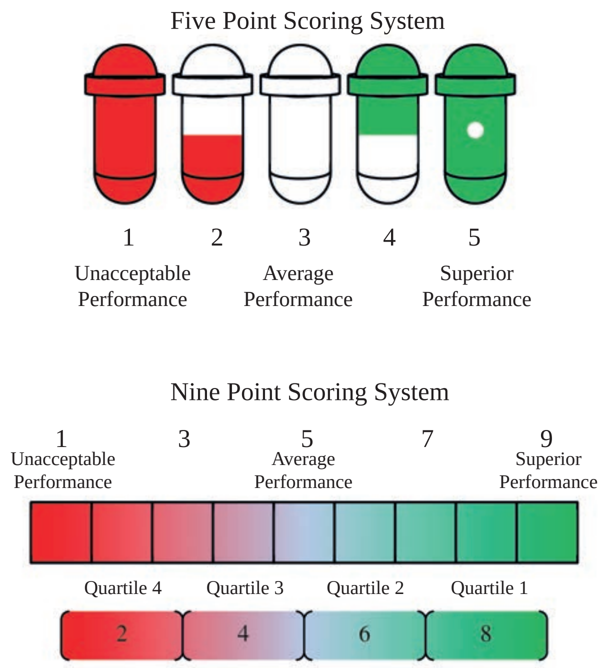

FIG. 3. Level of satisfaction scoring system.

5.3.1.4. Determining the metrics

(1) Setting the range (or consideration for the metric):
For example: capacity factor or availability factor: (0.8–0.95);
Outage length (on 18 month cycle, including refuelling and typical maintenance): 15–30 days.

(2) Three common ways to frame the extent of the range:
- (a) Use the industry performance;
- (b) Use a reasonable history (period);
- (c) Use reasonable ranges for common technology;

(Note: Consider performance differences between regions, environs, regulatory practices.)
Cautions:
- (a) It is not reasonable (and potentially will create a bias) to select too wide or too narrow a range. For example, setting the range for capacity factor from 0 to 100% will assign high values for performance for all candidate technologies. This approach (i) will not differentiate this feature well between candidates and (ii) will overweight capacity factor compared with other factors under consideration.
- (b) Setting the boundaries of the range at the low and the high values of the candidate technologies can be a viable approach:

A	B	C	D	E
94%	92%	95%	90%	91%
High				Low

However, this approach creates two important limitations:
- (i) It will limit the opportunity to easily conduct meaningful sensitivity studies, since values which need to be considered will be outside the range;
- (ii) It creates a model construction that is dependent on the input values so that the model will need to be adjusted if the data change or additional candidate technologies are added, or when candidates are eliminated.

(3) One end of the range can be set at the ‘boundary of the acceptable range’. That is, annual average capacity factor values of less that 80% may appear in the industry database, but would be considered unacceptable for

the project under consideration. This would then be a reasonable value to set for the lower boundary of the acceptable range. The other boundary, in this case the upper boundary of the acceptable range, may be set on the basis of credibility or uncertainty of the value. As examples:

(a) The assessment team could conclude that for the technology under consideration, annual average capacity factor values of greater that 97% are unrealistic. Therefore, if a technology holder insists that the performance achieved will be above this range, the credit will be limited to the upper boundary of the range (97%).

(b) The team could conclude that a core melt frequency (CMF) value for internal events, excluding fire, of greater than 5×10^{-5} is unacceptable (upper boundary), and that reported CMF values of less than 5×10^{-7} may be considered the result of variations in methodology or data that cannot be verified and beyond the limits of what should be considered as validated values (lower boundary).

(4) If the conclusion is that the technology performance is satisfactory when meeting the national regulatory limits (e.g. radioactive or thermal releases to the site and environs), then the assessment need only confirm that technology holder’s assertions are correct and that these limits are achieved. If the margin of the expected performance to these limits is not considered a matter of importance, then the performance parameter that is being judged will not be a differentiator.

5.3.2. Defining elements for the MAUT and Kepner–Tregoe approaches

Usually no one alternative will be the best for all goals. This will then require alternatives to be compared with each other on the basis of each of the criteria. The best alternative will be the one that most nearly achieves the project goals.

The elements should be:

— Able to discriminate among the alternatives;
— Complete — the set of elements should address all goals;
— Operational — meaningful to the decision maker’s understanding of the implications of the alternatives;
— Non-redundant — to avoid double counting;
— Few in number — to keep the problem dimensions manageable.

Using a few real discriminators will result in a more understandable decision analysis product. However, every goal must generate at least one element. If a goal does not suggest an element, it should be abandoned.

Several methods can be used to facilitate criteria selection:

— Brainstorming: Team brainstorming may be used to develop goals and associated element.
— Round robin: Team members are individually asked for their goals and the elements associated with them. The initial elicitation of ideas should be done non-judgementally — all ideas are recorded before criticism of any is allowed.
— When members of the goal setting group differ widely in rank or position, it can be useful to employ the military method in which the lowest ranking member is asked first to avoid being influenced by the opinions of the higher ranking members.
— Reverse direction method: Team members consider available alternatives, identify differences among them and develop criteria that reflect these differences.
— Previously defined criteria: End users, stakeholders or the decision maker(s) may provide criteria.

Input from the decision maker(s) is essential to the development of useful criteria. Moreover, the decision maker’s approval is crucial before the criteria are used to evaluate the alternatives.

5.4. TREATMENT OF POLICY, RISK AND UNCERTAINTY

Section 3.3.2 and Table 4 introduce the importance of including key elements of risk and uncertainty as non-technical factors in the decision making process. As described, there are a wide variety of factors that may influence the decision.

5.4.1. Risk considerations

For the present purposes, the treatment of these non-technical factors will be completed in what is termed the risk assessment portion of the decision making process. In some cases these factors may determine the final outcome or decision; in other cases they may be a strong influence that requires consideration in the decision. The evaluation approach accommodates these types of factors in an integrated RTA. The evaluation examines technology with respect to the goals and requirements of the Member State, incorporating risk considerations as a part of the decision process.

Tables 4 and 8 present a variety of decision making elements. Those that are important to include in the evaluation should be selected, rank ordered and weighted for importance using a process similar to that applied to the technical elements. Requests for additional information and key factors to include in technology holder proposals, as well as questions to help differentiate the technology holder offerings, should be prepared. For example, the inquiry may include the following for nationalization and localization evaluations. The proposals should elaborate the consequential benefits for capacity building in engineering, manufacturing and construction, operations, and maintenance.

(1) What are the short and long term benefits to local and regional community infrastructure development?
(2) Does localization (i.e. use of local labour force and local industries) reduce the costs or schedule for this project?
(3) Does localization improve the quality within this project?
(4) What is the long term benefit of localization (given that the costs of this project may be higher as a result of localization)?
(5) What is the long term potential for localization (potential for becoming a component supplier in the future)?
(6) Is there an established policy of cooperation for national participation with respect to technology transfer and infrastructure development?
(7) What are the recommended localization and regional plans and impacts anticipated for this project?

Similarly, the following example questions could be identified in relation to technology transfer offerings:

(1) Who will be the design authority during operation?
(2) Will the technology holder transfer design documents to the owner/operator?
(3) What support will the technology holder provide to domestic industries?
(4) What support and technology are offered to support future required modifications to the design basis?

5.4.2. Decision maker influences

The traditional model for the RTA assumes that the stakeholders in the process are:

— The owner/operator as the decision maker;
— The technology holders, architecture engineers and consultants as the suppliers of the technology and the information bases that feed the decision;
— The regulatory agency as an external influence on the decision process.

Another circumstance that must be considered is the case where the government takes a position of strong influence and/or is directly associated with the decision making process. In this case the decision may be made as part of a governmental process, either in conjunction with or on behalf of the operator/utility. The decision related to technology choice could be influenced more strongly by governmental structure or processes, the Member

State’s energy development programme or mission, or the status or structure of the Member State’s economy and technology development programme, for example.

A similar influence may develop in newcomer Member States due to the status of the country’s infrastructure development or to the nature of the infrastructure development process itself. An example of this situation could arise when early infrastructure development or negotiation establishes or affects relationships that may promote a certain technology, design or manufacturer. Once the relationship or influence is established, it may be difficult to change. The decision making process needs to consider the proper way to treat these circumstances. Again, even though in this case the final technology decision may be constrained or even predetermined by these circumstances alone, employing the features of the integrated RTA process can still add value to the nuclear power programme development and implementation.

5.4.3. Treatment of uncertainty

In the process of performing the RTA applications described in this report, there are uncertainties that can be identified with either the technical input for the analyses or the importance factors that are assigned to the elements or factors under consideration. It is important to recognize that these uncertainties exist and to investigate them. Secondly, there are ways in which these uncertainties may be considered in the integrated assessment. The evaluation approach that is recommended employs a direct treatment of uncertainty through the use of sensitivity studies. Although there are more elaborate techniques and mathematical constructs that may be considered to treat uncertainties, experience has shown that this extra effort rarely changes the final decision.

5.4.4. Importance of reactor technology assessment given risk and uncertainty considerations

As described previously, several benefits can be derived as a result of applying a formal RTA process. In general terms, these outcomes include a much better understanding of the reactor technology decision and, in particular, how well the chosen technology meets the goals and objectives of the project plan. Knowing these results allows the owner/operator to better evaluate the actual performance of the technology, to make wise choices to close any gaps between the expected and actual performance in construction or operation, and to establish a continuous improvement programme to optimize future benefit and quality in operations.

If risk factors such as those described in Section 3.3.2 and Tables 4 and 8 drive the decision making process, there may be a tendency to bypass the performance of the RTA or to set aside the results of the technical evaluations in the RTA. This approach would be short sighted, as it will diminish the capacity building benefits that should result from this application. Employing a structured technique to explore and document the strengths and weaknesses of the selected technology, especially in comparison with the owner/operator’s initial expectations or desires, should always produce beneficial outcomes.

Appendix

TECHNOLOGY ASSESSMENT EXAMPLE WORKSHEET

This integrated technology assessment is designed to demonstrate the application of the RTA decision analysis methods and approaches described in Section 5 as applied to the elements presented in Sections 3 and 4.

A.1. EXAMPLE APPLICATION

The methodology described below and displayed in Table 12 is one possible numerical approach to undertaking an RTA and evaluating a number of candidate designs. This example has been populated with the elements, features and subfeatures using the example policy objectives and key topics from Sections 3 and 4. A Member State would be expected to develop and use a different list appropriate to its policy objectives and the resultant assessment elements and features. This spreadsheet is designed to score each of the identified elements or subelements, generally using integer values from 1 to 5, where higher values correspond to better performance. However, in this example all of the ratings are set to a value of ‘2’.

This methodology uses the following steps:

(1) Identify the elements, features and subfeatures related to the key topics that are relevant to the selection of the nuclear power plant design.
(2) Identify any element, feature or subfeature that would disqualify a design from consideration if it is not acheived or addressed.
(3) Provide importance weighting for each of the key elements such that the summation of weights for all key elements equals 100%.
(4) For the features within an element, and where there are subfeatures within a feature, importance weighting needs to be established in a similar manner, equaling 100% in total.
(5) For each key feature or subfeature, identify what evaluation of merit would correspond to the scoring values of 1, 2, 3, 4 and 5.
(6) Each of the key features and key subfeatures can be ascribed to a ‘design’ feature, or a ‘delivery’ feature, as shown in the cell to the extreme left of the spreadsheet. This allows the summary results to show the extent to which the overall score is achieved by virtue of the nuclear power plant design or through the process of delivery by the technology holders (e.g. technology holder experience sharing and technology transfer, construction capability and risk sharing).
(7) The final candidate nuclear power plant designs to be assessed (those that successfully pass through Step 2 above) are displayed at the top of the scoring columns.
(8) Each key feature or subfeature is then assigned a score for each design based upon an assessment against the metrics established in Step 5 above.
(9) The levelized power generation cost key feature is included in this example for the RTA. If such a financial evalation is to be included, it is recommended that this part of the assessment be scored using non-integer values (e.g. 1.00–5.00). As described in Section 5.3.1, the range for the scoring of the financial features or subfeatures must be designed carefully and consistently.
(10) It is important that this example approach be used as guidance. As described in this report, the actual design assessment should align with the policy objectives, elements and features designed by the Member State.

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
	0.2	0.2	0.2	10	SITE SPECIFIC CONSIDERATIONS		
Design	2	2	2		10	Ambient site environmental conditions and ecology, including seismic, flooding, wetlands, ecology, population density	
Design	2	2	2		10	Heat sink temperature, condenser cooling water source and extent of water resources	
Design	2	2	2		10	Magnitude and frequency of all external events (design and safety considerations)	
Design	2	2	2		10	Site size requirements, boundary conditions, population, neighbours and environs	
Delivery	2	2	2		10	Transportation routes/facilities and access to required infrastructure for construction and operation	
Delivery	2	2	2		10	Site development and preparation requirements	
Design	2	2	2		40	Site structure plan; single- or multi-unit site requirements	
	0.16	0.16	0.16	8	GRID INTEGRATION		
Design	2	2	2		20	Grid stability, size, existing and future capacity, plant connectivity	
Design	2	2	2		20	Plant operation under normal grid, disturbed grid and isolated grid conditions	
Design	2	2	2		20	Off-site power requirements	
Design	2	2	2		20	Ability to house load the power station	
Design	2	2	2		20	Grid code restrictions applicable to plant	

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
	0.4	0.4	0.4	20	NUCLEAR PLANT SAFETY		
					10	Regulatory requirements in the Member State and the standards applied by the technology holder for the design, including:	
Delivery	2	2	2			50	Licensing process and issues, recent or ongoing, both in country of origin and on other export sites
Delivery	2	2	2			50	Language of original licensing material
Design	2	2	2		10	Safety design philosophy (e.g. fully active, fully passive, combination thereof)	
					5	Defence in depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage, including:	
Design	2	2	2			10	Assurance that the technology holder has sufficient technically qualified and appropriately trained staff at all levels
Design	2	2	2			10	Adequate quality management of the design process
Design	2	2	2			10	Key safety features to limit plant transients
Design	2	2	2			10	Key safety features to avoid core damage
Design	2	2	2			10	Key safety features to contain core damage
Design	2	2	2			50	Key safety features to reduce off-site release
					5	Degree of diversity and redundancy in meeting the above	
Design	2	2	2			20	Redundant plant safety related components segregated in different rooms with controlled access
Design	2	2	2			20	Plant main safety related structures, systems and equipment designed against human caused and natural external events, including internal and external flooding

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Design	2	2	2			20	Separate emergency control facility with capabilities to control safe shutdown in emergency or security events
Design	2	2	2			20	Features such as separation of redundant trains, major components, and compartmentalization of safety and non-safety systems
Design	2	2	2			20	Loads and load combinations including large missiles and jet impingement
					5	Spent fuel pool safety	
Design	2	2	2			50	Building location and integrity
Design	2	2	2			50	Alternate means for cooling and inventory control
					5	Defence against external events (see Fig. II–1 in Annex II)	
Design	2	2	2			20	Calculation margins in design base calculations
Design	2	2	2			40	Affected margins for best estimate calculations, e.g. seismic margins (high confidence/ low probability of failure)
Design	2	2	2			40	Determination of ultimate failure conditions
					5	Severe accident releases and response	
Design	2	2	2			10	Severe accident management programmes, processes
Design	2	2	2			10	Containment design (e.g. double containment with liner)
Design	2	2	2			10	Containment and penetrations design pressure failure point
Design	2	2	2			10	Post–core damage management (e.g. core catcher, in-vessel retention)
Design	2	2	2			10	Hydrogen management (e.g. recombiners)

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Design	2	2	2			10	Filtered containment vent
Design	2	2	2			10	Emergency technical support centre
Design	2	2	2			10	Communications
Design	2	2	2			10	On-site equipment access and habitability
Design	2	2	2			10	Power supply
Design	2	2	2		5		Safety equipment testing and surveillance requirements
Design	2	2	2		5		Classification of components and related quality requirements
Design	2	2	2		5		Reliance on off-site power supply integrity
					5		Probabilistic safety assessment scope, maturity and results
Design	2	2	2			20	Comparisons of initiating events
Design	2	2	2			20	Internal events results
Design	2	2	2			20	Fire evaluations
Design	2	2	2			20	External events analyses and results
Design	2	2	2			20	Is risk dominated by single issue or design feature, e.g. loss of off-site power (LOOP)?
Design	2	2	2		5		Safety margins against deterministic requirements
Design	2	2	2		5		Plant control and protection logic architecture

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					5	Operational expectations affecting safety	
Design	2	2	2			25	Human–machine interface and I&C design
Design	2	2	2			25	Plant design life and replacement provisions for safety systems, and components with foreseen shorter life
Design	2	2	2			25	Design provisions for safety systems, and components testability and maintainability, in particular during power operation
Design	2	2	2			25	Safety systems and components qualification requirements
Design	2	2	2		5	Due consideration of human factors engineering (including equipment accessibility post-accident)	
Design	2	2	2		5	Fuel and water supply for diesel generator, emergency feedwater and primary system make-up	
Delivery	2	2	2		5	Integration of technical specifications with SAR and PSA	
Delivery	2	2	2		5	Completeness of OTS, SAR and PSA	
	0.32	0.32	0.32	16	TECHNICAL CHARACTERISTICS AND PERFORMANCE		
					15	Unit size	
Design	2	2	2			50	Plant net rated output (MW(e)), plant efficiency (kW(e)/W(th)), auxiliary power consumption (MW(e))
Design	2	2	2			40	Regional average and expected capacity factor
Design	2	2	2			10	Potential for future plant up-rating

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					15		Plant lifetime
Design	2	2	2			30	Economic design life and physical life specification (years); listing of limiting equipment or components and their design lifetimes
Design	2	2	2			10	Replaceability of components intended to be changed within plant life (including impact on plant lifetime availability)
Design	2	2	2			10	Major component design margins, e.g. vessel fluence, containment and physical structures
Design	2	2	2			10	Materials assessment and availability, including spare parts and capability of common suppliers
Design	2	2	2			10	List of components and structures that meet the design life requirements without refurbishment
Design	2	2	2			10	Design margin analyses to ensure plant lifetime margin optimization for major components and structures
Delivery	2	2	2			10	Long term fuel supply assurance: (i) contractually and (ii) global/universal availability
Delivery	2	2	2			5	Long term assurance for component and replacement parts availability
Design	2	2	2			5	Design lifetime refurbishment plan
					10	Proven technology	
Delivery	2	2	2			10	Operating experience of the plant design and components
Delivery	2	2	2			10	Licensing and/or certification status for the design, including past, current and anticipated licensing issues and resolutions
Design	2	2	2			10	Comparison to utility requirements
Design	2	2	2			10	Comparison to regulatory requirements

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Delivery	2	2	2			10	Status of regulatory approval in different countries
Design	2	2	2			10	Comparison to local rules, if different
Delivery	2	2	2			10	Operating experience and/or reliability of new components
Delivery	2	2	2			10	Licensing status stage: certified standard design, construction permit and operation licence in the country of origin
Design	2	2	2			10	Characteristics of the design: proven, evolutionary and advanced reactors, or reactors of new technology
Delivery	2	2	2			5	Completeness of design: percentage of detail design completed
Delivery	2	2	2			5	Completeness of the procurement specification process
					10	Standardization	
Design	2	2	2			40	Standard plant design description with site envelope parameters
Design	2	2	2			10	Current and expected location of and schedule for plant design deployments
Design	2	2	2			10	Standardized design elements, components, materials (and suppliers)
Design	2	2	2			10	Changes that can be made to suit local conditions
Delivery	2	2	2			10	Completeness of design standardization
Delivery	2	2	2			10	Other similar plants being built in the region or in the world
Delivery	2	2	2			10	Opportunities for common spare parts inventory; common material and spare parts suppliers and procurement specifications

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					10	Simplification	
Design	2	2	2			20	Comparative design simplification for systems, components, operations and safety/non-safety for passive and active systems
Design	2	2	2			20	Human–machine interface systems to simplify plant operation and rapid maintenance
Design	2	2	2			20	Plant construction simplification with design to facilitate on-line maintenance
Design	2	2	2			20	Systems and equipment design and control room design to minimize plant operator demands during normal and emergency conditions
Design	2	2	2			20	Simplified control logics
					10	Constructability	
Delivery	2	2	2			25	Clear construction plan, management, schedule, resources and interfaces
Design	2	2	2			25	Extent of modular construction, demonstrated capability, manufacturing, management, transportation and installation support requirements
Design	2	2	2			25	Construction QA programme and demonstrated site construction quality
Design	2	2	2			25	Construction safety, health and nuclear employee concerns programme during and after construction
					10	Operability, inspectability, maintainability, reliability	
Design	2	2	2			20	Operational margins, design margins in normal operating modes
Design	2	2	2			20	On-line and on-line maintenance expectations versus experience
Design	2	2	2			20	Fuel transfer system capability and refuelling outage duration versus experience
Design	2	2	2			10	Remote technology options for inspection, monitoring and maintenance

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Design	2	2	2			10	Plant trip response design versus experience, including reactor, turbine, feedwater and main condensate pump trips
Design	2	2	2			10	System redundancy and logic switchover systems to avoid trip responses
Design	2	2	2			10	PSA reliability availability database comparisons
					10	Plant availability and capacity factors	
Design	2	2	2			70	Expectations and experience in plant availability and capacity factor for similar designs and installed units (from the IAEA Power Reactor Information System)
Design	2	2	2			30	Materials assessment and life expectancy
					5	Manoeuvrability (renewables impact)	
Design	2	2	2			20	Operational margins, design margins in normal operating modes
Design	2	2	2			20	Load follow and related operational manoeuvrability versus specifications
Design	2	2	2			20	Emergency remote shutdown requirements and capabilities
Design	2	2	2			20	Waste generation
Design	2	2	2			20	Fuel power limit constraints
					5	Major systems and components evaluations	
Design	2	2	2			20	Nuclear steam supply systems (NSSS)
Design	2	2	2			20	Conventional island (CI)
Design	2	2	2			10	Balance of plant (BOP)
Design	2	2	2			20	Instrumentation and control (I&C) systems

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Design	2	2	2			10	Electrical systems
Design	2	2	2			20	Containment and reactor building structures and layout
	0.2	0.2	0.2	10	NUCLEAR FUEL AND FUEL CYCLE PERFORMANCE		
Design	2	2	2		10	Considerations related to the design, procurement and operating experience for the nuclear fuel	
Design	2	2	2		10	Flexibility of plant operation to different fuels, including higher enrichment levels or MOX fuels	
Delivery	2	2	2		10	Services offered for the front end and back end supply	
Delivery	2	2	2		10	Availability and competitiveness of different fuel materials and components for the facility design	
Delivery	2	2	2		10	Assurance of fuel supply, and of component and replacement parts availability	
Delivery	2	2	2		10	Agreements with UF6 and associated fuel product suppliers	
Delivery	2	2	2		10	Demonstrated ability to manufacture fuel bundles	
Delivery	2	2	2		10	Characteristics of primary and alternate fuel and materials suppliers	
Delivery	2	2	2		10	Experience with similar fuel	
Design	2	2	2		3	Length of refuelling cycle and economic evaluation	
Design	2	2	2		3	Special nuclear materials management	
Design	2	2	2		2	Impact of the fuel cycle on the facility operation	
Design	2	2	2		2	Potential for increasing spent fuel pool storage capacity in the future	

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%) ←Weighting factors
	0.04	0.04	0.04	2	RADIATION PROTECTION	
Design	2	2	2		20	Separation of clean and radiation areas; radiation area zoning in the design plan
Design	2	2	2		10	ALARA and radiation protection procedures, shielding and radiation monitoring implementation in design
Design	2	2	2		10	Procedures and shielding required for exposure reduction during operation, refuelling and maintenance
Design	2	2	2		10	Remote maintenance equipment design and usage
Design	2	2	2		10	Access control and layout design criteria
Design	2	2	2		10	Estimated total annual site personnel dose exposure
Design	2	2	2		10	Personnel exposure estimates during operations, refuelling and maintenance activities
Delivery	2	2	2		10	Available projections versus actual exposure and exposure reduction comparisons during operation, refuelling and maintenance activities
Design	2	2	2		10	Post-accident vital areas accessibility and shielding
	0.04	0.04	0.04	2	ENVIRONMENTAL IMPACT	
Design	2	2	2		25	Impact projections considering water usage, ambient, wildlife and visual effects
Design	2	2	2		25	Impacts on wetland and natural terrain
Design	2	2	2		25	Radiological releases to the environment (normal operation and accident)
Design	2	2	2		25	Effect on local industry and economy

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%) ←Weighting factors
	0.04	0.04	0.04	2	SAFEGUARDS	
Design	2	2	2		100	Plans for equipment, installation and design basis treatment for the safeguards programme
	0.04	0.04	0.04	2	PLANT AND SITE SECURITY	
Design	2	2	2		20	Security plans
Design	2	2	2		20	Integrated plant access control system to include in the general plant design
Design	2	2	2		20	Diversity and redundancy of security facilities
Design	2	2	2		20	A dedicated security communication system with external support services
Design	2	2	2		10	The security access building and related security facilities design against security related threats
Design	2	2	2		10	Incorporation of the design basis threat
	0.04	0.04	0.04	2	OWNER’S SCOPE OF SUPPLY	
Delivery	2	2	2		30	General level of owner/operator involvement
Delivery	2	2	2		20	Owner/operator options related to site infrastructure
Delivery	2	2	2		10	Owner scope for BOP
Delivery	2	2	2		10	Simulator and training facilities
Delivery	2	2	2		10	Owner oversight of engineering, procurement and construction facilities

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Delivery	2	2	2		10	Owner oversight of engineering, procurement and construction labour	
Delivery	2	2	2		10	Division of responsibility on major tasks of construction and operational startup testing	
	0.04	0.04	0.04	2	SUPPLIER / TECHNOLOGY HOLDER ISSUES		
Delivery	2	2	2		10	Clear delineation of responsibilities related to the technology holder scope of supply	
Delivery	2	2	2		10	Contract model acceptable to technology holder	
Delivery	2	2	2		5	Risk sharing and dispute resolution	
Delivery	2	2	2		5	Plant contractor structure	
Delivery	2	2	2		5	One-step bidding process or two-step bidding process	
Delivery	2	2	2		5	Recent experience of technology holder and main subcontractors	
Delivery	2	2	2		5	Experience of key personnel	
Delivery	2	2	2		5	Global and political impacts	
Delivery	2	2	2		5	Quality assurance oversight and review of suppliers	
Delivery	2	2	2		5	Prioritized near and long term suppliers for key components and parts	
Delivery	2	2	2		5	Long term supply chain assurance	
Delivery	2	2	2		5	Warranties	
Delivery	2	2	2		5	Corrective action programme	
Delivery	2	2	2		5	Equipment commercial grade dedication	

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
Delivery	2	2	2		5	Industrial safety programmes and achievement record	
Delivery	2	2	2		5	Nuclear safety programme for facility construction through testing programmes and initial operation	
Delivery	2	2	2		5	Construction quality control programmes	
Delivery	2	2	2		5	Subcontractor quality, safety, SCWE, concerns and corrective action programmes	
	0.04	0.04	0.04	2	PROJECT SCHEDULE CAPABILITY		
Delivery	2	2	2		20	Schedule identification for procurement of long lead time items	
Delivery	2	2	2		20	Site preparation schedule	
Delivery	2	2	2		20	Critical path identification and contingency plan development	
Delivery	2	2	2		20	Impact of local conditions, for example, accommodation for labour laws, weather or transportation infrastructure	
Delivery	2	2	2		10	Integrated project schedule, including engineering, procurement, construction, startup	
Delivery	2	2	2		10	Identification of scheduling tools and software for scheduling and analyses	
	0.04	0.04	0.04	2	TECHNOLOGY TRANSFER AND TECHNICAL SUPPORT		
Delivery	2	2	2		20	Technical support capability provided by or transferred from the technology holder	
Delivery	2	2	2		20	Availability, transfer provisions and support of the design bases	
Delivery	2	2	2		20	Transfer of the tools and the technology that developed, comprise and support the design bases	
Delivery	2	2	2		10	Technical or operational support programmes available through owner/operator contacts	

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					10		Technical or operational support programmes available through technology holder contacts:
Delivery	2	2	2			50	Experienced utility or owners groups available for technical support
Delivery	2	2	2			25	Other regulatory or operational affinity support groups
Delivery	2	2	2			25	Industry support group programmes specific to the design — through WANO, INPO, EUR, EPRI
Delivery	2	2	2		10		Facilities or assets that can be used for technical support organizations
Delivery	2	2	2		10		Ease of technical support, such as local language, regional presence and programme resources
	0.4	0.4	0.4	20	ECONOMICS		
Design	2	2	2		50		Calculated levelized power generation costs (value of 1.00–5.00)
					10		Factors influencing capital costs
Design	2	2	2			30	Cash flow comparisons
Design	2	2	2			20	Comparison of material quantities
Design	2	2	2			10	Impact of local labour and productivity
Design	2	2	2			10	Licensing record of success
Delivery	2	2	2			10	Potential for major design changes during or after construction due to nuclear safety issues
Delivery	2	2	2			10	Missing equipment (e.g. hydrogen recombiners)
Design	2	2	2			10	Reliable estimates of equipment and technology holder prices (overnight)

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					20	Operating and maintenance (O&M) costs	
Design	2	2	2			10	Evaluation of projected O&M with comparisons to experience
Design	2	2	2			10	Staffing
Design	2	2	2			20	Plant features that can reduce or increase O&M costs
Design	2	2	2			20	Potential for localization versus O&M contract
Design	2	2	2			20	Opportunities and costs for shared spare parts pool
Design	2	2	2			10	Reliance on passive design and redundant system trains to optimize on-line maintenance and ease of operations
Design	2	2	2			10	Optimized outage schedules based on equipment performance and applicable trending data
					10	Fuel costs	
Design	2	2	2			20	Fuel costs projected with comparisons to applicable topical experience
Design	2	2	2			10	Fuel burnup and plant efficiency
Design	2	2	2			10	Impact of raw material price variations
Design	2	2	2			10	Trade-off between long cycle and outage times
Design	2	2	2			10	Spent fuel capacity
Design	2	2	2			20	Contractual opportunities for fuel supply and spent fuel disposal
Design	2	2	2			20	Competitive advantage between original equipment manufacturers and other suppliers/ fabricators

TABLE 12. REACTOR TECHNOLOGY ASSESSMENT USING MAUT (cont.)

Design/ delivery	Reactor design A	Reactor design B	Reactor design C	Key elements (%)	Key features (%)	Key subfeatures (%)	←Weighting factors
					10	Decommissioning costs	
Design	2	2	2			20	How decommissioning aspects have been considered in the design phase
Design	2	2	2			20	Design provision for decommissioning in comparison with similar plants
Design	2	2	2			20	Comparison of expected contamination of components and structures
Design	2	2	2			20	Quantities and waste categories of decommissioning materials expected, based on similar plant experience
Design	2	2	2			20	Anticipated scope, schedule, issues and costs of decommissioning

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ABBREVIATIONS

ALARA	as low as reasonably achievable
ALWR	advanced light water reactor
BOP	balance of plant
CCTV	closed circuit television
CMF	core melt frequency
CUC	common user consideration
EPRI	Electric Power Research Institute
EUR	European Utility Requirements for LWR Nuclear Power Plants
HVAC	heating, ventilation, air conditioning
HWR	heavy water reactor
I&C	instrumentation and control
ICRP	International Commission on Radiological Protection
INPO	Institute of Nuclear Power Operations
IS	information system
LWR	light water reactor
MAUT	multi-attribute utility theory
MOX	mixed oxide fuel
MTBF	mean time between failures
MTBM	mean time between maintenance
NEPIO	nuclear energy programme implementing organization
NSSS	nuclear steam supply system
O&M	operations and maintenance
OTS	operating technical specification
PSA	probabilistic safety assessment
QA	quality assurance
RFI	requests for (technology holder) information
RTA	reactor technology assessment
SAR	safety analysis report
SCWE	nuclear safety conscious work environment
SMR	small or medium size reactor
URD	utility requirements document
WANO	World Association of Nuclear Operators

Annex I

MAJOR SYSTEMS AND COMPONENTS

Nuclear steam supply systems (NSSS)

— Reactor design;
— Reactor internals design;
— Reactor coolant system design;
— Residual heat removal and shutdown cooling design;
— Emergency core cooling system design;
— Containment design;
— Reactor water cleanup and chemical volume control system design;
— Control rod design;
— Fuel design;
— Water storage and liquid radwaste design;
— Gaseous radwaste design;
— Main steam design.

Balance of plant (BOP) systems

— Main feedwater design;
— Condensate design;
— Main condenser design;
— Circulating water design;
— Service water design;
— Reactor building closed cooling water design;
— Turbine building closed cooling water design;
— Main turbine design;
— Steam bypass design;
— Heating ventilation and air conditioning design;
— Feedwater heating;
— Extraction steam and heater drains design;
— Service gas design;
— Fire protection design;
— Simulator;
— Fuel pool cooling design;
— Ultimate heat sink.

I&C systems

— Reactor protection system;
— Engineered safeguards actuation system;
— BOP engineering safeguards actuation system;
— Feedwater control system design;
— Steam bypass control system design;
— Nuclear instrumentation design;
— Radiation monitor system design;
— Remote shutdown system design;
— Regulatory Guide 1.97 compliance;
— Main control room and human factors design.

Electrical systems

— Off-site power system design;
— On-site power distribution system design;
— Diesel generator design;
— Class 1E DC system design;
— Class 1E 120 volt instrument AC system design;
— Non-class 1E DC system design;
— Non-class 1E UPS;
— Transformer design;
— Switchgear system design.

Containment and reactor building structures and layout

Annex II

SPECIAL CONSIDERATION OF KEY SAFETY AND ECONOMIC ELEMENTS AND FEATURES IN REACTOR TECHNOLOGY ASSESSMENT

There are several items which may deserve special attention in the evaluation of a variety of reactor designs and their applications. In the area of reactor safety there are a number of considerations that are being expressed with increasing emphasis and clarity following the Fukushima Daiichi accident. Clearly, the Member State, NEPIO or owner/operator must give careful consideration to the responses of the technology holders to the lessons learned from this industry experience. This may require evaluations that are expanded over previous evaluations and metrics related to safety. The same applies to certain aspects of the key features affecting economic evaluation. A primary example is the degree of difficulty that may be encountered in assessing or validating the data and methodology that technology holders may apply to the computation of capacity and availability factors. Examples are provided in these areas:

II–1. KEY SAFETY ELEMENTS AND FEATURES

(1) Diversity and redundancy of plant safety systems: The events and lessons learned as a result of the Fukushima Daiichi events are resulting in a heightened appreciation of the need for and value of diverse water systems, alternative cooling systems, electrical systems and steam driven cooling systems. It is important that new plant offerings include designs that include both first-line and secondary safety systems with these diverse characteristics. In addition, whenever valued risk reduction benefits can be demonstrated, diverse features should be coupled with redundancy of equipment components or systems. These include power supply and water delivery systems.
(2) Consideration of severe external events: It is appropriate to consider an expanded definition related to the expected external events that should examined in the delivery of current, new reactor systems. Figure II–1 shows an example listing that has been expanded well beyond factors that heretofore had been considered adequate.
(3) Reactor control and shutdown challenges in design and operation: Certain features in reactor design that have been considered acceptable in designs developed in previous generations of reactors should be re-examined in light of recent safety challenges and events. Reactor core design characteristics such as the allowance of positive moderator temperature coefficients may have been compensated by other features; however, elimination of such design approaches should make sense given modern safety expectations in design. Control logic that may accompany software assisted manual trips and other primary safety system functions is another example category where designers should be challenged to improve the safety case affected by these features.

As the lessons learned from these events become embedded in the future designs, these features should be clearly addressed. The challenge now is to examine current offerings carefully to ensure that correct choices are made for a facility that should operate for 60–80 years.

II–2. KEY ECONOMIC ELEMENTS AND FEATURES

Special attention is drawn to the evaluation of operational experience that can have a major impact on the operational cost evaluation, and therefore the overall cost evaluation for the facility. The key element and features that must be understood are the facility availability and capacity factors. The NEPIO or owner/operator must carefully examine both the technology holder information and the industry information when evaluating the bases for the claims of the technology holder. Operational experience that may be presented by the technology holders

- Accidental aircraft impacts
- Avalanche
- Biological events
- Coastal erosion
- Dam failures
- Drought
- Electromagnetic interference
- External fire
- External flooding
- Externally generated missiles
- Fog
- Forest fire
- Frost
- Hail
- High air pollution
- High summer temperatures
- High tide
- Hurricane/typhoon
- Ice cover
- Industrial or military facility accident
- Landslide
- Lightning
- Low lake or river
- Low winter temperature
- Meteorite/satellite
- Military action
- Pipeline accident
- Precipitation, intense
- Release of chemicals from on-site storage
- River diversion
- Sandstorm
- Seiche
- Snow
- Soil shrink-swell
- Solar storms
- Storm surge
- Toxic gas
- Transportation accidents
- Tsunami
- Volcanic activity
- Waves

FIG. II–1. Expansive consideration of external events.

should always be validated against the environmental conditions applicable to the site and region for reactor deployment:

— In particular, it is common for the technology holder to provide these values without carefully considering the local environmental characteristics of the site that will be used by the owner/operator. Site features including temperatures, humidity and even weather should be taken into account.

— Additionally, the owner/operator may review or cross-check the data provided by the technology holder by examining data from industry performance for the given design. When doing so, it is critical to consider the geographical, regulatory and other characteristics that may affect these factors. The environmental features are described above. Regulatory considerations can include plant maintenance and refuelling outage requirements, and other effects that may or may not be applicable such as fuel performance experience and core design and cycle length features.

Annex III

REVIEW OF PREVIOUS APPROACHES FOR INTEGRATED TECHNOLOGY ASSESSMENT

The following examples are presented to demonstrate the complexities that may develop in the detailed quantitative analysis for the RTA. The use of simplified applications must be considered carefully. These may be satisfactory in the decision making for less complex applications, but fall short of the goals set for RTA.

III–1. EARLY QUANTITATIVE NUCLEAR POWER PLANT TECHNOLOGY ASSESSMENT

One of the principal quantitative assessment methods in nuclear power plant decision making was first presented in 1976 as a short, two page article in Nuclear Engineering International [III–1]. This methodology follows a classic evaluation matrix technique for rational decision making. However, there is substantial elaboration in the definition of the design elements for consideration and in the derivation and application of importance weighting functions. In this approach, each of the technical design elements and the general technical aspects for the candidate nuclear power plant bids is evaluated through ranking; each is assigned an importance weighting, and their weighted ranking scores are summed to determine the optimal choice. Van Zijl, the author of this work, contributed to several earlier IAEA projects related to nuclear power plant bid evaluation, including the detailed IAEA report on technical evaluation of bids published in 1981 [III–2]. Some of the features of the detailed methodology were provided therein, but were presented in general terms. Accordingly, some elements of the method have been and are currently summarized briefly in subsequent IAEA documents [III–3]. However, the detailed quantitative approach introduced and documented in brief form in the original two page journal article was not included in the derivative IAEA publication [III–2], along with the specifics of the method. Since the focus of this report is to elaborate on this type of decision making process, it is important to describe here the details developed in this approach.

In essence, the approach follows the principles of the MAUT or a Kepner–Tregoe process, although it was not so described at the time. The basics of the methodology are summarized as follows:

(1) The technical design of the components, systems and what are termed the ‘technical aspects’ of the proposed design are identified and grouped for consideration into two category types. ‘Components and systems’ are identified, for example, as reactor systems, core and fuel, safety systems, reactor auxiliary systems, or instrumentation and control systems. ‘Technical aspects’ are identified as functions or programmes, such as ‘operational flexibility or operations and maintenance’, ‘safety’, or ‘quality assurance, quality control, codes and standards’.

(2) ‘Main evaluation criteria’ are selected. The following criteria are chosen for the ‘component and systems’ groupings:
   (a) Reliability;
   (b) Function and performance;
   (c) Safety;
   (d) Operations and maintenance;
   (e) Materials.

   In the publication, it is suggested that for some of the ‘technical aspects’, either this set or an alternative set of evaluation criteria may be chosen. Further direction is not provided. Therefore, the next steps focus on the application to the evaluation of ‘components and systems’.

(3) These evaluation criteria are assigned numerical values on the basis of judgements that relate to the expected performance of the components and systems. The judged ratings are determined based on comparisons with the expectations that were set in the user considerations for the facility. Each reactor option is evaluated as to whether the expectations have been exceeded or not. If the design evaluation shows that the user consideration requirements are not met, the design feature must be demonstrated to be acceptable. The ratings are assigned to reflect the degree to which each design in the assessment meets or exceeds the expectations.

(4) Once these ratings are established, the components, systems and aspects are also assigned an ‘importance factor’. In applying this method for ‘components and systems’, the approach defines an ‘importance factor

for operation', which is derived from a detailed evaluation of failure probability of the component or system multiplied by the amount of outage time that would result if that specific failure were to occur. The importance factor is used to weight the 'component and systems' sets of ratings. For each set of systems and components then this evaluation will yield summations of the weighted numerical values for each of the evaluation criteria and for each of the options.

(5) To derive the final evaluation score for the options for this set of 'components and systems', it remains to assign weighting factors for each of the evaluation criteria. The weighting factors for nuclear systems chosen in the publication are:
   - (a) 30% reliability;
   - (b) 15% function and performance;
   - (c) 30% safety;
   - (d) 15% operations and maintenance;
   - (e) 10% materials.

(6) Each set of 'components and systems' is treated in a similar fashion to derive a single numerical value for each. Ratings and importance weighting factors for each technical aspect are also determined and are computed to derive single numerical values for each. The final numerical score for each reactor design option is obtained by summing the resultant set of values.

(7) The author of Ref. [III–4] cautioned that the value assignment for technical aspects must be done carefully to ensure that their choice does not overweight or underweight the final results inappropriately. To achieve this, it is necessary to establish proper judgements of the relationships between the design of the 'components and systems' and 'design aspects'. The published article did not recommend processes to accomplish this balance.

The author also emphasized that this quantitative method relies heavily in several ways on the engineering judgement capability of the evaluation team and the care that the team can give to the integration of the results for both the components and systems design and to the design aspects. This reinforces the discussions regarding the resource planning describe in Section 2.4, that is, the need for an experienced and balanced engineering team that is well versed in the user considerations, the design features and aspects of those reactors being evaluated, as well as the evaluation process being used. The importance of the ability to understand and evaluate component, system and functional reliability is stressed. Finally, as has been discussed in previous sections of this report, the author identifies the important understanding that (i) the quantitative numerical evaluation results have an impact on the decision, but do not necessarily drive the decision alone, and (ii) documentation of these results not only supports decision making but can also provide future benefits in the construction, implementation and operation of the project.

III–2. QUANTITATIVE TECHNOLOGY ASSESSMENTS IN RELATED DISCIPLINES

The second example application to be described is taken from the technical evaluation methodology proposed for use by the World Bank, 'Standard Bid Evaluation Form'. Again, this evaluation follows a rational decision making matrix format, where design and application features affecting the decision are evaluated, numerically graded, weighted and summed to develop an overall score for the proposed options. The decision making application here is not for RTA, but is for the 'Supply and Installation of Information Systems' (IS). In a review of this work, it is apparent that both the problem under consideration and the approach are simple relative to the complexities of evaluation for the nuclear reactor design application that are presented in the previous section. It is because of these differences that it is useful to present this methodology here.

There are several specific differences apparent in comparing these two example methods of application. One major difference is that the process for the technical evaluation of the IS is performed in two steps. Phase 1 of the technical evaluation rates each proposed hardware system against the specifications. (The corresponding specifications for a nuclear RTA would be the user considerations.) The evaluation performed for the IS options is presented in a 'Technical Responsiveness Sheet' where each required design feature is evaluated against the design requirements or expectations for each proposed design. This work is performed by the evaluation team. The application here is reported as a broad-brush 'Go'/'No Go' review of these features, which are classified into three categories:

— All features meet the design objective: PASS to Phase 2 with no deviations; ‘Go’
— Major deviation in one design feature: FAIL to move to Phase 2; ‘No Go’
— Minor deviation in one or more feature: MAY PASS to Phase 2 with minor deviation

The evaluation team makes the determination as to whether an IS option with a minor deviation should be included in the next technical assessment phase.

Phase 2 constitutes the technical evaluation associated with the non-hardware evaluation. The categories of the design option proposals are: software, training and project management. In each of these categories there are several features that are defined. Each feature will be reviewed by the evaluation team and rated as follows:

— 0 Feature is absent
— 1 Feature is present but shows deficiencies
— 2 Feature fully meets the requirements
— 3 Feature marginally exceeds the requirements
— 4 Feature significantly exceeds the requirements

Next, the evaluation team develops a consistent set of numerical scores that are associated with these ratings for each feature. These are presented in a scoring matrix that displays scoring values for each feature as a function of the rating. Any feature that is rated as absent is assigned a score of zero. For some features, the scores are presented as a linear progression; that is, ratings of 1, 2, 3 and 4 are given scores of, say, 15, 20, 25 and 30. As the feature meets or exceeds the expectations, the value provided is determined to increase accordingly. For other features, a high value may be assigned for meeting the requirement, but no additional value is given for exceeding the requirements; that is, ratings of 1, 2, 3 and 4 are given scores of, say, 10, 40, 40 and 40. Features within the same category are assigned differing relative scores that depend on the value provided to the project; that is, ratings of 1, 2, 3 and 4 are given scores of, say, 15, 20, 25 and 30 for feature A, and, say, 20, 30, 40 and 50 for feature B. If a feature must meet the requirements, the rating ‘Feature is present but shows deficiencies’ is assigned a score of zero. In summary, this scoring matrix allows the evaluation team to assign appropriate scores (i) to capture the relative value of meeting or exceeding the requirements for the IS for each feature and (ii) to differentiate between the values of different features within the same category.

Next, the evaluation team assigns importance weights to each category. In this example, the categories of software, training and project management are assigned importance weights of 0.5, 0.2 and 0.3, respectively. These weights are applied to the corresponding sums of the scores of the factors in each category to derive a final technical evaluation score for each proposed hardware system. Finally, in the case that this work is performed in connection with a bid evaluation, the assigned importance weightings of the evaluated bid price and this technical evaluation (say, for example, weightings of 0.7 and 0.3) are applied in a normalized computation to determine the evaluated bid score.

As discussed in Section 5.4, this reference example also suggests that there can be other features, risks or uncertainties affecting the evaluation process that may be considered either qualitatively or quantitatively. The features identified as examples for this IS bid evaluation include the application of: ‘domestic preference’, if allowed; discounts for multiple contracts or future awards; or special pre-qualification or post-qualification considerations for one or more proposal teams.

Several of the features of this evaluation should be applicable to the process of RTA. Although there are some challenges associated with extending these simplified approaches to the evaluation of complex systems, there are advantages as well. The example demonstrates the required fundamental features that need to be applied and that may be extended to the more complex applications.

III–3. QUANTITATIVE NUCLEAR POWER PLANT TECHNOLOGY ASSESSMENT EXAMPLE USING THE KEPNER–TREGOE METHODOLOGY

The Kepner–Tregoe methodology has been applied to the selection process for new reactor design technology by one US utility company [III–4]. Although the results of the study and details of the approach for the study are proprietary, the general approach utilized the Kepner–Tregoe techniques to perform the quantitative evaluation of several technology options. The work focused the analysis on the design of plant systems and their effectiveness in operation and performance as determined by the evaluation team. Key technical considerations included:

- — Safety margins;
- — Design margins;
- — Operational margins;
- — Security considerations;
- — Unit availability considerations;
- — Operating experience;
- — Materials assessment;
- — Maintenance and refuelling considerations.

Systems and topics for review included:

- — NSSS;
- — BOP;
- — I&C systems;
- — Electrical systems;
- — Civil, security and fire protection;
- — Operational considerations;
- — Maintenance and refuelling considerations.

The evaluation team and the utility management found that this type of assessment was valuable in preparing and documenting the technical evaluation and its results to the senior management team. The work demonstrated the importance of a rigorous evaluation process and an experienced and diverse evaluation team.

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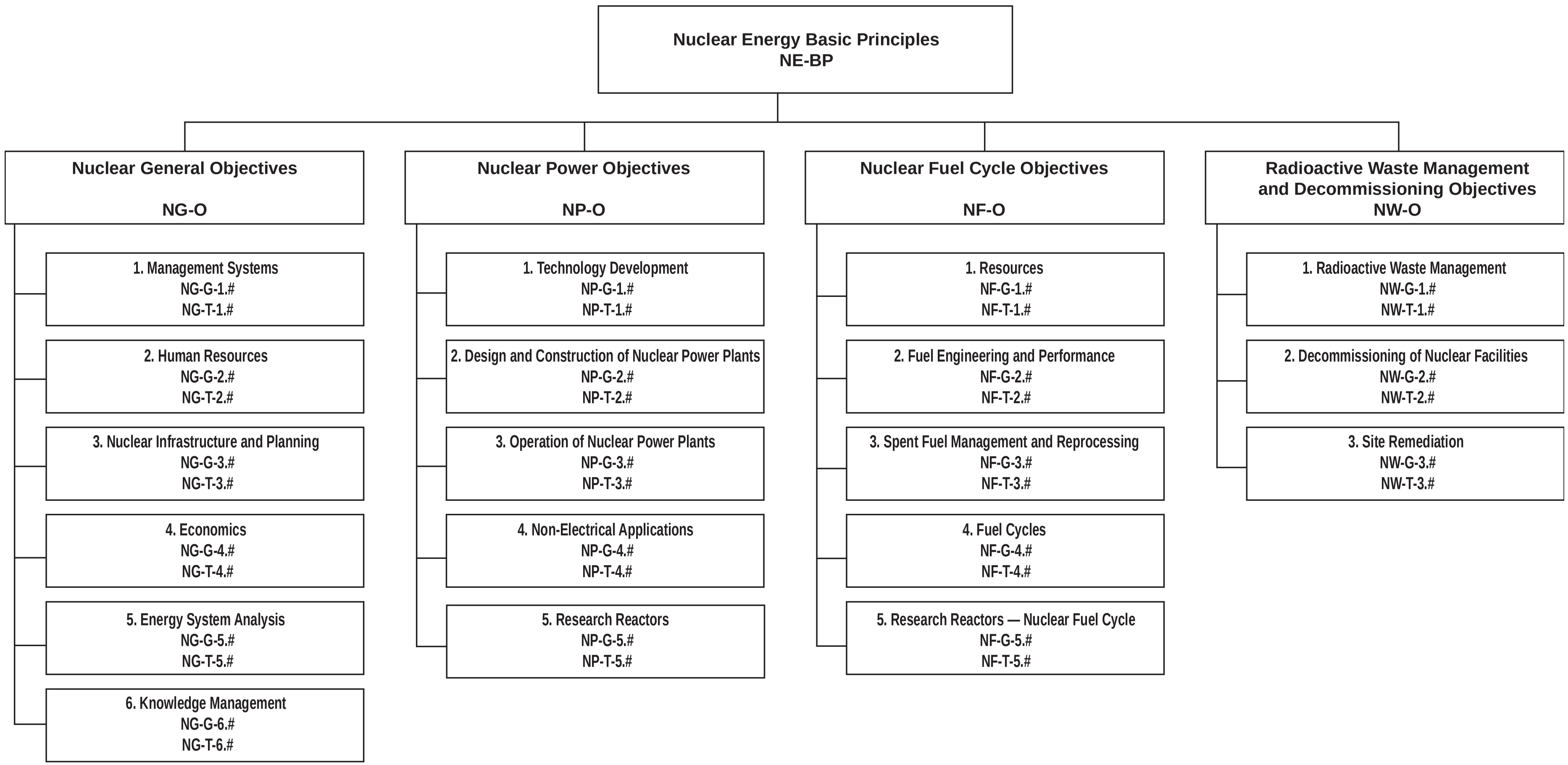

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