

RECENT DEVELOPMENTS IN THE UNITED KINGDOM PROGRAMME FOR THE DEEP DISPOSAL OF RADIOACTIVE WASTES

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ABSTRACT

Although the United Kingdom deep disposal programme is currently under review as a result of the Government decision in 1997 to reject underground investigation proposals at the potential repository site, three main areas of activity associated with the programme are being carried out as follows:

- the development of an institutional framework that will enable a waste management and disposal strategy to be successfully implemented in the future, and the implementation of cultural change within the disposal organisation to ensure increased openness and transparency in its activities;
- remaining, generic technical issues associated with the repository concept continue to be addressed; and
- raw wastes continue to be treated and packaged in a way which ensures their suitability for eventual disposal.

The paper provides an up-to-date account of activities in each of these areas.

INTRODUCTION

In the United Kingdom (UK), radioactive wastes are categorised as low, intermediate or high-level according to their radioactivity. Low-level wastes (LLW) are wastes having a radioactivity less than 4 GBq per tonne alpha or 12 GBq per tonne beta/gamma activity. Most of the UK's LLW is disposed of at the Drigg surface disposal facility operated by British Nuclear Fuels Ltd (BNFL) near to their Sellafield reprocessing works in the north-west of England. Volume reduction through supercompaction and limits on levels of key radionuclides are expected to enable this facility to continue to dispose of wastes well into the next century. LLW generated at the United Kingdom Atomic Energy Authority (UKAEA) fast breeder test reactor site at Dounreay in the North of Scotland is disposed of at an on-site facility.

Spent fuel is currently not regarded as a waste in the United Kingdom and is reprocessed. High-level waste (HLW) comprises the highly active first stage raffinate from reprocessing which is vitrified and stored in stainless steel canisters. These wastes are planned to be stored for around 50 years to allow them to cool sufficiently prior to deep disposal. A two-year study on HLW disposal sponsored by the Government Department of Environment, Transport and the Regions is nearing completion. The objective of the study is to formulate a programme for the

development of a deep repository for HLW and to identify the key elements of an underpinning research and development programme. As discussed later in this paper, Government policy on deep disposal of both intermediate- and high-level waste and the potential for co-disposal are currently under discussion.

The prime focus for development activity on deep disposal in the UK over the last ten years has been intermediate-level waste (ILW). Reprocessing has resulted in a substantial component of long-lived wastes within the ILW - hence the need for deep, rather than shallow, disposal.

The Nirex programme to establish a deep repository for intermediate and certain low-level wastes commenced in 1987 with a substantial public consultation exercise. Subsequently, a site selection process led to the identification of Sellafield and Dounreay as candidate sites - both adjacent to existing nuclear facilities - for investigation. Initial investigations indicated that both sites had the potential to meet the regulator's safety target but the advantage of the Sellafield site in minimising transport of waste (over 70% of the waste destined for the repository is located there) led to a decision in 1991 to concentrate further investigations there.

The extensive investigation programme at Sellafield, together with supporting research and safety assessment programmes, culminated in the "Nirex 97" post-closure safety assessment published in 1997 (1) which enhanced confidence in the ability to characterise a site satisfactorily and supported the previously established promise of the site to meet the safety target.

To achieve the high levels of confidence needed to support a decision on a proposal to construct a repository a stage of underground investigation was planned. A public inquiry into Nirex's planning application for the underground "Rock Characterisation Facility" (RCF) led to its refusal in March 1997. The Secretary of State's refusal reflected concerns of the Inquiry Inspector about the conventional environmental impact of the RCF, the site selection process, and that the planning application was premature.

As a consequence of this decision Nirex has terminated its investigations at Sellafield and considers that the outcome of the Inquiry has raised significant procedural issues which need to be addressed before a national site selection and characterisation programme is re-established. In particular, a stepwise process needs to be established which will have public support and enable the progressive development of a repository.

The three key areas of activity in respect of deep disposal in the UK are now therefore:

- Nirex and the nuclear industry are engaged with Government and other stakeholders in a process of consultation to inform the development of an institutional framework that will enable a waste management and disposal strategy to be successfully implemented in the future. Additionally, Nirex recognises that it has been perceived by some stakeholders as a secretive and arrogant organisation and hence is putting in place changes designed to ensure that it will become more transparent and will engage stakeholders to a greater degree than previously in a meaningful dialogue about its research programmes and future plans;

- Although, the substantial programme of scientific and engineering work carried out to date has established good technical foundations for future repository development, a number of generic issues continue to be addressed. The status of the existing knowledge base and the approach taken to managing the scientific and engineering programmes are described; and
- Raw intermediate-level wastes continue to be conditioned and packaged to create the first barrier of the disposal system in advance of a repository site being selected. The approach adopted enables the overall waste management and disposal system to be considered when developing and selecting waste treatment and packaging processes and provides an effective mechanism to manage the risks associated with the substantial investment in waste treatment and packaging prior to disposal.

The paper addresses each of these areas in turn.

FRAMEWORK AND CULTURE

Following the rejection of the RCF in March 1997 it is accepted by policy makers, regulators and the nuclear industry that Government must take the lead in re-establishing policy and strategy for waste management and disposal in the UK. Given the importance of support by a wide range of stakeholders, a new policy and strategy must be based on wide public consultation.

An important first step has been a House of Lords Select Committee Enquiry into "The Management of Nuclear Waste" which took evidence in the first half of 1998 and is due to report early in 1999 (reference 2 is a collation of the written evidence). This Enquiry has addressed 12 questions relating to whether the UK should pursue disposal and, if so, how and on what timescales.

Government have indicated that the conclusions of the House of Lords Select Committee Enquiry will be a key input to a public consultation process that they expect to launch in the latter half of 1999. It is anticipated that this consultation process will enable Government to draw up a revised policy and strategy by the end of 2000.

Some common themes have emerged in the balance of evidence to the House of Lords Select Committee Enquiry:

- the overriding requirement to build stakeholder acceptance of the waste management and disposal route;
- the consequent requirement for openness by the key players in any repository development programme and for transparency of the decision making processes;
- the need for a clearly defined framework within which individual organisations have well defined roles and responsibilities and which provides for appropriate checks and balances; and
- that responsibility for development of a repository should rest with an independent organisation, operating at arms length, but funded by, the nuclear industry.

While evidence from environmental groups questioned the availability of an adequate knowledge base and hence the ability to implement safely the disposal route, most evidence has supported the view that sufficient knowledge exists and that the disposal route should be pursued by the current generation. Generally the view has been that sustainability requires the current generation to provide subsequent generations with the option to dispose, rather than to require them to continue to have to manage actively the wastes.

Nirex expects to play a full part in the public consultation process and has already submitted evidence to the House of Lords Enquiry on the questions posed (2). Nirex believes that any new process and framework that is put in place to enable a repository programme should reflect the following key considerations:

- to achieve durability of the process and decisions made within it, there should be clarity and openness as to how decisions are made;
- there should be a distinct disposal company to implement the process. It is essential that the disposal company is subject to visible checks and balances and operates in an open and transparent way in order to engender trust;
- a future programme should proceed at a pace which facilitates a constructive dialogue with stakeholders;
- clear groundrules and the tests to be applied at each stage of the programme need to be set out in advance; and
- there needs to be continuing and clear Government commitment to the programme.

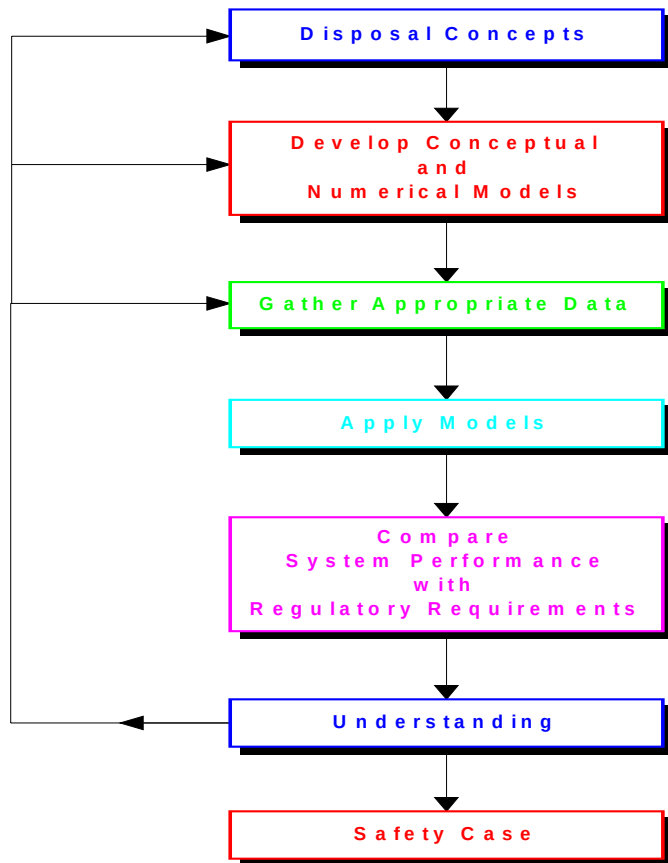
Recognising that being accepted as an open and transparent organisation is a prerequisite to gaining public trust and acceptance, Nirex has commenced an initiative to change its culture and means of operation to ensure that openness and transparency are embedded more firmly within it. The initiative comprises 6 main strands:

- to develop a Code of Practice for making information available to third parties on request;
- to improve the audit trail of decision making within the Company;
- to ensure that openness is a core value for staff;
- to develop approaches to constructive dialogue with stakeholders;
- to develop strategies for communication of key messages; and
- to enable stakeholder feedback on forward plans.

SCIENCE AND ENGINEERING PROGRAMMES

In respect of its scientific and engineering programmes, Nirex has developed a systematic approach to focus activities on key uncertainties and to take robust decisions on the levels of confidence required on issues. It is founded on estimating the reduction in model or parameter uncertainty consequent upon an activity and quantifying the relationship between the model or parameter uncertainty and confidence in the safety assessment. Good estimation of the costs of activities permits costs and benefits of options for activities to be examined. At the heart of the effective management of the programmes are the assessment cycles illustrated in Figure 1.

Figure 1: Schematic Illustration of the Assessment Cycle



Development of confidence in the assessment of repository performance and refinement of its design is an iterative process in which a series of ‘assessment cycles’ are implemented in order to achieve the requisite levels of confidence to underpin decisions on repository construction and operation. The assessment cycles are a central driver of the programme. Successive cycles lead to refinement of the repository concept and design and enable the programme to focus on addressing remaining issues which are critical to establishing the repository safety case.

The assessment cycles are supported by validation cycles in which model predictions are evaluated against independent data to build confidence in their application to post-closure performance assessment.

The scientific programme conducted to establish the suitability or otherwise of Sellafield comprised three main components:

- research on the near field, the engineered barriers and radionuclide transport processes in the geosphere and biosphere;
- site characterisation; and
- post-closure safety assessments.

The engineering programme on the design and operational safety of the repository proceeded in parallel and in close interaction with the scientific programme. The position achieved in each of these areas is summarised in the following paragraphs.

Research

The research programme on the near field and engineered barriers has reached a mature stage: several aspects have been completed, sufficient confidence having been gained in our understanding and models (3). An extensive programme of research into the corrosion of steel containers in the high pH, anaerobic conditions that will apply in the repository after closure and resaturation has indicated corrosion rates for stainless steel containers of less than $0.1\mu\text{m/yr}$ corresponding to effective container lifetimes of 9,000 to 16,000 years. Currently, models are being developed to represent the gradual release of radionuclides from partly-corroded or ventilated containers taking account of physical and chemical retention processes in the waste material itself, grouts and the container and its corrosion products.

In respect of the chemical barrier to be afforded by the specially formulated backfill grout (Nirex Reference Vault Backfill), a sound database and associated modelling capability have been developed on its chemical evolution and consequent solubilities and sorption behaviour of radionuclides. Recent work has focused on processes that could impact on performance such as long-term transformations of the mineral phases of the backfill. Taking account of these processes, and for groundwater flows modelled for a repository at Sellafield, work to date indicates that the backfill should condition groundwater to a pH of around 10 or greater for a period well in excess of one million years. Such alkalinity is sufficient to reduce substantially the solubilities of many key radionuclides.

In relation to the concept of using high pH conditioning of water in the repository near field, an extensive research programme has been carried out to examine the effects of such a modified water chemistry on rocks and minerals that would surround a repository. Sequences of mineral reactions have been defined and a good understanding is being developed of the effects that these reactions would have on the groundwater flow field local to the repository. The radionuclide sorption properties of the mineral reaction products have been determined. An encouraging picture of improved radionuclide retention has emerged from these studies and this is supported by modelling, using specially-developed coupled flow and reaction models, and research on the natural analogue system found at Maqarin in Jordan.

Significant developments have been made within the research programme in the field of groundwater flow and solute transport modelling. A new program has been developed to couple continuum and fracture-network modelling, and both the NAMMU continuum porous medium and the NAPSAC discrete fracture-network programs have been developed to enable coupled flow and salt transport calculations. A recognition of the importance of explicitly representing spatial heterogeneity in geosphere models led to the development of advanced techniques which have recently been demonstrated in respect of the sandstone formations at Sellafield.

Biosphere research has become increasingly focused on gaining a detailed understanding of the transfer of key radionuclides such as chlorine-36 in the environment. The observation of

concentration of this radionuclide in certain pasture grasses grown experimentally in contaminated soil has led to a detailed consideration of plant physiology with respect to chlorine. This approach gives realistic means for bounding the modelled uptake of radionuclides in plants and subsequent entry into the human food chain.

As indicated above, the research programme has reached a mature stage. Nonetheless, work continues to complete the knowledge base and to develop robust positions on processes that could significantly influence post-closure performance. Key areas of future focus are therefore:

1. For the near-field, the evaluation of localised effects driven by the characteristics of waste packages and the completion of databases of solubility and sorption particularly in respect of long-term processes and the impact of organics.
2. For the geosphere, the development of a better understanding of generic transport processes (in particular the role of colloids and the potential for groundwater to be driven by gas) and retardation processes (sorption and rock matrix diffusion).
3. For the biosphere, further work to develop and agree with regulators an approach to the treatment of potentially exposed/critical groups and the enhancement of understanding of the uptake of chlorine-36 in the biosphere.

Site Characterisation

Commencing in 1989 an intensive programme of activities was implemented to characterise the potential site for a repository at Sellafield. By the time site investigations ceased in March 1997, 29 deep boreholes (to depths of up to 2,000m) had been drilled and tested, complemented by over 10,000 line-km of geophysical surveys. An essential element of the management of this programme was the progressive definition of the investigation informed by the evolving understanding of site characteristics and the key sensitivities of the post-closure safety assessment.

Programmes at Sellafield and candidate sites in other countries have demonstrated the availability of the investigation and modelling techniques, and understanding of fluid flow and transport processes sufficient to characterise a site adequately for safety assessment purposes. However, some further generic work is required to develop a better understanding of generic transport processes (in particular the role of colloids and the potential for groundwater to be driven by gas) and retardation processes (sorption and rock matrix diffusion).

Safety Assessment

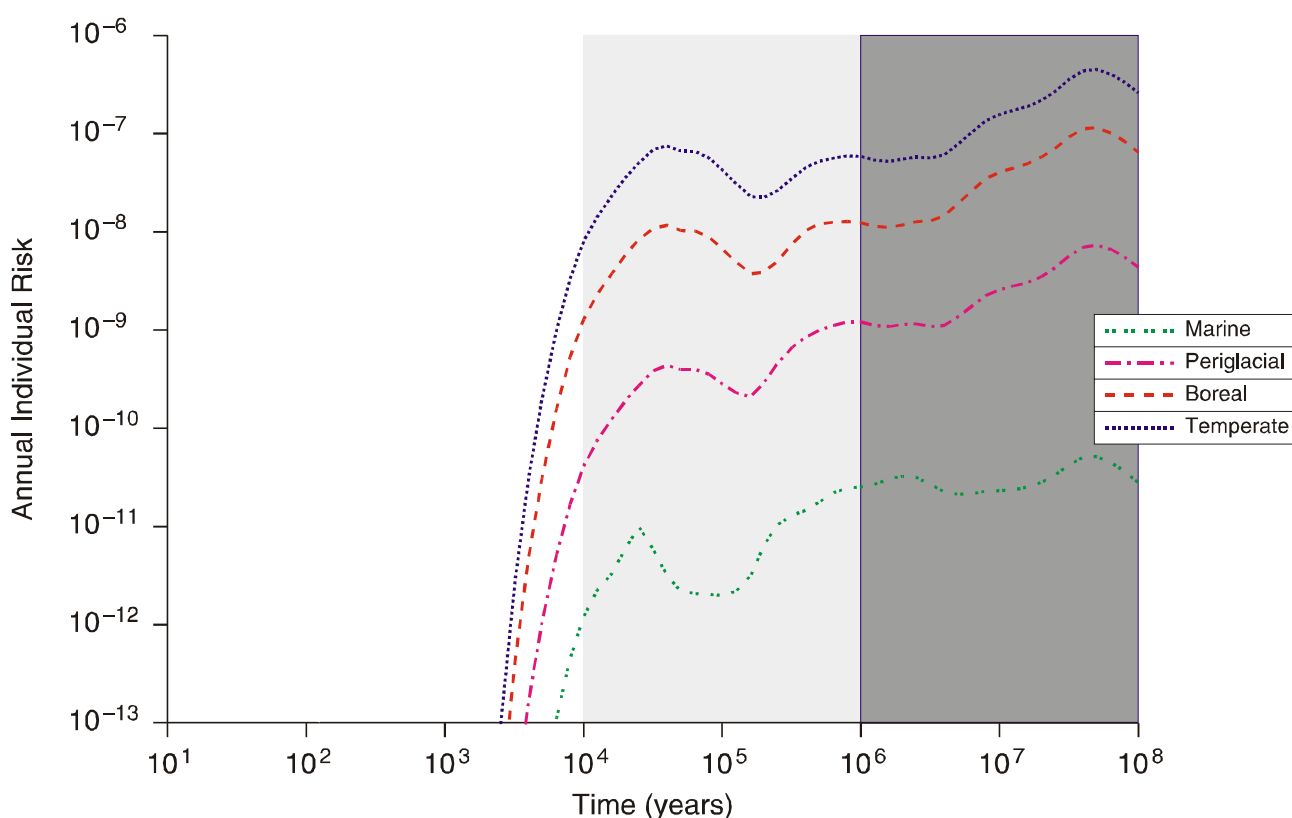
As described earlier, building confidence in the assessment of the post-closure performance of a repository is an iterative process in which successive assessment cycles are used to refine the repository concept and the models. Several assessment cycles were completed during the programme to establish the performance of a repository at Sellafield, the last two being published as Nirex 95 and Nirex 97 (4 and 1).

The Nirex 97 assessment considers the potential for release of radionuclides to the biosphere by both the groundwater and gas pathways.

The calculation of radiological risk from movement of radionuclides in groundwater is carried out using the probabilistic safety assessment program, MASCOT. Employing the Monte Carlo approach this models the various processes involved in the release of radionuclides from waste packages, their mobilisation and migration out of the repository vaults, their transport through the geosphere and biosphere and, finally, the consequent doses and risks to individuals. Inputs to MASCOT are derived from more detailed models of processes within the near field, geosphere and biosphere.

An important aspect of the Nirex 97 assessment has been to evaluate radiological risk for a range of conceptual models for the near field, geosphere and biosphere: results for the various models are described in reference 1. Calculations of radiological risk over time for the different model combinations follow a consistent pattern, as illustrated in Figure 2, for a particular model combination.

Figure 2: Model G1 S3 B1 (the reference assessment model): annual individual risk plotted against time for each of the biosphere states



The probabilistic safety assessment calculation of risk for a 'reference assessment model' (in shorthand G1 S3 B1) is presented in Figure 2. The curves, which represent a range of

biosphere/climate states, are similar to the equivalent calculations presented in Nirex 95 and more fully reflect the impact of improved understanding of geological conditions at Sellafield:

- Under current Temperate climate conditions, risks from a marine discharge are about four orders of magnitude lower than those for a terrestrial discharge; and
- For each climate state risks rise to a peak, fall and then rise again. The early peak in risk occurs at about 40,000 years and is primarily due to chlorine-36. The later peak arises primarily from radium-226 which is a decay product of the uranium-238 inventory in the repository.

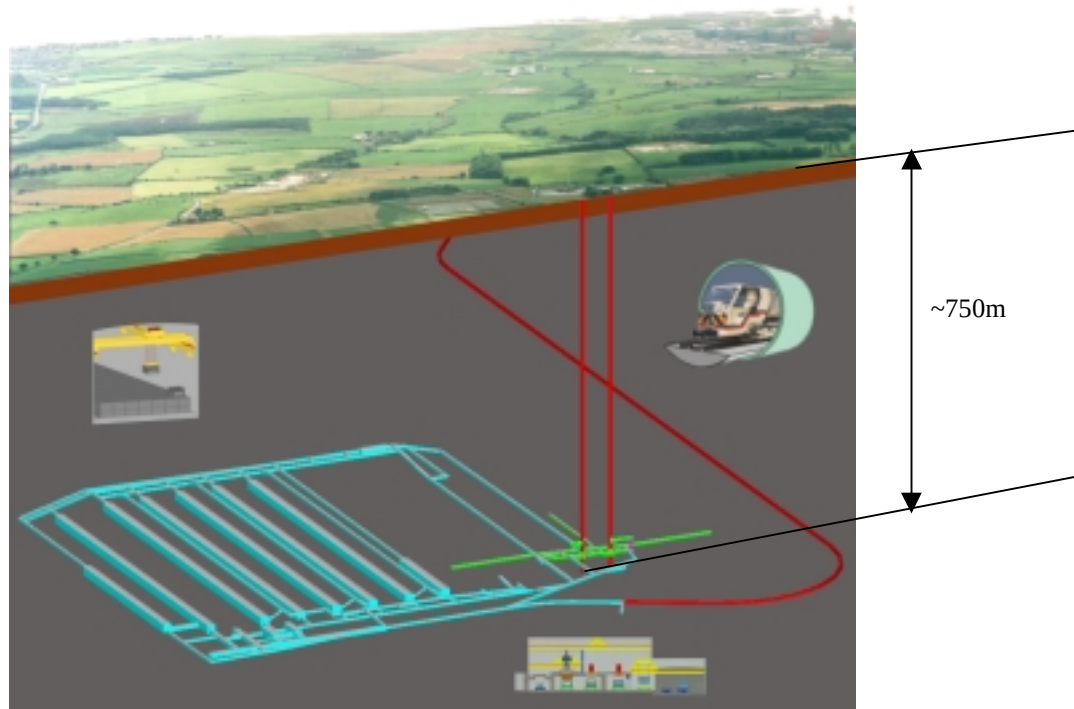
Engineering Programme

The Nirex engineering programme has been based on the iterative approach illustrated in Figure 1. At each iteration illustrated in Figure 1, definition of the disposal concept begins with the development of a disposal system technical specification (DSTS). The DSTS pulls together in a systematic way, constraints, requirements and data relating to the disposal system. Constraints include land availability, regulatory performance targets/limits and health and safety legislation, and are essential 'fixed'. Requirements are specified and justified by waste producers (e.g. nature and quantity of waste for disposal) and company staff responsible for aspects of disposal system performance (post-closure safety, operational safety, transport logistics and safety, and non-nuclear environmental impact). Data include results from site characterisation work, waste package performance research, and the scientific research programme.

A design concept is then developed that satisfies the constraints and requirements. The design concept is assessed in terms of its post-closure and operational safety performance, potential non-nuclear environmental impact, and cost. On the basis of these assessments the requirements originally specified are reviewed and, if necessary, revised. The DSTS is then re-issued, incorporating revised requirements and any new data, and the next iteration commences.

Figure 3 shows an illustration of the design concept that was developed for a Sellafield repository. Wastes would be transported by a rack-and-pinion rail system through a drift to a series of underground vaults, unshielded wastes being emplaced remotely in cavern vaults, and shielded wastes by manual operations in tunnel vaults. Two shafts, incorporated from the RCF, would be used for ventilation and access for staff and materials. Backfilling of vaults would be carried out prior to repository closure: prior to backfilling emplacement operations are readily reversible, subsequently trials have demonstrated that the wastes remain retrievable albeit at greater effort and cost. Further details of the design concept for a repository at Sellafield are given in reference 5.

Figure 3: Illustration of the Repository Design Concept for Sellafield



Current work (described in a companion paper to this conference: (6)) is generalising Sellafield specific design solutions to demonstrate the concept application in a wide range of geological environments. The issue of retrievability has become more prominent and further work is being carried out to establish the level of retrievability/reversibility achievable at different timescales.

WASTE PACKAGING

Some 200,000 to 275,000 m³ of ILW is expected to be generated in the United Kingdom in the period through to the middle of next century. A substantial proportion of these wastes already exist or are committed. Reprocessing has resulted in a substantially higher proportion of long-lived wastes than if just reactor operational wastes are considered. There is also a diverse and sometimes challenging range of wastes given that the UK is now seeking to treat, package and eventually dispose of its historical legacy of wastes. These include wastes generated in the 1950s and 1960s by military and reactor development programmes at a time when the requirements for long-term management of waste was not uppermost in management priorities. Major programmes are currently underway, particularly at BNFL and UKAEA to retrieve, condition and package such raw wastes. The following paragraphs summarise the approach taken by Nirex and the waste producers to waste packaging. A more detailed account is given in a companion paper to this conference (6).

In order to minimise the risks of double-handling and re-packaging of waste (and the associated costs and doses to workers) it is important to ensure that wastes are treated and packaged in a way that will be suitable for eventual disposal. Since an authorisation for disposal will not be granted until just prior to repository operation, there is uncertainty as to what the eventual waste acceptance criteria will be.

Nirex has therefore produced a set of guidelines which specify the requirements for packages considered necessary for disposal in order to assist waste producers in developing their waste management plans. The development of the specifications involved Nirex working closely with the waste producers taking account of waste producers' proposed waste management plans. This integrated approach has allowed both the waste producers and Nirex to work towards optimisation of the overall waste management and disposal system. The result has been to reduce expected overall lifetime costs for the treatment, storage, transport and disposal of waste while maintaining safety standards.

The specifications define dimensional, functional and performance criteria, and establish minimum levels of performance for all waste package designs (7). As such, they provide an essential link between waste package design and repository design to give the best possible assurance for the future and above all to guard against the possibility of having to re-package the waste. The present waste package specifications are conservative because they must ensure adequate performance in a wide range of potential disposal conditions. As the repository programme resolves these uncertainties, it may become possible to relax other criteria in the specifications.

It is not possible for the specifications to define fully all functional parameters for waste packages in view of the wide range of different waste types (currently numbering over 1,000 separate streams in the UK) and the multiplicity of different packaging plans. Therefore, in addition to generic guidance through the specifications, specific guidance on individual waste packaging proposals is provided by Nirex to its customers, following detailed assessment, by issue of a Letter of Comfort. Letters of Comfort provide assurances that the proposed packages are consistent with Nirex's disposal plans in all aspects of transportation to, operations at, and disposal in the waste repository. Detailed assessments are carried out against 15 technical areas to assess the compatibility of the proposed packages.

Waste producers will typically request a Letter of Comfort at three stages in the planning and development of a treatment and packaging plant:

- at the concept stage when major changes to the proposed process are still possible and there is time for research and development to address outstanding issues;
- prior to plant construction: subsequently only limited modifications to the process and hence package will be possible; and
- prior to plant active commissioning: a particular issue at this stage is to ensure that necessary QA and data recording arrangements are in place.

Where required, Nirex works closely with the waste producer through these various stages to evaluate options for waste treatment and packaging to seek to achieve optimal solutions to the overall waste management and disposal process.

Final stage Letters of Comfort have been issued to waste producers for a little less than 20% of wastes, as measured by volume. However, these wastes tend to be at the higher activity end of the spectrum and account for 30 – 40% of the inventory by activity. Four major packaging plants have started operations at Sellafield, with another at Dounreay. All of these plants use 500 litre drums, and the total now in store awaiting disposal passed the 20,000 mark during 1998.

The concept of Letters of Comfort has proved a useful one, with benefits for both waste producers and for Nirex. Customers have indicated a desire to obtain Letters of Comfort for all their wastes, covering current and future arisings, in addition to historical stored waste. A firm programme for the examination of packaging proposals has been established, linked clearly to planned start dates for the packaging process, which now extends for more than three years.

Complementing the development of waste package specifications and the advice to waste producers through Letters of Comfort, Nirex has defined a range of standard waste containers which are suitable for packaging the variety of wastes predicted to arise within the UK (6). These have been adopted by the UK Nuclear Industry, the standardisation resulting in economic and safety benefits throughout the waste management cycle. The number of containers in the standard range has been limited to six as this number is the minimum which best meets the needs of the UK waste packagers.

The six containers comprise 2 m and 4 m boxes for LLW and 500 litre drum, 3 m³ box, 3 m³ drum and 4 m box for ILW. The 500 litre drum, 3 m³ box and 3 m³ drum for ILW are relatively thin-walled steel containers which are not designed to provide radiation shielding (and hence require remote handling facilities and re-usable shielded containers for transport). The 4 m ILW box is provided with shielding and, when used with ILW with restricted activity content, can be used as a storage, transport and disposal container without requiring additional shielding. The 4 m box is particularly suitable for large decommissioning items and is currently approaching commercial application.

CONCLUSIONS

Despite the set-back to the UK repository programme due to the decision against the RCF planning application, the present period remains an active one as wastes are packaged in preparation for disposal, as generic scientific and engineering issues continue to be addressed through ongoing programmes, and as the UK debates the way forward on the disposal of wastes. Given previously unsuccessful attempts to site a deep repository in the UK, it is considered that firm and robust foundations must now be put in place through thorough consultation processes, prior to any re-launch of a site selection process in the UK.

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