IMPROVEMENT OF SAFETY ASSESSMENT METHODOLOGIES FOR NEAR SURFACE DISPOSAL FACILITIES

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ABSTRACT

The International Atomic Energy Agency (IAEA) Coordinated research program "Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities" (ISAM) has developed improved safety assessment methodology for near surface disposal facilities. The program has been underway for three years and has included around 75 active participants from 40 countries. It has also provided examples for application to three safety cases - vault, Radon type and borehole radioactive waste disposal facilities. The program has served as an excellent forum for exchange of information and good practices on safety assessment approaches and methodologies used worldwide. It also provided an opportunity for reaching broad consensus on the safety assessment methodologies to be applied to near surface low and intermediate level waste repositories. The methodology has found widespread acceptance and the need for its application on real waste disposal facilities has been clearly identified. The ISAM was finalized by the end of 2000, working material documents are available and an IAEA report will be published in 2002 summarizing the work performed during the three years of the program.

The outcome of the ISAM program provides a sound basis for moving forward to a new IAEA program, which will focus on practical application of the safety assessment methodologies to different purposes, such as licensing radioactive waste repositories, development of design concepts, upgrading existing facilities, reassessment of operating repositories, etc. The new program will also provide an opportunity for development of guidance on application of the methodology that will be of assistance to both safety assessors and regulators.

INTRODUCTION

Radioactive waste is generated in different activities (nuclear power plants operation, medicine, industry, etc.) and these wastes need to be managed in a safe manner including waste disposal. Safety assessment is an important tool for evaluating the acceptability of proposed, on-going or past waste disposal practice. Safety assessment can be seen to be an important component of practical decision making about the long-term safety of disposal facilities. Safety assessments should be structured in a manner that maximizes confidence in decisions, which are made about the disposal facility.

This paper presents the work of the IAEA on improvement of safety assessment methodologies for near surface waste disposal facilities and the application of these methodologies for different purposes in the individual stages of the repository development. The paper introduces the main objectives, activities and outcome of the IAEA research Coordinated program on Improvement of Safety Assessment Methodologies for Near Surface Waste Disposal Facilities (ISAM), held from 1997 to 2000. It summarizes the work performed by the six working groups within the ISAM program, i.e. Scenario Generation and Justification, Modelling, Confidence Building, Vault, Radon Type Facility and Borehole Test Case groups.

The conclusions reflect the main lessons learned from the ISAM program and consensus on the safety assessment methodology for long-term safety assessment of near surface repositories for low and intermediate level waste. More than 70 ISAM participants, actively participating in the program, achieved this common view. The authors acknowledge their gratitude to their colleagues and friends who provided support during the accomplishment and finalization of the program.

THE IAEA PROGRAM ON IMPROVEMENT OF SAFETY ASSESSMENT METHODOLOGIES FOR NEAR SURFACE WASTE DISPOSAL FACILITIES (ISAM)

An initial attempt at developing improved confidence in safety assessment approaches was made by the Agency's Coordinated Research Program (CRP) on the Near-Surface Radioactive Waste Disposal Safety Assessment Reliability Study (NSARS). The ISAM program took account of the NSARS experience. The primary focus of ISAM program was the methodological aspects of long-term safety assessment for near surface radioactive waste disposal with emphasis on the practical application of these methodologies on example waste disposal facilities for low and intermediate level waste.

The ISAM program had the following main objectives:

— to provide a critical evaluation of the approaches and tools currently used in the post-closure safety assessment of proposed and existing near-surface radioactive waste disposal facilities;

— to enhance the approaches and tools used;

— to provide participants with practical experience in the implementation of the approaches and tools; and

— to build confidence in the approaches and tools used.

In order to achieve these objectives, the associated work program focused on the review and enhancement of approaches and tools used for safety assessment of near surface disposal facilities and in particular for scenario development and justification; model formulation and implementation, including input data; and confidence building. Three Working Groups within the ISAM program were established to focus on the methodological aspects of the safety assessment process.

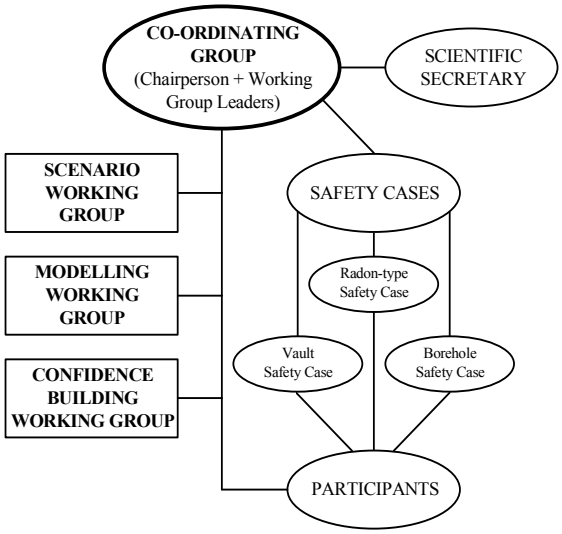
Three group safety cases were also developed in the ISAM program that addressed respectively:

— a typical example of current practices (Vault type of facility);

— a disposal facility representative of older practices (RADON type facilities); and

— a future facility (Borehole type facility).

The group safety cases were developed throughout the ISAM program and provided a reference for participants when developing their own safety cases. They also provided the basis for open discussion of the many practical issues encountered when undertaking an assessment with the aim of reaching consensus in as many areas as possible.



The ISAM program also provided an international forum for operators, regulators, safety assessors or experts from research organizations to exchange experience, views and ideas on safety assessment approaches used and ways for their improvement. The ISAM participants were specialists from the Member States, who had experience in technical activities, related to safety assessments for near-surface radioactive waste disposal facilities.

The ISAM organizational structure is shown in Figure 1.

Fig. 1. ISAM Organizational Structure

The ISAM Coordinating Group provided overall management and coordination of the program and activities of each working group. It was also responsible for the preparation and review of ISAM documentation, and the technical aspects of the Research Coordination Meetings (RCMs) and Working Group Meetings (WGMs). The IAEA, represented by the Scientific Secretary, has been responsible for the overall coordination of the ISAM program.

THE ISAM METHODOLOGY FOR LONG-TERM SAFETY ASSESSMENT FOR NEAR SURFACE WASTE DISPOSAL FACILITIES

The ISAM safety assessment methodology provides a systematic and logical procedure for evaluation of long-term safety of near surface disposal facilities in a traceable, well documented, and transparent manner.

The methodology includes the following key components (Figure 2):

— Specification of the assessment context;

— Description of the waste disposal system;

— Development and justification of scenarios;

— Formulation and implementation of models; and

— Analysis of results and building of confidence.

Each of these components is discussed below.

Assessment Context

The assessment context as a first step of the safety assessment process needs to identify clearly what you are trying to assess and why you are trying to assess it, i.e. for quantitative assessment what you are trying to calculate and why you are trying to calculate it.

The assessment context provides information concerning the following key aspects that need to be considered and taken into consideration once moving to the next steps of the safety assessment process.

Purpose of the safety assessment. Most post-closure safety assessments have the principal, high level purpose of demonstrating adequate protection of human health and the environment. However, depending upon the stage of development, operation, and closure of the disposal facility assessed, there can be a variety of additional purposes. It is also important to identify the audience as it can cover a large number of potential "stakeholders" (e.g. regulators, operators, waste producers).

*Regulatory Framework***.** In undertaking safety assessment it is important to consider the regulatory framework in place that applies to the safety assessment. At one extreme this might be a well-specified, quantitative framework, and at the other it might be extremely limited (non-prescriptive) or even requiring to be developed. In all cases, it is recommended that consideration should be given to international guidance and recommendations on the regulation of radioactive waste disposal**.**

Calculational End Points. The end-points of an assessment need to adequately defined and to correspond with its purpose and the associated regulatory framework. It is important that the endpoints take into account the assessment assumptions made concerning timescales and critical groups.

Assessment Philosophy. The assessment philosophy provides information on the extent to which the assessment is designed to provide a "realistic" estimate of the potential impacts from a repository comparison with the assessment end-points, or whether more cautious, or pessimistic assumptions should be adopted.

Radioactive Waste Characteristics. Radioactive waste is necessary to be well characterized, both according to its radiological, chemical, physical, thermal and other properties, in order to provide well justified input for the evaluation of the safety of the radioactive waste disposal facility.

Disposal System Characteristics. The description of the waste disposal system characteristics should be undertaken firmly in mind (in particular the assessment purpose, end-points, philosophy and timescales), and so ensure that the system is described to a level of detail that is appropriate for the context being considered in the safety assessment.

*Timeframes***.** Time-related factors that need to be considered in a safety assessment are specifically related to the half-lives of relevant radionuclides, the duration of the institutional control period (both the active and passive); the natural and human induced environmental changes; and the degradation of the engineered barrier system.

System Description

The disposal system description should contain information on:

- *The near field* – e.g. waste types, waste forms, waste inventory, disposal practices, engineered barriers (chemical and physical characteristics), facility dimensions;
- *The geosphere* – e.g. lithology, flow and transport characteristics; and
- *The biosphere* – e.g. exposure pathways, climate characteristics, human habits and behavior.

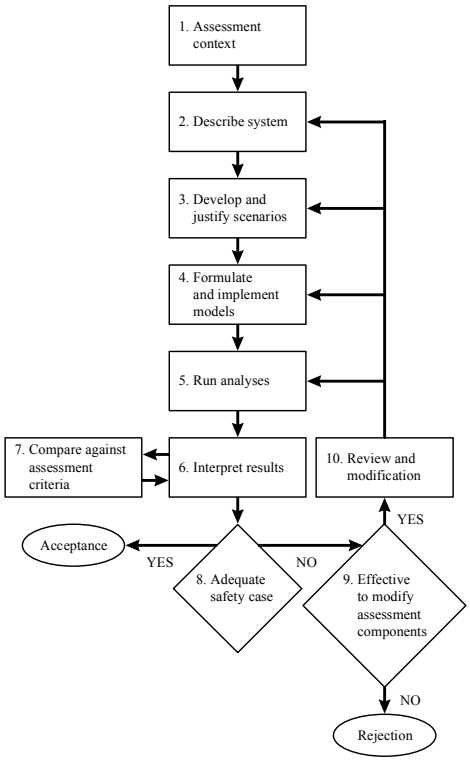


Fig. 2 Safety Assessment Methodology

It is important to ensure that the data collated is pertinent to the assessment context. For the first iteration of the approach, emphasis could be placed mainly on the collation of existing data rather than the collection of new data. For subsequent iterations, the emphasis could shift towards the collection of new data.

Development and Justification of Scenarios

There are several methods that can be used to generate scenarios, none of them claiming to be the only or right one. The techniques relevant to near surface disposal were reviewed in the ISAM program and include methodologies such as expert judgment, fault tree and event tree analysis. In most of the cases, the conclusions reached by the different techniques are very similar and the output is selection of a set composed of few scenarios that encompass most of the possibilities in terms of potential impact.

The ISAM program focused on scenarios generation and justification for near-surface disposal facilities and ensured that its work complemented other national or international programs. Taking into account the several well-documented methodologies already existing for generation of Features, Events and Processes (FEPs) lists, the ISAM program aimed at development of a systematic approach and procedures for development of justified scenarios from a consistent FEPs list. The ISAM program also aimed to compare and review existing and currently developing methodologies, focusing on their application to near surface disposal facilities. Any methods which had been developed were taken into full account. Since development of a FEPs list has been a common activity in many scenario generation methodologies, the development of a FEPs list for near surface disposal facilities was one of the activities within the ISAM project.

Formulation and Implementation of Models

Once the scenarios have been developed, their consequences in terms of the assessment context must be analyzed and a conceptual model, comprising of a set of model-level assumptions (about dimensionality, boundary conditions, FEPs, FEP relationships, etc.) needs to be identified for each of these scenarios. The mathematical models are developed from these conceptual models.

The Modelling working group focused on approaches that could be used to formalize the process of conceptual model development and justification. Approaches were evaluated for their robustness in treating alternative conceptual models and on their ability to produce a defensible and traceable safety assessment. The group also provided a summary of the models used in different safety cases, noting the associated assumptions and limitations. A list of mathematical models and computer codes were collated for the benefit of participants and other interested parties, which will be included in the TECDOC to be published in 2002. The primary issues associated with computer tools relate to their verification and the overall application of quality assurance in their development. These issues were also considered as part of the working group's activity. The ISAM program considered the issue of quality assurance and the degree to which it has an impact on the defensibility of the safety assessment. As the safety assessment requires considerable *data* related to the waste disposal system, the Modelling working group focused on the main parameters and data acquisition techniques.

Results Analysis, Confidence Building

Confidence building is involved in all aspects of developing safety assessment. It involves the use of transparent and logical multiple lines of reasoning, and accurate data to support the safety assessment. Application of a quality assurance program is another confidence building measure. Activities associated with the use of good science and good engineering practice can add an additional level of confidence in the safety assessment process. Consideration of sensitivity and uncertainty may also be helpful, as might the use of simple scoping calculations. In particular, sensitivity analysis can be used as a method for providing confidence in results. Sensitivity analysis may also allow attention to be focused on those components of the system where the greatest performance improvements can be obtained.

Comparison of safety assessment results with both national *regulatory criteria* and international guidelines and recommendations is an important element of providing confidence in the safety of a radioactive waste disposal facility. Therefore the Confidence Building Group has reviewed the main existing regulatory requirements and internationally agreed principles and standards applied in 17 countries. A list of relevant safety indicators was compiled by the ISAM Confidence Building Working Group. One of the tasks of the working group was to catalogue methods and tools that have been found useful in performing sensitivity and uncertainty analyses, as well as ensuring quality of the safety assessment. Different methods used for the presentation of results were compared as part of this task and the usefulness of these measures was investigated. The Confidence Building group also added means for ensuring transparency in all aspects of the safety assessment process.

It is also important that due care and attention is given to the presentation of results. Different methods can be used for the presentation of results and the selection of a specific presentation strategy depends to great extent on the purpose of the presentation, audience, and stage of the repository's development. Interpretation, analysis and presentation of the results is followed by

the decision process, which involves different factors to reach a decision on level of safety of a waste disposal facility.

The safety assessment process is an iterative one and this promotes the examination of improvements to the disposal system regardless of how favorable results initially appear.

THE ISAM SAFETY CASES

Safety Cases

Three group safety cases were addressed in the program:

— *Vault safety case* – based on proposed disposal using hypothetical engineered vaults with a Vaalputs geosphere and biosphere;

— *RADON safety case* – based on past disposal using a "RADON" type facility in the Russian Federation;

— *Borehole safety case* – based on the AFRA borehole disposal concept with a Vaalputs geosphere and biosphere.

Vault Safety Case

Of the three Safety Cases, the vault facility subgroup represents a type of facility for which safety assessments were most familiar. The Safety Case focused on assessment of a proposed disposal facility for miscellaneous commercial low-level waste, including power-plant waste, medical waste, and industrial waste. The facility design has been based on public domain documents about a proposed disposal facility and modified for the purposes of the Vault Safety Case. The disposal facility is a set of 20 concrete vaults located above ground level for the disposal of low-activity waste.

The Vault Safety Case developed and successfully applied a scenario development and justification procedure to identify a design scenario and several alternative scenarios. At various stages in the assessment process, it was found helpful to develop a summary flow diagram of the basic steps in particular sub-components of the overall methodology to clarify understanding and for communication purposes (for example, the process of scenario development and justification, see Figure 3). It was also found useful to review these flow diagrams after implementation and modify them in the light of experience, and this is another example of the iterative nature of the safety assessment process.

The Vault Safety Case has also focused primarily on the scenario generation and model development aspects of the ISAM methodology. It is recognized that further work on this case could consider in more depth the confidence building aspects of the safety assessment such as results presentation, treatment of uncertainty, quality assurance, etc. with suitable practical examples. Many of the assumptions and decisions made by the Vault Safety Case Group were made for pragmatic reasons to enable progress to be made with the limited time available. It is recognized that other safety assessments might require a more detailed and thorough implementation of the tools and approaches tested by the Vault Safety Case Group, depending upon the assessment context.

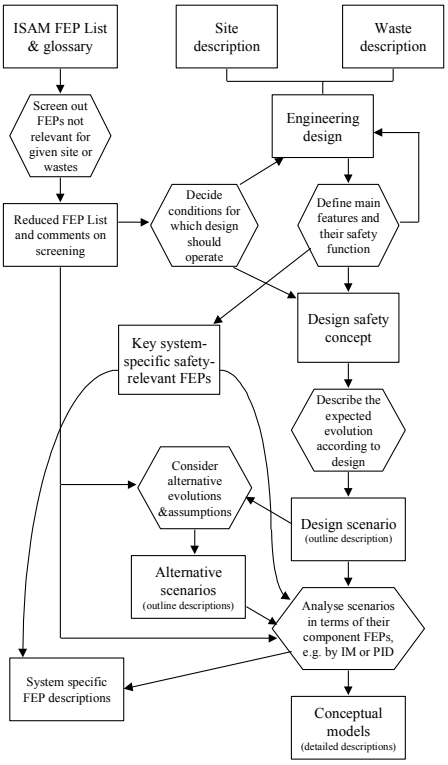


Fig. 3 Vault Safety Case Scenario Development Procedure

A range of different conceptual and mathematical models were applied by participants for the design scenario liquid release and human intrusion scenario calculations, but the resulting differences were often small (an order of magnitude or less), especially for the key radionuclides. Thus, based on these limited results, model uncertainties appear to result in smaller differences in doses (one order of magnitude) than uncertainties associated with the future evolution of the site (three orders of magnitude). The Vault Safety Case indicated that when assessing a near surface disposal facility, it can be important to consider release mechanisms in addition to liquid release. Human intrusion, gaseous and solid release can all be considered as important exposure pathways.

Radon Type Facility Safety Case

This safety case was based on the design and waste types typical for "Radon" disposal systems built in the former Soviet Union and some Eastern European countries in the 1960s. In comparison with the other ISAM safety cases, the Radon Type Facility Safety Case has the following specific features typical for this type of repository:

— Repository operation for more than 30 years and hence different levels of knowledge of the site, repositories and wastes disposed of in the past, etc.;

— Different types of disposal facilities located at one site, such as boreholes for disused sealed sources, vaults (for solid and biological RAW), and trenches;

— Location of the sites (close to populated areas).

The safety case was based on a hypothetical mixture of realistic site descriptions of several Radon repositories with vaults and waste inventories from different sites. Therefore this Safety Case is a good example of application of the ISAM methodology to this type of repository and the lessons learned can be used at specific real RADON-type disposal facilities.

One of the key outcomes of the RADON Safety Case was a rather broad agreement on high-level assumptions and concepts that should be applied in the assessment context. It was discovered that there was more variability among practices at these facilities than was previously understood.

The high-level ISAM FEPs list has been considered as a very useful tool for safety assessment. The Radon Safety Case Group used it in a limited way for scenario development, mainly as a

checklist to audit the scenarios after they were developed. At the same time the group noted that it could be helpful to develop a generic list of scenarios specific to RADON-type facilities. This could be done on the basis of specific features of typical disposal units at RADON-type facilities, taking into account typical geological and hydrogeological conditions at their sites. For example, the 16 existing sites in the Russian Federation could fit in a smaller number of categories, e.g. six types. Once developed, these scenarios should be verified using the FEP screening procedure for each specific facility. Additional scenarios might be developed if needed.

Conceptual and mathematical modeling can be applied to the calculation of end points (doses), and also to clarify missing data necessary for the safety assessment. This second approach is particularly important for historic "Radon" type facilities, at which some types of information are missing. The complexity of each component of the model, particularly those components dealing with groundwater flow and transport, depends on the assessment purpose, as well as on available data and knowledge of the system. Care must be used when combining different kinds of models into a joint system.

Within the ISAM project a limited number of scenarios were considered and calculated. In particular, in this Safety Case, solid releases of radionuclides from this near surface facility lead to higher doses than did groundwater releases. Solid releases were modeled as an aftermath of either erosion or human intrusion. Though both cases seem unlikely to occur in present conditions, the results show that these scenarios provide the potential for significant doses if institutional control over the site is lost. It also means that long-term study of erosion processes at Radon type facilities may be appropriate to provide specific data for real RADON facilities under assessment.

Two iterations were made in this safety case and calculational results varied. The iterations were the result of obtaining new data and clarification of existing data during the period of the ISAM program. The development of the Radon Type Safety Case is one of the first times such analyses have been conducted for a RADON-type disposal facility. The ISAM approach was found to be very useful for experts from countries with RADON repositories to understand the overall disposal system better.

Borehole Safety Case

The Borehole Safety Case was focused on demonstrating "proof of concept" for technology for disposal of disused sealed sources, that is under development in South Africa. The geological and biological setting has been chosen to be Vaalputs, South Africa, and additional data was used from the IAEA project on BOrehole Disposal of Sealed Sources (BOSS Project). The Borehole Safety Case followed the ISAM methodology, and, although not applied to its full extent, the ISAM methodology proved useful in performing safety assessments for near-surface disposal facilities in a structured manner. A first iteration of the methodology was completed and serves as a basis for future iterations. This preliminary assessment can be enhanced, as more resources are available. Therefore both the results and the decision-making process should be judged from this perspective.

The ISAM FEPs list was used in a limited way to incorporate two land use conditions in the scenario generation processes. The FEPs list was reviewed, and external FEPs were identified that might lead to potential exposures. The FEPs list proved to be very useful as an audit trail and to facilitate model development. Interaction matrixes complemented this process, but were used

only to a limited extent. Further iterations could be undertaken once more information on critical parameters are available and to include a wider spectrum of scenarios.

The results again indicated that, when assessing a near-surface disposal facility, it is often important to consider release mechanisms other than the liquid release.

This initial iteration led to the conclusion that when performing site specific safety assessment it is necessary to consider alternative ways to represent results, treatment of uncertainties, quality assurance and to perform detailed evaluation of the results in order to gain reasonable level of confidence in the compliance of the results with the safety requirements and criteria.

CONCLUSIONS

There are different ways to perform safety assessment and there is no single way to do it. The experience worldwide has shown that there is a need for development of formal approaches for safety assessment and there are different tools available, non of them obligatory. The ISAM safety assessment methodology provides a tool for evaluation of the long-term safety of near surface disposal facilities in a traceable, well documented, and transparent manner.

Scenario generation, which is commonly followed today in post-closure safety assessments to address uncertainties in the future evolution of a disposal system, is central to the safety assessment process and for building confidence in the overall process. More than one method can be used to generate and justify scenarios. There is no prescriptive approach, while commonalities and differences exist among the different approaches. The approach selected should ensure that it is directed to the overall objective of the assessment. A systematic scenario generation framework (i) provides a formal basis for scrutiny of the logic of the underlying assumptions leading to the safety assessment, (ii) assures that the assessment has effectively addressed all potentially relevant FEPs and FEPs interactions to produce qualitatively different outcomes or scenarios and (iii) provides the setting for demonstrating how uncertainties are addressed and incorporated in the safety case.

The ISAM FEPs list consists of high level FEPs that could influence the behavior of the disposal system. The FEPs included in the ISAM list as lower level FEPs are very useful to facilitate model development. The ISAM FEPs list plays a pivotal role in most scenario generation approaches, although its application may vary depending on the assessment context. The list can be reduced (or enlarged) to satisfy site-specific needs using expert judgment or predetermined screening criteria. Documenting the screening processes is necessary for traceability, transparency, and confidence building.

To assess the influence of external FEPs on the behavior of the system, a common approach is to identify a single scenario that represents, in some sense, the conditions that are most important for consideration. In ISAM, for consistency, the term Design Basis Scenario was chosen for this primary scenario, although other terms exist with subtly different meanings and implications. The scenario defined in this way becomes the benchmark against which alternative scenarios are measured. It should not be misconstrued to be the "most likely" or "best estimate" of the repository performance. The Design Basis Scenario serves as a useful reference to assess the significance of alternative scenarios. The consideration of alternative assumptions about external

influences and their implications for the system leads to alternative evolutionary behavior of the system, which are referred to as alternative evolution scenarios.

Several tools can be used to visually represent FEPs and their interactions in a logical, traceable, and systematic way and there is no one technique that is the best available for this purpose. Each technique has particular strengths and weaknesses. However, most ISAM participants felt that interaction matrices are a useful tool for clarifying scenarios and conceptual models, and in documenting assumptions made in their development.

There is a need to develop the models in a formal, defensible manner transparent for independent review, taking in mind that the level of detail to which the models are developed will be a function not only of the assessment context, but also of the stage of the repository life-cycle. The uncertainties associated with the models used, as well as the other steps of the safety assessment process need to be identified, reduced, and, as far as possible, quantified as part of the safety assessment.

Uncertainty analysis is recognized as a key factor in the decision making process related to safety assessment. Understanding uncertainty is also a major factor in the acceptance of the safety case by technical audiences, including the regulatory authorities. The identification of sources of uncertainties as well as the types of uncertainties is necessary in order to find the best way to quantify and consequently improve the degree of confidence in the safety analysis.

A majority of disposal regulations are based on predicted doses to individuals, with predicted risk to individuals also used in some jurisdictions. It is apparent that safety assessment will use other criteria, in addition to the regulatory criteria, for comparison with the modeling results. For example, one of the most common safety indicators used for comparison of predicted doses is the natural background exposure levels.

The availability of the ISO 9000 standards can be considered as a positive development for the safety assessment process, as many organizations have no specific quality assurance standards, and have been adapting QA standards from other jurisdictions. The Document Review Form and Parameter Input Form were two specific initiatives the ISAM program developed for use within the ISAM project, presented in the technical document under preparation by the Agency.

A variety of communication methods are actively being used by various organizations involved in radioactive waste disposal. It was found that most organizations expend little effort to determine the most effective ways to provide information and gather feedback from various audiences. Most organizations use methods that they have observed in use by others and the safety cases are in most cases prepared with the regulator in mind. The safety case documentation appears to be the main method of communicating results to the regulatory authorities, which is often the audience of prime concern.

It is important to note that the experience drawn from the ISAM program had been implemented in the development of real safety cases even before the program finished. An example is the safety assessment performed for the Duckovany repository in Czech Republic.

IAEA PROGRAM ON APPLICATION OF THE SAFETY ASSESSMENT METHODOLOGIES FOR NEAR SURFACE WASTE DISPOSAL FACILITIES (2002-2004)

The successful completion of the ISAM program led to the discussion of possible follow up. The 3rd RCM held in September 2000 initiated development of proposals on the relevant topics of interest. These suggestions were discussed and further developed by the ISAM Coordinating group at its last meeting in October 2001 in order to comply with the objective of the new Coordinated research project (CRP) – Application of Safety Assessment Methodologies for Near Surface Disposal Facilities. Based on the proposals made during the ISAM meetings and by different experts it can be noted that there is common understanding of the need for guidance on the application of the safety assessment methodologies and on the review of performed safety assessments. The role of the safety assessment in the decision making process in terms of intervention, upgrading, or remediation, is considered as an important aspect for further consideration. Periodical performance of safety assessment and its role in the decision on the safety of a waste disposal facility is another area of interest, especially for repositories built according to past safety requirements and standards.

With respect to the importance of the safety assessment in the decision making process it appears that development of regulatory review plan for the safety case will be useful, as well as guidance on establishing priorities in the performance of long-term safety assessment for near surface waste disposal facilities. Confidence building in the overall safety assessment process and in the safety case with focus on presentation of the results is another area proposed for the new CRP. The specific technical subjects that could be considered of common interest for many experts are the evaluation and justification of engineering barriers performance, of human intrusion, and institutional control of waste disposal facilities. The potential near surface waste repository types that are considered of interest are vault and borehole, mining tailings and Radon type disposal facilities.

The new IAEA program is planned to commence in November 2002 and last for three years. It is expected to be attended by regulators, operators, safety assessors, researchers and experts with different knowledge and experience in the field of radioactive waste disposal and safety assessment of waste disposal facilities.

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