7th European ALARA Network Workshop on "Decommissioning and Site Remediation
29 – 31 October 2003, Arnhem, (The Netherlands)

THE USE OF A WASTE CONVERSION INDEX AS A LONG TERM PERFORMANCE INDICATOR FOR CIVIL NUCLEAR LAIBILITIES.

Pauline Fawcett/BNFL **David Spencer/BNFL**

Richard Jarvis/BNFL **George Linekar/UKAEA**

Abstract

In November 2001 the UK Government issued a statement on the future management of public sector nuclear liabilities and in its white paper "Managing the nuclear legacy" proposed the establishment of a Liabilities Management Authority, or the Nuclear Decommissioning Authority (NDA) as it is now called. With the advent of the NDA, whose aim will be to safely and cost effectively reduce nuclear liabilities, and existing Government Policy which requires systematic and progressive reduction in hazard, there is a need for some form of index to demonstrate progress. Although there are many indices in use, mainly within the chemical industry, none of these are considered suitable for this purpose.

A Waste Conversion Index is currently being developed to satisfy these needs. The Waste Conversion Index will reflect an emphasis on passive safety rather than the more traditional safety analysis which focuses on risk. It is intended to be applicable across all UK civil nuclear sites and may act as one of a number of long-term performance indicators. This paper describes how the index is formulated, and the various factors used in the calculation together with its main uses including its use as a predictive tool to demonstrate progressive hazard reduction as nuclear liabilities are reduced. In addition the paper warns against the misuse of the index as a sole means of decision making in developing hazard reduction strategies, prioritising projects and allocating funding. Finally, some examples are given of its application to existing facilities.

Introduction

In November 2001 the Government issued a statement on the future management of civil nuclear liabilities, and in its white paper "Managing the Nuclear Legacy" (Ref 1) proposed the establishment of a Liabilities Management Authority (LMA), or the Nuclear Decommissioning Authority (NDA) as it is now called. The NDA will be responsible to Government for ensuring that the nuclear legacy is cleaned up safely, securely, and cost effectively and in ways that protect the environment. The NDA will set the framework for managing delivery of the clean up but will not directly manage the sites for which it is responsible. Rather it will contract with site licensees who will be responsible for delivering an agreed clean up programme. These contracts will provide for the sharing of business risk, set key performance indicators and establish payment mechanisms. In line with its commitment to openness and transparency, the NDA will publish details of these arrangements including the performance measures set for contractors and their performance against them. It will also publish details of performance indicators which will measure the achievements of the NDA. These performance indicators have yet to be fully developed and are required for two basic purposes, firstly to measure a contractors performance, and secondly to explain to stakeholders what progress is being made and how value for money is being achieved. The Waste Conversion Index is seen as a useful indicator for measuring and communicating progress.

With the advent of the NDA, and existing Government policy (Ref 2), which requires systematic and progressive reduction of hazard, there is a need for some form of index which illustrates how 'hazard' is reducing as work progresses. No such index currently exists and the Waste Conversion Index has been developed to satisfy these needs and quantify the benefits of conversion of materials to more passively safe forms thus reducing the potential for harm. The index has been developed by BNFL in conjunction with UKAEA and used UKAEA's semiquantitative “Hazard Reduction Index” (Ref 3) as the starting point and built on this foundation. Its development has also been usefully influenced by other key stakeholders including the regulators, and more recently the Liabilities Management Unit (LMU). This latter body is a unit set up within the Department of Trade and Industry to strengthen its ability to drive forward work on the nuclear legacy and help to prepare the ground for the Nuclear Decommissioning Authority (NDA).

Nomenclature

Currently there is a wide range of definitions/interpretations of the terms hazard and risk and it is not uncommon for these terms to be used interchangeably, particularly in everyday vocabulary. The definitions identified below are those used in this paper which are consistent with those used by HSE (Ref 4).

Hazard: The intrinsic or inherent ability of a substance or structure to cause harm –can be measured in many different ways e.g. kinetic energy, toxicity, suffocation potential, etc.

Consequence The effect of a particular hazard being realised through an event and causing harm or damage – can be measured in a variety of ways e.g. death, human health effects, environmental damage

Probability The likelihood that a given event will occur in a specified period - usually measured as events per annum

Risk: The chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard usually measured as the probability of a given event per annum e.g. deaths per annum. Numerically RISK = CONSEQUENCE X PROBABILITY

Passivity Passive safety (Ref 5) measures the degree to which radioactive wastes and materials are immobilised in a form that is physically and chemically stable and stored in a manner which minimises the need for control and safety systems, maintenance, monitoring or other human intervention.

The Index

According to the HSE hazard is a measure of the potential to cause harm, and risk is the likelihood of that harm being realised (Ref 4). The WCI attempts to measure both a material’s harm potential and the extent to which the waste form is passively safe. This is somewhat of a departure from much safety analysis since most work for operating plant focuses on probabilistic *risk* assessment, reduction and management (colloquially harm *will not* be realised) rather than *hazard* reduction and management (colloquially harm *cannot* be realised).

Towards this end, the index has been derived from a baseline measuring hazard, rather than risk. However, focusing on the intrinsic hazard alone would not show any benefit in the retrieval and treatment of waste, and their subsequent storage in more passively safe forms, and yet both of these are important in keeping the material away from man. For this reason the waste conversion index takes hazard as a base line and then additionally considers

- The potential for the material to be dispersed. This includes the physical form of the material as well as its physical and chemical stability.
- The physical barriers preventing the material being dispersed, for example the drums and buildings.
- The resulting waste conversion index can be viewed as a measure of how passively safe material is at discrete points in time.

Having discussed the background to the index, it is now worth considering the form of the index that has been developed, and is now being used in BNFL to inform decision making by showing how waste management actions may impact on the ‘hazard’.

The Waste Conversion Index uses numerical values for four factors:

Inventory
Form
Containment
Reactivity
These four factors are multiplied together to give an overall score. Thus the waste conversion index is calculated using the following expression:

Waste Conversion Index = Inventory x Form Factor x Containment Factor x Reactivity Factor

The following section outlines the basis for the four factors.

Inventory

One possible inventory term would be the activity of the material (i.e. the total number of Becquerels), another would be the amount of the material i.e. the volume. However, neither of these seem to be an appropriate measure of 'potential to cause harm', since different radionuclides have different potential to cause harm and physical measures such as volume or activity do not take this into account. The inventory term chosen is, therefore the instantaneous toxic potential (ITP) of the waste which takes into account the specific nature of individual radionuclides in terms of their half life, persistence in the body etc and calculates a theoretical dose. It is therefore a better measure of the potential harm to man. The ITP is a quantity derived from Annual Limits on Intake, an internationally accepted concept and has been accepted by the Governments Radioactive Waste Management Committee (RWMAC) as a valid method of establishing equivalent hazards of different waste types (Ref 6). The ITP is the volume of water required to dilute the material to a form that would be safe to drink if a population used the mixture as its sole source of water.

Form Factor

The form factor represents the physical state of the material e.g. whether it is a gas, liquid, or solid. The form factor will affect the mobility of the material and hence its potential for dispersion in the environment and its ability to cause harm subsequently to that environment or to people. This factor recognises the reduced potential for dispersal if the wastes are stored as solids rather than liquids or gases since this reduces the ease with which material can be lost from its location should the containment be breached.

Containment Factor

This factor models the integrity and number of barriers (e.g. drums and buildings) which prevent release to the environment and relates to the likelihood of a structure retaining its integrity over time. It is intended to provide a reasonable indication of the relative effectiveness of each containment structure.

Reactivity Factor

This factor relates to the chemical reactivity or physical energy inherent in the material, which could alter the state and mobility of the material and/or affect the integrity of containment structures. It also includes the amount of time to react to, and safely recover from, an unplanned event resulting from the reactivity of a stored material. Examples of this are the self-heating potential of highly active liquors which may result in liquids becoming vapours if not adequately managed, and corrosion or radiolysis leading to hydrogen gas generation.

Numerical values ascribed to the various factors are detailed in the Table I below.

Table I - Numerical Values Assigned to the Factors

Form		Containment		Reactivity	
Gas	1	Significant remedial action required in short term, say, 5 years	1	High reactivity, high % of activity could be lost, little time to react	1
Liquid	0.1	Multiple barriers provided which will	0.1	Medium reactivity, only a fraction of	0.1

		be maintained without major refurbishment for lifetime of plant		material released, moderate period of time to react	
Powder	0.01	Multiple barriers provided which will be maintained, without significant intervention for over 100 years	0.01		
Solid	0.001				
Immobilised Waste	0.0001			No/negligible reactivity, no active systems ad control achieved passively	0.0001

In the early stages of development attempts were made to provide a rigorous scientific underpinning to the values used by the use of experimentally derived release fractions and decontamination factors used in safety cases. Unfortunately, these were specific to certain accident scenarios and not suited to scoring the inherent mobility of the material. Furthermore even with this approach judgement had to be applied to the relative weighting between factors. However, whilst not scientifically based the index has a sound logical basis and extensive sensitivity analysis has been performed to demonstrate the relative insensitivity of the output to changes in the factors.

Thus, the current values, although arbitrary, have been ascribed using both a common sense approach (good containment is better than failing containment) and some informed judgement. They span several orders of magnitude in order to reflect the large differences between for instance, the mobility of a gas and that of a vitrified solid waste. The magnitude of the factors also allows the inventory or hazard term to be sufficiently modified to reflect the projected benefit of the changing form, reactivity, or containment. Given the subjective approach to ascribing values to the factors, it is important to note the index is not intended as an absolute measure of the safety or environmental hazard rather it is a relative measure of the hazard/passivity of a plant and allows comparison between plants.

In addition the index can be readily applied to a plant, and given a knowledge of the plant inventory and other factors the calculation can be performed rapidly. This compares with the more traditional risk assessment techniques which require a detailed analysis of plant safety systems and can take months to complete. Given that the factors are subjective there is a need to consider how the index might vary with differing sets of factors in order to provide confidence to a wide range of informed stakeholders that acceptable results have been obtained without the benefit of rigorous scientific underpinning (difficult and excessive for an index of this sort).

In order to demonstrate this, a wide range of sensitivity studies have been undertaken which considered different target groups and pathways in deriving the Instantaneous Toxic Potentials, and significant changes within and between the different factors. In all cases there were changes in the absolute numerical values but the relative differences between individual facilities remained similar and the overall the trend remained.

Moving on to the application, this index has been calculated for a number of facilities on the Sellafield site. The results of this exercise can be seen in Figs 1 and 2 which show the ITP and WCI values respectively.

Figure 1 ITP values for various waste streams stored on the Sellafield site

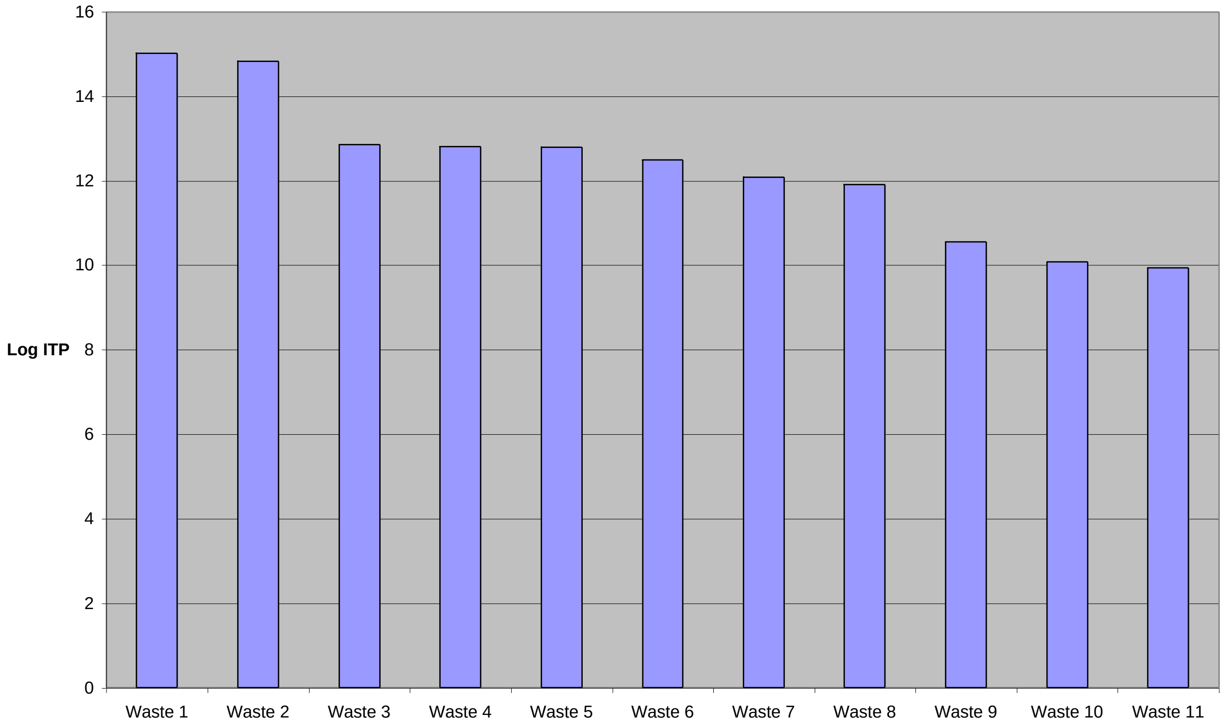
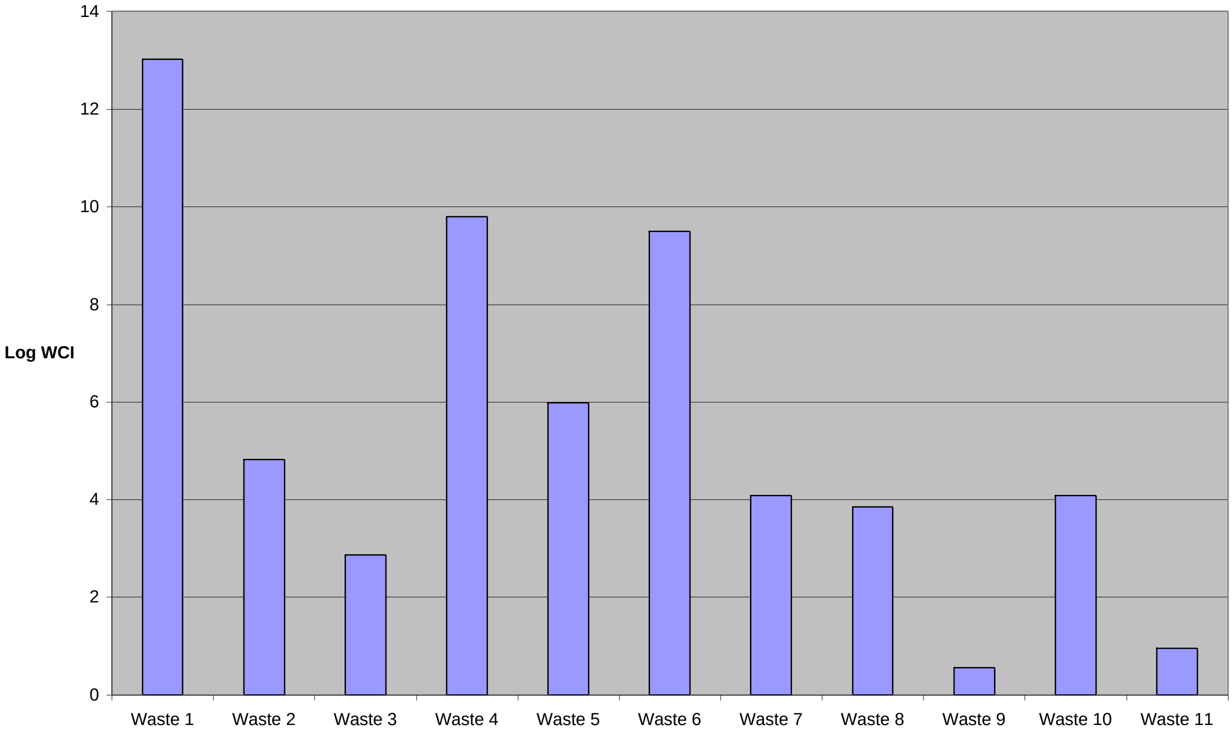

Log ITP
16
14
12
10
8
6
4
2
0
Waste 1
Waste 2
Waste 3
Waste 4
Waste 5
Waste 6
Waste 7
Waste 8
Waste 9
Waste 10
Waste 11

Figure 2 WCI values various waste streams stored on the Sellafield site

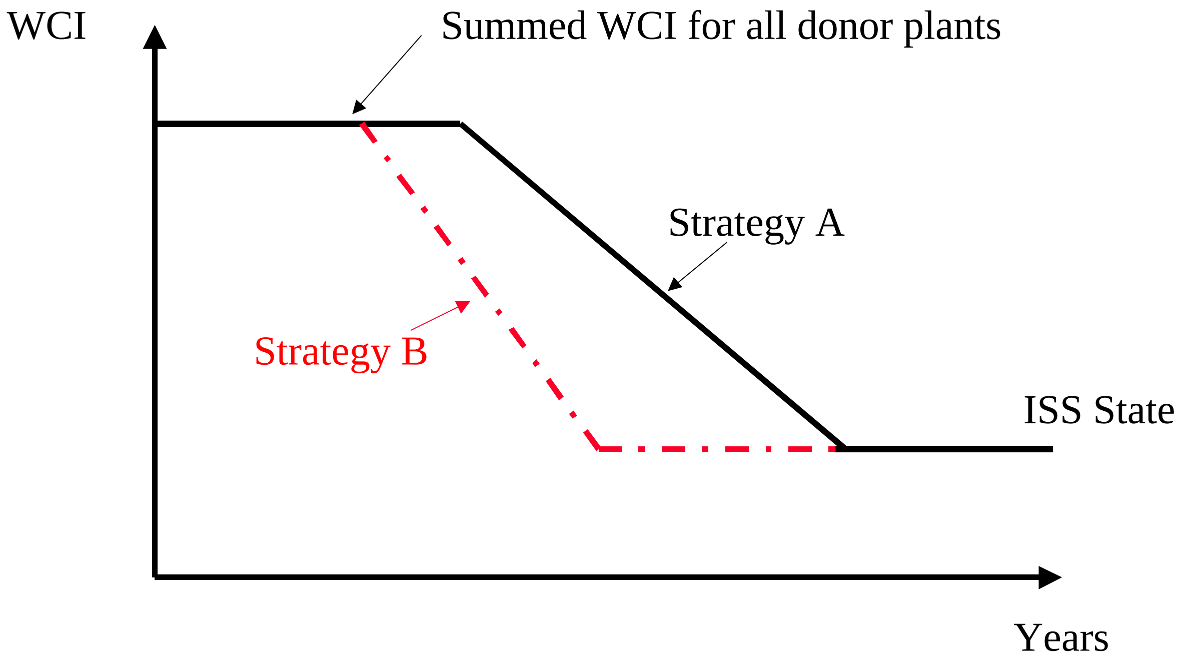


These figures show a very different ordering between ITP values and the WCI which is as expected given the aim of the WCI to model ‘passive safety’ and the ‘potential to cause harm’ rather than just the intrinsic hazard.

As can be seen there are many orders of magnitude between the highest and lowest scoring facilities for both ITP and WCI. This is not surprising given the very different inventories and also reflects the importance of the other attributes. However, it is important that this information is not used inappropriately or out of context. For instance, it can be very tempting when viewing these graphs to focus attention on the highest scoring facility. This could be misguided in that the WCI is attempting to measure the hazard rather than the risk and it may be wiser to focus attention on a high-risk facility. Conversely, treatment routes or facilities may not be available for dealing with waste from the highest scoring facility at a given point in time. These examples merely illustrate the fact that if all other things were equal then the WCI could be used as a prioritisation tool, but it is highly unlikely that all other things will ever be equal, and other factors are likely to drive the decision.

Nevertheless looking to the future the WCI can be a useful tool to illustrate the effect of particular strategy as shown in Figure 3. This demonstrates the reduction in WCI at discrete points in time as waste sludges are removed from the silos, immobilised and placed in store. However, it does not take into account any change in hazard/risk during the waste retrieval or treatment phases, it only considers *before* and *after* states.

Figure 3 Illustrative WCI profile for retrieval of sludge from historic waste silos



The WCI is also a useful indicator when comparing the effects of different strategies although it cannot be emphasised enough that many other factors need to be taken into account during the decision making process. For complex decisions this would usually involve multi-attribute decision analysis where WCI may be one input. Figure 4 demonstrates this comparison.

Figure 4 Illustrative Example of WCI profiles for two alternative strategies leading to interim safe storage (ISS)

Figure 4 shows that there are differences in some cases between different strategies and in this particular example the Strategy B would deliver more rapid hazard reduction and passivity, leading to interim safe storage (ISS). This is obviously beneficial, all other things being equal, but as already stated this is unlikely to be the case and therefore the decision as to which strategy to adopt must take into account all relevant factors not just the WCI profile. However, the WCI can certainly be useful in informing decisions and is also helpful as an indicator once a decision has been made as to the progress that can be expected.

In developing the index as a means of demonstrating systematic and progressive reduction in hazard it has emerged as one of a number of potential long-term performance indicator for liabilities management. This is as a result of many of its attributes, which include the fact that it can be applied not only to individual building but across a site, and across all UK civil nuclear sites. It can be used predictively to forecast progress against an agreed programme, and is a simple way to demonstrate the benefits obtained from dealing with legacy materials. It is based on the potential to cause harm to the public and the environment, thus reflecting an emphasis on passive safety, yet is easy to understand and explain. Conversely, it is not an accurate measure of the safety or environmental hazard posed by a site but the results do accord with informed judgement as evidenced by wide peer review acceptance.

In essence, the index gives an idea of the potential to cause harm, while safety systems, a qualified and experienced workforce, and regulation prevent this from becoming what *will* happen. A consequence of this is that there are applications for which use of the index is legitimate and others where use of the index will be inappropriate, or even misleading. These circumstances have already been discussed and are summarised below.

Main Uses of the Index

These can pitched at an individual project level or at site level, or at cross site level

- As a communication tool, to provide the context for clean-up programmes so that stakeholders and the general public can see progress being made.
- As one of many inputs into an overall decision making process which will define the programme of work
- As a means of demonstrating how ‘hazard’ varies as wastes are retrieved, packaged and put into storage. This can either be predictively or as an output measure of programmes

The Index should not be used:

- As the sole basis for making decisions or prioritising work programmes. There are many, many other factors that need to be taken into account when deciding what to do when including regulatory requirements, availability of waste disposal routes and treatment facilities, and confidence in the technology to name just a few.
- For allocating funding between sites or within a site. Again there are many different drivers in addition to those already mentioned above, examples of which are security, public acceptability, re-use of a building or land area etc.
- For accurately measuring the safety or environmental hazards posed by a site (it does not ‘replace the safety case’ or other legal requirements). The index is a relative measure of ‘passive safety’.

Conclusions

In conclusion a waste conversion index has been developed which attempts to model ‘passive safety’ in a robust but admittedly subjective way. The index appears to be relatively insensitive to large changes in and between factors in that although the absolute values change the relative ranking of various inventories remains virtually constant. The ranking of the results also accord with informed judgement as evidenced by the results obtained for a wide selection of facilities at Sellafield. It allows ‘systematic and progressive reduction of hazard’ to be demonstrated and communicated and is easy to understand and explain. This is seen as a key benefit as it can be used by site operators to show progress against programmes and can also be used to inform strategies.

Next steps are for BNFL to continue to expand its application to a wider selection of wastes and apply it across a range of projects. BNFL are also involved in a working group set up by the LMU to consider the merits of the index as one of a suite of indices for use by the NDA.

Acknowledgments

The authors would like to express their thanks to everyone involved with this project both within BNFL and from external organisations. In particular we are indebted to the representatives from EA, SEPA, NII, LMU and RWMAC who have given their time freely and participated in many stimulating and helpful discussions.

References

Ref 1 Managing the Nuclear Legacy. A strategy for action (CM 5552).
Ref 2 Review of radioactive waste management policy, final conclusions Command paper (Cm) 2919, 1995.
Ref 3 Private Communication with DTI.
Ref 4 Reducing Risks, Protecting People. HSE's decision-making process.
Ref 5 Regulatory guidance from HSE "Management of Nuclear Matter, including Radioactive Materials and Waste on Nuclear Licensed Sites" March 2001.
Ref 6 Radioactive Waste Advisory Committee, Response to the Government's Consultation Document: "Managing radioactive Waste Safely", June 2002.