THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT
ACHIEVING INTERNATIONALLY ACCEPTABLE SOLUTIONS

BY ABEL J. GONZÁLEZ

Like telling fingerprints, the wastes we leave behind characterize our human civilization. They show the ways in which we live and how we care for the world around us.

Over the past century, radioactive wastes have become an inevitable, detectable, and in some ways controversial byproduct of using nuclear and radiation technologies. To modern societies' credit, radioactive wastes from peaceful application of nuclear energy have been generally subject to much stricter controls than those applied to other type of wastes. The guiding safety and technical principles are unique -- rather than diluted and dispersed into the environment, highly radioactive wastes are confined, contained, and isolated. The distinct approach stands behind the establishment of a good safety record for the radioactive wastes generated from peaceful nuclear applications.

Yet problems and challenges remain to be solved, mainly tied to uncertainties surrounding past practices and future disposal plans.

For one, there is uncertainty raised by the handling of radioactive wastes generated by military activities during the Cold War. Reported cases have been serious, costly, and indicative of perhaps larger problems. They undeniably cast a large shadow over all types of radioactive waste storage and disposal, and regrettably distort views about the safety record of waste management from civilian operations.

For another, there is uncertainty surrounding the final disposal of the most highly radioactive wastes, those requiring isolation for thousands of years into the future. Governments for various reasons have been unable to reach definitive decisions on the final disposal of high-level waste -- though technological solutions are considered in hand and pilot facilities are showing the way forward. The situation has influenced public perceptions and attitudes about the continuing development of nuclear energy.

Hopefully, at the international level, a new consensus is emerging on ways to move ahead. Actions call for the more visible demonstration of solutions for radioactive waste disposal and the strengthening of the international framework for ensuring safe management of all types of radioactive waste. It is a framework more sensitive to the needs and requirements of the public, policymakers, and all other interested parties (i.e., the so called "stakeholders") in the process of deciding complex issues of radioactive waste management.

The IAEA today finds itself at the forefront of this changing and challenging environment. Through various programmes, the Agency and its Member States are playing a catalytic role for more effective international cooperative action. This article reviews recent developments shaping this pivotal period for the safety of radioactive waste management and the future of nuclear development.

Even before the landmark United Nations Conference on Environment and Development in 1992 spawned the bywords "sustainable development", environmental issues began to top the international agenda. But the Conference in Rio de Janeiro signaled a dramatic change, a renewed commitment, and rising public expectations about what needs to be done.

Governments there adopted an action plan for the 21st century -- called Agenda 21 -- rooted in the dynamic interconnections between social, economic, and environmental development for managing the Earth's resources. It is an agenda that engages governments, individuals, and organizations alike to achieve sustainable solutions for common problems.

Agenda 21 has far-reaching consequences, not least for how societies ensure that their wastes do not endanger the air, seep into rivers, reservoirs, and seas, or contaminate fertile lands for generations to come. Three of the nearly 40 major issues singled out for priority action are related to the management of hazardous wastes. In the field of radioactive wastes, the IAEA is

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NATURAL SOURCES OF RADIOACTIVE WASTES

Many people are surprised to learn that a large producer of radioactive waste is Nature itself. An enormous reservoir of primordial radioactive material lies on the surface and beneath the terrestrial crust. Natural processes, like volcano eruptions, mineral water springs, erosion and movements of sand, can bring fractions of this huge radioactive inventory into the human habitat.

At Oklo, Gabon, 1.8 billion years ago, a spontaneous fission process in a rich uranium deposit produced the same type of radioactive waste generated in nuclear power plants.

Mining, Milling, & Processing of Naturally Occurring Radioactive Materials. Natural processes have been accompanied by industrial activities such as mineral production that extract primordial radioactive materials from the Earth, use part of them, and leave the rest as radioactive residues. The mining, mining, and industrial use of naturally occurring radioactive materials (generally referred to as *NORM*s), cover a range of mineral resources and industrial activities. The main industries include elementary phosphorus production; phosphoric acid production; fertilizer production; primary iron and steel production, coal tar processing; coke production; coal- and gas-fired power plants; extraction of coal, peat, oil and gas; cement production; the ceramics industry; mineral sand; titanium pigment production, and uranium and thorium mining. In some of these industrial processes, the concentration of radioactive materials in the product and in the waste can be much higher than in the ore. *(See box, pages 38 & 39.)*

The world inventory of radioactive waste that has been accumulated by natural processes and generated by industrial processing of NORMs is largely unknown. The known amount of such natural radioactive waste is formidable, however, and it has not drawn the same level of interest as radioactive waste from human activities. This is the case even though the levels of public radiation exposure attributable to some natural waste can be up to two orders of magnitude above the limits established in international safety standards for radioactive waste generated by human activities.

In many parts of the world, natural barriers have isolated NORMs for remarkably long time periods. At the Cigar Lake uranium mine in Canada, for example, containment has been so effective that neither a chemical nor radiological indication of the ore deposit exists at the earth's surface. At the Alligator Rivers mine in Australia, uranium and its decay products have moved only tens of meters from the ore body although it is located in geological formations with relatively rapid groundwater flow.

seen to play the leading international role.

Despite the safety record established for radioactive waste management from peaceful nuclear activities, more work is required to meet the higher expectations and demands opening this century -- and to more clearly communicate the work already done since the discovery of radioactivity more than 100 years ago.

The main challenge today is to strengthen an international regime for the safety of radioactive waste management, which is growing under the aegis of the IAEA. Doing so will mean greater cooperation on ways to exchange experience and expertise; improved coordination of efforts for ensuring the implementation of solutions; and a broader dialogue for sustaining public confidence and support.

This initiative is a timely response in the context of international developments and the expanding dimensions of issues related to radioactive waste management and disposal.

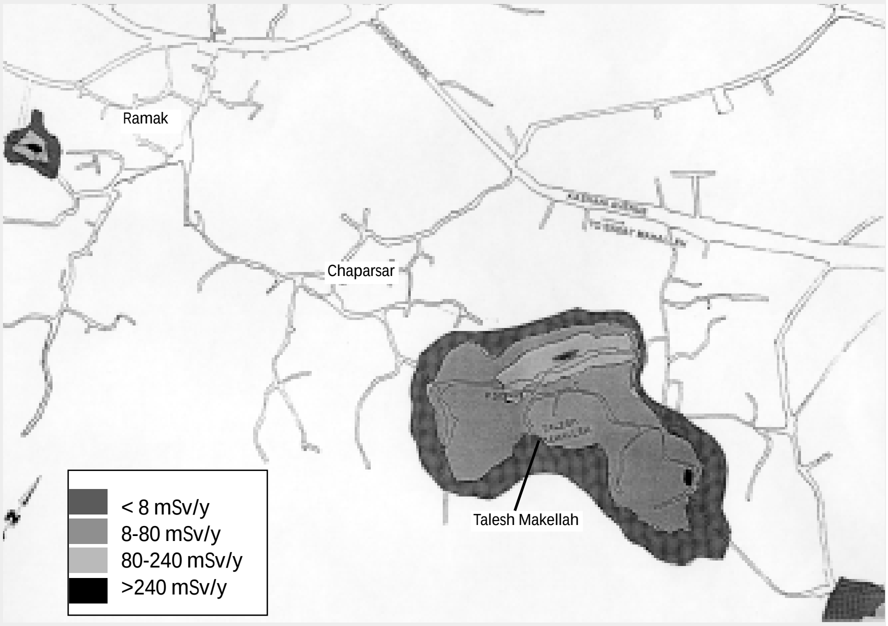
CHALLENGING DIMENSIONS

Depending on where we live, we could be walking on ground that can be classified as "radioactive waste". Essentially all substances contain radioactive elements of natural origin. The levels of such natural radioactivity in the environment vary around the world, and in some places, can be quite high.

Natural radioactivity in the Earth generally is not considered a part of the world's waste agenda. By setting a yardstick, however, Nature's radioactivity plays an important role in the bigger picture of risk management and how radioactive waste should be regulated to protect public health, safety, and the environment.
(See box this page & next.)

Nature has always been a prime generator of radioactive wastes. For instance, the amount of natural radioactivity

RADIOACTIVE MATERIALS IN NATURE



■ **Radium-226 from Natural Waters.** The map shows areas of the Caspian Sea near the city of Ramsar, Islamic Republic of Iran, where spring waters rich in radium-226 emerge and deposit "tailings" of precipitates; these tailings have radioactivity levels that can deliver high radiation exposures to residents. They can be more than 100 times above the international exposure limit applicable to radioactive waste disposal (currently one millisievert per year). *(Source: 5th International Conference on High Levels of Natural Radiation, Munich, 2000)*

■ **Monazite Sand in Coastal Areas.** Sand deposits in the states of Rio de Janeiro and Espirito Santo, Brazil, may deliver radiation exposures that, on average, are 3.6 times higher than the international limit, and in some cases more than 30 times higher. The same type of deposits in Kerala and Tamil Nadu, India, may deliver radiation exposures that on average are about nine times more than the limit, and in some cases are more than 30 times higher.

■ **Volcanic Deposits.** Volcanic deposits in Mineas, Gerais, and Goias, Brazil, may deliver radiation exposures that on average are 13 times higher than the limit, and in some cases more than 80 times higher. The same type of deposits on Niue Island may deliver exposures above five times the limit.

■ **Thorium-Bearing Carbonalyte.** Deposits in Mombasa, Kenya deliver radiation exposures that can be more than 30 times higher than the limit.

in the seas is estimated to be on the order of 10,000 exa-becquerel (EBq). (This is a large number: as expressed in the international unit of radioactivity or becquerel (Bq), it contains 22 digits. One Bq represents an extremely small amount of radioactivity and therefore large numbers are required to express a significant amount). The natural radioactive waste generated over time -- and more recently by industries processing naturally occurring radioactive materials, or NORMs -- is simply impossible to quantify (just in the areas of Chkalovsk and Taborsha in Tajikistan, for example, residual waste tailings from past mining and milling operations have been estimated to be around 50 million tonnes with a total amount of long-lived radioactivity of up to 0.001 EBq). Thousands of these tailings exist in other parts of the world.

Public concerns mainly focus on wastes from "artificial" sources of radioactivity, in other words, those arising from human activities. Civilian nuclear operations, including the worldwide production of nuclear power, produce just a part of the world's radioactive wastes. A large fraction of global radioactive wastes has been generated from military nuclear programmes including atmospheric weapons testing during the Cold War period.

Serious problems have come to light from past waste management practices that are first beginning to receive more international attention. *(See box, pages 8 & 9, and IAEA Bulletin, Vol. 40, No. 4, 1998)*

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), as a consequence of the Cold War practice of nuclear weapon testing, more than1000 EBq of radioactive waste was simply freely discharged into the atmosphere; while most of this was short-lived waste, a fraction of around 1% was relatively long-lived waste. Moreover, just in one nuclear-weapon State, the military

THE COLD WAR'S LEGACY OF RADIOACTIVE WASTES

Over the past decade, the military dimensions of radioactive waste management have drawn increasing attention. Large amounts of radioactive waste subject to military jurisdiction have accumulated at numerous sites throughout the world, particularly in the United States and in the former Soviet Union, during the Cold War period. Reports and studies have documented problems arising from military waste management practices, and steps that are being taken in response to them.

A significant amount of radioactive waste from military operations entered the environment due to the production of nuclear weapons and their atmospheric and underground testing, large-scale radiation accidents, and disposal of radioactive wastes into seas. Especially during the initial period of operations, several mishaps occurred which led to discharges of radioactive wastes into the environment. In the former Soviet Union, discharges entered the Techa River and later Karachay Lake and other open water reservoirs in the Chelyabinsk region; the Yenisei River, near Krasnoyarsk and the Tom River, near Tomsk. Accidents included the explosion of a tank with radioactive wastes at Mayak and a wind-borne scattering of radioactive dust from the banks of Karachay Lake, both in the Chelyabinsk region, in 1957 and 1967, respectively, and the explosion of a reprocessing plant in Tomsk in 1993.

The US Programme. In the USA, large amounts of financial resources are being obligated for managing radioactive waste from defense activities. The US Department of Energy's (DOE) Environmental Management Programme (EMP) is responsible for addressing the environmental legacy of nuclear weapons research, production, and testing and of DOE-funded nuclear energy and basic science research. *(See box, next page.)* These activities collectively produced large volumes of nuclear materials, spent nuclear fuel, radioactive waste, and hazardous waste, resulting in contaminated facilities, soil, and groundwater at 113 sites around the country.

The EMP manages some of the most technically challenging and complex work of any environmental programme in the world. Despite the complexity and size of its mission, EMP has already completed active cleanup at 69 of the 113 sites. Since 1997, EMP has been implementing a site closure initiative to improve programme management, accelerate and complete cleanup, and close as many sites or portions of sites as possible by 2006. The cost of this major operation is huge and will probably approach several hundreds of billion US dollars. The life-cycle cost estimates include approximately $35 billion in costs incurred by EMP from the programme's inception in 1989 through fiscal year 1996. EMP still faces formidable tasks that are likely to require $168 to $212 billion to complete.

Russian Federation & Cooperative Programmes. On the other side of the Atlantic, the International Institute for Applied Systems Analysis (IIASA) has established the Radiation Safety of the Biosphere (RAD) project to conduct a series of studies on the problems created by the radioactive waste in the former USSR. Within the Russian Federation, the problems of this radiation legacy are being handled in the framework of the Russian Federal Programme called"Management of Radioactive Wastes and Spent Nuclear Materials, Their Utilization and Disposal for 1996-2005." An important contribution to this programme is being made through a project called Radleg of the International Science and Technology Center (ISTC). IIASA is an initiator of this project and its major customer. The results of the Radleg project are tp provide major inputs into the broader RAD project.

In addition, a Contact Expert Group was set up in 1995 for international cooperation in areas of radioactive waste management in the Russian Federation. A document now is nearing completion on an Overall Strategy for Radioactive Waste and Spent Fuel Management in the Russian Federation to facilitate financial support for high priority projects. Financial arrangements for some priority spent fuel storage and waste processing activities have already been completed. *(See article, page 64.)*

In the former USSR the structure of the nuclear complex included plutonium and tritium production reactors; nuclear fuel manufacturing for the reactors; highly enriched uranium (HEU) production; the reprocessing of spent fuel (SNF) from production reactors aimed at plutonium recovery; nuclear weapon components production from metallic HEU and plutonium; plants and institutions engaged in design and manufacturing of nuclear warheads and related devices; the production works for manufacturing nuclear fuel for naval ship propulsion reactors (SPRs) and facilities for SNF reprocessing; nuclear power plants, research reactors, civilian nuclear SPRs, nuclear fuel manufacturing plants and SNF reprocessing plants; facilities for production of radioactive isotopes and ionizing radiation sources for use in the national economy; and enterprises for radioactive waste processing and disposal (Radon Special Enterprises). The production of primary nuclear materials for both military and civilian purposes was conducted, as a rule, at common industrial facilities. The main facilities of the Soviet nuclear complex were the Industrial Association Mayak in Chelyabinsk region, the Siberian Chemical Combine in Tomsk region, and the Mining & Chemical Combine in Krasnoyarsk. The Russian Federation has inherited more than 80% of the nuclear industrial potential of the former USSR and therefore its radioactive wastes. The total amounts of radioactive waste

AMOUNTS OF RADIOACTIVE WASTE AND SPENT FUEL FROM DEFENSE ACTIVITIES IN THE UNITED STATES

In the USA, the management of radioactive wastes from defense activities involves:

- remediating nearly 10 trillion liters of contaminated groundwater, an amount equal to approximately four times the daily US water consumption;
- remediating 40 million cubic meters of contaminated soil and debris, enough to fill approximately 17 professional sports stadiums;
- safely storing and guarding more than 18 metric tons of weapons-usable plutonium, enough for thousands of nuclear weapons;
- managing over 2000 tons of intensely radioactive spent nuclear fuel;
- storing, treating, and disposing of radioactive and hazardous waste, including over 160,000 cubic meters that are currently in storage and over half a billion liters of liquid, high-level radioactive waste;
- deactivating and/or decommissioning about 4000 facilities that are no longer needed to support active missions;
- implementing critical nuclear non-proliferation programmes for accepting and safely managing spent nuclear fuel from foreign research reactors that contains weapons-usable highly enriched uranium; and
- providing long-term care and monitoring -- or stewardship -- for potentially hundreds of years at an estimated 109 sites following cleanup.

AMOUNTS OF RADIOACTIVE WASTE AND SPENT FUEL ACCUMULATED IN THE RUSSIAN FEDERATION

Ministries, departments, and organizations	*Liquids*		*Solids*		*Spent Fuel*	
	m^3	Bq	m^3	Bq	Tons	Bq
Ministry of the Russian Federation for Atomic Energy (Minatom) Uranium ore mining and processing, uranium enrichment, nuclear fuel manufacturing, nuclear power production, spent fuel reprocessing, and nuclear weapon materials production	$4.0\ 10^{8}$	$6.3\ 10^{19}$	$2.2\ 10^{8}$	$8.14\ 10^{18}$	8700	$17.02\ 10^{19}$
Ministry of Defense of the Russian Federation (Navy) Operation and utilization of nuclear ships and submarines	$1.4\ 10^{4}$	$4.44\ 10^{12}$	$1.3\ 10^{4}$	$29.6\ 10^{12}$	30	$5.55\ 10^{17}$
Ministry of Economy of the Russian Federation Department of Defense Industry Construction, repair, and utilization of nuclear ships and submarines	$3.2\ 10^{3}$	$18.5\ 10^{10}$	$1.5\ 10^{3}$	$3.7\ 10^{12}$	*	*
Ministry of Transport of the Russian Federation Operation and utilization of nuclear icebreakers	$4.4\ 10^{2}$	$5.5\ 10^{13}$	$7.3\ 10^{2}$	$3.7\ 10^{16}$	10	$17.39\ 10^{17}$
Radon Special Enterprises Processing and disposal of radioactive materials, used in medicine, scientific research, industry, etc.	-	-	$2.0\ 10^{5}$	$7.77\ 10^{16}$	-	-
Total	**$4.0\ 10^{8}$**	**$6.29\ 10^{19}$**	**$2.2\ 10^{8}$**	**$8.51\ 10^{18}$**	**8740**	**$17.39\ 10^{19}$**

*More than 100 nuclear-powered submarines and their spent fuel are awaiting decommissioning.

and spent fuel accumulated in the territory of the Russian Federation is estimated at more than 600 million cubic meters of radioactive waste and 8700 tons of spent fuel awaiting final disposal *(see table)*, in addition to large amounts of residual wastes from mining and milling activities. According to IIASA, these radioactive wastes “are being managed in a way that does not completely meet modern international standards of radiation safety”.

operations for producing weapons materials have left a legacy of around 1000 EBq of residual waste, most of it in precarious containment. Furthermore, between 1946 and 1993, as a result of "normal" dumping operations, around 0.1 EBq of radioactive waste has been disposed of into the North Atlantic, Pacific and Arctic Oceans. Much more has been dumped *de facto* into the world's seas as a result of "accidents and losses", including many sunken nuclear submarines (the latest being the *Kursk* in August 2000) and even from nuclear-powered satellites that fell back to Earth.

The wastes from peaceful uses of nuclear energy tend to receive the lion's share of public scrutiny, even when they are properly managed, contained, and have radioactivity levels similar to those from other sources that are not managed as well. The amount of radioactivity in waste accumulated as a result of nuclear power production around the world during the last half century is also on the order of 1000 EBq; this inventory is growing at a rate of approximately 100 EBq per year.

The volume of civilian radioactive waste is not very large either. All the high-level waste accumulated so far -- though intensely radioactive -- could be accommodated in a large store of around one hectare, or one city block. This is the result of the efficiency of nuclear fuel and the strict strategy of concentration and confinement of waste followed by the civilian nuclear industry. Operating a 1000 megawatt-electric nuclear power plant requires around 27 tonnes of fuel per year. An equivalent fossil fuel plant would consume per year approximately 2.6 million tonnes of coal (or 5 trains of 1400 tonnes each per day) or 2 million tonnes of oil (or 10 supertankers per year). Not surprisingly, these differences are seen in the wastes being generated. The nuclear plant will produce around 27 tonnes of high-level radioactive waste, 310 tonnes of intermediate level, and 460 tonnes of low level waste, whereas the equivalent coal plant will release into the environment 6 million tonnes of greenhouse gases, 244,000 tonnes of sulphur oxides, 222,000 tonnes of nitrogen oxides, and 320,000 tonnes of ash containing 400 tonnes of toxic heavy metals. These ashes contain large amounts of concentrated NORMs which may commit the human race to higher collective doses than those attributable to wastes discharged into the environment by nuclear plants generating the same amount of electricity.

In a real sense, Nature's own processes and the bomb's radiation legacy have complicated the picture of radioactive waste management. They invariably raise questions about how waste is handled from nuclear power production and other peaceful nuclear applications, and about the extent of international cooperation in this field over the past four decades. These questions may never completely go away -- in the public's view, where radioactive waste comes from may be far less important than its safe handling and disposition -- until problems are addressed as a whole and acceptably resolved with a broader base of support.

Radioactive Waste Management. This concept generally is used to describe a sequence of operations starting with the generation of radioactive waste, including its storage (meaning the temporary retention of waste) and disposal (meaning the discarding of waste with no intention of retrieval). For nuclear power, the process encompasses the management of spent fuel from nuclear reactors and ends with the safe disposal of the unusable radioactive substances. These include discarded radiation sources that, as a byproduct of nuclear energy, serve beneficial applications in medicine, industry, and other fields. After the termination of activities involving the use of radioactive materials, some radioactive waste may remain in the site and its surroundings: these are usually termed *radioactive residues*. The release of effluent radioactive waste into the environment is usually termed *radioactive discharges.*

The international dimensions of radioactive waste management extend to these multi-faceted activities. A number of major issues are receiving particular attention:

- the management of spent fuel from nuclear reactors;
- the disposal of highly radioactive wastes;
- the management and disposal of radiation sources;
- the potential consensus for achieving international solutions on the safety of

radioactive waste management and disposal.

Spent Fuel Management. Some countries consider spent fuel from nuclear reactors as high-level radioactive waste; others regard it as an asset because usable material can be *reprocessed* into new reactor fuel, with the waste separated and concentrated into stable and durable glass.

About 10,000 tonnes of spent fuel are discharged every year by the world's 433 operating nuclear power plants, the IAEA estimates. Over the past four decades, the cumulative amount of spent fuel discharged worldwide was about 220,000 tonnes by the end of 1999. About 145,000 tonnes were in safe storage facilities, while about 75,000 tonnes were reprocessed. By the year 2015, the cumulative amount of spent fuel is projected to surpass 340,000 tonnes. *(See graph this page.)*

The projected increase is posing problems, since storage sites in some countries already are nearing full capacity. On a worldwide basis, however, sufficient storage capacity is available or planned to meet projected reactor requirements. In some countries, geological repositories for spent fuel are planned.

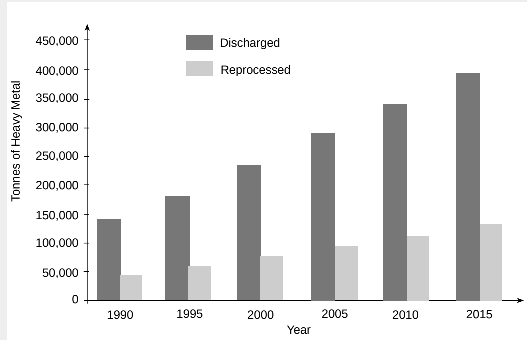
Spent fuel also is generated at nuclear research reactors. IAEA data shows that 58 countries, including 40 developing countries, operate 293 research reactors, and 15 more are under construction. Many of the discharged fuel assemblies remain at the site, and some have already been in storage for more than 30 years. Rough estimates are 63,000 in storage and another 23,000 in reactor cores. Of the stored assemblies, some 46,000 are in industrialized countries and 17,000 in developing countries. A central issue is the final disposition of spent fuel assemblies in developing countries that originally imported the nuclear fuel. Importing agreements called for the future return of the spent fuel to the supplying country, but in many cases specific arrangements remain to be negotiated.

Other sources of spent fuel are reactors utilized for producing nuclear weapons material, and civilian and nuclear powered military vessels. The management of military spent fuel is a matter of growing concern.

Radioactive Waste Disposal. Nuclear applications produce different types of radioactive waste. In terms of volume, most of it is "low-level radioactive waste" that is disposed of in facilities just below the Earth's surface. More than 100 of these shallow disposal facilities have been built and more than 30 are under development worldwide. They receive low-level waste from nuclear power plants and research reactors, as well as from medical, industrial and research activities.

The situation is different for high-level waste, either spent fuel or its reprocessed waste, which must be safely isolated for millennia. The scientific and technical community generally agrees that disposal of this relatively low-volume but highly radioactive waste can be carried out in stable geological formations, such as ancient salt domes or granite tunnels several hundred meters below surface. Multiple natural and engineered

SPENT FUEL FACTS & TRENDS



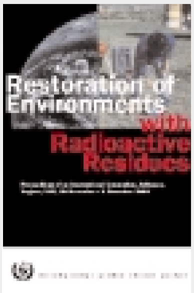
barriers would protect against human intrusion and ensure long-term confinement. However, no concept for the long-term disposal of commercial high-level waste has been licensed in any country.

Last year, an international assessment of progress towards geological disposal was issued by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. The report emphasizes that geological disposal is technically safe, and that licensing and opening of disposal facilities is needed to convincingly demonstrate that it can be done.

One important step towards demonstrating the disposal concept was the opening in March 1999 of the Waste Isolation Pilot Plant (WIPP) in the United States. Located 700 metres deep in a salt formation, WIPP is the world's first geological repository certified for disposal of long-lived radioactive waste. The site is approved for receiving US defense-related wastes, and is not licensed for high-level waste disposal.

Progress in studying and planning geological disposal for high-level waste is being seen on several fronts in the

RADIOACTIVE RESIDUES: FOCUS ON ENVIRONMENTAL RESTORATION



The International Symposium on Restoration of Environments with Radioactive Residues, in Arlington, Virginia, USA, 29 November to 3 December 1999 addressed issues related to radioactive residues arising from both human activities and from natural sources. Data presented by experts demonstrated that the scale of problems from human activities is large, and that the size of problems associated with naturally occurring radioactive residues are even larger, and may be more widespread. One conclusion was that there is a clear need to harmonize the characterization of both natural and human-made residues in a consistent way so that both risk management and site remediation can be addressed with a common understanding. Participants further emphasized the need for promoting more public understanding of issues and to involve the stakeholders in planning remediation efforts. Proceedings of the symposium are available from the IAEA.

United States, Finland, France, Sweden, and other countries. Significant hurdles are faced in many cases, however, primarily related to issues of public acceptance, siting and safety demonstration.

Technological developments in the nuclear fuel cycle may help address some concerns. At the La Hague reprocessing plant in France, for example, new volume reduction techniques can convert the waste in spent fuel into vitrified solid high-level waste. If the world's annual generation of spent fuel could be reprocessed with equivalent volume reductions, rough estimates are that the resulting vitrified solids would be on the order of 1000 cubic meters; that is, a cube of about 10 metres on each side per year of world nuclear energy production.

Disposal of Disused Radiation Sources. An emerging problem in waste management is arising from radiation sources used in medicine, agriculture, industry and other fields. When these sources are no longer useable, they must be disposed of safely. However, many of the "disused" sources have not been properly managed, sometimes remaining "orphan" from regulatory control. Serious incidents have occurred in several countries where lost and abandoned sources caused deaths and injuries before being recovered. In response to problems, the IAEA launched an Action Plan to assist countries in improving their capabilities for ensuring the safe control and disposal of radiation sources. *(See article on page 60 and the IAEA Bulletin, Vol.42, No.3, September 1999.)*

EMERGING CONSENSUS ON WAYS FORWARD

The International Framework for the Safety of Radioactive Waste Management. The challenge of achieving an international consensus on the safety of radioactive waste management is a formidable one. It touches upon complex scientific, technical and ethical issues upon which professional opinions do not always coincide. The initiative to strengthen the international framework is fundamentally tied to the need to harmonize approaches and lay the groundwork for enhancing public acceptance of waste management solutions.

Some of the questions being raised include:

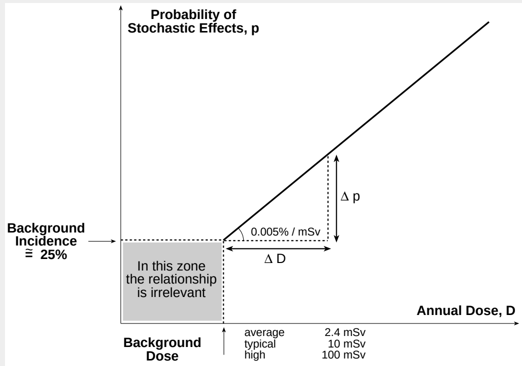
- Should radioactive wastes from natural sources be controlled as strictly as those generated from human activities?
- What ethical values should guide decisions on the safety of waste disposal, considering that future generations could be exposed to harmful radiation arising from the waste left by our generation?
- What health effects can be attributed to the low-level radiation exposure which is expected to be incurred from well-managed radioactive waste? *(See box, page 13.)*
- Should waste management decisions depend on new technological developments or apply the best available technology today? By extension, is it better to proceed with the final disposal of radioactive waste at this stage or wait and see how technology develops in the future?
- Should the safety of waste disposal be purely a national decision or is it a matter of international concern given the potential transboundary dimensions of problems and solutions?

There are no easy answers to such questions. Importantly, they are being raised and debated through the exchange of views at international

REGULATING RADIOACTIVE WASTE: REAL & PERCEIVED ISSUES

When properly managed, radioactive waste is expected to deliver exceedingly low levels of radiation doses to people. However, a confusing professional debate about the assumptions underlying the regulation of low radiation doses may be affecting public perceptions in the wrong way. The academic controversy centres on what is called the "linear non-threshold", or LNT, hypothesis, which expresses the overwhelming international consensus (including the UN family) on the health effects attributable to radiation exposure. The LNT is usually formulated in a simplistic manner as follows: the likelihood of somebody incurring cancer from radiation exposure is proportional to the level of radiation dose, without a safe threshold of radiation dose at any dose however small. However, the international formulation is more subtle. It can be expressed as follows: above the varying levels of pre-existing background radiation (which on average are 2.4 millisievert (mSv), with typically high levels of about 10 mSv that may go up to 100 mSv), an increment in radiation exposure will plausibly cause a propotional increment in the incidence of cancers above the pre-existing incidence level (which is known to be extremely high – in the western world around 25% of people die of cancer). The graph presents the situation.

The shape of the relationship for radiation levels below background is an interesting academic question but it does not have any regulatory influence. The regulator has to consider the plausibility of health effects for radiation doses above the unavoidable background; moreover, because of the ubiquity of radiation, the considerations should probably be based on the typically highest (rather than the lowest) background levels. It is to be noted that, even under



these conditions, the likelihood of incurring a cancer attributable to an incremental radiation exposure is exceedingly small. Currently, the United Nations Committee on the Effects of Atomic Radiation estimates that it is five-thousandths of a percent (0.005%) per mSv of radiation exposure; the expected public exposure from well-managed radioactive waste is a small fraction of 1 mSv.

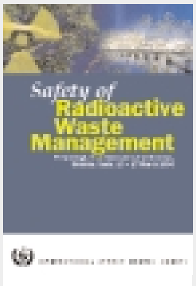
Over the years, the LNT controversy has engaged radiobiologists, regulators, and others, with some taking rather extreme positions about the risks from exposure to low levels of radiation. The fractious debate has added to the problems of regulating radioactive waste and its low-level radiation doses. One undesired outcome of the dispute has been a more confused, rather than enlightened, public. Another unfortunate result is the inconsistent regulation of low-level radioactive wastes. In a number of cases, the regulatory process has imposed severe penalties on society and, unwittingly, hindered the utilization of beneficial nuclear and radiation applications.

conferences, in professional bodies, and through initiatives within the IAEA's own programmes on safety of radioactive waste management. Several recent international developments are helping to define ways forward.

The International Commission on Radiological Protection (ICRP) recently issued new recommendations in areas of radioactive waste management. They are ICRP Publication 77, *Radiological Protection Policy for the Disposal of Radioactive Waste;* ICRP Publication 81, *Radiological Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste;* and ICRP Publication 82, *Protection of the Public in Situations of Prolonged Radiation Exposure.* *(See article, page 21.)* Additionally, the International Nuclear Safety Advisory Group has issued a new report, *The Safe Management of Sources of Radiation: Principles and Strategies.* *(See article, page 19.)*

Experts, policymakers, safety specialists and other "stakeholders" further have met at important recent international gatherings organized by the IAEA. One was the International

THE CÓRDOBA CONFERENCE



The outcome of a major international conference earlier this year is strongly influencing the emerging agenda for radioactive waste management. *The International Conference on the Safety of Radioactive Waste Management*, convened in Córdoba, Spain from 13 to 17 March 2000, was organized by the IAEA in cooperation with the European Commission, Nuclear Energy Agency of the Organization for Economic Co-operation and Development and the World Health Organization, and hosted by the Government of Spain. More than 300 senior officials and scientists from 55 Member States and six international organizations took part.

The Conference's principal objective was to enable an open dialogue among members of the scientific community, representatives of facilities which produce radioactive waste, officials from bodies responsible for radioactive waste management and from nuclear regulatory bodies, and representatives of public interest groups. The encounter provided policy and decision-makers with a basis for political action, and proved to be an important step in the search for building the essential international consensus for radioactive waste management.

The Conference concluded that -- since radioactive waste already exists, and doing nothing with it is not a sustainable option -- it is the duty of the present generation to avoid imposing an undue burden on future generations, and to devise and implement viable solutions for the safe management, including disposal, of that waste. In each country, it is the responsibility of parliament and government to establish the legislative framework and take the political decisions necessary for the implementation of a national radioactive waste management policy.

The Conference recommended that a national radioactive waste management policy should reflect the following considerations:

- The producers of radioactive waste have the prime responsibility for its safe management, and it is they who should propose appropriate options and secure the economic resources necessary in order to discharge that responsibility.
- Radioactive waste management should be dealt with "holistically", so as to avoid actions which, while resolving immediate problems, could constrain future decision-making.
- As there are uncertainties -- not only scientific and technical, but also legal and political -- inherent in the various options for the safe management of radioactive waste, it is necessary to pursue robust management approaches that will be acceptable in a wide range of possible future situations.
- Safety issues should be addressed independently, so as to ensure compliance with regulations and formally defined criteria that may need periodic revision in order to take into account scientific and technical developments.
- The effective implementation of disposal options requires the clear definition, at the national level, of a step-by-step and transparent approach that enables the different interested parties, including the general public and public institutions, to participate in the decision-making process.

In almost all technical sessions, there was discussion of the need to involve all interested stakeholders in the decision-making processes related to radioactive waste management. In this context, an IAEA initiative for the establishment of an *ad hoc international forum* was welcomed.

The Conference covered a wide range of topics and paved the way for strengthening international consensus in key areas of radioactive waste management. Proceedings are available from the IAEA Division of Publications.

Symposium on the Restoration of Environments with Radioactive Residues, which neared agreement on the delicate issue of rehabilitation of human habitats contaminated with residual radioactive waste. *(See box, page 12.)* The latest and largest forum was the International Conference on the Safety of Radioactive Waste Management in Córdoba, Spain, from 13 to 17 March 2000. *(See box this page.)*

CÓRDOBA: THE EMERGING AGENDA

Participants at the Córdoba Conference reached significant conclusions on a wide range of topics influencing future international directions. Through their technical observations, conclusions and recommendations, they underlined a number of points on key topics, including:

Siting of Radioactive Waste Management Facilities. The Conference emphasized the importance of gaining the trust of the public as a very important element in successfully progressing in the siting of radioactive waste repositories. A siting process that provides interested parties an opportunity to participate early in a well-defined and transparent process would afford greater chance of success.

Effectively communicating with the public is an important element in building trust, maintaining confidence and encouraging meaningful contributions to the decision-making process. Technical specialists need to express complex waste management issues in terms that are clear and understandable to all interested parties. The media can assist in this effort as well, but the Conference recognized that journalists operate under their own pressures.

Disposal of Low-Level Radioactive Waste. The Conference noted that near surface repositories for low- and intermediate-level radioactive waste from nuclear power plants are used in many countries, where they have been accepted both politically and by the public. In this case, institutional control can reasonably be expected to prevent intrusion for the limited time until most of the activity in the waste has decayed.

Because of the very large volumes of naturally radioactive waste from uranium mining and milling (as well as from other industries processing NORMs), the only economically feasible disposal option is on or near the surface. Although the concentrations of radioactivity are not high, the radionuclides in mining and milling waste are extremely long-lived, and therefore near-surface disposal facilities for such waste would require institutional control "in perpetuity" to prevent human intrusion.

For most types of waste disposal, institutional control is one element in a defense-in-depth system; indeed, in the case of geological disposal its main purpose would be to provide reassurance rather than contributing to safety. For mining and milling waste, it may be the only feasible line of defense for the future. Issues of this type go far beyond the purely technical stage, and need further discussion with a much broader spectrum of people to develop realistic solutions that can attract widespread support.

Geological Disposal. The Conference considered in particular the deep geological disposal of high-level radioactive waste, recognizing that it raises a number of safety and ethical issues. It must be handled safely both now and in the future, and the current generation must bear in mind the needs and the safety of future generations. The key issues to be considered include: demonstrating the safety of deep geological disposal for long-lived radioactive waste, and gaining public acceptance of and commitment to it; the safety and sustainability of long-term surface storage; the safety implications of providing retrievable underground storage pending disposal; and the merits of international or regional disposal facilities to help small countries and limit the number of disposal sites.

Repository siting has local, national and international dimensions. Explanations of disposal needs, as well as related criteria and process needs, should be provided at both the local and the national level. Increasing public confidence at the local level is an important step in any disposal siting process.

A key issue in the licensing of repositories is the standard of proof expected of safety cases, i.e. what constitutes "reasonable assurance" that the repository will meet safety criteria in the long term. At present there appears to be no substitute for the exercising of judgement.

The Conference recognized that a good deal of work has been done on research and development, including geological laboratories, and there is sufficient technical knowledge to enable this generation to safely manage and dispose of radioactive waste; however little progress has been made internationally in the actual provision of geological disposal facilities. Those instances where there have been advances have shown the advantages of public participation throughout the decision-making process. The benefit of communication and public involvement is now fully recognized.

There is still a need for an international consensus on standards and criteria for the safety of geological disposal. This will have to be developed in parallel with consultative processes.

■ Perpetual Storage. The Conference emphasized that the perpetual storage of radioactive waste is not a sustainable practice and offers no solution for the future; rather, it is an interim phase in the integrated management of radioactive waste. Although the monitored, retrievable and passively safe storage of waste may be achievable for decades, progress must be made towards developing disposal.

Storage must not be used as an open-ended "wait and see" option; there will always be future developments that can be awaited, and the incentive and determination to proceed to disposal could be lost, which without effective control could lead to degraded safety performance and environmental damage. Participants further noted that long-term storage is not a simple or a cheap process, and will require institutional control by a body with the necessary knowledge, expertise and financial resources. Investigations have indicated that storage can be continued safely for many decades, provided that control is maintained. However, even if technological advances were to make safe storage feasible for long terms, the issues concerning the maintenance of institutional control could be a limiting factor.

■ Retrievability of Disposed Waste. The Conference considered with some detail the controversial issue of retrievability of disposed radioactive waste. Some degree of explicit provision for waste retrievability in the design and implementation of geological repositories is now widely recognized as an important way to build public confidence in the ability to engineer the safekeeping of radioactive waste, and to avoid foreclosing options for future generations.

However, this must be achieved without compromising the long-term safety of the repository, and it should not remove the requirement for assessing the long-term safety and suitability of the repository before waste emplacement starts. It is important to recognize that for as long as retrievability is maintained, institutional control will be necessary to protect the public and the environment. Such controls should provide for the necessary nuclear safeguards for repositories containing spent fuel or other fissile materials.

■ International Repositories. International repositories could ultimately offer the possibility of geological disposal to countries that do not have suitable geological formations on their own territory. They could also offer countries with small amounts of waste the opportunity to pool economic and technical resources rather than each undertaking its own repository programme, and this co-operation could contribute towards a more broadly based consensus on waste safety issues.

However, the Conference concluded that there seems to be little prospect of such projects achieving public acceptance until some national geological repositories have been demonstrated successfully. Furthermore, it might be counter-productive to pursue this concept at this time as it could undermine national repository programmes.

■ Safe Management of Radiation Sources. The Conference recommended that the safe disposal of disused radiation sources is basically a national responsibility. If such sources are stored for long periods of time, this will increase the probability of control somehow being lost. The purchasing price of sources should perhaps include some provision for the eventual cost of disposal.

For countries that have no disposal facilities, safe disposal will most commonly mean transferring the sources to another country -- normally the country of the supplier -- that has the infrastructure to dispose of them safely. A possible alternative would be to develop inexpensive methods for the safe disposal of sources. An alternative under development is the so-called "borehole concept".

As regards the possibility of returning sources to suppliers, the Conference stressed that in many cases the supplier is not the same entity as the original manufacturer. Some suppliers are prevented by the legal system in their country from -- or have shown reluctance to commit themselves to -- accepting returned sources. This problem might be eased if attention were focused on those sources that represent the highest risk, i.e. by categorizing sources, and seeking commitments at least to accept the return of these types of source. When suppliers go out of business, States need to provide a "backstop" to make sure that sources are not allowed to fall out of control as a result.

The Conference expressed its support for the Agency's *Action Plan for the Safety of Radiation Sources and the Security of Radioactive Material* and its interest in the ongoing development of an international *Code of Conduct* in this area.

Transboundary Movement of Radioactive Waste. The Conference discussed the transboundary movement of radioactive waste; i.e., waste moved from one jurisdiction, namely that of the country of origin, to another jurisdiction, namely that of the country of destination. Such movement is often via one or more other jurisdictions -- that or those of the country or countries of transit, or the high seas. By necessity, therefore, different legal regimes apply at different stages of the movement of such material. This in turn requires far-reaching international harmonization in this field.

In the nuclear field such harmonization is comparatively far advanced, as demonstrated by international consensus documents such as the IAEA *Regulations for the Safe Transport of Radioactive Material*. Responsibility for the observance of these international standards for the maritime transport of radioactive material lies with the Flag State -- although the International Maritime Organization (IMO) is expected to shortly make the observance of such standards mandatory.

The Conference noted that there is no general requirement under international law for approval by coastal States of shipments of radioactive waste through their territorial waters, provided that the necessary safety precautions are taken. At present, liability is to a large extent governed by private international law, with all the uncertainties arising therefrom for potential victims. Given the role those uncertainties play in promoting opposition to the international transport of radioactive waste, wider adherence to the international nuclear liability regime would assist in gaining greater acceptance of such transport. The international transport of radioactive material has an excellent safety record; however, there is a very wide gap between public perception and reality in this regard. A constructive and open dialogue with stakeholders is needed to explain the, albeit sometimes complicated, regime for the international transport of radioactive material, including waste, and the safety record.

International Regime for the Safety of Radioactive Waste Management. A major outcome of the Conference was its support for the IAEA international regime for the safety of radioactive waste management *(see box, page 18)* namely: (i) the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, as an incentive legal instrument presupposing a high level of commitment by Contracting Parties to the safe management of radioactive waste; (ii) the international safety standards already in place; and (iii) the international mechanisms for providing for application of these international safety standards.

The Joint Convention imposes binding national commitments -- backed by international peer review -- to pursue internationally agreed safety objectives, and thus provides a mechanism to build confidence in national programmes.

The Conference noted that there is now a well-established and understood basis for developing national legislative and regulatory frameworks for the safe management of radioactive wastes. Economic globalization has increased the potential benefits of internationally harmonized safety standards. Yet the prospects for the adoption of such standards are limited, because some countries consider that to adopt them could detract from their national sovereignty. This perceived conflict between international harmonization and national sovereignty is a political question beyond the remit of the technical community.

OUTLOOK: UNTYING THE KNOT

The future of radioactive waste disposal, and consequently of nuclear energy, are major issues on the international agenda. The IAEA can serve as a catalyst in the pursuit of a consensus that has long eluded the world community.

In his keynote speech at the Córdoba Conference, the US Resident Representative to the IAEA, Ambassador John B. Ritch III, indicated that in the realm of nuclear energy, our need is for a broad discussion -- in two senses. We must have a broad range of participants that includes governments, operators,

INTERNATIONAL REGIME FOR THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

An *international regime for the safety of radioactive waste management* is being fostered under the aegis of the IAEA. The regime encompasses three key elements: *committing to legally binding international conventions among States; establishing globally agreed international waste safety standards; and providing for the application of those standards.*

■ Committing to Legally Binding International Safety Conventions. In recent years, commitments by States have come to play a crucial role in improving nuclear, radiation, and waste safety. The IAEA assists the process by facilitating such agreements and fulfilling a range of functions to the Contracting Parties once the agreements are in force. These functions include acting as Secretariat to the Parties and rendering services to them upon request; regarding waste safety, one such agreement is the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, which States adopted in 1997.

■ Establishing International Waste Safety Standards. The IAEA, in serving the needs of its Member States, has developed and issued more than 200 standards of radiation and nuclear safety, including standards on the safety of radioactive waste management. The first safety standards specific to radioactive waste were issued within a few years of the IAEA's creation. By the 1980s, the IAEA had created a high-profile ad hoc corpus of standards called the "Radioactive Waste Safety Standards" (RADWASS). A main document of this series, *The Principles of Radioactive Waste Management*, was issued in 1995, and formed the technical basis for the Joint Convention. *(See article, page 24.)*

■ Providing for the Application of Safety Standards. The IAEA's strategy to provide for the application of the RADWASS standards is focused on five main areas of activity:

- to foster the systematic exchange of waste safety-related information,
- to promote education and training in waste safety,
- to support and coordinate waste safety-related research and development,
- to provide cooperation and assistance programmes for the application of waste safety standards, and
- to render relevant services to Member States as requested.

This international regime is available to the international community for use as a tool for achieving the safe management of radioactive waste and for facilitating the solution of related problems.

industry, regulators, non-governmental organizations, respected experts, and citizen groups -- indeed any and all vessels or shapers of public opinion. We also need a broad range of subject matter, so that public dialogue is expanded beyond the narrowly contentious issue of where and how waste will be deposited. Our debate must be holistic, including a full and realistic discussion of energy alternatives -- aimed *inter alia* at identifying a reasonable and accepted role for nuclear power and its byproducts.

He used an appropriate analogy to describe the state of affairs, recalling that, in Greek mythology, an oracle stated that he who could untie the impossibly tangled Gordian knot would rule all Asia. According to legend, Alexander the Great simply cut the knot with his sword and achieved the glory that had been foretold. The metaphor of slicing through problems with quick and deft solutions is an apt one. Today, as we face the challenge of achieving consensus from the controversial debate over radioactive waste management and peaceful nuclear development, no such facile answer is at hand.

As Ambassador Ritch concluded, if we are to take control of our destiny, and guide ourselves rationally in meeting the urgent imperative of producing more and cleaner energy, we will not do so by slicing through the current impasse. Obstacles cannot be overrun or ignored. We must untie the Gordian knot, carefully and painstakingly, using all of our resources and democratic institutions wisely and well.

The IAEA can provide a much-need *forum of stakeholders* for advancing a consensus involving all interested parties -- one that may lead to the achievement of acceptable solutions for all types of radioactive wastes and that will stand the test of time. ❒

-- In September 2000 at the IAEA General Conference, a Scientific Forum on radioactive waste management issues brings together experts and policymakers from organizations and the Agency's 130 Member States.