Role of Human Intrusion in Decision-Making for Radioactive Waste Disposal – Results of the IAEA HIDRA Project - 16287

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ABSTRACT

Disposal of radioactive waste aims to protect people and the environment from the potential hazards of the materials by removing the wastes from the human environment. This approach is considered desirable to dispersal of the waste in the environment. However, the waste becomes concentrated in one location, which poses potential hazards should the waste become disturbed at a future date. For radioactive waste, it is generally expected that in preparing safety cases for such disposal facilities, the possibility of the wastes being inadvertently disturbed at some point in the future and the potential consequences of such an intrusion need to be considered. Potential inadvertent human intrusion (IHI) has a role in the decision-making and the safety case throughout the lifecycle of a disposal facility.

In 2013, the International Atomic Energy Agency (IAEA) formally initiated a project entitled “Human Intrusion in the Context of Disposal of Radioactive Waste” (HIDRA) to provide insights regarding the role of IHI for these decisions and to provide a common framework for consideration of IHI as part of development of a safety case for a disposal facility. HIDRA was implemented with a series of annual plenary meetings involving participants from more than 20 countries organised into three working groups. The working groups addressed: societal factors, stylised scenarios, and protective measures. The project resulted in a general approach with specific suggestions for consideration of IHI during the lifecycle of a disposal facility. From a general perspective, it was emphasized that IHI is a contributing factor to the safety case, but does not outweigh considerations related to safety of operations and long-term performance for the normal evolution of the facility.

INTRODUCTION

The IAEA has set out a framework of internationally agreed standards for nuclear safety, radiation protection, transport and radioactive waste disposal. This paper summarizes results from the IAEA HIDRA project that can be useful to supplement current IAEA Safety Requirements and Guides for near-surface and geological radioactive waste disposal facilities [1, 2, 3, 4]. HIDRA was coordinated with activities related to the safety case for the PRISM and GEOSAF projects and projects from the European Commission and the Nuclear Energy Agency.

The IAEA has a statutory obligation to establish standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards (Article III of the IAEA Statute). The IAEA also has a statutory obligation to provide for exchange of information among its member states relating to the peaceful uses of atomic energy (Article VI). The development of the safety standards is aided by having a degree of international consensus on the “what” and “how” of waste safety—something that projects such as HIDRA work towards. The results from the HIDRA project can inform the application of the IAEA safety standards by providing foundation material to clarify requirements related to inadvertent human intrusion and to support expert missions, training events and peer reviews carried out under the IAEA’s Technical Cooperation Fund. Exchange of information among the Member States was also fostered by participating in the various HIDRA meetings and presentations of project activities.

IHI refers to human actions that result in a direct disturbance in the area occupied by a disposal facility. The disturbance can affect the integrity of a disposal facility and potentially give rise to radiological consequences to the intruder or someone that resides on the site after intrusion occurs. Notably, the depth of geologic disposal inherently provides substantial protection against IHI. Consistent with international standards and recommendations, potential IHI is considered for radioactive waste disposal facilities (e.g., someone unknowingly disrupts the facility). Due to unavoidable uncertainty regarding future actions, robustness against intrusion is generally considered using stylised scenarios based on current habits (e.g., drilling, excavation) rather than speculating about what may actually occur far in the future.

PROJECT DESCRIPTION

The objectives of the HIDRA project were to:

- Share experience and practical considerations for the development and regulatory oversight of activities to consider potential IHI during development of the safety case
- Provide a structured approach for identifying and selecting protective measures and/or scenarios that are applicable for site-specific safety assessments
- Describe the role of assessments of IHI for decision making throughout the lifecycle of the safety case
- Provide suggestions for communication strategies to describe the rationale for assessments of future human actions and for interpretation of the conclusions of those assessments for the public
- Provide recommendations for the Waste Safety Standards Committee (WASSC) and Radiation Safety Standards Committee (RASSC), as appropriate, for clarification of existing IAEA requirements and guidance relevant to the consideration of human intrusion.

The HIDRA project addresses IHI involving a disruption of the disposal facility, occurring after closure and following the loss of institutional control for a properly closed facility. IHI is not possible during active control or direct oversight. Passive controls (knowledge management, land use restrictions, etc.) can also serve to delay the timing of intrusion. Factors that influence the timing of when intrusion is assumed to occur are also addressed. Potential disruptions that may occur during operations or prior to loss of institutional control are not considered in this project, but are an area that needs to be addressed in the framework of a safety case, i.e. as accident scenarios. Likewise, as discussed previously, future human actions outside the near-field disposal system and deliberate or intentional acts leading to disruption of the disposal system are not addressed.

Near surface and geological radioactive waste disposal facilities are addressed, including Very Low Level Waste (VLLW) facilities, facilities for Low Level and Intermediate Level Waste (L/ILW), High Level Waste (HLW), Spent Nuclear Fuel (SF) as applicable, and boreholes. Participants provided experience from regulatory and implementation perspectives for facilities with a broad spectrum of designs, waste characteristics, regulatory frameworks and from differing levels of development of national radioactive waste management programmes. The influence of these different considerations on regulatory and implementation aspects of addressing IHI was a key topic for the project. Approaches for considering IHI as part of decision-making in the context of the safety case throughout the lifecycle of a disposal facility (e.g., siting, design, waste acceptance criteria) have been a particular emphasis of the project.

HIDRA was organized with a coordinating group and three Working Groups addressing the following specific areas of interest:

- Societal Factors
- Stylised Scenarios, and
- Protective Measures.

Examples of interfaces between those working groups are illustrated in Figure 1. The three Working Groups fed input to a coordinating group tasked with addressing the overall integration of the different aspects into an approach for identifying scenarios and/or measures that are applicable for including human actions in the safety assessment of a specific disposal facility, and also providing perspective in the context of decision-making associated with the overall safety case.

DISCUSSION

The results from HIDRA addressed several topical areas related to implementation and application of the results from assessments addressing IHI. Four areas are addressed below: role of intrusion for decision-making during the lifecycle of a disposal facility, societal factors, development of stylised scenarios, and the use of protective measures to reduce the potential for and/or consequences of human intrusion.

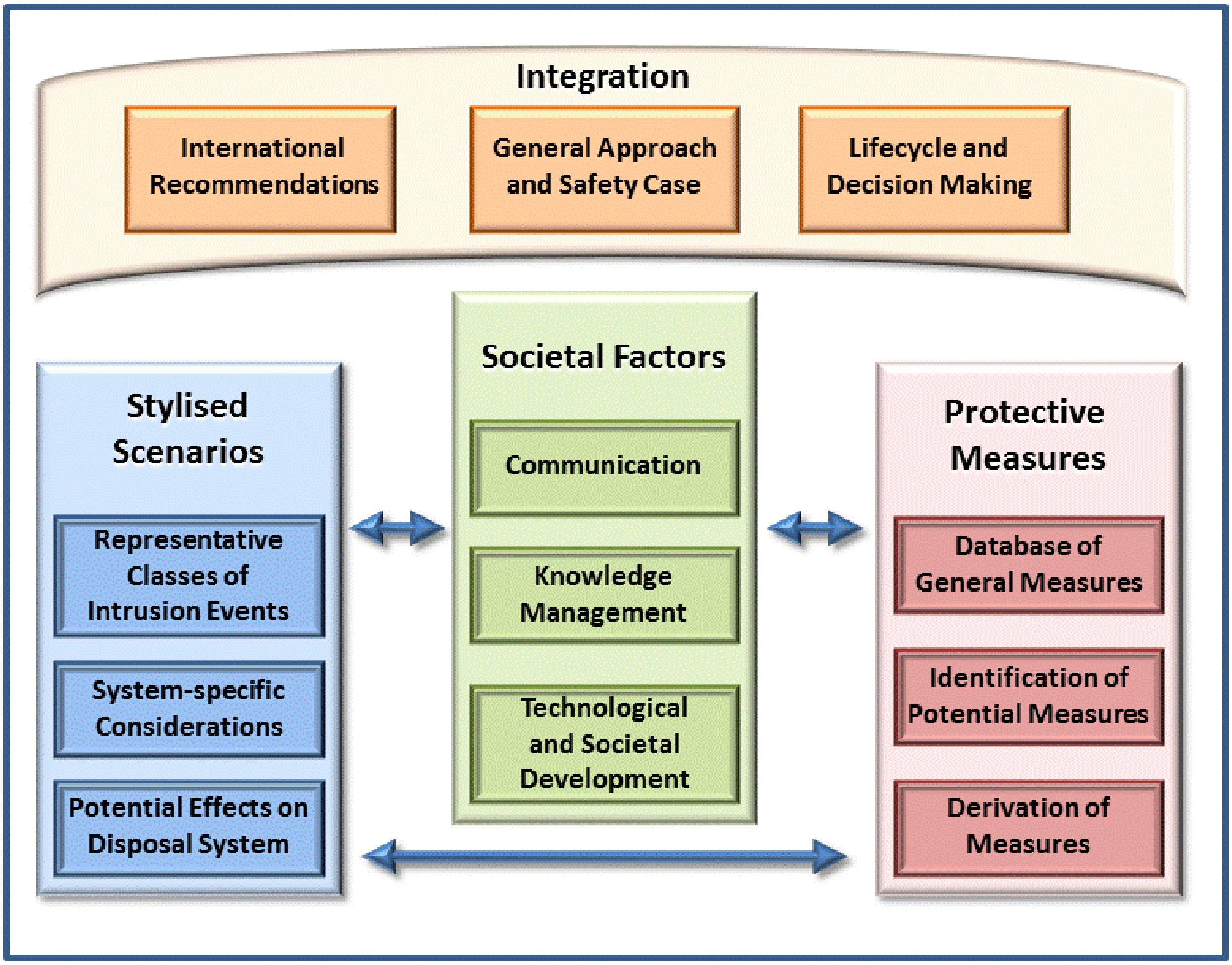

Fig. 1. Summary of Working Groups in the HIDRA Project.

Decision-Making During Facility Lifecycle

The HIDRA project addressed IHI in the context of the safety case and decision making during the life-cycle of a disposal facility, as described for the IAEA PRISM Project [5] (see Fig. 2).

The safety case considers all factors related to the safety of a disposal facility. IHI is a contributing factor to the safety case, but does not outweigh considerations related to safety of operations and long-term performance for the normal evolution of the disposal system. Given the speculative nature of IHI, stylised scenarios are typically considered separate from normal evolution scenarios. IHI is viewed from a different perspective in the safety cases for geological and near-surface disposal facilities, respectively.

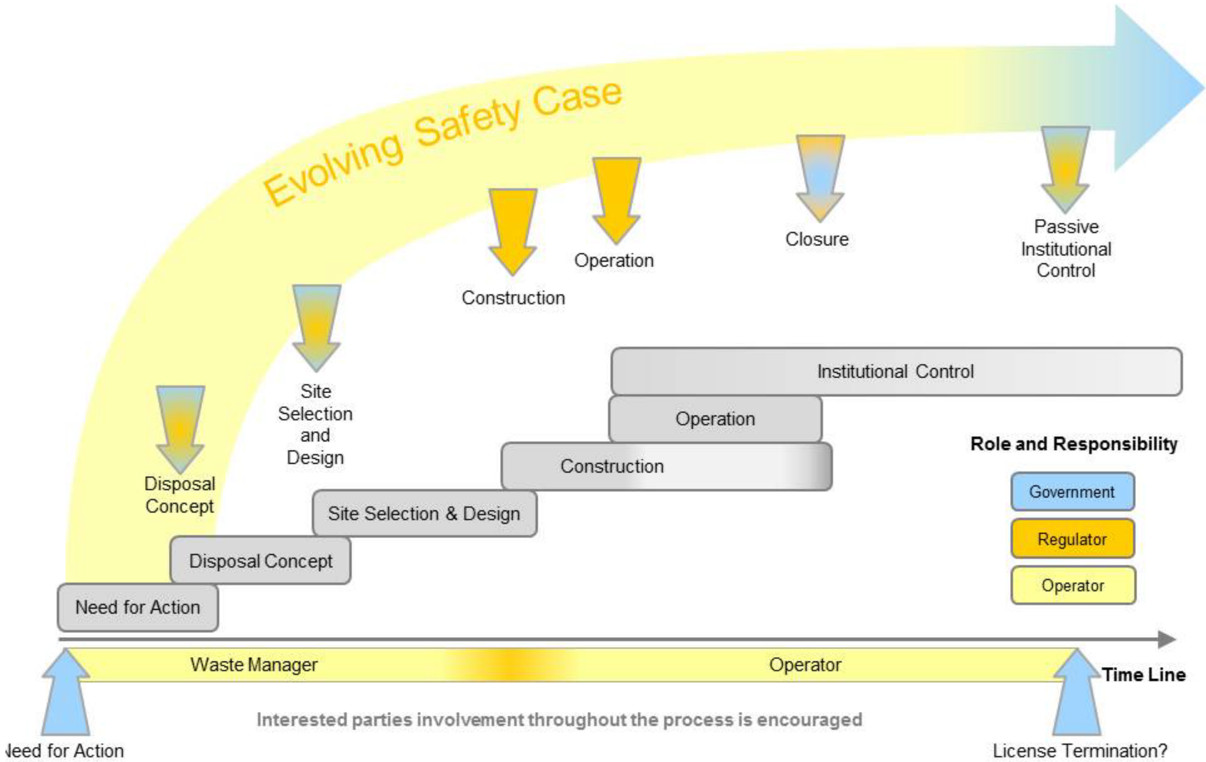

Fig. 2. Disposal Facility Lifecycle and the Safety Case.

For geological disposal, given the inherently protective nature of the concept against intrusion, IHI consideration in the safety case can be qualitative or quantitative, but is generally secondary to the main design optimization process. For near-surface disposal, quantitative approaches are used and often form the basis for waste acceptance criteria and provisions for institutional control, as well as optimization of protection to improve the overall robustness of the safety case.

The development of a radioactive waste disposal facility involves a number of key decisions, typically taken when moving from one stage of the facility life cycle to the next. These decisions are generally supported by the production and examination of a safety case. The HIDRA project developed a general process to address IHI at each step in the lifecycle of a disposal facility. The approach uses recommendations from each of the working groups to identify facility specific scenarios to be considered and to identify measures that could be adopted to reduce the potential for and/or consequences of intrusion (see Fig. 3).

At each decision stage all factors relevant to the safe development and implementation of a disposal facility need to be considered. Considerations related to potential IHI have an evolving role for added robustness at each step in the lifecycle. For example, at the Disposal Concept stage, a choice to adopt geological disposal substantially reduces the potential for and consequences of inadvertent intrusion, and thus, is the preferred approach to manage intermediate and high-level wastes and spent fuel.

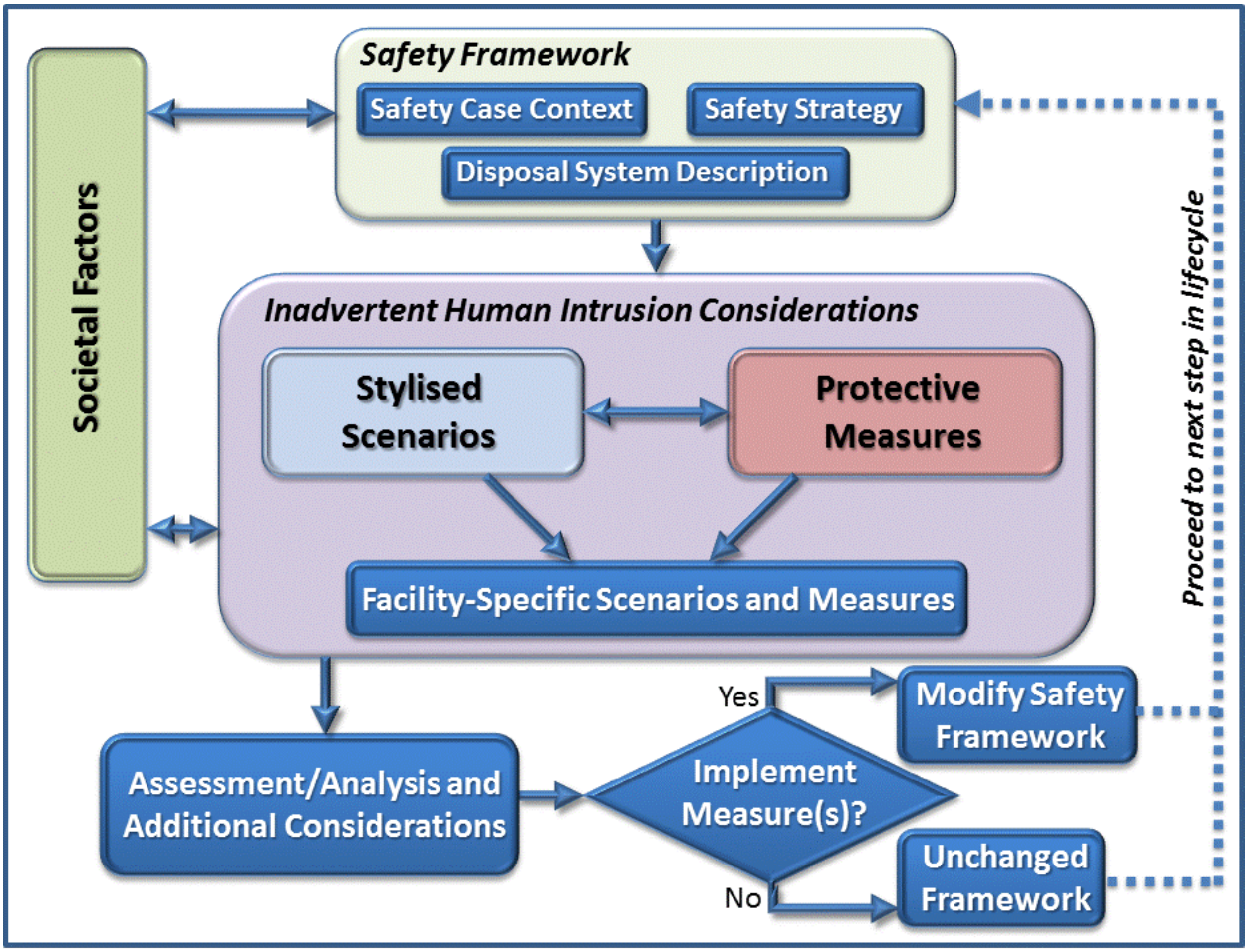

Fig. 3. General Approach to Identify Scenarios and Measures at Each Step in the Lifecycle.

Design and operational decisions can play a significant role for IHI for near-surface disposal facilities. For example, the operational procedures for depth of disposal and thickness of cover can preclude some scenarios leading to contact with disposed waste, such as construction of a basement for a home. Use of barriers can also serve to delay the timing of when intrusion could occur. For example, robust concrete vaults or containers can serve as a barrier to drilling while they remain sufficiently intact.

Post-closure institutional control assumptions can also serve to preclude or delay the timing of when intrusion can occur. TABLE I includes considerations related to different stages in institutional controls. For example, active institutional controls or oversight precludes the potential for IHI. Passive controls and oversight can also delay the potential for intrusion or preclude some scenarios by preserving knowledge of the facility. In general, the most effective means for deterring inadvertent intrusion are deep disposal and maintaining knowledge of the facility.

TABLE I. Post-Closure Phases and Considerations for IHI.

	Time Frames		
	Active Control	**Passive Control**	**Loss of Memory**
Societal Control	Physical security at site	Knowledge management, records, land use restrictions, site markers	Assume no knowledge of hazardous nature of site
Design safety features	Depth of disposal, barriers	Depth of disposal, barriers	Depth of disposal, barriers may be degrading
Implications for likelihood of IHI	No inadvertent HI	Inadvertent HI extremely unlikely – safety case can justify exclusion of major HI scenarios	Inadvertent HI is a possibility, but may still be mitigated by enduring design safety features or depth
Hazard of facility	Disposal inventory	Decaying inventory	Decay may be significant for near-surface, low-level waste facilities

Societal Factors

One aspect of the future that is particularly uncertain over the timescales considered for radioactive waste disposal facilities, is how human society will evolve and what human activities may take place in the future at the location of the radioactive waste disposal facility. The incorporation of societal aspects into IHI scenarios can be different in different projects, since there is no common understanding of how to address these uncertainties in IHI scenarios within a safety case. Differences arise because of different interpretations of different international guidance in national level regulations and also because of other potentially important assessment-specific issues, such as the special interests of particular local stakeholders or features of the local geology and geography. Examples of how societal factors are addressed in IHI scenario development, the interpretation of the results, and how to communicate these results to stakeholders are provided in international collaborative work described in [6].

As part of the societal analysis, assumptions of future human actions need to be defined and justified. The future evolution, behavior, and actions of humans cannot be predicted with any certainty. Nevertheless, it is possible to describe different possible societal contexts based, for example, on the assumed level of societal development [7]. IAEA [8] notes that the types of societal assumptions needed to support the assessment are dependent on the degree of conservatism or realism desired in the analysis and the end points to be considered. It would appear reasonable to select IHI societal assumptions which are consistent with societal assumptions used to support other assessment scenarios. Therefore, in order to derive IHI scenarios, it is important to look at the complete societal context developed in the safety case. In addition, societal aspects play a role in defining mitigation measures against IHI.

The discussion of societal factors highlighted the importance of effective communication, both for describing the purpose and cautiousness of considering human intrusion for radioactive waste disposal and for reducing the potential for intrusion by maintaining knowledge of the disposal facility after it is closed. Maintaining knowledge of the facility is recognized as one of the most effective means of limiting the potential for inadvertent intrusion and a number of potential recommendations were provided to preserve knowledge. Another important consideration discussed by the working group was distinguishing what would be considered deliberate intrusion rather than inadvertent intrusion (e.g., at what point does the intruder recognize that they have contacted something unusual and take reasonable measures to assess the nature of the waste?).

The Societal Factors working group also provided information regarding consideration of technological development and human diets and habits when addressing very long time frames. The general recommendation is that current habits and technologies are appropriate for the purposes of IHI.

Stylised Scenarios

There is a general acceptance in international recommendations that one or more stylised scenarios can be used to assess IHI. The use of stylised scenarios recognizes that it is not possible to predict future human actions on the time frames associated with a safety case. The IAEA Safety Guide on the Safety Case [4], Paragraph 6.61 addresses the use of stylised scenarios as follows:

> "*Human intrusion scenarios should be developed on the basis of stylised representations of the nature of the intrusion and the actions of the intruder, and it should be recognised that there is an unavoidable uncertainty associated with human intrusion. Human intrusion scenarios are not meant to convey any authoritative statement about the evolution of the site and future societal activities, but are designed to provide illustrations of potential impacts of human intrusion. If stylised scenarios are being used, they should be based on the assumption of present day technologies and procedures.*"

The Stylised Scenarios Working Group developed a general method for identifying, developing, and customizing site-specific IHI scenarios. Figure 4 provides a high-level overview of the method. The first step is to consider the safety context, including any regulatory requirements that address scenarios or other specific aspects of IHI. This is followed by describing the safety strategy, including identification of the type of disposal system (e.g., near surface disposal, geological disposal) and attributes of the system description including characteristics of the radioactive waste disposal system (e.g., facility design, waste forms, canister materials) and the natural environment (e.g., geology, hydrology, biosphere). Often for disposal facilities, the attributes of the disposal system will be consistent with features, events, and processes in the normal evolution scenario (e.g., if there is a long time before intrusion occurs, the barriers may degrade, as they would in the normal evolution scenario).

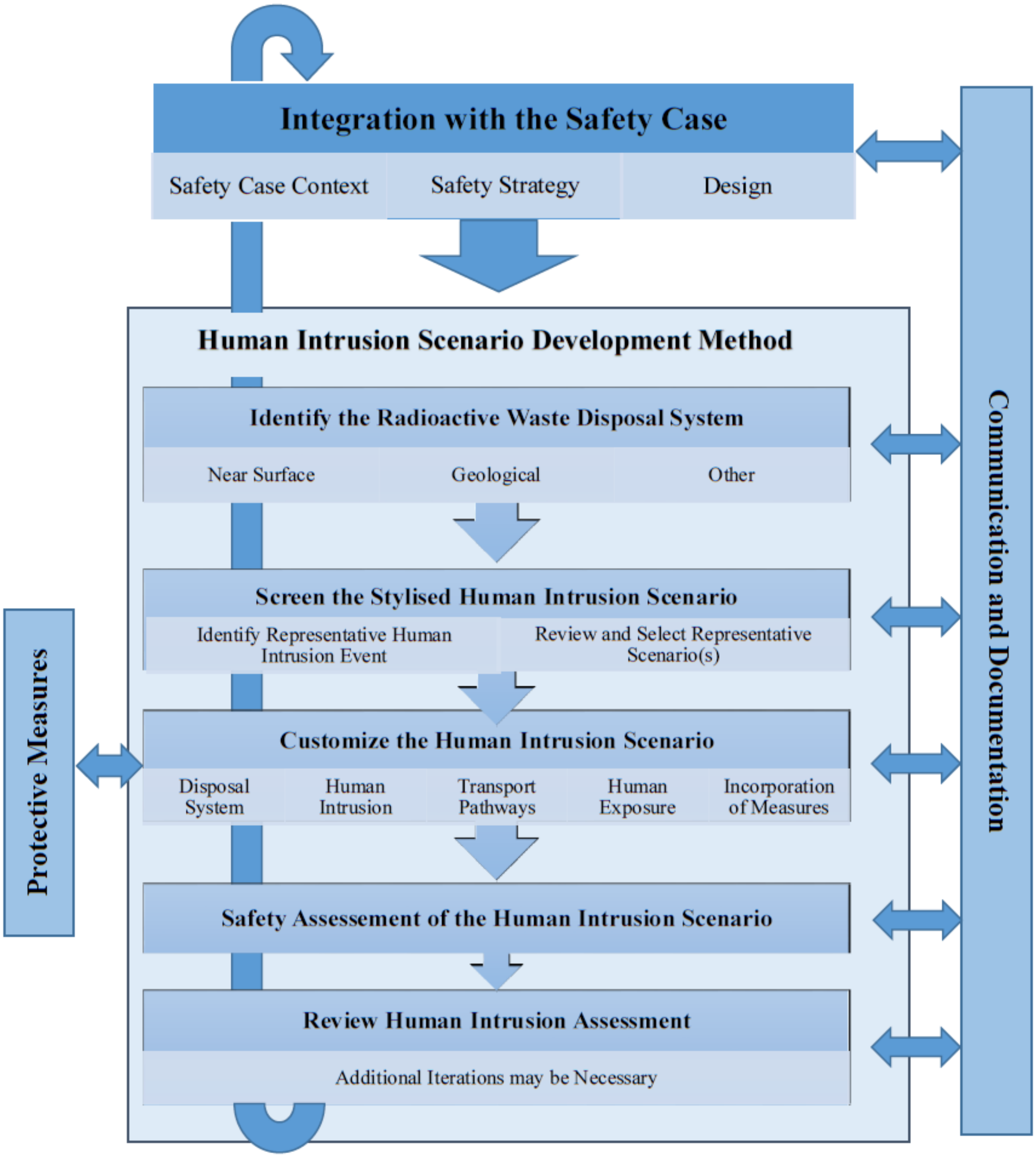

Fig. 4. General Approach to Address Facility-Specific Stylised Scenarios.

The third phase involves identifying and screening the representative IHI events and resultant stylised IHI scenarios. The stylised IHI scenarios are representative of scenarios most commonly used by Member States, for applicability to the specific circumstances described above. The fourth phase customizes the stylised IHI scenario (e.g., drilling methods, equipment) and identifies the impacts of the representative human intrusion event (e.g., transport pathways, exposure, indicator performance). The final phase reviews the outputs and identifies whether additional iterations of this process are warranted. These additional iterations may result in the incorporation of protective measures. The figure also highlights the importance of communication and documentation through the entire process of considering IHI.

The Working Group identified classes of scenarios that are considered representative of future human actions that could impact a disposal facility, namely drilling and excavation. For near-surface disposal, excavation can include, for example, a basement for a home or potentially a roadway. For geological disposal, excavation could include some form of mining. Drilling directly into waste in a geologic disposal facility for HLW is considered highly unlikely, but drilling in the area of the facility is often considered. The working group described assumptions regarding the different types of intrusion and potential radionuclide transport and exposure pathways that would be associated with different scenarios and considerations related to assessing the effectiveness of different measures.

Protective Measures

The third working group focused on identification of potential measures that could reduce the potential for and/or consequences of IHI (i.e., delay or preclude different scenarios). This was one of the most substantial efforts of the project and resulted in a large database of measures that can be considered. An important consideration on which there is general consensus is that any measures taken to reduce the potential for IHI should not compromise the safety performance of the disposal system. Therefore, appropriate measures have to be derived or identified. The Working Group developed a general approach for identifying and addressing potential protective measures as illustrated in Fig. 5.

This reflects the general intent of intrusion as part of optimization of the disposal system against IHI. This is already required in some regulations as part of the optimization process [9, 10]. Maintaining a focus on the use of intrusion in the context of optimization is a key concern of the underlying methodology regarding the treatment of IHI in a safety case. There are several definitions of the term optimization in national and international safety reports and guides. The following definition from the ICRP [11] provides a general description of optimization which can be assigned to different safety issues including IHI:

> "Optimisation has to be understood in the broadest sense as an iterative, systematic, and transparent evaluation of protective option, including Best Available Techniques, for enhancing the protective capabilities of the system and reducing its potential impacts (radiological and others)."

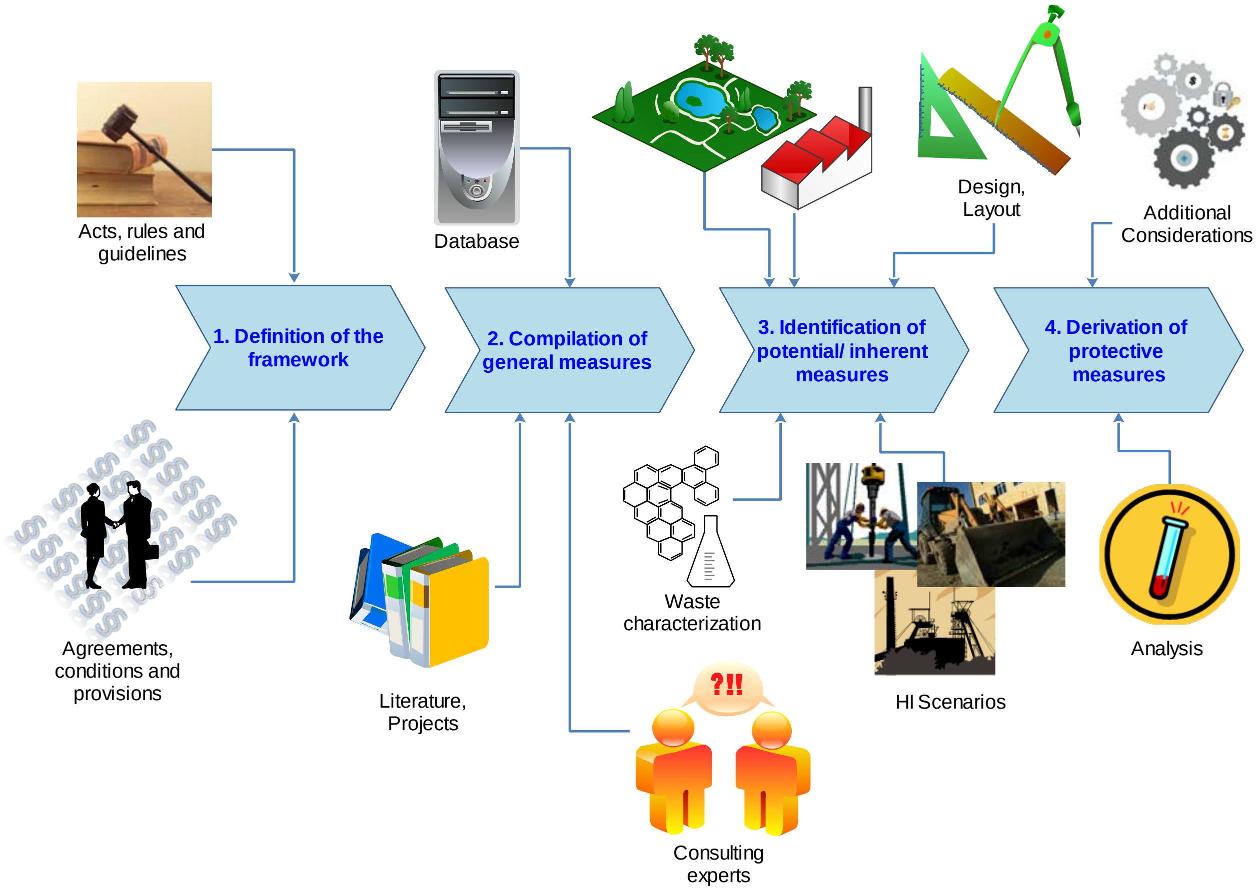

Fig. 5. Schematic of Four Steps to Identify and Derive Effective Protective Measures.

The main task is therefore the derivation of “protective measures” which will contribute to the objectives of reducing the potential occurrence of IHI and reducing the radiological consequences if IHI should occur. In this context, a systematic approach was developed that identifies, evaluates and selects protective measures in a stepwise manner. TABLE II provides general descriptions of the terminology that was used by the Working Group.

Different protective measures may be considered at different stages of the life cycle of the disposal facility. The measures can also be categorized generally into groups as passive or active measures. Examples of different roles for measures include: warning, informing, preventing, delaying, impeding and controlling. The Working Group organized the database to distribute the measures into several general categories:

TABLE II. Terminology Used by the Working Group.

Type of measure	Description
Measures	Generic term for all measures considered in this report
General measures	The overall list of measures which are considered in the process of deriving potential measures (compiled in step 2 and input for step 3)
Potential measures	Measures identified as appropriate candidates for a specific facility (identified in step 3 and input for step 4)
Inherent measures	Features that are already part of the site, disposal concept, disposal design/layout etc. For example, the location of the disposal facility in deep geological formations which reduces the potential or possible radiological consequences of HI (identified in step 3 and input for step 4)
Protective measures	Measures which meet the technical criteria and regulatory requirements and are recommended for implementation for a specific facility (derived in step 4 and input for a possible iteration of optimisation)

- Monitoring/Surveillance
- Design (waste placement, engineered barriers, etc.)
- Knowledge Management
- Siting
- Waste Types and Characteristics.

The Working Group identified a number of examples and considerations to support the process of identifying, evaluating and selecting measures on a facility-specific basis. The selection criteria include regulatory, technical, and feasibility considerations. Evaluation of the effectiveness of measures is closely integrated with considerations from the Societal Factors and Stylised Scenarios Working Groups.

When protective measures are derived and implemented, the purpose is optimization and there is no implied guarantee regarding how future generations will act when respective measures are encountered/ detected (will they avoid the facility or explore it?). Also, there are measures which may be inappropriate for a specific site and disposal facility, but the same measures can be useful for other sites and disposal facilities depending on the specific circumstances.

Conclusions

Disposal of radioactive waste aims to protect people and the environment from the potential hazards of the materials by removing the wastes from the human environment. This approach is considered desirable to dispersal of the waste in the environment. However, the waste becomes concentrated in one location, which poses potential hazards should the waste become disturbed at a future date. For radioactive waste, it is generally expected that in preparing safety cases for such disposal facilities, the possibility of the wastes being inadvertently disturbed at some point in the future and the potential consequences of such an intrusion need to be considered.

The IAEA, ICRP and OECD agree that only inadvertent human actions that may impact a disposal facility need to be considered. This is because today's society cannot be expected to protect future societies from their own intentional and planned activities if they are aware of the consequences. This is valid irrespective of the intent of the planned actions, i.e. regardless of whether they are carried out for benevolent or malicious reasons. International recommendations and national regulations generally state that in the safety case human intrusion scenarios should be considered separately to the normal evolution scenarios. In particular, and especially for geological disposal facilities, it may not be required to demonstrate compliance with any dose constraints for the IHI scenarios. Rather, the potential consequences arising from IHI are considered in the context of identifying opportunities to reduce the potential for and/or consequences of human intrusion and, where appropriate, for opportunities to enhance the robustness of the disposal facility.

The HIDRA project has developed a general approach for the consideration of IHI into radioactive waste disposal facilities, addressing both geological disposal facilities and near-surface disposal facilities. The project specifically addressed differences in the approaches for addressing intrusion for the two general classes of disposal (near surface and geological). The approach developed to consider inadvertent intrusion is intended for application in an iterative manner that supports decision-making throughout the lifecycle of a disposal facility. The general focus of the approach is to identify and consider the effectiveness of different measures that may be adopted to reduce the potential for and/or consequences of IHI to improve the robustness of the disposal facility.

Some of the key outcomes from the working groups included: information on effective communication regarding human intrusion, approaches to enhance the duration of knowledge of the disposal facility, a set of stylised scenarios that can be considered as a starting point for a safety assessment, a database of measures that can be considered to help reduce the potential for and/or consequences of IHI and general approaches to develop site-specific scenarios and identify protective measures that would be effective for a disposal facility.

References

1. IAEA, Disposal of Radioactive Waste, Specific Safety Requirements No. SSR-5, International Atomic Energy Agency, Vienna, 2011.
2. IAEA, Near-surface Disposal Facilities for Radioactive Waste, Specific Safety Guide No. SSG-29, Vienna, 2014.
3. IAEA, Geological Disposal Facilities for Radioactive Waste, Specific Safety Guide No. SSG-14, International Atomic Energy Agency, Vienna, 2011.
4. IAEA, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Specific Safety Guide, No. SSG-23, International Atomic Energy Agency, Vienna, 2012.
5. Seitz, R., J. van Blerk, C. Gelles, And G. Bruno, Managing Uncertainties Associated with Radioactive Waste Disposal: Task Group 4 of the IAEA PRISM Project -11190, WM2011 Conference, February 27 – March 3, 2011, Phoenix, AZ, 2011
6. Smith GM, Molinero J, Delos A, Valls A, Conesa A, Smith K, Hjerpe T, 2013. Human intruder dose assessment for deep geological disposal. Posiva working report 2013-23.
7. SKI/SSI/SKB. Biosphere Scenario Development: An Interim Report of an SKI/SSI/SKB Working Group. Issued by Swedish Nuclear Power Inspectorate, SKI TR89:15. Stockholm. 1989.
8. IAEA, Reference Biospheres for Solid Radioactive Waste Disposal: Report of BIOMASS Theme 1 of the BIOsphere Modelling and ASSessment (BIOMASS) Programme, IAEA-BIOMASS-6, IAEA, Vienna (2003).
9. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste, as at 30 September 2010.
10. EA and NIEA, Geological Disposal Facilities on Land for Solid Radioactive Wastes Guidance on Requirements for Authorisation, UK, February 2009.
11. ICRP, Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste, ICRP Publication 122, 2013.