PACKAGING OF RADIOACTIVE WASTES IN THE UK FOR SAFE WASTE MANAGEMENT

John D Palmer and Stephen V Barlow
United Kingdom Nirex Ltd., Curie Avenue, Didcot,
Oxfordshire, OX11 0RH.

ABSTRACT

The role of Nirex is to provide the United Kingdom with safe and environmentally sound options for the long-term management of radioactive waste generated by the UK's commercial, medical, research and defence activities. This includes intermediate level waste and some low level waste (ILW and LLW). One of the key objectives of Nirex has been to ensure that when waste is packaged, it is in a form suitable for its future safe management including storage, transport, handling and potential disposal.

To provide a basis for developing waste packages that are compatible with future phases of waste management, Nirex has developed standards and performance specifications for waste packages that include wasteform and container design, quality assurance and data recording requirements. In addition to the specifications, Nirex also provides detailed advice on the suitability of specific packaging proposals and plant designs against the foreseen requirements for future storage, transport, handling and potential disposal, to inform current packaging decisions. Where packaging proposals meet these requirements, Nirex is prepared to endorse the proposed approach through the issue of a 'Letter of Comfort'.

This approach has enabled the commencement of waste packaging operations with a high degree of confidence that the waste product will meet future waste management requirements, including potential disposal requirements. This paper provides a summary of the standards and specifications developed by Nirex for waste packages, and of the assessment process applied by Nirex in providing advice and endorsement of specific packaging proposals.

INTRODUCTION

The role of Nirex is to provide the United Kingdom with safe and environmentally sound options for the long-term management of radioactive waste generated by the UK's commercial, medical, research and defence activities. This includes intermediate level waste and some low level waste.

Following the rejection in 1997 of Nirex proposals for the construction of an underground Rock Characterisation Facility, Government has indicated its intention to undertake a wide-ranging consultation on future waste management options in order to ensure that whichever option is finally chosen, it should command widespread public support. As of January 2001, this public consultation has yet to be initiated. In October 1999, in an interim statement, Government indicated that Nirex should:

> *'… maintain an active scientific programme, continue to advise the industry on conditioning and packaging waste and should also contribute to consultations on the review of policy.'* [1]

Despite uncertainty about the eventual management option, the development of packaging concepts and the design and operation of packaging plants is ongoing. The waste producers, who are responsible for the waste, are required by Government White Paper [2], to take account of the following factors when developing packaging plans:

> *(a) the need for continuing safe storage of the waste, treated and/or contained as necessary;*
> *(b) the benefits of placing the waste in a chemically and physically stable form, so that safety may be achieved by passive means;*
> *(c) the risk that treated waste will be incompatible with future disposal requirements and the practicability of re-working treated waste in the future, for disposal or for a period of future storage, should this be necessary;*
> *(d) the state of storage facilities, including the benefits which would be derived from refurbishing or upgrading;*
> *(e) the need to minimise waste degeneration, secondary waste arisings and releases to the environment;*
> *(f) the need to minimise dependence on active safety systems, maintenance, monitoring and human intervention; and*
> *(g) the retrievability of the waste for disposal.*

The UK nuclear regulator (Nuclear Installations Inspectorate (NII)) has recently emphasised that the stabilisation of historic wastes, especially the conditioning of reactive wastes, is a priority. Therefore, a key issue facing the UK waste producers is how to progress the packaging of waste without unduly compromising the requirements of the future, including potential disposal. Nirex in its role of investigating the safe, long-term management of the waste, therefore, provides independent advice on conditioning and packaging of waste. This involves a process by which Nirex formally assesses current packaging proposals against the foreseen requirements for future safe long-term management and potential disposal. This allows waste producers and regulators to make today's decision informed by the needs of the future.

Nirex informs current packaging activities of the requirements of the future through:

i) providing standards and specifications for packages which are compatible with the foreseen requirements for future transport, handling and disposal, and which are fully compatible with the concept of phased disposal;
ii) formally assessing individual proposals against these standards, the phased disposal concept and Nirex's Packaging Principles. In addition, compatibility of the packages actually being produced, against the needs of the future is also checked through a system of auditing by Nirex.

Specification of Waste Packages for the Present and the Future

The packaging standards for intermediate level waste are set-down and defined within Nirex's suite of Waste Package Specification and Guidance Documentation which are issued to all waste packagers and the regulators (a summary version is available as Waste Package Specification for Intermediate Level Waste [3]). The Specification has been developed over many years taking cognisance of both national and international experience in waste management and is designed around the range of wastes in the UK inventory and developed

using Nirex experience in developing disposal systems. This approach reflects international best practice as advised in IAEA guidance. It is therefore comprehensive and covers key aspects of the waste package including dimensions, handling and other features, performance requirements, wasteform characteristics, quality assurance and data recording requirements. The Waste Package Specification addresses both the waste container and the conditioned waste within - the wasteform.
As it has been developed over a number of years, based on a number of inputs, the Waste Package Specification is not specific to a particular waste management option, but is derived from considerations of generic requirements for safe storage, transport, handling and potential disposal. The Waste Package Specification therefore facilitates the production of waste packages that should be suitable for all phases of waste management, including the option of phased deep disposal that has been specially investigated and developed by Nirex over the past decade.

Future Demands on Waste Packages

Following its production, a waste package may be expected to undergo some, or all of the following phases:

- Interim storage, usually at the site of arising.
- Transport to a disposal or storage facility.
- Handling and emplacement at the storage or disposal facility.
- Disposal

Each phase will place its own demands on the waste package. These can be summarised as follows.

Interim storage

Interim storage of packaged waste is the responsibility of the waste producer. During this phase, packages need to be maintained within appropriate storage arrangements to ensure compliance with site licence conditions and associated safety requirements. Packages need to be kept in a manner so that future transport, handling and potential disposal requirements will not be compromised or that any deterioration can be monitored and rectified to enable safe future use.

Transport

Although the siting and design of future long-term waste management facilities have yet to be finalised, future transportation of packages will be required. The requirements and design of the transport system needed to transfer packaged waste between stores or to any future facilities are well understood.

The transport system, which may involve both road and rail transportation (and potentially sea transport should such a facility be located on an off-shore island), will need to accommodate both remote handled and contact handleable waste package types. The transport system will need to meet all UK regulations for transport of radioactive materials, which like almost every other country are based on International Atomic Energy Agency (IAEA) Transport Regulations.

Handling and Emplacement

Although the design of any future storage and/or disposal facility will not be completed until the preferred waste management option is identified, such a facility can however be described in terms of the following generic elements and operations:

- receipt of transport packages, which will either be a shielded transport container (with shielded, remote handled disposal packages as contents) or as contact handleable "one-shot" disposal packages;
- handling of the transport packages at surface facilities, which will comprise facilities for receiving and checking of transport packages (most of which will be remote operations) as well as management, administrative and other support functions;
- remote transfer of transport packages to underground facilities via shaft or drift tunnel (assuming an underground facility is being considered);
- in the case of packages transported inside shielded transport containers, the unloading of waste packages in a shielded inlet cell;
- emplacement of waste packages in shielded vaults, where operations will permit monitoring and retrievability as necessary.

Nirex in developing concepts for safe long-term management of waste is actively investigating options for monitoring and retrievability. Nirex is working with the industry, regulators and the public to inform developments in this area.

Disposal

Nirex recognises that deep geological disposal is only one possible solution for the long-term management of the UK's radioactive waste and is the option Nirex has most experience of to date. This concept is based on isolating packaged wastes in vaults excavated at depth in a stable geological environment. The concept makes use of engineered and natural barriers, working in conjunction, to achieve the necessary degree of long-term waste isolation and containment. This multiple-barrier approach to containment takes credit for the fact that wastes are immobilised in an appropriate matrix, the immobilised wastes are packaged in metallic or concrete containers and are emplaced in underground vaults. The vaults will be backfilled with a cementitious grout material at an appropriate stage before sealing and backfilling accesses from the surface.

In addition to these engineered barriers, the host rock will provide additional natural barriers, both physically and chemically, to the transport of radioactive material back to the human environment. Following cessation of repository operations, it is expected that the waste packages will experience;

- a period of care and maintenance under institutional control, prior to final closure;
- backfilling of the disposal vaults with a specially formulated cementitious grout mixture to provide chemical conditioning and sorption of key radionuclides.

The requirements for all the above phases have been assessed in detail by Nirex and this has been captured within a suite of documents addressing the concept of phased deep disposal [4]. Such requirements have been incorporated when developing the Waste Package Specification. More detail on the content of the Waste Package Specification and the generic phased disposal concept is available on the Nirex website (www.nirex.co.uk).

ASSESSMENT AGAINST THE NEEDS OF THE FUTURE

Although generic standards and guidance have been issued, waste producers are encouraged to discuss their detailed waste packaging plans with Nirex throughout the project life cycle, in order to obtain independent advice on specific aspects of individual packaging proposals. Nirex gives advice on each application by considering the combinations of radioactivity, chemistry and physical form, based on its knowledge of waste package behaviour under storage, transport, handling and disposal conditions. Nirex then checks this for consistency with the performance requirements and underlying principles for the phased disposal concept. This advice normally takes the form of one or more *Letters of Advice*, which are reports issued by Nirex following assessment of a waste packaging proposal. The advice identifies further information requirements, or may highlight issues that need further development and thus is used to inform waste producers' future development programmes and strategic thinking.

Nirex is also prepared to provide assurances that the proposed waste packages are consistent with the envisaged transport and disposal system. This assurance is provided in the form of an endorsement known as a *Letter of Comfort*. A Letter of Comfort may be sought for management purposes (for example, before making capital expenditure commitments) or for regulatory purposes before commencing active operations on a packaging plant. The Letter of Comfort system has been in existence for more than 10 years and was established in the 1980s when the industry first started to condition and package wastes in a form ready for ultimate disposal.

Nirex continues to work closely with the regulators and the nuclear industry, to ensure that the packaging advice process meets the needs of all parties and provides an appropriate level of transparency to decision making. The advice and Letter of Comfort process is being used by all the major waste producers as a component part of their waste management strategies as described shortly. The process has been modified to include a reporting system to enhance regulatory visibility and access to the process.

Assessment and Advice

Packaging proposals from waste producers are subjected to a formal assessment and review process, covering 16 packaging assessment areas. Twelve of these test compliance with the Waste Package Specification, three cover the transport, operational and post-closure safety assessments that have been conducted by Nirex for the generic concept defined previously. The remaining one relates directly to the *Principles underlying Packaging Advice* [reported in 5] which sets down the ten principles underlying the assessment process, against which Nirex is prepared to offer formal endorsement. The 16 technical areas together with a summary of the main issues to be considered, are listed in Table 1.

Table I.The Sixteen Waste Package Assessment Topics

Nature and Quantity:	amount of waste, number of packages of each type, variation in activity between packages.
Wasteform:	suitability of wasteform design and behaviour under storage and disposal conditions.
Criticality:	criticality safety of packages in a deep waste repository, both initially and after degradation.
Container Design:	consistency of the container with Nirex standards and performance requirements.
Container Corrosion:	adequate corrosion performance of the container for handling and containment of short-lived activity.
Impact Performance:	sufficiently low releases from the waste package under impact accidents.
Fire Accident Performance:	sufficiently low releases from the waste package under credible fire accidents.
Quality Assurance:	production of waste packages under an appropriate Quality Assurance system.
Data Recording:	recording of appropriate data on packages to allow their transport and disposal.
Physical Protection:	necessity for special physical protection measures on the basis of package contents.
Safeguards:	necessity for keeping the wastes under safeguards on the basis of package contents.
Policy:	consistency of packages with the Nirex remit, and with UK and international regulatory guidance.
Transport Safety:	transport in accordance with IAEA requirements and consistency with transport safety requirements.
Operational Safety:	consistency of the possible package releases with repository operational safety requirements.
Post-closure Safety:	consistency of package releases with anticipated repository post-closure performance.
Non-nuclear Environmental Assessment:	appropriate use of resources for package manufacture and transport (conceptual stage only).

Experience has shown that there is benefit to both waste producers and Nirex in making packaging submissions throughout the project life-cycle. Assessment and advice stages, which coincide with regulatory submissions during the development of plants, have been found to be particularly beneficial. These include:

- the conceptual stage (as designs are developing, prior to sanction of capital schemes);
- an interim or project pre-commitment stage (at completion of plant design, when seeking sanction of major capital expenditure); and
- a final or pre-operational stage (following plant completion, but prior to active operations).

In addition, some waste producers seek Nirex input when considering alternative processing options i.e. at the optioneering stages. These early interactions often have proved particularly beneficial in developing packaging strategies, which most readily meet the needs of both the present and the future.

Endorsement of Packages for the Future

Nirex is prepared to provide formal endorsement of specific proposals only when it can be demonstrated that the proposed waste packages should enable future safe management as assessed through compatibility with the Waste Package Specification, the Nirex transport and disposal concept and Nirex Packaging Principles. In support of this, Nirex Specifications also cover quality assurance and data recording requirements and allow for assessment of packagers' quality management systems both during development of the process and subsequently during active plant operations.

In cases where Nirex has been provided with the necessary evidence, sufficient to determine that the waste packaging proposal is consistent with the Waste Package Specification, the transport and disposal concept and the principles outlined above, Nirex is able to provide the waste producer with a Letter of Comfort. Where packaging proposals are found to be inconsistent with the above, Nirex provides detailed advice, which can then be used to inform future development and discussion with those regulating the project.

The arrangements for assessing waste packaging proposals, for the provision of advice and endorsement by the issue of Letter of Comfort, are subject to formal procedures within Nirex and are overseen by a Waste Management Advisory Committee which provides a mechanism for regulatory overview of waste packaging and safety related matters.

Proposals are reviewed by considering their potential safety significance and are assigned a categorisation consistent with the following scheme.

Category 3

The physical nature, and chemical and radionuclide content of the waste, is judged to fall fully within previous Nirex experience (as reflected in the WPS and safety assessments), and the proposed packaging process uses known technology in a standard manner.

These proposals are assessed in the standard manner to confirm that they satisfy the safety requirements for, and are consistent with, the overall disposal concept.

Category 2

The nature or content of the waste, and/or the technology proposed for its encapsulation, falls outside previous Nirex experience, but produces packages or revises the inventory in a manner consistent with previously assessed concepts. Assessment of the compatibility of proposed packages with future waste management can be evaluated using existing assessment methods.

Where the performance of the proposed waste package is found to be within the previously agreed bounds, a Letter of Comfort and Advice can be issued, as for Category 3 proposals. If found to be outside these bounds, then only advice can be given to the waste producer. If the waste producer wishes to pursue the proposal and requests formal endorsement, this will become a Category 1 proposal.

Category 1

The nature or content of the waste, and/or the technology proposed for its encapsulation, falls outside Nirex experience, and it is judged that significant new issues may be raised concerning waste storage, transport, handling or potential disposal.

Proposals may be found to be outside the defined bounding envelope of package properties and performance for two reasons. First, they may represent a new packaging concept, for which existing assessment methods are inappropriate, in which case a new approach would be required. Secondly, the nature or content of the waste may be such that assessed performance would lie outside established bounds. In these cases it would be necessary to consider altering the relative reliance on different system components to deliver overall safety performance, and the potential or necessity to invoke mitigating features. This would require an assessment of the implications for design and safety cases. This process is illustrated in Figure 1.

NIREX PROCESS IN ACTION

The following examples demonstrate how the process has been used in today's waste management decision processes.

Example 1 - Iodine-129 bearing wastes

Iodine-129 has consistently been identified as a 'head-line' radionuclide in post-closure performance assessment work for disposal facilities in the UK because of its high solubility, low sorption and biological significance. The importance of iodine-129 is compounded by the fact that chlorine-36 behaves in a similar way and for the Nirex concept it has been shown that I-129 and Cl-36 give rise to risks of a similar magnitude, which occur at the same time. Therefore, any future disposal facility is expected to have a limited ability to accommodate I-129 (and this is likely to be dictated by scenarios involving water extraction from wells downstream of the facility).

Recent packaging submissions to Nirex, have included waste streams that may potentially contain significant quantities of Iodine-129 in liquors arising from fuel reprocessing operations. Difficulties in sampling these wastes had resulted in substantial uncertainties in the reported inventories for individual wastestreams. This has necessitated assessments being undertaken which review each waste stream in the context of the ability of the Nirex disposal facility to accommodate the whole UK inventory of I-129.

The assessment concluded that it should be possible to find a site that can meet the post-closure risk target for the UK inventory, in the event that the deep geological disposal option is pursued. This conclusion was based on the understanding generated from site specific investigations at Sellafield and from generic performance assessments for other disposal facilities. It was concluded that, by applying significant constraints on the siting of any future disposal facility (and its associated hydrogeological properties), the required post-closure performance for wastes bearing long-lived mobile radionuclides such as iodine-129 should be obtainable.

In view of the above, Nirex has been able to endorse waste packaging proposals containing the declared inventories of Iodine-129. There is a clear need for a robust and defensible

inventory of this radionuclide coming from all key streams. A systematic review of the arisings of iodine-129 and potential routings for wastes, is therefore being instigated as an essential element in developing a robust strategy for the long-term management of this key radionuclide. Improvements in analytical techniques available for the measurement of iodine are also being investigated to avoid challenging the safety case for any future disposal facility with 'fictitious' iodine-129.

Example 2 - technetium-99 abatement technologies

BNFL is the largest nuclear operator in the UK with fuel fabrication and reprocessing businesses and several nuclear power plants. The reprocessing works are located at the Sellafield site in the North-west of England and operations there give rise to effluent discharges, which are authorised by the UK environmental regulator - the Environment Agency. These discharges are currently undergoing review by the Environment Agency. This review will have regard for government policies and commitments such as that made by government ministers under the Oslo and Paris (OSPAR) conventions to protect the marine environment of the North East Atlantic. In particular the agreement reached at Sintra in 1998 (the Sintra Agreement) aims to ensure that by 2020 radioactive discharges add virtually nothing to historic concentrations of radioactivity in the marine environment.

Of particular concern is the radionuclide technetium-99. BNFL are working to identify modifications that can be implemented on the effluent treatment systems that can remove Tc-99, and the Environment Agency has required BNFL to provide information on potential techniques for reducing technetium-99 discharges. One such technique investigated has been proposals to precipitate and subsequently trap technetium-99 using a tetraphenyl phosphonium (TPP) salt within the existing liquid effluent treatment plant EARP. This would be used to treat the existing high technetium bearing stream known as Medium Active Concentrate (MAC) which would produce a predominantly iron floc containing the TPP-Tc complex. This would then be conditioned by cementation in readiness for long-term storage and potential disposal.

Nirex has considered this proposal and provided advice to BNFL. This identifies major uncertainties regarding the ability to safely dispose of the resultant waste products within geological facilities such as that embodied by the phased disposal concept. The long half-life and potential mobility of Tc-99 make it potentially a significant radionuclide for disposal. The proposed process for trapping and subsequently encapsulating the technetium was found to give rise to a substantial increase in the inventory requiring disposal. The chemical form of the technetium (i.e. in the VII oxidation state and associated with a complex of unknown stability), raises a number of issues and may adversely affect both solubility and sorption. There is therefore the potential for the Tc-99 to be extremely mobile in a deep repository environment and could lead to this radionuclide dominating the risk from any disposal facility. There are also uncertainties regarding the behaviour of the TPP on wasteform properties and on the mobility of other radionuclides. As such Nirex have been unable to endorse these proposals based on current knowledge. Nirex are working closely with BNFL to investigate possible treatments and to enhance knowledge of the behaviour of this potential waste to establish if this waste can be packed in a manner that will be disposable.

Example 3 - Pond water ion exchange cartridges

Nuclear power plants of the Magnox design have generally utilised water filled cooling ponds for the storage of spent fuel pending transport off-site for reprocessing. The power plant operators are looking to install a new generation of pond water clean-up system to reduce off-site discharges and operator dose. Consequently they have sought Nirex advice as to the acceptability of the form of the ion exchange materials proposed and on the form of their packaging that would facilitate future handling and disposal, once units are taken out of service.

The ion exchange material adopted for this process is an inorganic molecular sieve. This material was chosen to reduce the organic burden to a future disposal facility and thus avoid the introduction of potential problems of radionuclide complexation by organic degradation products. The proposed packaging of this waste would entail grouting the cartridge into a 500 litre drum.

A major concern identified initially, was the ability of the cementitious grout proposed as the encapsulation medium, to successfully infiltrate and therefore immobilise, the ion exchange material. In view of the considerable uncertainties over the long timescales for which these packages will need to be managed, handled and potentially disposed, the possibility for significant releases during accidents was identified with the potential to undermine the safety and public confidence in a future facility.

As a consequence, Nirex has worked closely with the operator to ensure that the form of waste packaging is compatible with future phases of waste management including storage, transport, handling and potential disposal. As a result, research into alternative immobilisation media and, as a fall-back position, provision for dismantling and intimate immobilisation of the material is being made.

CONCLUSIONS

Nirex has developed standards and performance specifications for waste packages. These provide a basis to assess the compatibility of waste packages with storage, transport, handling and potential disposal requirements.

Nirex undertakes detailed assessments of the packaging proposals developed by the waste producing organisations. On the basis of these assessments, Nirex provides detailed advice on the suitability of specific packaging proposals and plant designs against the foreseen requirements for future storage, transport, handling and potential disposal in order to inform current waste management decisions.

Where there is evidence that packaging proposals meet the foreseen requirements for future safe management Nirex is prepared to endorse the proposed approach through the issue of a 'Letter of Comfort'.

Nirex has developed and continues to maintain, generic concepts for the transport, handling and potential disposal of wastes, based on the nature and volume of wastes defined by the National Inventory of Radioactive Waste that fall within the Nirex remit. Feedback between the packaging advice given at present and the development of future management concepts is a key synergy of the process.

It is expected that the Waste Package Specifications and the Letter of Comfort process will continue to provide a firm basis for packaging wastes in the future, despite remaining uncertainties as to the final solution for the long-term management of the wastes. This approach has enabled the commencement of waste packaging operations with a high degree of confidence that the waste product will meet future waste management requirements, including potential disposal requirements.

The continued application of an approved quality management system, and the provision and retention of data records, is necessary to allow future generations to take waste management decisions with confidence, without incurring significant additional dose or financial burdens.

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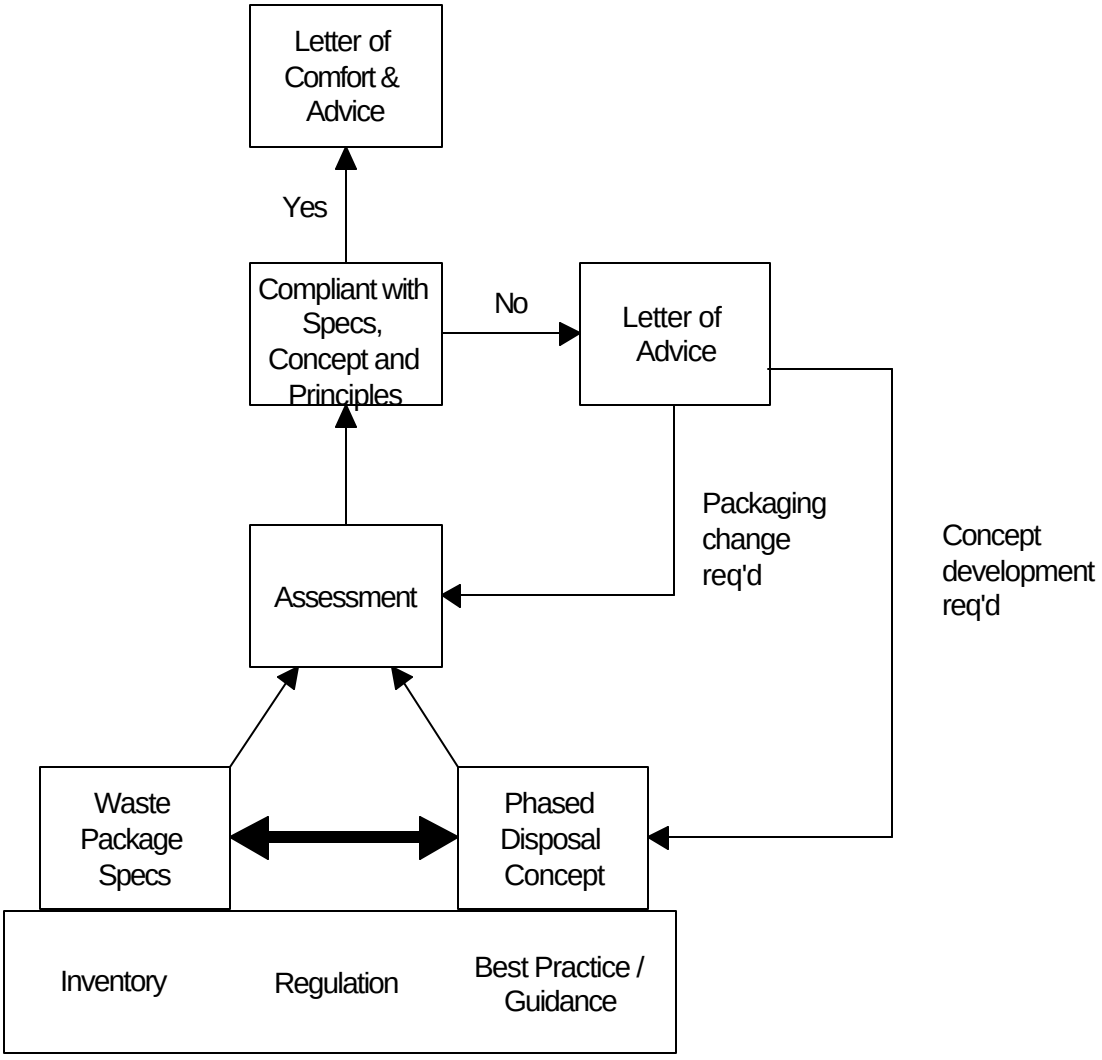

Fig. 1. Basis for Provision of Advice and Endorsement to Waste Producers