ASSESSING WASTES FROM FUEL CHAINS OF ELECTRICITY GENERATION

FINDING COMMON GROUND

BY ROGER SEITZ

Safety assessments for radioactive waste disposal from the nuclear fuel chain have been routinely conducted and are often subject to detailed public debate. However, such assessments are not common for the disposal of non-radioactive, hazardous wastes or wastes comprising enhanced concentrations of naturally occurring radioactive materials which result from exploitation of natural resources. The logic for this disparity is not clear, because many of these wastes contain substances, which when not properly managed, pose potential impacts on human health far into the future.

When comparing energy options, it is important to gain perspectives regarding the safety of disposal practices for wastes from the entire fuel chains of electricity generation (including extraction, fuel processing, plant operations, and decommissioning). Toward this end, the IAEA is sponsoring a project on Safety-Related Information on Wastes from Different Energy Generation Systems, within the framework of its overall Programme on Comparative Assessment of Energy Sources.

The objectives are to provide information on the amounts, characteristics, and disposal practices associated with the fuel chains and to evaluate approaches for assessing and comparing the effects on human health and the environment. A Co-ordinated Research Project (CRP) has been initiated as part of the work to provide data and practical experience toward the resolution of important issues for comparative assessments.

Wastes from nuclear and non-nuclear fuel chains comprise combinations of radioactive and non-radioactive substances. Thus, an important consideration is the need for harmonized methods for assessing *on a common basis* the potential effects of radioactive and non-radioactive substances that may be placed in a variety of different disposal facilities. This article presents information on current proposals for resolving key issues in the development of a harmonized approach for assessments of effects on human health that may result from different waste disposal practices. Also part of the project, though not considered in this article, are ecological and environmental effects — such as impacts on flora and fauna and impacts of land use — and the effects of discharges from operating facilities.

International Cooperation. Besides the IAEA, a number of international organizations – including the International Commission on Radiation Protection (ICRP), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), European Commission (EC), United Nations Environment Programme (UNEP), World Health Organization (WHO), and Organization for Economic Co-operation and Development (OECD) — are addressing issues related to the health and environmental effects associated with disposal of radioactive and/or other hazardous wastes. Input from these organizations is being used, as appropriate, in the course of the IAEA project.

For example, in the case of radioactive substances, dose-response functions are specified by the ICRP and incorporated in IAEA guidelines for international use. For non-radioactive substances, international organizations and national regulators use different approaches and data to derive dose-response functions.

Mr. Seitz is a staff member in the IAEA Division of Radiation and Waste Safety.

SURFACE WASTE DISPOSAL

Uncovered surface disposal is a system used for certain categories of waste that provides minimal long-term protection. The unstabilized liquid or solid wastes are assumed to be distributed on the ground with no cover or engineered features (a lining may be considered for surface impoundments). This approach could be followed as an intended practice or it could result over time from the erosion of cover material and/or degradation of engineered barriers in the case of a near-surface disposal facility.

Photos: Top left, wastes from oil- or gas-fired energy production can be disposed of on so-called land farms. Below left, an airborne view of a temporary uranium mill tailings pond, which will be drained and covered with a multi-layer engineered barrier upon its closure.

EXAMPLES OF DISPOSAL PRACTICES FOR SOLID WASTES FROM ENERGY FUEL CHAINS*

	Disposal on Ground Surface**	Near Surface Disposal***	Geological Disposal	Ocean, Sea Disposal
Nuclear				
- radioactive		■	■	
- non-radioactive		■	■	
Coal/Lignite				
- radioactive	■	■	■	
- non-radioactive	■	■	■	
Oil/Natural Gas				
- radioactive	■	■	■	■
- non-radioactive	■	■	■	■

*Includes solid wastes from the fuel chains (not including wastes from transportation, maintenance, construction, etc.)
**Disposal without cover.
***Includes disposal at the ground surface (covered landfills, etc.) and disposal to depths of a few tens of meters (all near-surface facilities are assumed to include provisions to cover the waste).

Important issues. Various issues need to be resolved to assess on a common basis health effects associated with disposal of solid wastes from different fuel chains for electricity generation.

Two of these issues are addressed in this article.

The first concerns the development of a tractable approach to harmonize assessments for the wide variety of different types of waste, disposal practices, and environmental conditions associated with fuel chains for electricity generation. *(See box and photos, this page and pages 37 and 38.)* The second is the

COVERED WASTE DISPOSAL

The approach of "near-surface" disposal is a system that provides varying levels of long-term protection. Stabilized (e.g., grout, bitumen) or unstabilized wastes are buried near the ground surface (above or below the water table). They are assumed to be covered by clean soil/rock or other more sophisticated multi-layer engineered covers upon closure. Disposal in specialized waste packages and/or concrete vaults could also be included in this approach.

Photos: Top right, a, site for disposal of low- and intermediate-level waste. Concrete vaults or packages are used. They are covered to prevent leakage during disposal operations. When the disposal site is closed, a multi-layer engineered cover is added. Below right, a site for disposal of coal ash and mining wastes; there are no engineered barriers.

need for an approach to compare the health effects associated with radionuclides and non-radioactive substances.

DIFFERENCES & SIMILARITIES

Waste management associated with fuel chains for electricity generation involves a variety of wastes in different forms, disposal facilities, and local environments (see the *IAEA Bulletin,* Vol. 38, No. 2, 1996).

Potential health effects from the disposal of any type of waste are dependent on a combination of several factors related to these differences, which poses a challenging problem for comparative assessments. The factors include the amount of the waste, the toxicity and concentrations of contaminants in the waste, the physical/chemical form of the waste, the presence or absence of barriers around the disposed waste, and the environmental conditions and demographics/habits associated with people living near the disposal site.

Radioactive & Non-Radioactive Substances. Many wastes associated with fuel chains for electricity generation comprise a combination of radioactive and non-radioactive substances. For example, nuclear fuel chain wastes can include toxic metals and/or hazardous organic substances in addition to radionuclides.

In wastes from non-nuclear fuel chains, radionuclides often result from naturally occurring radioactive materials which are extracted along with the fuel or other raw materials and become concentrated in wastes. Thus, an approach for comparative assessment would benefit from the capability to assess on a common basis effects of radioactive and non-radioactive substances. Resolution of this issue is the

WASTE DISPOSAL DEEP UNDERGROUND

Geological disposal of wastes is a system that provides substantial long-term protection. Stabilized or unstabilized solid wastes are placed in deep mined cavities or liquid/slurried wastes are injected in geologic formations at depths of several hundred meters or more. These approaches may include the use of engineered barriers such as concrete vaults, waste packages or specially designed shaft or drift seals.

Photos: Top left, the disposal of low- and intermediate-level waste in hard rock formations. Below left, the disposal of radioactive and non-radioactive hazardous wastes in salt formations.

primary emphasis of coordinated research activities related to the Agency's project.

Similarities and differences. Although there is often an impression that radioactive substances are very different from non-radioactive substances, there are actually many similarities. *(See box, page 39.)*

In terms of their behavior in the environment, some radionuclides are persistent and require disposal practices that are effective for longer time frames (e.g., those with long half lives such as carbon-14, iodine-129, plutonium-239, radon-226, and thorium-232). This is also the case for many non-radioactive substances (e.g., metals, which do not decay or degrade).

Other radionuclides and a number of non-radioactive substances decay within a relatively short time (e.g., short-lived radionuclides such as cobalt-60, caesium-137, strontium-90 and degradable organics). Potential effects from their disposal essentially can be eliminated by controlling them until they decay or degrade to safe levels.

In terms of health effects, radionuclides and a number of non-radioactive substances are known to be genotoxic carcinogens and thus their health effects can be modelled in a similar way. Identifying such similarities is an important step in the process of harmonizing assessments for wastes that include radioactive and non-radioactive substances. Some differences between radioactive and non-radioactive substances pose challenges for the development of a harmonized assessment approach.

One of the more challenging issues is related to differences in health effects that can result from exposure to different substances. The formation of cancer is an effect of concern for radionuclides and many non-radioactive substances.

However, other effects can result from exposure to non-radioactive substances found in wastes from fuel chains for electricity generation (e.g., kidney failure, brain damage, reproductive effects). Genotoxic effects like cancer are generally treated differently than other types of effects. These two categories of effects can be termed non-threshold and threshold-based effects.

A linear non-threshold model is typically assumed for genotoxic carcinogens. This model implies that there is an increasing probability of cancer incidence as the dose increases

SUBSTANCES POSING POTENTIAL HAZARDS TO HUMAN HEALTH AND THE ENVIRONMENT

	Radioactive substances	Non-radioactive substances
Naturally occurring in the earth	uranium-238, thorium-232, and progeny (e.g., radium-226)	arsenic, cadmium, chromium, nickel
Persistent substances*	plutonium-239, iodine-129, carbon-14 (wastes from nuclear facilities) radium-226, thorium-232 (wastes from naturally occurring radioactive materials)	arsenic, cadmium, chromium, mercury, nickel, PCBs
Short-lived substances**	cobalt-60, caesium-137, strontium-90	benzene, toluene, vinyl chloride
Transformation to substances posing greater hazards	plutonium-241 decays to neptunium-237 radium-226 decays to radon-222, bismuth-214, and lead-210	Inorganic arsenic or mercury converted to methylated forms by bacteria Oxidation of benzo[a]pyrene

*require isolation for longer times, if concentrations are significant
**require isolation for amount of time sufficient for decay or degradation to acceptable levels

(i.e., any dose has a probability of causing cancer, although very small probabilities at low doses).

All radionuclides and many non-radioactive substances (e.g., arsenic, benzene, nickel) are assumed to be genotoxic carcinogens. In both cases, dose-response functions that are specific to particular substances are identified that translate a given level of exposure or dose into a cancer risk.

Epidemiological data from human exposures and/or laboratory data from animal studies are typically used as the underlying basis for dose-response functions.

In both cases, the dose-response functions are often based on observations at relatively high doses. These are then extrapolated down based on the linear non-threshold assumption to apply to low doses associated with potential releases from waste disposal facilities.

For threshold-based effects, there is evidence that there is a dose or exposure level below which no effect occurs. Different organizations use different terminology to represent these threshold doses or exposures. Derivation of regulatory threshold values is not standardized among the various organizations conducting assessments.

TOWARD A HARMONIZED APPROACH

The two important issues identified so far in this article addressed (1) the need to have a harmonized assessment approach for assessing a wide variety of wastes and disposal practices, and (2) the desire for an approach to compare on a common basis effects of radionuclides and non-radioactive substances. A number of approaches are being considered to overcome these difficulties.

Development of reference disposal practices and biospheres. Wastes associated with fuel chains for electricity generation can be liquid or solid. They can also be solidified in solid matrices and may be placed in different types of containers. Furthermore, the wastes may or may not be surrounded by man-made barriers and placed on the ground surface without a cover, placed beneath a cover at the surface, or at some depth near the surface or into geological formations.

As noted previously, each of these factors can have an effect on the potential health and environmental effects associated with a given disposal concept. The IAEA is developing a set of reference categories of wastes and disposal methods, consistent with typical practices or plans, to help facilitate a harmonized assessment approach. In order to provide further consistency for assessments of different waste disposal practices, relevant contaminant transport pathways and exposure scenarios are being identified for each applicable combination of waste form and reference disposal practice.

Three different reference disposal practices have been proposed: surface disposal (without cover); near-surface disposal; and geological disposal. These separate categories are identified because, for example, potential transport pathways (air, groundwater, surface water, etc.) and exposure scenarios (drinking water, contaminated foods, direct contact with the waste, etc.) that need to be considered for a given waste are closely related to the type of disposal facility.

For example, the inhalation or ingestion of airborne (suspended) waste particles, direct surface water transport of contaminants in the waste, transport of waste through erosion and direct ingestion of the waste (soil ingestion) are only credible for uncovered wastes on the ground surface.

Within each of the three categories, there are a number of different waste forms and/or man-made barriers. They include covers and other barriers that can influence the transport pathways and exposure scenarios which need to be considered in a specific case.

For example, encapsulation of waste in a grouted, concrete container and placement of that container in a concrete vault, would significantly limit, if not preclude, releases of contamination during the effective lifetime of the container. Likewise, direct contact with the waste would not be possible while the concrete barriers are intact, even if the cover erodes. Thus, relevant transport pathways and exposure scenarios need to be identified in consideration of both the waste forms and disposal practices in the proposed framework.

The final part of the harmonized framework is the development of reference biospheres to be used for the assessments. Current proposals include development of multiple reference biospheres in order to represent different climate conditions (e.g., tropical, temperate) and human characteristics and habits (primarily based on ICRP recommendations, but also potential alternatives to recognize specific cultural differences).

A limited set of reference biospheres should provide sufficient choices to represent living conditions of different cultures as well as different climates. The country-specific results of test cases being conducted as part of the IAEA project will be used in conjunction with results from earlier IAEA projects (called BIOMOVS and BIOMASS) to develop reference biospheres for use in comparative assessments.

In general, the harmonized framework needs to permit the distinction of benefits of different levels of containment or isolation of wastes, which is critical in the context of a comparative assessment. The framework will also provide for some level of consistency in assumptions that are made about transport pathways and exposure scenarios. This is an important consideration when many different analysts are expected to be doing comparisons.

Common Basis for Comparison of Health Effects. As described previously, health effects can be divided into two general categories (i.e., threshold and non-threshold based effects). Non-threshold effects will need to be considered for radionuclides and both threshold and non-threshold effects will need to be considered (depending on the substance) for non-radioactive substances in releases from wastes associated with electricity generation fuel chains.

The first step is to seek a general approach to compare on a common basis non-threshold-based effects for radionuclides and non-radioactive substances. Then, it is necessary to seek an approach to compare these non-threshold effects with threshold effects which result from exposure to some non-radioactive substances. Test cases being conducted as part of IAEA coordinated research projects focus on gaining practical experience in applying different comparison approaches for a variety of different wastes.

Radionuclides and non-radioactive substances that are considered genotoxic carcinogens are both assumed to have dose-response functions for cancer risk, based on the linear non-threshold model. On the surface, it appears possible to make a direct comparison of health effects by simply comparing the cancer risks.

However, if such an approach is adopted, it should be recognized that the basis for the dose-response functions for radionuclides and non-radioactive substances can be different. The differences include the use of varying

PROJECT FINDINGS

Work to date through the IAEA project on wastes has led to a number of interesting findings. Two of them are described here. They illustrate that even though detailed assessments are often not conducted, the potential hazards associated with disposal of wastes from non-nuclear fuel chains do warrant careful consideration.

Wastes from different fuel chains containing enhanced concentrations of naturally occurring radioactive materials (NORM) generally have not been assessed on a site-specific basis to determine the potential hazard associated with their disposal. *(See IAEA Bulletin, Vol. 38, No. 2, 1996, for a description of these wastes.)* However, a relatively simple calculation illustrates that many of these wastes have the potential to result in doses in excess of ICRP limits.

The graph illustrates the result of a calculation of the radiation dose to a person living in an area containing NORM waste which has been spread on the ground surface as a result of previous activities at a site. The results demonstrate that a concentration of 1 Bq/g of thorium-232 or radium-226 (progeny reach equilibrium over time) in 15 centimeters of surface soils results in doses in excess of 1 mSv/year (the ICRP dose limit for practices) due only to the external dose pathway (Radon inhalation and ingestion pathways would also need to be considered in a comprehensive assessment.) This suggests that potential hazards associated with wastes containing enhanced concentrations of NORM should be carefully evaluated to support decisions about acceptable management practices.

From the perspective of non-radioactive hazards, an interesting study was conducted for the EC. It illustrates the application of techniques commonly used to assess radioactive wastes for assessing hazards associated with non-radioactive substances in wastes. One set of calculations in the study were used to derive a set of "limits" for concentrations of non-radioactive substances in nuclear power plant decommissioning wastes that could be placed in a concrete vault type facility. Using these derived "limits", the study suggests that due to the concentration of non-radioactive contaminants, decommissioning steel may require disposal in a geological facility. As a point of comparison, the "limits" derived from the EC study were compared with concentrations of non-radioactive substances from other electricity generation wastes as identified in the course of this project. *(See table.)* Following the study's logic, the table suggests that a concrete vault may not be sufficient isolation for some coal ash and some other common wastes from fuel chains. Presently coal ash and other wastes are typically disposed of without the benefit of additional barriers provided by a concrete vault; thus, limits in that case could, potentially, be more restrictive than those derived for a concrete vault facility in the EC study.

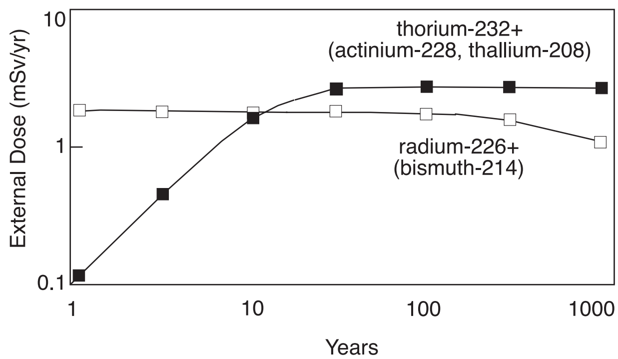
This example illustrates that hazards associated with non-radioactive waste disposal warrant consideration in a comparative assessment. It further shows that caution is necessary when drawing conclusions from preliminary calculations for waste disposal facilities. Overall the example underlines the importance of conducting studies that are specific to a site, facility and waste form, before drawing any final conclusions about the safety of a given waste disposal practice.

COMPARATIVE CONCENTRATIONS OF SUBSTANCES IN WASTES FROM FUEL CHAINS

Material	**Example Concentrations** (mg/kg)		
	Chromium	**Mercury**	**Nickel**
Coal Ash/Slag	1 - 200	not reported	50 - 300
PP Wash Water Sludge	<1 - 10,000	0.1 - 3	28 - 20,000
FGD Sludge	3 - 210	<1 - 70	20 - 240
NPP Decommissioning Steel	3000	not reported	2000
MSW Ash/Slag	200 - 2300	50	50 - 180
Oil Refinery Sludge	10 - 5080	2.1 - 4	40 - 2000
"Limits"*	70	5	1000

* Limiting concentrations for near-surface disposal of wastes as calculated in the report,"Application of Procedures and Disposal Criteria Developed for Nuclear Waste Packages to Cases Involving Chemical Toxicity", Little et.al., EUR 16745 EN, European Commission (1996).
Notes: PP=Power Plant; NPP=Nuclear Power Plant; FGD=Flue Gas Desulphurization; MSW=Municipal Solid Waste

EXAMPLE EXTERNAL RADIATION DOSES FROM NATURALLY OCCURRING RADIOACTIVE MATERIALS



methods for extrapolations from observed effects at high doses to risks at low doses, which are more common in the case of waste disposal.

Identification of an approach to compare non-threshold and threshold based effects is more difficult.

One proposal involves the comparison of a threshold dose with a dose leading to a specified cancer risk. This assumes that there is some level of cancer risk that is equivalent to a threshold dose.

The advantage of this approach is that it provides a relatively straightforward comparison.

However, there are also some disadvantages. For example, it invites debate regarding the choice of cancer risk value to be directly compared with a threshold. It also involves the comparison of experimentally observed data (for threshold-based effects) with cancer risk data extrapolated from, in some cases, much higher doses at which effects have actually been observed.

Two other general classes of comparison approaches are also being considered. These are referred to as approaches based on "margin of protection" and "margin of exposure".

The first involves the comparison of a predicted dose for a substance with a substance-specific criterion from an international organization or national regulator. It provides a relatively simple method for comparison.

Disadvantages of this approach include the fact that comparisons would not always be based on health-related considerations. This is because, within a regulatory structure, criteria for individual substances can be based, for example, on esthetic, cost/benefit, or other considerations rather than strictly health concerns.

The second type of approach involves the comparison of predicted exposures with actual exposures in the everyday environment or with exposures at which actual health effects have been observed.

The advantage is that the basis for comparison is linked to actual exposures or actual health effects rather than derived criteria.

For example, the predicted exposure to arsenic or radiation from a waste that has been disposed of would be compared with the exposure that would be expected for arsenic or radioactivity in the natural environment. Likewise, from a more health-based perspective, predicted exposures could be compared with exposures that have resulted in observed health effects. This is a potential method that can be used to avoid basing decisions on extrapolations from observed data at high doses to assumed effects at lower doses.

The approach holds a number of disadvantages. They include the implicit assumption that, in the first case, natural levels of exposure are acceptable and, in the second case, that doses are only significant at levels at which effects have been observed (this point would be especially controversial for genotoxic carcinogens).

FUTURE DIRECTIONS

Through IAEA-supported actitivies, a proposed set of reference disposal practices and waste forms has been identified. They are accompanied by suggestions for transport pathways and exposure scenarios that should be considered in each case. Work has also started on development of a set of reference biospheres that reflect climates and living conditions in different regions of the world.

Future efforts will focus on refining the reference disposal facilities and choices of transport pathways and exposure scenarios through the use of example calculations. The results of country-specific test calculations being conducted as part of an IAEA coordinated research project will be used, in conjunction with results from two other previous projects. The information will serve as background material to help develop the reference biospheres for a comparative assessment.

The calculations being conducted for the coordinated research project will also provide detailed examples of the utility of different approaches for calculating and comparing health effects associated with combinations of radioactive and non-radioactive substances.

These results will be critical inputs for proposals regarding approaches to be used in comparative assessment calculations. Expert groups are also evaluating methods for conducting these calculations, and they are reviewing selected proposals resulting from these and other project activities. ❐