Performance of the IAEA Transport Regulations in Controlling Doses and Risks from a Large-scale Radioactive Waste Transport System

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The role of United Kingdom Nirex Limited is to provide the UK with safe, environmentally sound and publicly acceptable options for the long-term management of radioactive materials generated by the UK's commercial, medical, research and defence activities. An important part of this role is to set standards and specifications for waste packaging.

Waste producers in the UK are currently developing processes for packaging many different types of intermediate-level waste (ILW), and also those forms of low-level waste that will require similar management to ILW. When packaging processes are at the proposal stage, the waste producers consult Nirex about the suitability of the resulting packages for all future aspects of waste management. The response that Nirex provides is based on detailed assessments of the proposed packages, their compliance with Nirex standards and specifications, and their predicted performance through the successive phases of waste management.

One of those phases is transport through the public domain. This paper draws on experience gained from more than 200 separate transport safety assessments, which have cumulatively covered a wide range of waste types, waste packages and transport packages.

1. Functions of Transport Safety Assessment

Each transport safety assessment by Nirex begins with a check that the proposed transport packages will comply with Nirex specifications that incorporate relevant aspects of the IAEA Transport Regulations [1]. This is a Pass/Fail test: if the proposed packages will comply with the requirements, then the rest of the assessment can proceed. If they would not comply, Nirex will advise the waste producer about changes that should be made.

Historically, the rationale of the IAEA Transport Regulations has been that if each individual transport package complies with the Regulations, then adequate safety has been achieved for the entire transport operation. That rationale is supported by decades of world-wide practical experience. Examples include the transport of millions of radioisotope and radiopharmaceuticals packages that usually contain small quantities of radioactivity; and at the opposite extreme, spent fuel transport operations which involve very large quantities of radioactivity but far smaller numbers of packages. However, there is little world-wide experience of transport operations that involve both large quantities of radioactivity *and* large numbers of packages – which is exactly the kind of radioactive waste transport operation that Nirex is planning in the UK.

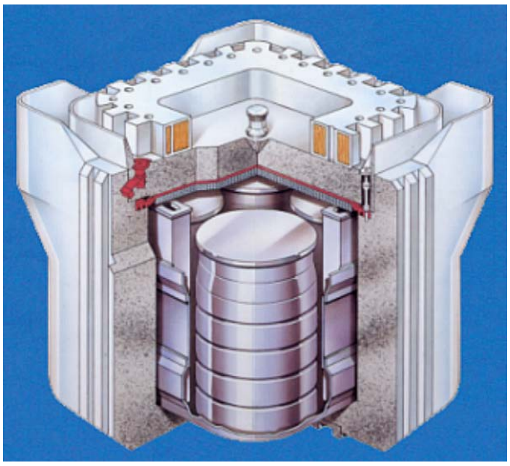

Figure 1: Typical proposed ILW transport package, four 500 litre drums of immobilised waste in a reusable shielded transport container

Waste packages are currently being manufactured and stored at 30 different nuclear sites across the UK, and eventually there will be over 200,000 waste packages, most of which will be ILW. The UK national policy for radioactive waste management is under further review at present [2], but the majority of options for a national ILW management strategy will involve the transport of most (or even all) of those 200,000 packages through the public domain. Therefore it is vital to develop a waste transport programme that is both safe and publicly acceptable.

Such a waste transport programme would be of unprecedented scale in a country as small and densely populated as the UK. The operation is envisaged to last for about 50 years, and is estimated to require about 70,000 large transport packages. Most of these would have to be Type B packages comprising four unshielded 500 litre ILW packages inside a reusable shielded transport container (Figure 1). Reusable transport containers avoid the unnecessary disposal of shielding materials, and this policy has many advantages in reducing the size and cost of the management facility, and in enhancing its long-term safety [3]. The disadvantage of reusable transport containers is that they need to be returned empty for the next shipment. Although empty containers would only be at most mildly contaminated, they would almost double the number of movements required. On an average day, about seven large transport containers would be in public view on major rail and road routes, so this operation would inevitably have a high profile.

Nirex believes that the scale and duration of this operation would take radioactive materials transport into new territory, where it cannot be automatically assumed that package-by-package compliance with the Transport Regulations will guarantee acceptable safety for the transport operation as a whole. Therefore Nirex decided to carry out an in-depth, quantitative transport safety assessment for all of the waste packages involved.

There are many other strong reasons for doing this:

- There is a long-standing requirement in the IAEA Transport Regulations that "*radiation exposure shall be kept as low as reasonably achievable...*" ('ALARA'). The latest edition [1] includes a requirement to establish a Radiation Protection Programme [para 301] in which "*the nature and extent of the measures to be employed in the programme shall be related to the magnitude and likelihood of radiation exposures*." The Radiation Protection Programme must also meet a more detailed ALARA requirement [para 302] that "*protection and safety shall be optimized in order that the magnitude of individual doses, the number of persons exposed, and the likelihood of incurring exposure shall be kept as low as reasonably achievable...*"

  Particularly for a new or proposed operation, these strengthened and more detailed requirements in the current IAEA Transport Regulations [1] can best be met by an in-depth, quantitative assessment of doses and risks.

- UK health and safety laws require risk assessments for a very wide range of regulated activities, which include the transport of radioactive materials. The general requirement is that risks – and where applicable, radiation doses – must be kept "*as low as reasonably practicable*" [4]. 'ALARP' has a specific legal meaning which is different from 'ALARA', but both criteria require the same kinds of safety assessments (and the two terms may be regarded as equivalent for the purposes of this paper). Package-by-package compliance with the IAEA Transport Regulations has historically been deemed a sufficient demonstration of safety in the UK, but this position may no longer be tenable given the increased emphasis on ALARA in the Regulations themselves.

  For fixed nuclear sites, specialised safety assessment principles have been established to implement the UK approach to health and safety [5]. These assessment principles apply to the sites where waste packages are presently being manufactured and stored, and very similar principles would apply when the packages arrive at the dedicated waste management facility proposed by Nirex [6]. For consistency and continuity throughout all phases of waste management, Nirex also applies the same basic assessment principles to the intervening transport phase.

- The UK public have identified themselves as 'stakeholders' in radioactive waste transport, based on the perception that transport is likely to affect them more directly than any other aspect of radioactive waste management [7]. Objectively assessed risks are very different from the simple likelihood of encountering a transport package, so it will be essential to produce clear and convincing arguments why the operation should be publicly acceptable. To help guide its future work on radioactive waste transport, Nirex is vigorously developing ways to obtain input from all stakeholders, both institutional and public.

The public naturally expect that all applicable regulations will be obeyed; but regulatory compliance fails to convince the public that risks will be acceptably low [7]. There are also technical reasons to agree with this perception, because the regulatory limits for transport packages are based on deterministic dose assessments [8]. Although a deterministic approach is valid for the purpose of setting limits, it is a fundamental principle that a deterministic assessment does not offer any information about risks [4]. Likewise, the use of pessimistic assumptions in deterministic assessments does not support any argument about the acceptability of risks. Therefore Nirex agrees with the public perception that regulatory compliance and risk are two different topics, that need to be addressed separately.

For all of these reasons, Nirex believes it is good practice to make in-depth quantitative assessments of dose and risk for the proposed radioactive waste transport programme. By pursuing this policy, Nirex has acquired unique information on how well the IAEA Transport Regulations would control the risks arising from such a large-scale, intensive and extended programme.

2. Generic Transport Safety Assessment

To meet the anticipated need for a waste transport programme of national scale, Nirex has designed the necessary transport system in considerable detail. The Generic Transport System Design includes the necessary hardware, and Nirex has developed tools for real-life route planning and logistics [9, 10]. The companion Generic Transport Safety Assessment (GTSA) has then assessed the risks that would arise [11].

All transport routes are assumed to converge on the site of a single national facility, but its location is as yet unknown [2]. The challenge for the GTSA is therefore to make the transport safety assessment 'generic' with respect to the destination location, while still retaining a strong focus on realistic detail. This is achieved by considering ten different notional destinations, each in a different region of the UK. Detailed real-life transport routes have been developed, from each of the 30 nuclear sites to each of the ten destinations. The entire risk assessment has then been carried out ten times, creating ranges of results. In effect the GTSA contains a built-in analysis of the sensitivity of each result to the assumed destination location, so the GTSA succeeds in providing dose and risk estimates that are both generic and robust.

The GTSA methodologies are in routine use to assess the transport safety aspects of proposals for waste packaging. As mentioned in the Introduction, more than 200 proposals have been assessed so far. Each specific proposal replaces part of the waste inventory that had previously been assumed for the GTSA, and custom software then applies the GTSA methodologies for transport safety assessment. This procedure keeps the GTSA results updated between major updates of the whole assessment, and it allows the transport safety of the current proposal to be assessed within the context of a national transport programme. A proposal for waste packaging will only be judged compatible with a range of future options for waste management if both the effect of that proposal and the cumulative effect of all proposals meet specific published criteria [12].

During the present generic design phase, the GTSA results are being used to highlight areas where improvements may be needed in the existing transport system design. However, Nirex has the capability to apply the same methodologies to a transport safety assessment for any specific location that may be named in future for a national waste management facility.

3. Coverage of Risk Assessments

The Generic Transport Safety Assessment methodology [11] identifies six different risk categories:

- **Radiological risks to the public from accidents** – individual and collective doses from inhalation of releases to atmosphere, from direct exposure to an airborne plume, and from subsequent ingestion of contaminated foodstuffs.

- **Radiological risks to workers from accidents** – risks to the workers who handle the waste packages, and to transport crews.

- **Radiological risks to workers from routine operations** – for example, the radiation exposure of transport crews and package handlers.

- **Radiological risks to the public from routine operations** – scenarios in which members of the public might frequently encounter packages in transit.

- **Radiological societal risks** – the likelihood of specific numbers of fatalities, which is a criterion used by the UK Health and Safety Executive to judge the tolerability of risks [4].

- **Non-radiological accident risks** – the risks of fatal traffic accidents arising from this waste transport operation, and from the associated movements of spoil, construction material and personnel.

4. Criteria for Doses and Risks

In judging the acceptability of predicted doses and risks, Nirex follows the principles laid down by the UK's Health and Safety Executive (HSE), as summarised in Figure 2.

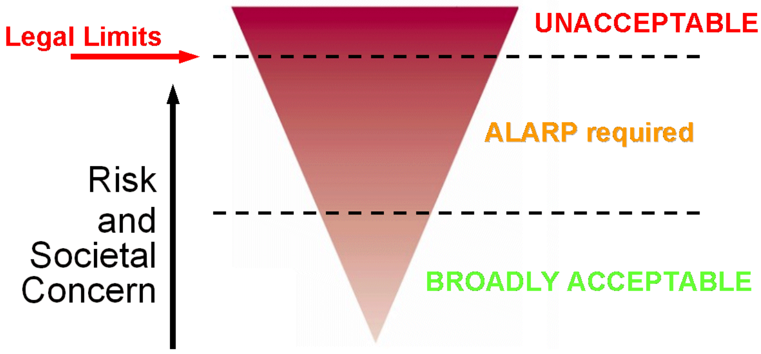

Figure 2: The UK Health and Safety Executive's principles for the acceptability of risks [4].

The HSE defines three broad regions on a rising scale of risk and societal concern [4]. Regulatory limits mark the borderline of risks that are deemed 'Unacceptable'. Below this borderline is a range of 'Tolerable' risks, that may be acceptable if they can be demonstrated to be As Low As Reasonably Practicable. Below the 'Tolerable' band is the region where risks are considered to be 'Broadly Acceptable'; this region has no lower limit. If the assessed risks fall into the 'Broadly Acceptable' region, they are deemed to satisfy the ALARP criterion without a formal demonstration.

Nirex has followed those underlying principles in its own *Radiological Protection Policy Manual* [13], which develops more specific criteria for the acceptability of the risks arising at a radioactive waste disposal facility. For consistency, Nirex then applies the same criteria when judging the acceptability of risks arising from radioactive waste transport.

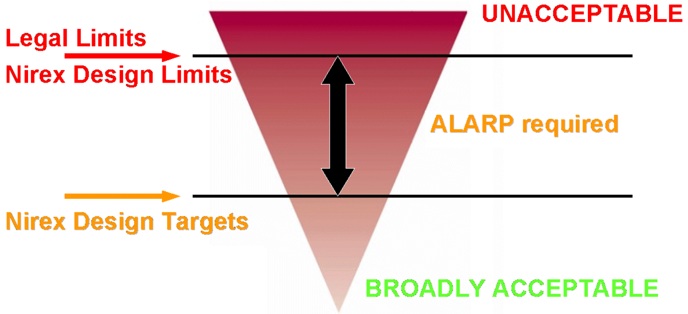

Figure 3: Nirex Radiological Protection Policy is an interpretation of HSE principles.

Figure 3 summarises the Nirex approach. Nirex Design Limits mark the borderline of doses or risks that are unacceptable, and Nirex Design Limits for doses are generally equal to the corresponding legal limits. If a predicted dose or risk exceeds a Nirex Design Limit, then the design must be changed. If predictions fall below the Nirex Design Limit, the designer must demonstrate that doses and risks are ALARP; but if they also fall below the corresponding Nirex Design Target (generally a factor of 10 lower than the Design Limit), the risk level is deemed 'broadly acceptable' and the designer is not compelled to seek further improvements.

However, in practice there is a strong preference for predicted doses and risks to be *below* the relevant Design Targets. In cases where predicted doses or risks are between the Design Target and the Design Limit, an ALARP assessment is always an option; but during the early stages of development it is more prudent to hold that option in reserve. In general it is preferable to work on improving the relevant design features, so that doses and risks are reduced below the Nirex Design Targets and the ALARP assessment is no longer needed.

Following the HSE approach, Nirex policy also includes a strong preference for the control of risks or doses by built-in features of the design [4, 13]. Operational controls may be used if there are no further options for risk management by design, but once again this is a less favoured option during the early stages of development.

5. Application to Transport Risks

This section explores how the IAEA Transport Regulations influence the predicted risks arising from the proposed radioactive waste transport programme.

Figure 4 presents the predicted radiological accident risks to the public, using an 'F-N' (Frequency vs Number) plot of societal risk as recommended by the HSE [4]. Destination 9 is the notional destination that gives the highest predicted risks, and Destination 4 the lowest; the predicted risks for all the other notional destinations fall between these two lines. Even for Destination 9, the predicted risks are at least a factor 10 below the boundary of what HSE classifies as 'broadly acceptable'.

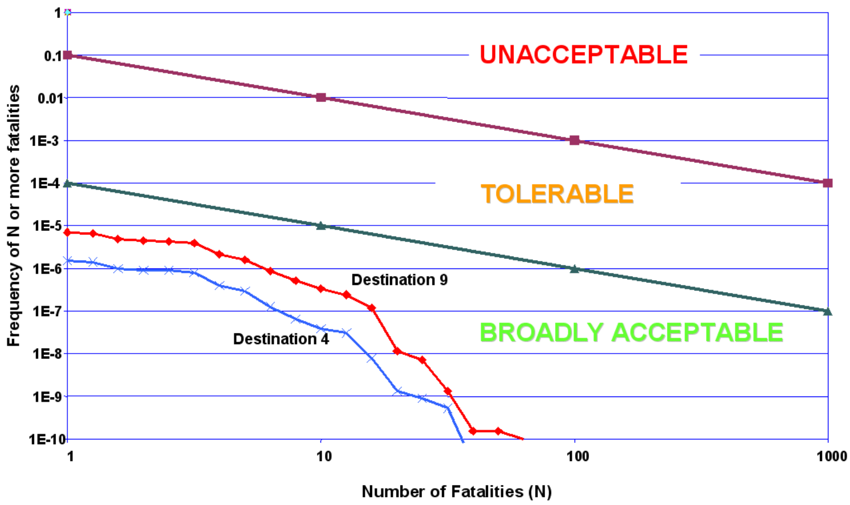

Figure 4: F-N plot of predicted radiological accident risks (highest and lowest of the 10 notional destinations).

The IAEA Transport Regulations appear to provide good control over radiological accident risks for this proposed transport system, but the means by which they do so is quite indirect. The Regulations impose deterministically-based limits on package contents and dose rates [8], and set standards for the performance of the transport package under impact and fire conditions. Nirex then takes these transport-related constraints into account when setting its own specifications for the performance of waste packages and transport containers [14]; but the ultimate effect on the risk predictions also depends on other factors.

Important contributing factors in the GTSA methodology include the probabilities and severities of accident events that might lead to releases of activity. These factors depend on the lengths and characteristics of specific transport routes, and are assessed in some detail. However, the GTSA assumes a highly simplified relationship between accident severity and the resulting releases of radioactivity from the transport packages. For accidents less severe than the regulatory test conditions, the release is assumed to be zero; but the release for all more severe accidents is assumed to be 100%. Such a step-function is clearly pessimistic because there are many engineering reasons to expect a more gradual progression; but given the 'broadly acceptable' results of the existing simplified predictions, it is not a high priority to refine this area of the GTSA methodology. Hence it is unlikely that more detailed information on the influence of the IAEA Transport Regulations upon accident risks will become available from this source.

The influence of the Regulations can be more clearly seen in the doses arising from routine, incident-free operations. A national radioactive waste transport system will only be operationally feasible if it makes the best possible use of all its assets. All the reusable transport containers, transport vehicles and transport personnel would be based at the assumed central waste management facility, and all would be employed in the most efficient manner possible. However, it is essential to ensure that the pursuit of efficiency does not result in undue concentrations of dose and risk to certain small groups of individuals, either workers or members of the public.

This example will concentrate on the drivers of waste package transport vehicles. Because of the policy of centralisation, the road transport crews would be specialists who work full-time on transporting radioactive waste, subject only to the normal legal limits on drivers' working hours. Under certain circumstances, the GTSA methodology indicates that routine radiation doses to this small group of individuals could approach or exceed the Nirex Design Target.

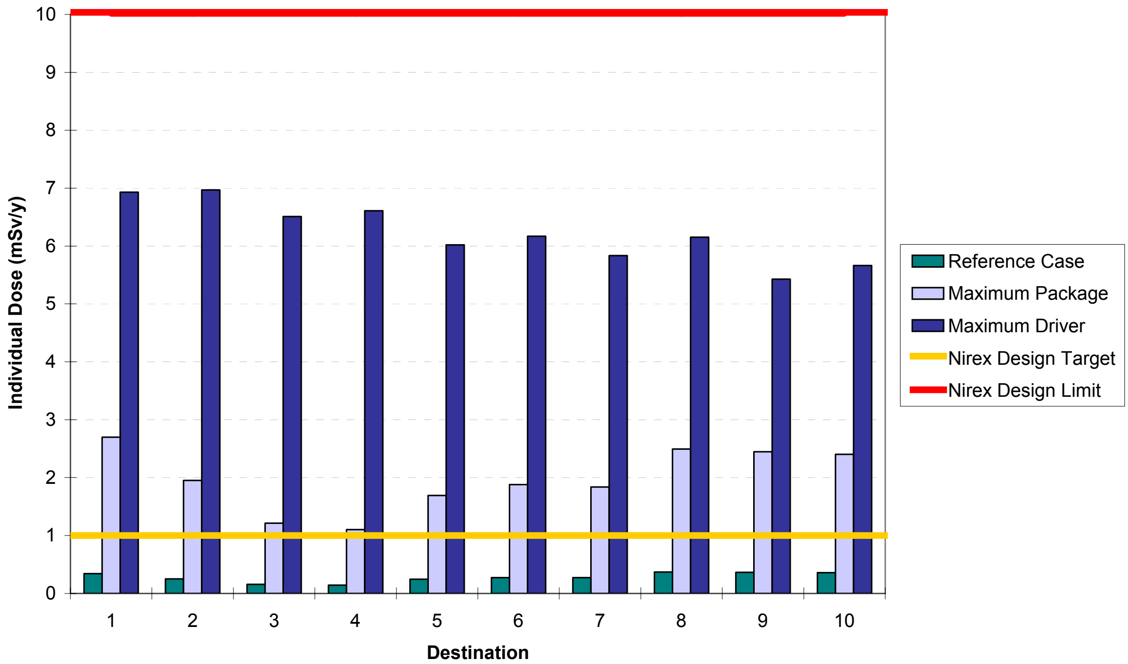

Figure 5: Predicted annual doses to road transport drivers, for three assumed operational scenarios and the 10 notional destinations.

The routine doses to drivers are proportional to the external dose rates from the packages that they transport. These dose rates in turn depend on a number of operational factors: how the packages are filled with radioactive waste during manufacture; how the stored waste packages are selected for transport; and the working patterns of the transport crews themselves. Figure 5 shows the effects of three different sets of assumptions affecting package dose rates.

- 'Reference Case' means that the dose rates from packages are as predicted from the assumed waste package inventories, with implicit averaging over all packages, all drivers and all 50 years of the transport programme. Although the predicted annual doses for any of the ten notional destinations are well below the Nirex Design

Target, no account is taken of the variability in package dose rates. The next two scenarios show that the dose to any given driver in any given year could be considerably higher than these averaged values.

- 'Maximum Package' represents one attempt to bound the problem, by making the simple assumption that the dose rates from all transport packages equal the maximum permitted by the Nirex Waste Package Specification. This limit of 0.1mSv/h at 1m [14] is derived directly from the limit in the IAEA Transport Regulations for non-exclusive use [1]. As Figure 5 shows, the 'Maximum Package' scenario leads to driver doses (averaged over the entire 50-year programme) that are above the Nirex Design Target. However, it is operationally impossible to fill every single package to produce the maximum allowable dose rate, so this oversimplified scenario is not examined further.

- 'Maximum Driver' represents a bounding operational scenario in which one individual driver is assumed to transport the packages with the highest available dose rates, subject only to the operational constraints identified by the Nirex logistics software [10]. Under this assumption, the maximum dose in one year could be significantly higher than under the previous two scenarios (Figure 5). Obviously there would be no deliberate intention to utilise any individual driver in such a systematic manner; but there are a number of operational factors that, if left uncontrolled, could systematically tend towards this scenario. Examples include: a 'last in, first out' policy at the waste store, which would minimise the mitigating effects of radioactive decay; a policy to clear all the most radioactive packages out of a store in a concentrated campaign; and a driver's possible preference to be assigned to particular transport routes. Any of these factors could systematically associate a particular driver with particular types of waste packages, and the present design of the transport system does not prevent such scenarios from arising.

Nirex is considering what further opportunities exist to optimise the transport system design, in order to reduce the average doses to drivers and bring the potential variations under closer control. In addition, the methodology of the GTSA is being reviewed, and wherever possible, simple but pessimistic assumptions will be refined to give more realistic predictions of doses and risks. However, the methodology review is also paying greater attention to other factors such as human error, so overall decreases in predicted doses and risks are by no means guaranteed.

Under the present assumption of a single national waste management facility, all transport routes converge on that one location. This leads to possibilities of undue concentrations of risk to small groups of the public who live or work close to the regular transport routes. Examples include families living beside traffic lights where waste transport vehicles might regularly have to halt; road or rail commuters whose daily schedule regularly brings them close to waste packages passing by; or families living close to rail marshalling yards or secure parking areas, where waste packages may remain for several hours. The predicted annual doses to these groups of the public are significantly lower than to transport drivers who are occupationally exposed, but some of the optimisation measures aimed at transport drivers will also benefit the public in direct proportion. Measures that are more specific to each of these groups will also be considered.

6. Conclusions

Nirex has developed plans for a large-scale national transport system for radioactive waste in the UK, that comply with the IAEA Transport Regulations in every detail. This paper has outlined the probabilistic risk assessment of the proposed transport system, and has examined how the IAEA Transport Regulations have contributed to the control and optimisation of risks in general and radiation doses in particular.

The examples given above are supported by much more detailed analyses, and have led Nirex to the following conclusions about the influences and effects of the Regulations.

- Compliance with the specific requirements of the IAEA Transport Regulations about the properties and performance of transport packages leads to adequate control of radiological accident risks from the proposed transport system, although it achieves this by very indirect means. No further optimisation of accident risks is necessary, although optimisation of the proposed transport programme for other reasons will benefit accident risks as well.

- For routine (incident-free) operations, compliance with limits on package dose rates derived from the IAEA Transport Regulations will lead to worst-case annual individual doses that are below the Nirex Design Limits, and also below the UK legal limits.

- However, for this large-scale and intensive transport system, compliance with package dose rate limits will *not* automatically lead to doses below the Nirex Design Targets, that would be classifiable in the UK as 'broadly acceptable'. To reach that situation, doses and risks need to be optimised to make them As Low As Reasonably Achievable, as required by paragraphs 301 and 302 of the current IAEA Transport Regulations (and also ALARP, as required by UK national regulations).

- Among the optimisation measures that Nirex may consider is a reduction in the maximum package dose rate allowed by its own Waste Package Specifications. This would reduce the variability in doses to small groups of individuals that could arise from routine transport operations. However, an essential feature of optimisation is that such measures are always specific to a single context, in this case the proposed waste transport system in the UK. Nirex is *not* suggesting any change to the package dose rate limits in the IAEA Transport Regulations themselves.

- The existing requirements for optimisation in the IAEA Transport Regulations are unequivocal, and need no change. They only need to be applied.

A further conclusion of importance to Nirex is that the UK public are 'stakeholders' in radioactive waste transport, whose views on the safety of the proposed transport programme should be consulted and respected. Therefore it will be essential to produce clear and convincing arguments that transport will be acceptably safe. To help guide its future work on radioactive waste transport, Nirex is vigorously developing ways to obtain input from all stakeholders, both institutional and public.

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