

THE IMMOBILISATION AND PACKAGING OF RADIOACTIVE WASTES FOR DEEP GEOLOGICAL DISPOSAL IN THE UK – CURRENT STATUS AND FUTURE CHALLENGES

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ABSTRACT

Implementation of UK Government Policy for the management of Intermediate Level Wastes (ILW) has led to the packaging of wastes in preparation for ultimate disposal in a deep geological repository. These activities have now been ongoing for the past decade. In the UK, packaging of ILW is the responsibility of the waste producer, whereas development of disposal facilities for the packaged waste is the responsibility of UK Nirex Ltd (Nirex).

A key issue facing the UK waste producers has been how to ensure that packages produced would meet anticipated disposal requirements in advance of a repository being available. Therefore Nirex have developed a number of specifications for waste packages to ensure that waste producers' plans for treating waste would be compatible with deep disposal. These specifications, which have been generated in collaboration with waste producers and are used in the development of their waste management strategies, are based on the Nirex repository concept and are robust to the eventual choice of repository site. They cover a range of requirements including quality assurance, wasteform, containers and data recording.

In addition to the development of specifications, Nirex provides detailed advice on individual packaging concepts with respect to the suitability of specific packaging plans and plant designs. Advice is based on assessment of each packaging proposal against fifteen technical areas, including the nature of the waste, wasteform, container design, accident behaviour, transport and operational requirements, and post closure safety. This approach has enabled the commencement of waste packaging operations with a high degree of confidence that the waste product will meet anticipated disposal requirements.

The paper provides a summary of the work carried out by Nirex to develop specifications and to provide advice. This includes the development of generic (i.e. non site-specific) disposal concepts and safety cases, to ensure that the technical basis of advice to waste producers is transparently underpinned. The current status of waste packaging activities in the UK will be summarised, and the new challenges being faced arising from changes in waste management practices, are discussed.

INTRODUCTION

United Kingdom Nirex Limited (Nirex) is responsible for developing facilities and providing a service for the safe, environmentally sound and efficient disposal of the United Kingdom's intermediate-level waste and certain low-level waste. In due course, Nirex will issue waste acceptance criteria and all waste packages will have to comply with these before being accepted for disposal. The acceptance criteria will be determined principally by the safety standards to be

achieved, including requirements specified in the authorisation for disposal, but will also take account of design constraints, legal, transport, operational and economic factors.

However, the nuclear industry (Nirex' customers), who are responsible for the waste, are currently developing packaging concepts and designing packaging plants for early waste encapsulation. The customers therefore need confirmation that the waste packages produced by these encapsulation plants will meet the requirements currently foreseen by Nirex as being necessary for storage, handling, transport and disposal. As part of that service, Nirex provides advice to its customers on the conditioning and packaging of waste for disposal. Because a specific site and site-specific design for a repository have yet to be established, that advice must be based on a generic disposal system concept applicable to a wide range of potential sites in Great Britain.

This paper consists of a summary of the work carried out by Nirex to develop package specifications and to provide packaging advice, and the development of generic disposal concepts and safety cases to underpin the technical basis of advice to waste producers in a transparent manner. It also contains an outline of the current status of waste packaging activities in the UK, and a discussion of the new challenges being faced, arising from changes in waste management practices.

STANDARDISATION AND WASTE PACKAGE SPECIFICATIONS

Prior to publication of waste acceptance criteria for a deep repository, Nirex has implemented a strategy to facilitate early waste packaging, whilst minimising the risk of future reworking of packages, by providing guidance through a suite of Waste Package Specifications. The specifications provide a basis against which waste packagers can develop packaging proposals, using a range of standard waste containers, and against which Nirex can assess specific proposals and provide advice on their suitability for disposal.

Waste Containers

Nirex has defined a range of six standard waste containers that are suitable for packaging the variety of wastes predicted to arise within the UK. Standardisation has been shown to produce economic and safety benefits throughout the waste management life-cycle, and six is the minimum number that meets the needs of the UK waste producers. The standard containers are described in Table I.

Table I Nirex Standard Containers

<i>Intermediate - level Waste</i>		
500 litre Drum	the normal container for most operational ILW	0.8m diameter x 1.2m high
3m ³ Box	a larger container for solid wastes	1.72m x 1.72m plan x 1.2m high
3m ³ Drum	a larger container for in-drum mixing and solidification of liquid and sludge type wastes	1.72m diameter x 1.2m high
4m ILW Box	for large items of waste especially from dismantling operations	4m x 2.4m plan x 2.2m high

<i>Low - level Waste</i>		
4m LLW Box	for general LLW	4m x 2.4m plan x 2.2m high
2m LLW Box	for general LLW	2m x 2.4m plan x 2.2m high

Waste Package Specifications

The Waste Package Specifications have been based on the following general principles:

- **Waste Package Specifications are independent of repository site and design.** Specifications are based on bounding conditions and form a benchmark against which Nirex can provide advice and assurances. The bounding conditions are derived from design and safety considerations of the generic deep disposal system proposed for the UK.
- **Waste Package Specifications will be subject to continued development.** Specifications are provided on the basis of best practice and will be subject to periodic review as the deep repository project progresses. The intent will be to relax the bounding conditions as results from on-going development programmes into package performance reduces the uncertainty in the behaviour of specific package types during transport, operation and following disposal. In addition, when the repository site and design are confirmed, final safety cases will be established and this will enable Nirex to identify any conservative margins and address the criteria accordingly when defining the waste acceptance criteria.

Specifications are provided for:

- Waste Package
- Wasteform
- Quality Assurance
- Data Recording
- Package Identification

Waste Package

Specifications have been produced for each of the standard waste packages. The specification is applicable to the waste package as a whole, that is to say, the waste container plus its contents, the wasteform. The specification defines dimensions and key features of the container and sets down minimum performance standards for the complete package. Criteria are specified for activity content, dose rate, heat output, surface contamination, dimensions, lifting feature, mass, venting, integrity, properties of the wasteform, impact and fire performance, stackability and identification. In the case of packages which are also transport packages, additional criteria are specified to meet the applicable regulations (e.g. Transport Regulations).

Following from the principle that specifications should be independent of repository site and design, the Specifications are based on generic repository concepts and safety considerations. With respect to waste package performance under accident conditions, the Specifications include criteria based on safety analyses. These take credit for the predictability of impact release fraction offered by cementitious wasteforms, and make reasonable assumptions regarding the efficiency of underground ventilation and filtration systems, and the extent of particulate deposition in the event of an accident.

Wasteform

Wasteform specifications have been produced to augment the waste package specifications by specifying in more detail any limits on the contents of packages and best practice for producing a wasteform with the required chemical and physical properties. The specification covers immobilisation of radionuclides, mechanical and physical properties, chemical containment, hazardous materials, degradation processes and wasteform stability, gas generation and nuclear properties. One of the key aspects of the wasteform specification is the control of the criticality hazard of packaged waste. The Nirex strategy for the control of fissile material in waste packages is outlined elsewhere [1].

Quality Assurance

Consistent with company policy and regulatory guidance, a system of quality assurance has been established for all activities that affect the repository safety case, including the packaging of wastes. The purpose of the QA system is to provide the evidence to demonstrate that waste packages comply with a defined product specification, which can be assessed against future waste acceptance criteria.

The Quality Assurance Specification is mandatory and describes the QA programmes and plans, the Waste Product Specification and the system of verification required to be put in place by the waste packager. The Quality Assurance Specification requires that for all activities affecting product quality, waste packagers demonstrate that QA arrangements consistent with the Specification are in place, that these arrangements are being implemented, and that appropriate corrective actions are taken where necessary. A more detailed description is provided in reference [2].

Data Recording

As the developer and operator of the deep repository, Nirex will need access to information for each waste package consigned for disposal. The required data will differ between package types, but can be summarised as a realistic and justifiable record of the nature and content of each package. This should: cover the physical, chemical and radionuclide content; identify or enable prediction of package properties and performance, and; allow prediction of the evolution of the package characteristics with time, and of the effect of interactions with other packages and repository components. A more detailed description is provided in reference [3].

Package Identification

The specification for the waste package identification system defines the format of the unique identifier which is to be applied to each waste package destined for the deep repository. The specification also defines the check algorithm which is used to generate 'check digits' which are incorporated within the identifier.

PROPOSAL AND ASSESSMENT CYCLE

Nirex is prepared to give advice on specific packaging proposals and, where appropriate, to provide a 'Letter of Comfort' to customers. Letters of Comfort provide assurances to customers that the proposed packages are compatible with Nirex plans for the repository and associated transport system. They may also be required to meet managerial or regulatory requirements.

Detailed guidance on the Nirex requirements for package performance is provided in the Waste Package Specifications and Guidance Documentation (WPSGD), which is provided to UK waste producers on request. The WPSGD provide the link between the design of the waste package, and the design and safety case for the repository. Nirex makes an assessment of each customer packaging proposal against fifteen technical areas. The fifteen assessment areas, and the main issues addressed by each, can be summarised as follows:

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|------------------------------|---|
| 1. Nature and Quantity | amount of waste, number of packages of each type, variation in activity between packages; |
| 2. Wasteform | suitability of wasteform design and behaviour under storage and disposal conditions; |
| 3. Criticality | criticality safety of packages in a deep waste repository, both initially and after degradation; |
| 4. Container Design | consistency of the container with Nirex handling and performance requirements; |
| 5. Container Corrosion | adequate corrosion performance of the container for handling and containment of short-lived activity; |
| 6. Impact Performance | sufficiently low releases from the waste package under impact accidents; |
| 7. Fire Accident Performance | sufficiently low releases from the waste package under credible fire accidents; |
| 8. Transport Regulations | transport of the waste package through the public domain in accordance with IAEA requirements; |

9. Quality Assurance	production of waste packages under an appropriate Quality Assurance system;
10. Data Recording	recording of sufficient data on packages to allow their transport and disposal;
11. Physical Protection	necessity for special physical protection measures on the basis of package contents;
12. Safeguards	necessity for keeping the wastes under safeguards on the basis of package contents;
13. Post-closure Safety	adverse effects on the post-closure performance of the repository;
14. Operational Safety	consistency of the possible package releases with repository operational safety requirements;
15. Policy	consistency of packages with the Nirex remit, and with UK and international regulatory guidance.

The final stage of the assessment process is the formulation of detailed advice for issue to the customer. The advice will cover issues such as further information requirements, research and development needs, data that should be recorded on the content of each waste package or improvements that could be made to the package design. Experience has shown that there is benefit to both customers and Nirex in making a submission for a Letter of Comfort on up to three occasions. These are:

- the initial or conceptual stage;
- a second or project pre-commitment stage; and
- a final or pre-operational stage.

This three-stage approach is illustrated in Figure 1.

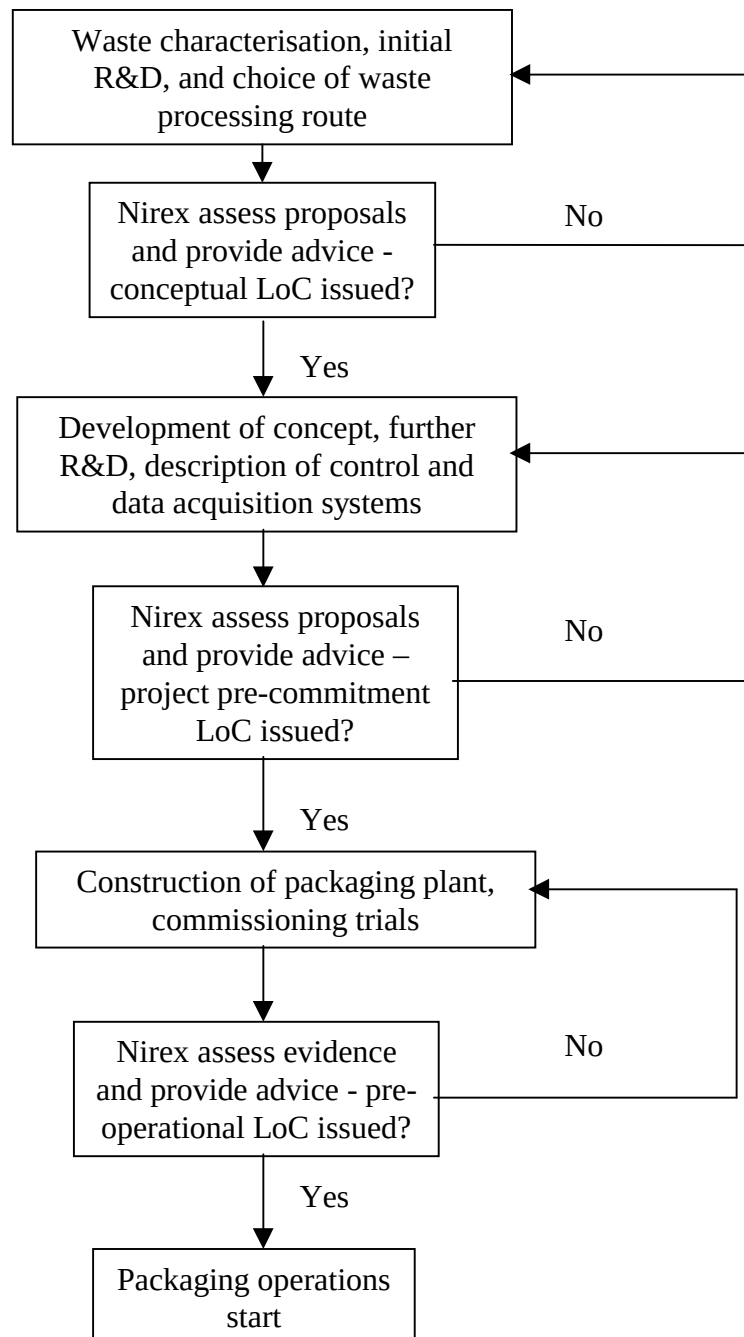


Fig. 1 Nirex role in the Development of Waste Packaging Solutions

At the conceptual stage, Nirex assesses the feasibility and compatibility of the proposed packaging concept with the requirements for storage, handling, transport and disposal. At the project pre-commitment stage, Nirex need to be assured that the intended product from the packaging process is consistent with the Nirex waste package specifications. At the final or pre-operational stage, Nirex need to be assured that the packaging plant is capable of making the

product specified. The issue of these Letters of Comfort has allowed waste producers to progress with the implementation of their waste management strategies.

GENERIC DISPOSAL CONCEPTS AND SAFETY ASSESSMENTS

Nirex is able to give packaging advice on the basis of the knowledge and experience gained through developing a concept for the deep disposal of the UK's radioactive wastes over the past 15 years. This knowledge base is being compiled into a suite of documents that applies the Nirex understanding of the disposal system performance in a generic way. That suite of generic documents will be updated to incorporate future changes arising from Government policy, legislation and regulations, and the needs of customers. The documents will be used to underpin waste packaging advice, demonstrate the viability of the Nirex disposal concept, and may also be used to inform the development of a framework for future site selection. The suite of documents will comprise:

- Generic Disposal System Specification (GDSS);
- Generic Transport System Design;
- Generic Repository Design;
- Generic Transport Safety Assessment;
- Generic Operational Safety Assessment;
- Generic Post-closure Performance Assessments.

The GDSS specifies the entire 'disposal system'. Thus it covers a large number of interacting variables relating to the waste, its packaging, transport and disposal. External constraints imposed on the system form an integral part of the specification. For example, constraints arise from the nature and quantities of waste requiring disposal, which influence the design of waste packages and operational requirements of waste producers. Other constraints arise from the legislation and regulations under which the disposal system must operate, including those related to safety and the environment.

Most importantly, the GDSS also integrates the results and experience from Nirex's scientific and technical programmes, to provide a unified and justified system specification for use in design work and in assessments of transport, operational and post-closure safety. This specification allows Nirex to develop generic designs for a potential repository and the generic transport system to a future repository. These 2 design documents (Generic Repository Design & Generic Transport System Design) are then used as the basis for carrying out 3 safety assessment which collectively make up the safety case for a repository. The 3 safety assessments focus on:

- transport of wastes to the repository;
- operations at the repository;
- post-closure performance of the repository.

This allows Nirex to develop advice to customers, who are packaging waste and incurring financial outlay today on packaging waste, on an understanding of the transport and disposal requirements that may apply to a future repository. There is a feedback mechanism between the

packaging advice given at present and the disposal concept plans for the future. This is formally documented via changes to the UK inventory, as illustrated in Figure 2.

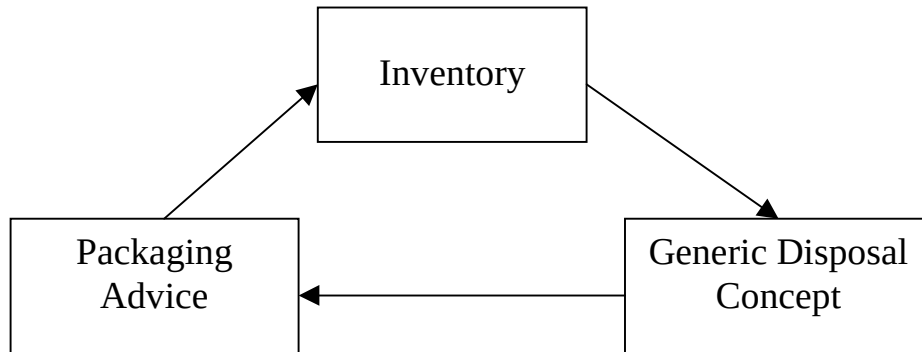


Fig. 2 Relationship between Packaging Advice and Disposal Concept

The UK Inventory [4] is produced by Nirex on behalf of the UK Government. It is a compilation of data on all the radioactive waste produced in the UK, including past arisings and that predicted to arise in the future. Through the inventory both the Government and the Industry are able to gain a common view on issues such as standardisation of treatment packaging and storage and policy. Nirex has been producing the UK Inventory on behalf of the Government for about 12 years, and it continues to be used as a common reference for the UK Nuclear Industry.

The provision and retention of data records is required to allow future generations to take waste management decisions with confidence without incurring significant additional dose or financial burdens. Nirex are taking the lead in developing a waste management database, called BRIMS, on behalf of the nuclear industry in the UK.

CURRENT STATUS OF WASTE PACKAGING IN THE UK

Radioactive wastes have arisen in the UK as a result of nuclear power generation, spent fuel reprocessing, the nuclear weapons programme, specialist isotope generation and use, and a broad range of associated research activities. The wastes include activated components, contaminated items and process sludges, and are divided into categories on the basis of their activity content (high, intermediate, low) and their origin (operations and decommissioning).

Historically, wastes have been stored in the raw state, at the site of arising, pending availability of a final disposal route. More recently, some operational wastes have been packaged as they have been produced, for example fuel cladding wastes arising from operation of the Magnox and THORP fuel reprocessing facilities at Sellafield. Few decommissioning wastes have been produced in the UK to date, although substantial volumes will require packaging in the future. None of the decommissioning wastes fall into the high-level waste category. Typical examples of the intermediate-level wastes that are produced in the UK are shown in Table II.

Table II Typical ILW in the UK

Origin	Typical Composition
Fuel Cladding and Hardware	Zircaloy and stainless steel hulls and ends, Magnox and aluminium swarf, stainless steel braces and wrappers, graphite struts
Effluent Treatment Wastes	Sludges, slurries, floc, ion exchange materials
Technological Wastes	Metals, organic wastes, graphite, decommissioned plant and building materials
Transuranic Wastes	Solid and sludge/floc wastes contaminated with plutonium

The current central estimate of the total volume of intermediate- and low-level waste arising for deep geological disposal before 2060 is about 263,000 m³. Within the formal proposal/assessment cycle, Nirex has assessed the suitability for disposal of about 40 volume % of this waste, containing some 60% of the activity. At the current time, somewhat less than 10% has been packaged, although this represents more than twenty thousand 500 litre drums. These packaged wastes are currently in storage, mostly at Sellafield, awaiting the availability of a final disposal route.

Main UK Radioactive Waste Producers

BNFL operate fuel cycle services in the UK, and the vast majority of their more active wastes are produced and stored at the Sellafield site in Cumbria. The wastes arise mainly from fuel handling, storage, decanning and reprocessing operations, including plutonium finishing. The BNFL waste management strategy for ILW at Sellafield is based around six multi-million pound waste treatment and packaging plants. Four of these plants are now operational, with the other two under construction.

Nuclear utility companies operate the 11 Magnox (8 operating, 3 shut down), 7 AGR and 1 PWR nuclear power stations in the UK. The Magnox stations are now run by Magnox Generation, a division of BNFL, whereas the other stations are operated by British Energy (Nuclear Electric and Scottish Nuclear). Spent fuel is generally decay stored at site and then despatched to Sellafield for reprocessing, whereas operational wastes such as pond wastes and fuel furniture are stored at the stations. After the stations close, and accumulations of waste cease, they can be retrieved and packaged. Solid and sludge wastes are likely to be dealt with separately.

UKAEA have responsibility for nuclear research sites at Culham, Dounreay, Harwell, Windscale and Winfrith. A wide variety of wastes exist at these sites, including those arising from reactor research (thermal and fast neutron fission, and fusion systems) and associated fuel reprocessing. Strategies are being developed to package these wastes in an economically efficient manner.

The Ministry of Defence (MoD) operates nuclear research and manufacturing sites at various locations in the UK. The wastes arising from these are similar in scope to those arising from the rest of the nuclear industry. The MoD is also responsible for wastes arising from the operation of the UK's fleet of nuclear-powered submarines. Plans for waste treatment and packaging are advanced at several of the MoD sites.

Radioactive wastes also arise from 'minor waste producers', such as industry, university research, and hospitals. Many of the wastes contain very short-lived isotopes, and fall into the category of 'very low-level waste'. These wastes can be managed for disposal at local facilities. More radioactive material, especially industrial sources (e.g. Co-60 and Cs-137), are being stored to allow radioactive decay, and a dedicated company, Safeguard International, has been established for this purpose.

FUTURE CHALLENGES RESULTING FROM CHANGES IN WASTE MANAGEMENT PRACTICE

The plans for a deep disposal facility in the UK have been delayed due to a decision by the UK Government, in March 1997, to refuse planning permission for the Rock Characterisation Facility, which was to have been located at the Longlands Farm site adjacent to Sellafield. This has inevitably delayed the timescale for the availability of a deep waste repository. The implications of this delay are that wastes are likely to spend significantly longer in store [5].

Furthermore, the UK nuclear regulator has recently emphasised that the stabilisation of historical wastes, especially the conditioning of reactive wastes, is a priority [6, 7]. As described previously, the packaging of some reactive wastes, notably Magnox fuel cladding, is now being undertaken at the time of arising. However, some wastes have been stored for several decades, and require retrieval and treatment in the near future, because the design life of the buildings in which they are stored will otherwise be exceeded.

However, since the strategy for issue of Letters of Comfort, which has been successfully followed for the past 10 years, is based on generic disposal requirements and best practice, it is not specific to a particular site or design. Therefore it is expected that the Waste Package Specifications and Letter of Comfort process will continue to provide a firm basis for packaging wastes in the future, irrespective of where and when the disposal facility ultimately becomes available.

Although the technical challenge of packaging waste for disposal is being addressed in detail, and with a high degree of confidence, there are a number of challenging issues that are likely to play an equally important role in determining whether the wastes will be disposable. These cover a range of technical and non-technical subjects, and require the development of a broad consensus for disposal through public acceptance. The technical issues include detailed consideration of the control of storage conditions and the retrievability of wastes.

In order to build the necessary public acceptance for radioactive waste disposal, it will be necessary for Nirex to adopt a thoroughly transparent approach, throughout the development of a robust safety analysis for the range of wastes for disposal. This will need to be demonstrated against a range of credible disposal concepts and host geological environments, and is a key output of the generic studies, as described above. Further initiatives are in place within Nirex to yield a consensus of stakeholders, as the repository concept is developed in a step-wise fashion.

The control and maintenance of appropriate storage conditions, both in engineered stores and after emplacement in the repository, will be a major factor in the demonstration of the suitability

of packaged wastes for final disposal. To this end, Nirex is giving consideration to the definition of a specification for environmental conditions (e.g. temperature, humidity, radiation environment), and to a programme of condition monitoring, designed to demonstrate the longevity of the waste packages.

Provision for the retrievability of the wastes is a feature that is being increasingly demanded by environmental groups and the general public. Nirex is responding by developing designs that would allow the reversal of the emplacement process, for a period of up to several hundred years. In order to provide this, there are demands on the retention of sufficient technical data, and a need to extrapolate performance over the appropriate period of time. The provision and retention of data records is required to allow future generations to take waste management decisions with confidence, and without incurring significant additional radiological or financial burdens. As noted above, Nirex is taking the lead in developing the BRIMS waste management database, on behalf of the nuclear industry in the UK.

SUMMARY AND CONCLUSIONS

1. Nirex has a role in the UK to provide advice on the treatment and packaging of radioactive wastes. Advice is given on the basis of the Nirex knowledge base of disposal, which means that Nirex can advise on the suitability of proposals for the packaging of radioactive wastes against the requirements for storage, handling, transport and ultimate disposal.
2. Nirex advice to the packagers of radioactive waste is based on Waste Package Specifications and associated guidance to waste producers, and is implemented through a systematic review against 15 technical assessment areas. These are based on a generic repository system, which is neither design- nor site-specific.
3. Nirex is also responsible for compiling the UK Inventory of Radioactive Wastes in the UK for the Government. This inventory is used as a common reference to inform initiatives such as standardisation and policy. Nirex is taking the lead in developing a waste management database for the retention and future provision of data records for packaged wastes.
4. The plans for a deep disposal facility in the UK have been delayed due to a decision by the UK Government to uphold the refusal of planning permission for a Rock Characterisation Facility at Sellafield. Although this decision will extend the period of interim storage, the nuclear industry needs to continue with the treatment and packaging of radioactive wastes, prior to a disposal route becoming available. Nirex is facilitating this through the development of Waste Package Specifications and generic safety documentation, which form the basis of the Letter of Comfort process.
5. Nirex is faced with a number of new challenges following the inevitable delay to the timescale for the availability of a deep waste repository. These include building a consensus of public acceptance, developing an appropriate storage regime, and designing

the disposal system with capacity for waste retrieval. These issues are being progressed against a backdrop of regulatory pressure to make progress with the stabilisation of historical accumulations of waste.

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