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An Example of an INPRO Assessment of an INS in the Area of Waste Management

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ABSTRACT

Following a resolution of the General Conference of the IAEA in the year 2000 the International Project on Innovative Nuclear Reactors and Fuel Cycles, referred to as INPRO, was initiated.

INPRO has defined requirements organized in a hierarchy of Basic Principles, User Requirements and Criteria (consisting of an indicator and an acceptance limit) to be met by innovative nuclear reactor systems (INS) in six areas, namely: economics, safety, waste management, environment, proliferation resistance, and infrastructure. If an INS meets all requirements in all areas it represents a sustainable system for the supply of energy, capable of making a significant contribution to meeting the energy needs of the 21st century.

Draft manuals have been developed, for each INPRO area, to provide guidance for performing an assessment of whether an INS meets the INPRO requirements in a given area. The manuals set out the information that needs to be assembled to perform an assessment and provide guidance on selecting the acceptance limits and, for a given INS, for determining the value of the indicators for comparison with the associated acceptance limits. Each manual also includes an example of a specific assessment to illustrate the guidance.

This paper discusses the example presented in the manual for performing an INPRO assessment in the area of waste management. The example, chosen solely for the purpose of illustrating the INPRO methodology, describes an assessment of an INS based on the DUPIC fuel cycle. It is assumed that uranium is mined, milled, converted, enriched, and fabricated into LWR fuel in Canada. The LWR fuel is assumed to be leased to a utility in the USA. The spent LWR fuel is assumed to be returned to Canada where it is processed into CANDU DUPIC fuel, which is then burned in CANDU reactors. The assessment steps and the results are presented in detail in the paper. The example illustrates an assessment performed for an INS at an early stage of development.

INTRODUCTION

The Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established to help to ensure that nuclear energy is available to contribute, in a sustainable manner, to the energy needs in the 21st century.

In six different areas – economics, safety, waste management, proliferation resistance, environment, and infrastructure – requirements to be met by innovative nuclear energy systems (INS) have been identified. As well, a methodology has been developed to assess whether an INS complies with the requirements. On the basis of this assessment, the need for innovations in existing nuclear technology, to be achieved via research, development and demonstration, can be identified.

In this paper, a short description of the INPRO methodology in the area of radioactive waste management and an example illustrating the application of the methodology are presented.

The INPRO WM Manual has not been written to provide guidance on implementing waste management activities. Rather, the intention is to decide whether such activities and processes are or can be implemented to meet the INPRO Criteria, and hence the User Requirements and Basic Principles for Waste Management.

Generally, an assessment is carried our for a specific innovative nuclear energy system (INS) or systems that have been proposed to meet, in part, the energy demand, as a function of time, of a specific energy scenario. For assessing compliance with the Basic Principles and User Requirements in the area of Waste Management the details of the energy scenario are of secondary importance but the assessment must take into account the wastes arising from the complete INS and its components including those from mining and milling, uranium refining, conversion and enrichment, fuel fabrication, reactor operation, fuel reprocessing, where it is part of the INS, waste processing, transportation activities, and decommissioning of the components of the INS. Given the diversity of the wastes and associated related waste management strategies, such an assessment will require input from a variety of technical specialists.

A number of activities may be common to a variety of INSs, such as mining and milling, uranium conversion and enrichment, and for the majority of activities there already exists extensive experience with managing the associated wastes, including their final disposition. This experience needs to be referenced in performing any assessment of an INS. Given this experience base, the emphasis of a given assessment may, in many cases, be focused on one or two components that represent a significant departure from past experience.

INPRO WASTE MANAGEMENT BASIC PRINCIPLES, USER REQUIREMENTS AND CRITERIA

In the area of waste management four basic principles have been enunciated by INPRO [1], namely that to contribute to sustainable development:

1. Generation of radioactive waste in an INS shall be kept to the minimum practicable.
2. Radioactive waste in an INS shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur.
3. Radioactive waste in an INS shall be managed in such a way that it will not impose undue burdens on future generations.
4. Interactions and relationships among all waste generation and management steps shall be accounted for in the design of the INS, such that overall operational and long-term safety is optimized.

In total, seven user requirements are linked to these basic principles, as shown in Tables 1 to 4 (end of paper).

The proposed indicators for assessing waste minimization, Table 1, are useful when comparing two different INSs or when comparing two different components. But, a number of other factors need to be considered. So, at this stage of preparation of the Manual, a more qualitative approach is utilized whereby the assessor prepares a reasoned argument that the INS includes facilities and processes to reduce waste arisings and to place the wastes ultimately into a safe end state. In this more qualitative approach, the indicators specified in Table 1 can be considered to be parameters (variables) that are used to support the reasoned argument. In effect, this means that, at his stage, an INS is deemed to have met acceptance criteria if a waste minimization study has been preformed, leading to a waste minimization strategy and plan for each component of the INS. Such a qualitative approach may evolve towards a more quantitative assessment based on the indicators of Table 1 when comparing different INSs.

Protection of human health and the environment, Basic Principle 2, from facilities in any part of the nuclear fuel cycle, including waste management facilities, is covered by the chapters dealing with Safety of Fuel Cycle Facilities and with the Environment. This Basic Principle and related user requirements have been included in the WM Manual and the WM Chapter of ref [1] for completeness. They are not considered further in the present paper.

Minimizing the burden placed on future generations, Basic Principle 3, requires that waste must ultimately be placed in an end state that provides permanent safety. The end state is to protect people and the environment today from any harmful effects of the waste and to protect people and the environment in the future to at least the same level that is acceptable today. The definition of each end state should include: the waste form and package; the final repository containing the waste packages; a safety case for the final repository; and a schedule for achieving the end state.

By definition, the state of the waste that provides permanent safety without further modification is the end state. A safety case, defined as the sum total of all evidence (quantitative and qualitative), needs to be prepared to support the determination that the waste management system will be acceptably safe. A minimum requirement is the determination that all applicable laws and regulations will be satisfied. The defined end state must be permanently safe in the sense that future generations will not be exposed to risk that is not acceptable today. The safety case will need to include an analysis of any risks related to failure of institutional controls. It is expected that the safety case will be more easily made for those end states that are based on passive safety, i.e., where long-term institutional controls are not necessary for safety.

Minimizing the burden on future generations also means that people in the future should be provided with the means to maintain the waste in a safe condition. The responsibility for providing these resources, including funds and proven technology, rests with those who have benefited from the generation of the waste and the associated costs should be included in the estimated cost of energy. The internalization of all costs is a fundamental requirement of sound environmental management.

Taking into account the interactions and relationships among waste generation and waste management steps to optimize safety, Basic Principle 4, requires that all steps from the generation of waste to its final disposition in a safe end state need to be carefully considered and planned, including the wastes that will arise from decommissioning. The costs of all steps, for all wastes, from all facilities in the life cycle of the INS need to be identified and be included. Thus, for each facility that comprises a given INS, a waste management plan should be available that sets out, for the various wastes that are produced in that process/facility, and the various steps to be taken in processing and managing the wastes until it is placed into its end state. So, compliance with the acceptance limit requires that such plans exist for each facility, and hence for the complete INS, in one form or another. Almost all of the steps and processes in such a plan are already being practiced, in one Member State or another, with the notable exception of the geologic disposal of spent fuel and high level waste from reprocessing, and so, such plans can be expected to be based on proven technology. Innovations leading to process improvements can be expected to be introduced from time to time consistent with the overall goal of moving waste into a safe end state as soon as reasonably practicable. Where an innovative waste management process is proposed as a necessary part of an INS, evidence should be presented that the process is feasible and a project plan for bringing the process into operation on a schedule that is compatible with the deployment of the INS should have been developed.

INTRODUCTION TO THE EXAMPLE OF AN ASSESSMENT IN THE AREA OF WASTE MANAGEMENT

A partial INPRO assessment in the area of Waste Management is discussed for a hypothetical INS to illustrate the application of the INPRO Methodology in this area through the evaluation of selected indicators to determine whether or not they comply with the associated acceptance limits. The assessment begins with a definition of the INS and its component parts.

It is assumed that the assessment is performed as part of a study carried out under the leadership of a university professor. The professor is leading a team of graduate students who are examining the establishment of a uranium enrichment facility, an LWR fuel manufacturing plant, and a DUPIC fuel manufacturing facility.

This is purely a hypothetical example chosen to illustrate the application of the INPRO methodology in the area of waste management. The assumptions presented below, while technically realistic, have not been tested with regard to their political feasibility or interest on the part of US or Canadian utilities or governments.

The study is based on an INS for the production of electricity using a combination of light water reactors and CANDU reactors. Used fuel from the LWRs is processed and re-cycled through the CANDU reactors utilizing the DUPIC fuel cycle [2]. It is assumed that uranium is mined in Saskatchewan, refined and converted to UF6 at facilities in the province of Ontario, Canada, and then enriched and manufactured into LWR fuel at a new Nuclear Fuel Cycle Facility (NFC). The LWR fuel is assumed to be leased to utilities in the USA for use in a once through cycle in LWR reactors. The used LWR fuel is then returned to the NFC to be 'reprocessed', using the OREOX process, into CANDU DUPIC fuel for use in CANDU reactors in the province of Ontario. For the purposes of the study, it is assumed that the DUPIC CANDU fuel is sold to the operating utilities and that the Canadian Nuclear Waste Management Organization, NWMO, takes responsibility for the long term management of the spent fuel, using funds provided by the utilities.

A graduate student working towards a graduate degree in public-policy-making has been assigned the task of performing the INPRO assessment in the area of waste management. The student is basing the INPRO assessment on published information and interviews with relevant organizations concerning their waste management practices. The student assumes that the new facilities for uranium enrichment, LWR fuel manufacture, and the conversion of spent LWR fuel to CANDU DUPIC fuel that are yet to be built will incorporate provisions for appropriate waste management practices and that the INPRO assessment will provide useful input into the specification and design of these processes.

The student recognizes that the scope of the INPRO assessment is somewhat limited by the fact that conceptual designs of the proposed new facilities have not yet been developed. But, the proposed enrichment facility and LWR manufacturing facility can be considered to be established industrial practices. On the other hand, the proposed facility for converting spent LWR fuel into CANDU DUPIC fuel will utilize processes that are still in development and that development is still in the first stage of establishing conceptual feasibility, as described in section 3.4.3 of ref. [1]. It is noted in section 3.4.3 of ref. [1] that the INPRO methodology should not be applied at a maturity level of pre-conceptual "other than to carry out a preliminary screening to identify at an early stage any clear showstopper." The student recognizes that the assessment in the area of waste management represents such a screening and that one outcome is expected to be the identification of issues that require further study.

As a first step, the student identifies the various activities that comprise the INS and associated wastes that arise from these activities and the organizations responsible for managing the associated wastes. He then considers the waste management strategies and processes these organizations are following or would be expected to follow (for new facilities) from the generation of the waste to its placement in its end state. The student then assesses whether these waste management strategies and processes comply with the INPRO requirements.

All components of the INS, all wastes, and all requirements need to be taken into account in the assessment. In this paper, however, for brevity, we limit the example to the consideration of only one Basic Principle and associated criteria, namely Basic Principle 3, dealing with the end state for the wastes. A detailed discussion of whether the INS complies with this Basic Principle is presented to indicate the extent of the analysis that an assessor would be expected to carry out in assessing compliance with INPRO requirements.

WASTE END STATES

The student has reviewed the literature and based on that review has completed Table 5 setting out the proposed end states for the various waste streams and his judgment of whether the associated criteria are satisfied (yes) or not (no). The rationale for arriving at these judgments is set out below.

Wastes from Uranium Mining Such wastes currently exist in Canada and are being managed under licenses issued by the Canadian Nuclear Safety Commission (CNSC). The INS, incorporating DUPIC fuel, changes neither the nature of uranium mining nor the nature of the wastes. Thus, end states exist for the waste and as mining proceeds the waste is being placed into these end states. Hence, all INPRO acceptance limits are judged to be met for mine wastes.

Wastes from Uranium Refining and Conversion Extensive recycling is currently practised in refining and converting uranium in Canadian facilities and consequently only very small volumes of wastes contaminated with uranium, if any, need to be placed into a radioactive end state facility. Disposal options include near surface disposal, including shallow rock caverns, and geological disposal. Because of the small volumes of such waste and the fact that it is contaminated with minor quantities of natural uranium the student considers that such wastes would be placed into a facility built to accept other wastes, such as waste now being stored at AECL's Chalk River Laboratories. Near surface disposal facilities have been licensed and are in operation in a number of countries and AECL has submitted a preliminary safety case for such a facility to the CNSC [3]. The WIPP facility is receiving TRU waste in the USA and the Canadian utility OPG has carried out a preliminary safety assessment of geological disposal at its Bruce site [4],[5]. Thus, the student judges that a safety case that would meet the regulatory requirements of the CNSC could be made. As well, the technology for both near surface and underground disposal has been demonstrated so that the student judges that the technology is already available. Canada does not yet have disposal facilities in operation. But, OPG has indicated [4] that it is planning to submit its safety case and environmental assessment study for geological disposal of its low and intermediate level waste to secure construction approval by about 2012. The student expects that this development will stimulate progress in disposing of waste currently stored at AECL's Chalk River site. Since the INS is only at an early stage of development, the student judges that sufficient progress will have been made on disposal that the criteria related to resource availability and timing of end state facilities will be satisfied on a time scale consistent with the deployment of the INS. Of course, as progress is made towards deployment of the INS, the assessment will have to be revisited to ensure that the progress on establishing disposal facilities for LILW in Canada is consistent with the schedule for deployment of the INS.

Wastes from Uranium Enrichment and the Manufacture of LWR fuel The arguments presented above are also applicable to any operational waste that arises from uranium enrichment and the manufacture of LWR fuel, except that the waste material will be contaminated with enriched uranium. None-the-less, the small amounts of such material that are expected to arise mean that the waste can, in all likelihood, be disposed in either a near surface or a geological facility created to accept a range of low and intermediate level wastes. So, the student judges that the criteria are satisfied for these wastes as well.

Operational and Decommissioning Wastes from LWRs Waste disposal facilities for operational wastes are licensed and operating in the USA. It is possible that new facilities will have to be brought into service as the exiting fleet of operating reactors reach their end of life and are decommissioned. But the student assumes that this will be done, if necessary, and that there are no significant issues with establishing the safety of such facilities since a number are already in operation (Sighting facilities may, however, be difficult). But, at this stage of development the student judges that the criteria related to the end state are satisfied for LWR operational and decommissioning waste.

Wastes from Converting LWR Fuel to DUPIC CANDU Fuel The wastes from the conversion process include the hulls from the spent LWR fuel and operational materials contaminated with powders/dust from the OREOX process which are similar to wastes that arise from conventional reprocessing and from the manufacture of MOX fuel. It is also similar to TRU waste that is being disposed in the WIPP facility in the USA. The Swiss waste management co-operative Nagra, has recently submitted a safety case [6] for the disposal of such material. Thus, the student judges that an adequate safety case can be made for the disposal of such waste in a geological repository.

The other major wastes are the trapped volatiles such as Cs and Ru that are released in the OREOX process. Since the DUPIC process is still at an early stage of development the techniques for trapping such volatiles and the stability of the resulting wastes forms under expected disposal conditions are not well known, although some preliminary work has been done. [2], [7]. In safety assessments studies of the disposal of spent fuel [6], [8], [9], [10] Cs and Ru do not contribute significantly to doses and the transport of these nuclides in the geo-sphere is relatively slow. Thus, the student judges that a satisfactory safety case can, in due course be made for the safe disposal of such wastes in a geological repository, possibly of the type used for LIL waste. The heat generated by the decay of Cs-137 would have to be taken into account but the challenge presented by decay heat can be reduced by utilizing interim storage for a period of ~ 100 years or more. But the student recognizes that a significant amount of work remains to be done and concludes that the management of trapped volatiles as a radioactive waste will need to be addressed as development of the DUPIC process proceeds and that a development plan, including cost estimates, for this work will need to be produced. So, for now, the student concludes that the indicator for the safety case is not met.

CANDU Spent DUPIC Fuel The NWMO, has submitted its study report to the government [11] recommending centralized containment and isolation in a deep geological repository in a suitable rock formation, such as crystalline rock of the Canadian Shield or Ordovician sedimentary rock, for the long term management of Canada's used fuel. Substantial development has been done in Canada on disposal of used fuel in crystalline rock of the Canadian shield [8],[9],[10] and elsewhere and in clay formations similar to Ordovician sedimentary rock [6]. Based on this work, the student judges that the technology for geological containment is available or reasonably expected to be available on a schedule compatible with the schedule that would be considered for the commercial introduction of the INS. Experience to be gained by OPG in the disposal of LILW in a deep repository in Ordovician sedimentary rock at the Bruce site will be valuable in addressing technical issues for the disposal of used fuel in such rock and the safety of doing so.

The recommendation put forward by the NWMO is to deal with the waste from the reactors currently operating in Canada. It has estimated the total waste arisings, assuming different operating lifetimes of these reactors (30, 40 and 50 years). (See appendix 4 of ref [11]). It has also noted that its recommendations are intended neither to promote nor to penalize decisions about the future of nuclear power in Canada. At the same time, the NWMO, in its report, discusses the processes followed in Canada to provide financial surety for used fuel management (See section 11.2 of ref [11]). OPG also discusses the issue of financial resources in ref.[12]. Based on a review of this information, the student judges that the required resources will be available to bring used DUPIC fuel to its end state.

Used DUPIC fuel is similar to used LWR and NU CANDU fuel for which numerous assessments of the safety of geological disposal has been evaluated in a number of studies [6], [8], [9], [10]. Accordingly, the student judges that a case for the safety of geological confinement as recommended by the NWMO can be developed, once a site has been selected and characterized, to meet the regulatory standards of the Canadian regulator.

The NWMO has presented a schedule for geological confinement that covers a time span of ~ 300 years with the emplacement of used fuel in a deep repository beginning in about 90 years. The schedule is meant to be illustrative and conservative. It notes that the time for the front end of the process, site selection and the construction of an underground characterization laboratory, 30 years, is believed to be realistic based on experience in Canada and other countries, and notes that the actual implementation schedule could be shorter. The student accepts the illustrative schedule as conservative and assumes that progress will be made as quickly as reasonably practical, noting the need for on-going public consultation and review as part of the phased adaptive management approach recommended by the NWMO.

CANDU Operational and Decommissioning Waste As noted above, OPG is currently working to establish a deep geological disposal facility at its Bruce site [4]. A preliminary assessment on the safety of the proposed facility has been performed [5] and a preliminary schedule for its establishment has been developed [4]. The schedule indicates that a construction license is expected to be obtained in ~2012 and that waste emplacement is expected to start by ~2017. In October 2004, the Municipality of Kincardine and Ontario Power Generation reached agreement on the terms and conditions under which Kincardine would volunteer to host such a DGR facility, subject to achieving all regulatory approvals. The DGR concept was selected by Kincardine's

Council members because it was expected to have the largest margin of safety of all options considered. Given the development work done on developing geological repositories for used fuel and high level waste from reprocessing spent fuel, the fact that the WIPP facility for transuranic wastes is operating in the USA and shallow rock caverns for low level wastes are operating in Sweden and Finland and that the feasibility and safety of disposal of intermediate level waste has recently been assessed in Switzerland [6], the student judges that technology availability, technology development time, and safety of the end state have been satisfactorily addressed and the student accepts the schedule proposed by OPG as being as short as reasonably achievable (given the fact that no disposal facilities currently exist in Canada for reactor operational wastes). Based on OPG's stated intention to proceed with developing the disposal facility and the financial information published by OPG [12], the student also judges that the resource availability indicator has been met.

Summary The student judges that, with one exception, all indicators related to User Requirements 3.1 and 3.2 have been met for the current stage of development. But the student notes that significant work will need to be done to develop the safety case for the disposal of the volatile wastes released from spent LWR fuel during the OREOX oxidation/ reduction stages, including the evaluation of industrial scale processes for trapping and stabilizing such wastes. This is an area that the student judges that the indicator has not been met and which is identified for future work. But the student judges that, in due course, a satisfactory safety case can be made.

CONCLUDING REMARKS

In this paper the INPRO requirements in the area of waste management have been briefly introduced and an example of an assessment for a hypothetical INS has been presented, to a limited extent, to illustrate the extent of such an assessment. The starting point of such an assessment is the definition of the INS and its components and activities. Wastes arising from all parts of the INS need to be considered when performing an assessment and all requirements must be addressed. In such an assessment it would not be unusual to identify shortcomings in existing or proposed waste management practices, when judged using the INPRO requirements. Such shortcomings would then be the subject of R&D programs.

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Table 1. User requirement and criteria arising from waste management basic principle BP1

Waste management Basic Principle BP1: (Waste minimization) ***Generation of radioactive waste in an INS shall be kept to the minimum practicable.***		
User Requirement	**Criteria**	
	Indicators	**Acceptance Limits**
UR1.1 (Reduction of waste at the source): *The INS should be designed to minimize the generation of waste at all stages, with emphasis on waste containing long-lived toxic components that would be mobile in a repository environment.*	Alpha-emitters and other long-lived radio-nuclides per GWa.	ALARP*
	Total activity per GWa.	ALARP
	Mass per GWa.	ALARP
	Volume per GWa.	ALARP
	Chemically toxic elements that would become part of the radioactive waste per GWa.	ALARP

- As low as reasonably practical

Table 2. User requirements and criteria arising from waste management basic principle BP2

Waste management Basic Principle BP2: (Protection of human health and the environment) ***Radioactive waste in an INS shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur.***		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
UR2.1: (Protection of Human Health) *Exposure of humans to radiation and chemicals from INS waste management systems should be below currently accepted levels and protection of human health from exposure to radiation and chemically toxic substances should be optimised.*	2.1.1 Estimated dose rate to an individual of the critical group 2.1.2 Radiological exposure of workers 2.1.3 Estimated concentrations of chemical toxins in working areas	2.1.1 Meets regulatory standards of specific Member State*. 2.1.2 Meets regulatory standards of specific Member State. 2.1.3 Meet regulatory standards of specific Member State.
UR2.2: (Protection of the Environment) *The cumulative releases of radio-nuclides and chemical toxins from waste management components of the INS should be optimised.*	Estimated releases of radio-nuclides and chemical toxins from waste management facilities	Meet regulatory standards of specific Member State.

* When the regulatory requirement of a Member State is indicated, available international guidance should also be taken into account.

Table 3. User requirements and criteria arising from waste management basic principle BP3

<table>
<tr><td colspan="3">Waste Management Basic Principle BP3: (Burden on future generations)

Radioactive waste in an INS shall be managed in such a way that it will not impose undue burdens on future generations.</td></tr>
<tr><th rowspan="2">User Requirements</th><th colspan="2">Criteria</th></tr>
<tr><th>Indicators</th><th>Acceptance Limits</th></tr>
<tr><td rowspan="5">UR3.1 (End State):
An achievable end state should be specified for each class of waste, which provides permanent safety without further modification. The planned energy system should be such that the waste is brought to this end state as soon as reasonably practicable. The end state should be such that any release of hazardous materials to the environment will be below that which is acceptable today.</td><td>3.1.1 Availability of technology.</td><td>3.1.1 All required technology is currently available* or reasonably expected to be available on a schedule compatible with the schedule for introducing the proposed innovative fuel cycle.</td></tr>
<tr><td>3.1.2.Time required.</td><td>3.1.2 Any time required to bring the technology to the industrial scale must be less than the time specified to achieve the end state.</td></tr>
<tr><td>3.1.3 Availability of resources.</td><td>3.1.3 Resources (funding, space, capacity, etc.) available for achieving the end state compatible with the size and growth rate of the energy system.</td></tr>
<tr><td>3.1.4 Safety of the end state (long-term expected dose to an individual of the critical group).</td><td>3.1.4 Meet regulatory standards of specific Member State.</td></tr>
<tr><td>3.1.5 Time to reach the end state.</td><td>3.1.5 As short as reasonably practicable.</td></tr>
<tr><td>UR3.2 (Attribution of Waste Management Costs):
The costs of managing all waste in the life cycle should be included in the estimated cost of energy from the INS, in such a way as to cover the accumulated liability at any stage of the life cycle.</td><td>Specific line item in the cost estimate</td><td>Included.</td></tr>
</table>

* The word "currently" refers to the time at which the acceptability of a nuclear energy system is being evaluated. The criterion is explicitly intended to allow innovative methods of waste management, such as partitioning and transmutation or advanced waste forms, to be investigated.

Table 4. User requirements and criteria arising from waste management basic principle BP3

<table>
<tr><td colspan="3">Waste Management Basic Principle BP3: (Burden on future generations)

Radioactive waste in an INS shall be managed in such a way that it will not impose undue burdens on future generations.</td></tr>
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<tr><td>3.1.2.Time required.</td><td>3.1.2 Any time required to bring the technology to the industrial scale must be less than the time specified to achieve the end state.</td></tr>
<tr><td>3.1.3 Availability of resources.</td><td>3.1.3 Resources (funding, space, capacity, etc.) available for achieving the end state compatible with the size and growth rate of the energy system.</td></tr>
<tr><td>3.1.4 Safety of the end state (long-term expected dose to an individual of the critical group).</td><td>3.1.4 Meet regulatory standards of specific Member State.</td></tr>
<tr><td>3.1.5 Time to reach the end state.</td><td>3.1.5 As short as reasonably practicable.</td></tr>
<tr><td>UR3.2 (Attribution of Waste Management Costs):
The costs of managing all waste in the life cycle should be included in the estimated cost of energy from the INS, in such a way as to cover the accumulated liability at any stage of the life cycle.</td><td>Specific line item in the cost estimate</td><td>Included.</td></tr>
</table>

* The word "currently" refers to the time at which the acceptability of a nuclear energy system is being evaluated. The criterion is explicitly intended to allow innovative methods of waste management, such as partitioning and transmutation or advanced waste forms, to be investigated.

Table 5. Proposed End States and Assessment of Criteria 3.1.1 to 3.1.5 for each waste steam of the INS

Waste	**End State**	**Technology Availability**	**Tech. Dev. Time**	**Resource Availability**	**Safety Case**	**Time to End State**
U-mine tailings and waste rock	See text	Already available yes	None yes	In service yes	Licensed now yes	In service yes
U- refining and conversion	Near surface or geological disposal	In service in other countries yes	In service in other countries yes	Waste volumes small yes	In service in other countries yes	INS at preliminary stage yes
U –enrich operational wastes	Near surface or geological disposal	In service in other countries yes	In service in other countries yes	Waste volumes small yes	In service in other countries yes	INS at preliminary stage yes
DU	Not	Considered	To be	a	Waste	At present
LWR operational and decommiss. waste	Near surface or geological disposal	In service in USA yes	In service in USA yes	In service in USA yes	In service in USA yes	In service in USA yes
DUPIC Conversion wastes	Geological disposal	INS at preliminary stage yes	INS at preliminary stage yes	INS at preliminary stage yes	Gap in Safety case no	INS at preliminary stage yes
CANDU spent DUPIC Fuel	Geological isolation and containment	Significant development work done yes	INS at preliminary stage yes	INS at preliminary stage yes	Safety cases exist yes	INS at preliminary stage yes
CANDU operational and decom wastes	Geological containment (disposal)	Significant dev wrk done yes	INS at prelimary stage yes	See text yes	Prel. safety case yes	INS at preliminary stage yes