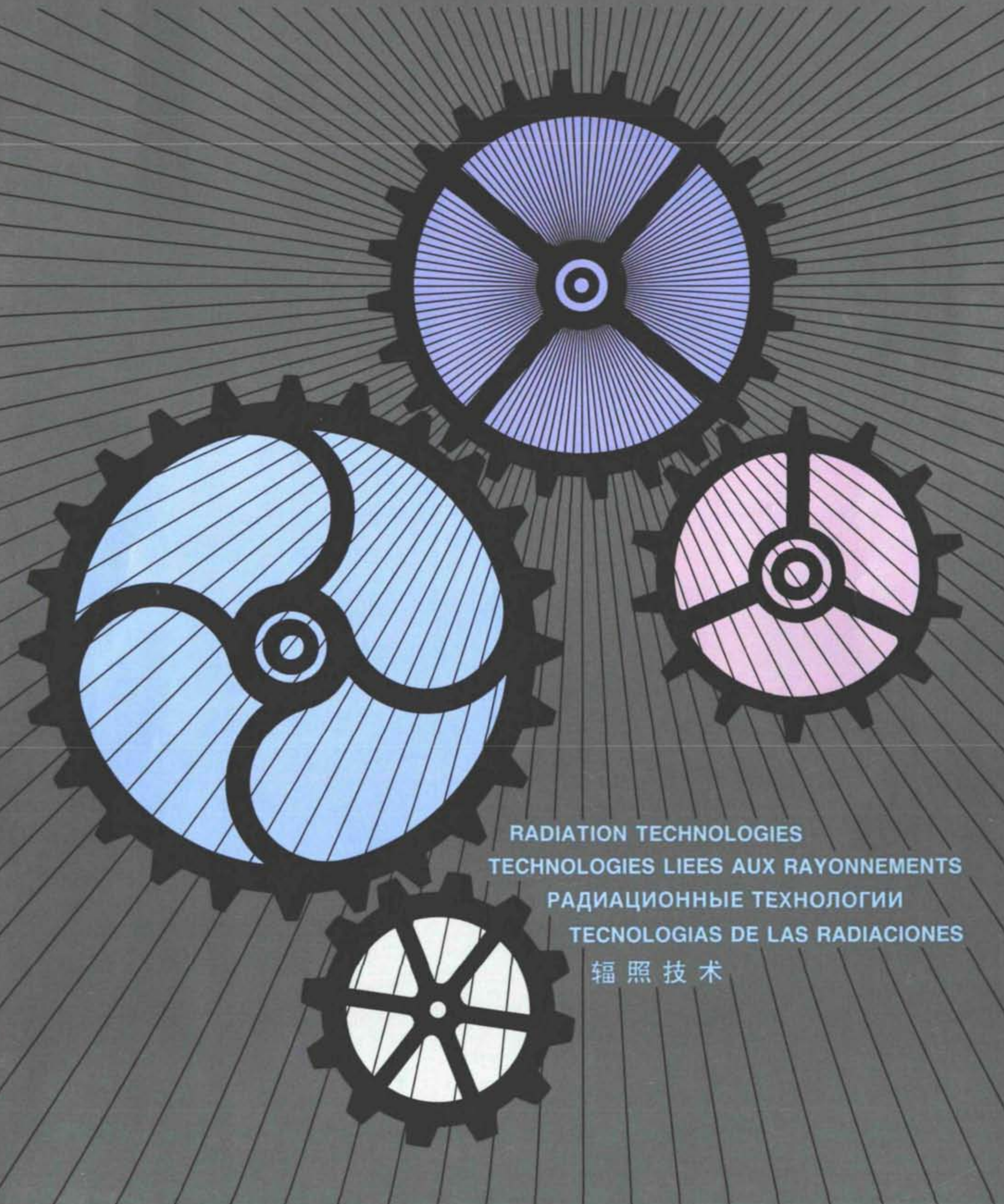
IAEA BULLETIN

VOL.36, NO.1
1994
VIENNA, AUSTRIA

QUARTERLY JOURNAL OF THE INTERNATIONAL ATOMIC ENERGY AGENCY



RADIATION TECHNOLOGIES
TECHNOLOGIES LIEES AUX RAYONNEMENTS
РАДИАЦИОННЫЕ ТЕХНОЛОГИИ
TECNOLOGIAS DE LAS RADIACIONES
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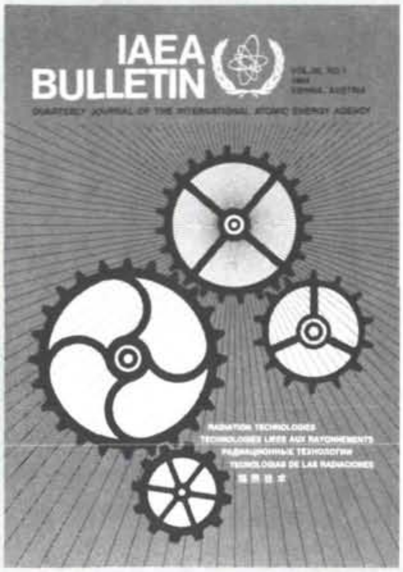


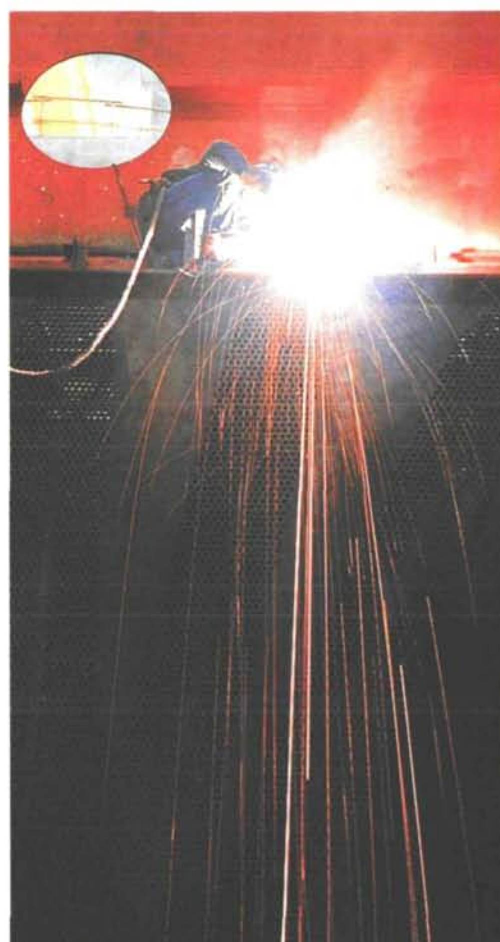
Front cover: Radiation at work — for industrial safety and efficiency, health care, environmental protection, and a range of other beneficial applications — is an unfamiliar phrase for many people. Yet nuclear and radiation technologies are helping to improve the way we live and work, the products we use, and the environment we share. This edition features some of the everyday industrial applications of these modern and innovative tools. *(Cover design: Ms. Hannelore Wilczek, IAEA)*

Facing page: A stroll in the "Wienerwald", the forest in the hills of Vienna, Austria. In some countries, radiation technologies are being applied to analyze and control emissions of toxic pollutants that are linked to tree-threatening "acid rain". *(Credit: Katholitzky for IAEA)*

CONTENTS

ISSN 0020-6067

RADIATION AT WORK: In many ways, radiation technologies offer practical benefits to industries. Their use, for example, is helping (clockwise from top left) to determine the ash and mineral content of coal; sterilize medical products for hygienic safety; analyze the quality of welding processes; ensure the safety of pipelines; and preserve foods. *Facing page:* In the energy industry, various radiation technologies are used for assessing potential oil and gas reserves. *(Credits: AECL; Ontario Hydro; Sodel Photothèque EdF; ANSTO; CEA)*



Nuclear and radiation applications in industry: Tools for innovation

An overview of how radiation technologies can be put to work

by S. Machi and R. Iyer

Applications of nuclear and radiation technologies have been contributing to industrial efficiency, energy conservation, and environmental protection for many years.

Among the practical industrial uses:

Manufacturing industries: Radiation processing technologies are playing increasing roles during manufacturing of such everyday products as wire and cable, automobile tires, plastic films and sheets, and surface materials.

Production processes: Other techniques employing radioisotope gauges are indispensable for on-line thickness measurements during paper, plastic, and steel plate production. Processing and quality checks are made using nucleonic control systems that are common features of industrial production lines.

Industrial safety and product quality: Nondestructive examination or testing using gamma- or X-ray radiography is widely used for checking welds, casting, machinery, and ceramics to ensure quality and safety. Additionally, radiotracer techniques are unique tools for the optimization of chemical processes in reactors, leakage detection, and wear and corrosion studies, for example.

Environmental protection: An innovative technology using electron beams to simultaneously remove sulfur dioxide (SO_2) and nitrogen oxides (NO_X) has been under development in Germany, Japan, Poland, and the United States. Acid rain due to SO_2 and NO_X still continues to deteriorate forests, lakes, and soils. The electron beam technology is very cost competitive and its byproduct can be used as agricultural fertilizer.

This article presents an overview of the recent status and future prospects for industrial applications of commercial nuclear technologies. The IAEA, through its various co-operative progammes, is actively engaged in transferring these technologies to developing countries interested in their use.

Radiation processing

Radiation processing is a widely used technology on industrial production lines. Compared to more conventional processing methods, it has a number of advantageous characteristics. They are related to its energy efficiency; ease of control; and flexible capabilities for applications involving various types of materials.

Industrial applications of radiation processing are widespread in many countries, and growing in others. In Japan, for example, 280 electron beam accelerators were being used for industrial

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purposes and for research and development as of early 1994. In developing countries, radiation technologies are being increasingly applied, frequently with support from the IAEA for the development of required human resources and acquisition of equipment. Some areas of key interest are:

Polymeric products. Commercial production of cross-linked polyethylene for insulation of wire and cable was first achieved by using radiation processing in the United States in the 1950s. Since then, research and development activities have brought successful industrial applications. Examples of specific materials produced using radiation processes include cross-linked wire and cable (heat resistant); foamed polyethylene; heat shrinkable tubing and sheets; cured surface coatings for wood panels, paper, roof tiles, steel plates, gypsum tiles, and floppy disks; adhesive tapes; wood-plastic composites (abrasion-resistant, water resistant); polymer flocculants (high molecular weight); automobile tires (cross-linking); Teflon powder (by decomposition of used Teflon); contact lenses; water absorbents (for disposable diapers, etc.); deodorant fiber; cross-linked polyurethane (cable for anti-lock brake sensor); cross-linked nylon; and battery separators.

These products have unique properties. In many cases, radiation processing provides distinct advantages over conventional processes in terms of product properties, economies of production, wide range of processing temperatures, and environmental protection.

In a number of developing countries, such as China and the Republic of Korea, radiation cross-linking of insulation wire and cable has been used on a commercial scale for several years.

Research and development now is being carried out on the preparation of advanced materials, such as new drug delivery systems, biocompatible materials, and silicone carbide (SiC) fibers that are highly resistant to temperatures.

A new super high-temperature resistant SiC fiber has been developed at the Japan Atomic Energy Research Institute (JAERI). The fiber was prepared from radiation cross-linked polycarbosilane (PCS) fiber followed by heat treatment at 1200°C. It has shown much better heat resistance than SiC fiber prepared from chemically cross-linked PCS (the conventional method). *(See graph.)*

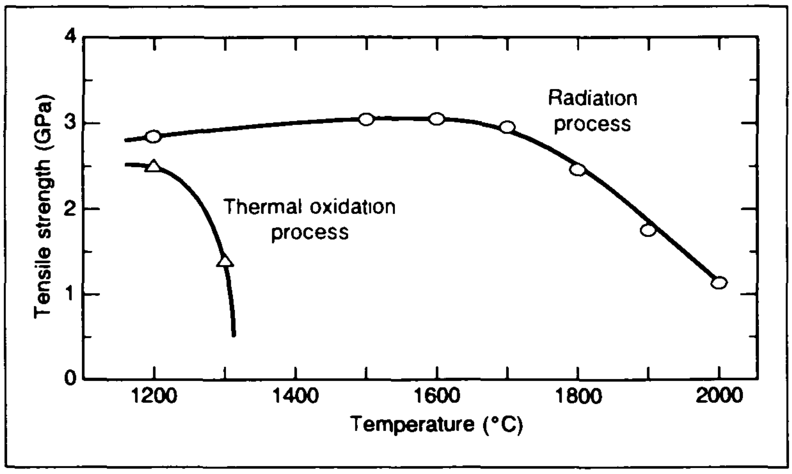
The dose requirement for cross-linking is 10 MGy by an electron beam accelerator. JAERI operates a pilot plant by which 4.5 kg of PCS is irradiated per batch in a vacuum. The project was initiated to develop the technology and to construct a commercial plant to produce one ton of SiC fiber per month. This level of production is planned for 1996.

Radiation applications for curing surface coatings are expanding, both in terms of the amount of products being processed and the development of new products. The expansion is tied to the technology's advantages in areas of product quality, energy efficiency, and environmental protection. In conventional thermal curing of coatings, organic solvents are evaporated to produce polymer films on substrate. The evaporated solvents (hydrocarbons) are emitted into the atmosphere as greenhouse gases and they form oxidants. World consumption of conventional coatings is approximately 20 million tons per year. As a consequence, 8 million tons of organic solvents (40% of the total consumption of surface coatings) are emitted into the environment each year. Curable coatings produced by electron beams and ultraviolet light do not contain solvents, and their use thus avoids such emissions. However, these radiation-curable coatings still constitute only 1% of all coatings used. In the interest of environmental protection, use of this new coating is expected to grow rapidly.

Sterilization of medical products. In industrialized countries, between 40% to 50% of medical products are sterilized by radiation processing. The percentage is expected to reach approximately 80% in years ahead. The process employs either electron beam accelerators or cobalt-60. Radiation processing has proved to be better than the conventional ethylene oxide process with regard to safety for workers and consumers, reliability of disinfection, and simplicity of processing.

This application is projected to grow rapidly in developing countries. The IAEA and United Nations Development Programme (UNDP) have implemented projects for radiation sterilization

Comparison of heat resistance for SiC fiber produced by thermal and radiation processes



plants in India, Republic of Korea, Chile, Hungary, Iran, Turkey, Peru, Bulgaria, Portugal, Syria, Ecuador, and Ghana.

Also gaining wider acceptance is the radiation sterilization of cosmetic products and raw materials for pharmaceuticals.

Cleaning of flue gases. Acid rain due to SO_2 and NO_X in flue gases from the burning of fossil fuels is causing serious damage to the environment. Innovative technology using electron beams to simultaneously remove these pollutants by irradiation was first developed in Japan and followed by research groups in the United States, Germany, Italy, and China. A pilot-scale plant is currently in operation in Warsaw as a joint project of the IAEA and Poland. The pilot plant has the capacity to clean 20 000 m^3 of coal-burning flue gases from the local heating plant.

Recently, the plant's continuous operation for more than one month successfully removed 90% of the SO_2 and 85% of the NO_x from flue gases. As an IAEA model project, an industrial-scale electron beam plant for treating emissions from Poland's coal-burning power stations is planned.

In Japan three pilot-scale electron beam plants for treating flue gases from coal-burning power stations, municipal waste incinerators, and traffic tunnels, respectively, are operating smoothly.

Disinfection of sewage sludge and its recycling. Disinfection of sewage sludge by radiation has been studied at pilot- and full-scale plants. In Germany and India, full-scale plants are in successful operation. Irradiated sludge is used on farm land as an organic fertilizer. In Japan, the technology of sludge irradiation followed by composting has been developed to produce disinfected compost for agriculture. The IAEA plans to start a new programme to enhance the transfer of this technology to end users.

Cleaning of water. Removal of organic pollutants by radiation in waste water and in natural drinking water also is being studied. A pilot-scale plant is operating in Austria for the treatment of drinking water using electron beams and ozone. In Miami, Florida, an engineering study has been carried out to evaluate the efficiency and cost-effectiveness of electron beam treatment for removing toxic pollutants in water streams, such as groundwater, secondary effluents, and potable water.

Radiotracers. A tracer is a substance intentionally added to a system to study its dynamic behaviour. Radioactive tracers — which have excellent detection sensitivity and are convenient to measure — are widely used. They render possible the observation of chemical reactions and physical processes even in closed systems, at high temperatures and high pressures, and in real time by non-invasive measurement techniques. Applications include leak detection and blockage location in buried pipelines and other industrial systems (e.g. in the petroleum and petrochemical industry); mixing/blending studies in the metallurgical and chemical industries (e.g. alloy manufacturing); wear rate measurement and wear monitoring of rotating machines, (e.g. machine tools and pistons of internal combustion engines); studies of residence time distribution in process vessels (e.g. petrochemical plants); optimization of process parameters; and investigation of the dispersion of pollutants in the environment.

These applications are now well established and are extensively practiced in industries all over the world. The real benefits from these applications are indirect in that in their absence, the manufacturing cost and lack of optimization of process parameters would have made the industry inefficient, wasteful, and therefore non-competitive.

Nucleonic control systems. The application of on-line analysis in the mining, mineral processing, metallurgical, and energy industries has opened up new possibilities for the improved control of processes, and thus the reduction of costs and wastes. On-line analysis systems based on nuclear radiation — grouped together under the generic heading of nucleonic control systems (NCS) — have emerged as critical tools in this technological advance. Having the twin advantage of non-destructive measurement and operation even in hostile conditions of high temperatures and high pressures (unlike conventional methods), NCS provide continuous information on parameters to control production quality in an industrial plant.

From nuclear borehole logging to assess the quality and complexity of ores in mine shafts, to assessing mineral compositions and their subsequent processing, nucleonic gauges have become essential tools in the mineral and metal industries. On-stream rapid analysis of varying compositions in real time leads to improved control of mining, processing, and blending operations with increased recovery of valuable minerals. A number of techniques — such as neutron-induced prompt gamma, neutron thermalization, gamma absorption, and isotope-induced X-ray fluorescence (XRF) — have in recent years revolutionized plant operation and efficiency.

The coal industry was one of first major beneficiaries of NCS utilization. A continuous assessment of the ash (mineral) content of coal is a very important parameter for the supplier and the consumer. Since the predominant use of coal is in power generation, the information is important from the point of view of boiler efficiency, boiler lifetime, and atmospheric pollution. Detailed information on total ash contents, its elemental composition, and moisture content are continuously needed on line, and modern NCS provide the required degree of accuracy of information and reliability. Typically using a californium-252 neutron source and gamma detectors, gamma rays from the coal are spectroscopically analyzed in real time to arrive at the elemental composition. The critical elements for boiler efficiency control are aluminum, silicon, calcium, iron, sulfur, chlorine, nitrogen, potassium, and titanium.

Since the core industrial sector in all countries is the base metal manufacturing and mineral processing industry, the impact of increased use of this advanced technological application has become quite apparent. For example, in Australia alone the number of nucleonic gauges in 1961 was about 125 whereas in 1990 it was over 12 000. These include density gauges, thickness gauges, belt weighers, moisture gauges, borehole probes, coal ash monitors, bulk and on-stream analyzers, and industrial radiography units. This phenomenal growth in the number of these gauges in Australian industries is clear proof of the technical and economic benefits derived from their use. In Australia, productivity increases arising from the use of nucleonic gauges are estimated to be more than US $50 million per year.

Although the basic technology of NCS is well known, new and innovative applications are reported in the technical literature every year. Among these are coal ash estimation using the natural radioactivity of the ash; concentration of acids in chemical plants; ultra-purification of metals for the semi-conductor industry; and bulk and on-line analysis of raw feed limestone for the cement industry. Thousands of portable XRF analyzers are currently used by mineral and metal industries for identifying incoming metals and scraps; verifying alloys on site; controlling quality; analyzing melting and welding processes; identifying hazardous waste; and analyzing contaminated soil and groundwater on site.

Nuclear borehole logging and activation analysis. The use of nuclear borehole logging in the petroleum industry is well known. Its importance lies in measuring potential oil-bearing horizons; assessing petroleum and gas reserves and their exploitation; and analyzing established oil fields to optimize oil recovery methodology. For example, gamma-ray scattering from the borehole walls provides information on the density and average atomic number of rock formations below the surface. Neutron scattering measurements reveal the average size of pores of rock formations surrounding the borehole — the larger the pores the greater the capacity of the rocks to hold hydrocarbons. The study of interactions of gamma rays and neutrons with oil-bearing rock and mineral formations remains a major area of research. Combined with other geophysical and geochemical logging information and modelling studies, the research provides the quantitative relationship between the oil-bearing rock properties and the detected signals. These data eventually lead to complete information on the subsurface environment, even at depths of several kilometers.

Another technically well-known method — airborne gamma ray spectroscopy — has been utilized extensively for discovering uranium mineralizations. It also has been used for identifying other important minerals, since uranium mineralization is associated with pathfinder elements such as gold, silver, beryllium, bismuth, cobalt, nickel, copper, mercury, molybdenum, niobium, lead, tin, zinc, zirconium, and titanium, among other elements. The technique of instrumental neutron activation analysis (NAA) has been an important tool for geochemical and geological mapping of mineral bearing horizons. The method is inherently insensitive to contamination and matrix effects and does not need extensive sample preparation stages. It chiefly provides data on the concentration of more than 40 elements in the periodic table. Even though the limited access to a nuclear reactor for irradiation of samples has inhibited the widespread use of NAA in many countries, it is still the preferred method for gold and platinum prospecting.

Tools for innovation

In many ways, nuclear and radiation technologies have become valuable tools for innovation. For many countries, the transfer of these technologies through IAEA co-operative research and technical assistance programmes has been, and continues to be, of prime importance to their economic development.

Experience has shown that the optimum and appropriate application of nuclear and radiation technologies holds a considerable number of practical benefits. Their use can help propel industries which adopt them to the forefront of industrial productivity for now and well into the future. ❒

Electron beam processing of flue gases: Clearing the air

Stricter environmental standards are demanding a system that simultaneously removes SO_2 and NO_x from the burning of fuels

by Norman W Frank and Vitomir Markovic

Much has happened over the past 5 years to establish the economic and environmental credentials of what could be a timely radiation technology — electron beam processing for the removal of pollutants from combustion flue gases.

- Studies have indicated that the airborne transport of pollutants such as sulfur dioxide (SO_2) and nitrogen oxide (NO_x) are more widespread than previously thought.
- NO_x emissions are considered to be an equal cause of acid rain when compared to SO_2, a fact which is leading to the development of systems that simultaneously remove both gases.
- Many countries have passed more stringent air quality regulations which will require higher removal efficiencies.
- The use of byproducts from removal systems will be more important in the future to eliminate another waste problem which occurs from the sludges produced in many systems.
- The electron beam process has had extensive testing over the past 3 years, and many improvements have been made in its reliability and energy requirements.

It is easy to see why many countries are beginning to consider more stringent regulations to remove SO_2 and NO_x at the source of emissions — they recognize the transport and conversion that can take place in the atmosphere. *(See figure, next page.)* Emissions from combustion gases from a boiler can be carried many kilometers. Along the way, they undergo numerous conversions, as the SO_2 aerosols change into sulfuric acid and the NO_x aerosol into nitric acid. This then creates a wet disposal of sulfuric and nitric acids in rain, sleet, and snow. Currently, dry depositions of the original pollutants travel great distances from the source.

More stringent environmental regulations have been put into effect throughout Europe, Japan, the United States, Asia, and several Latin American countries. It is anticipated that increasingly stricter regulations will appear in the future, in light of continuing concerns over both sulfur and nitrogen pollutants.

It is further anticipated that meeting requirements for "ozone non-attainment" will require more stringent NO_x standards. This is already being seen in some of the coming regulations. It is foreseen that extremely efficient simultaneous SO_2 and NOx removal systems will be needed.

At the present time, the conventional technologies to reduce SO_2 and NO_x emissions are basically used for low-sulfur coals that are burned in Japan and Europe. These systems are referred to as wet flue gas desulfurization (FGD) and selective catalytic reduction (SCR). SCR is the most popular NO_x removal system, even though it has not been proven for use with high-

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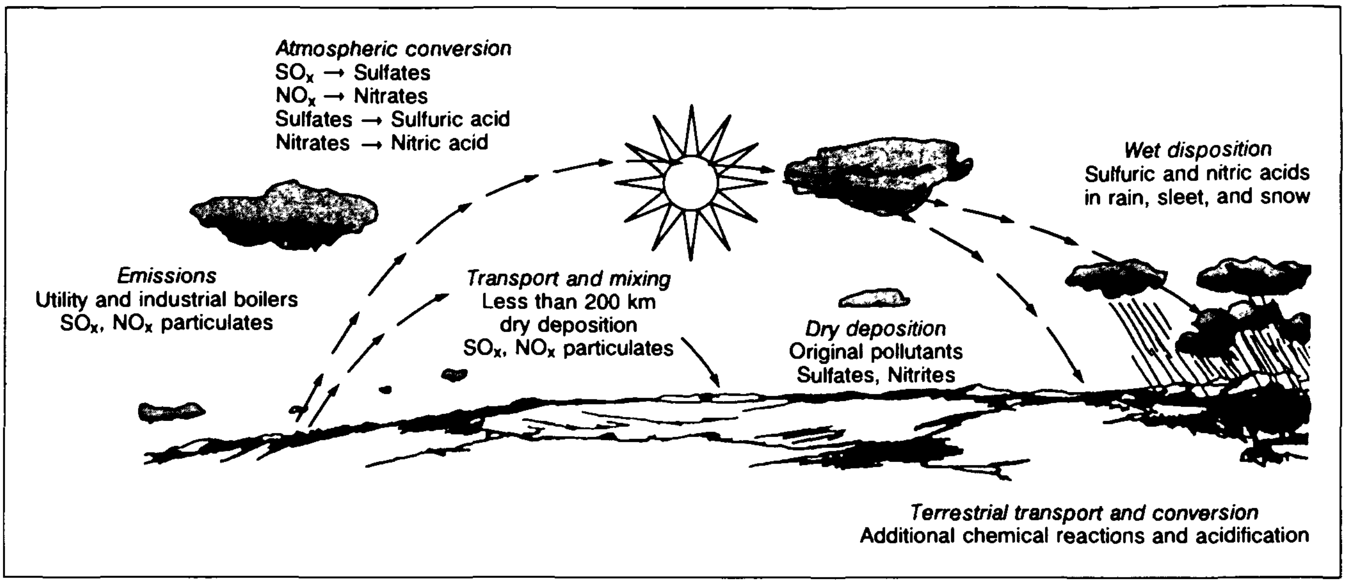


Atmospheric transport processes

sulfur coal. FGD and SCR are systems which require two different technologies integrated into a pollution control process for the boiler.

Therefore, it is important that systems utilizing a singular technology be developed to meet the future requirements for the *simultaneous* removal of both SO_2 and NO_x from both low- and high-sulfur coal and oil.

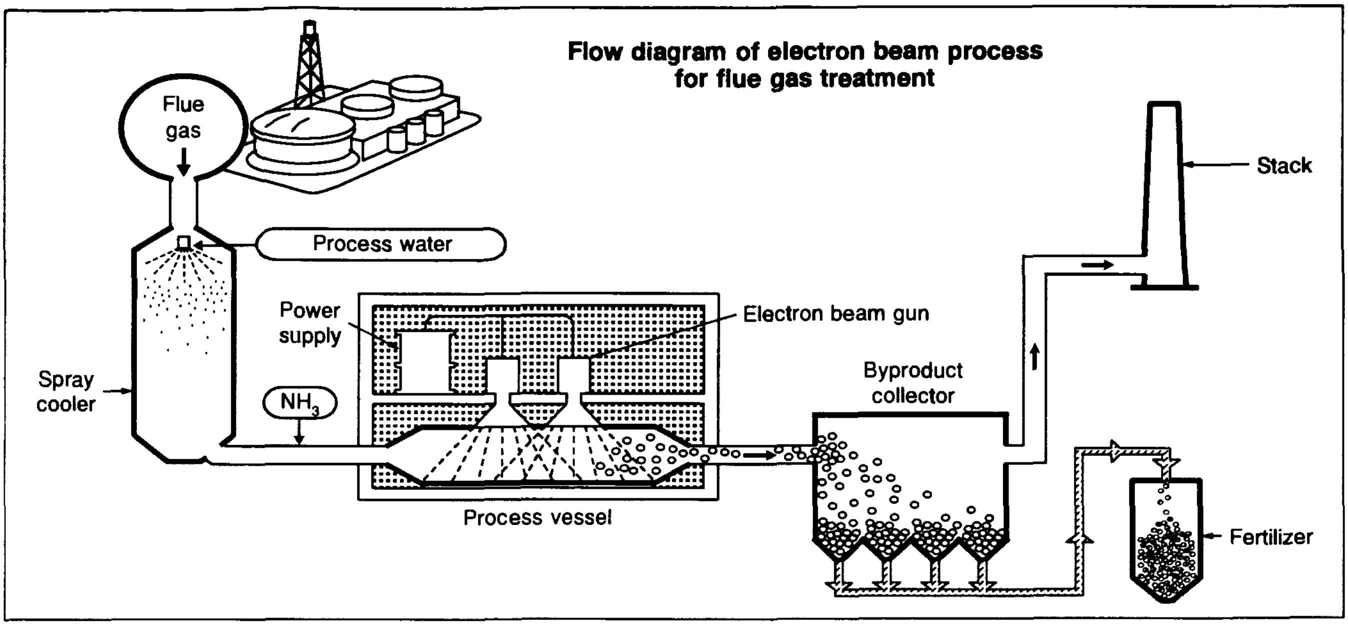
The electron beam process fits very well into this category since it is a system which utilizes the same basic technology to simultaneously remove both pollutants. *(See diagram.)* Japanese, German, United States, and Polish demonstration plants have shown that the system's total efficiency for SO_2 removal normally exceeds 95% and reaches 80% to 85% for NO_x removal. That level of efficiency meets the most stringent regulatory requirements.

NO_x removal requires more energy than SO_2 removal, which is why numerous studies have been done on the technique known as zone irradiation to lower the energy requirements for NO_x removal. Tests have been and are currently being conducted to minimize the energy input for NO_x removal. By utilizing zone irradiation, the results have shown that energy savings of 20% to 30% can be realized, which would bring the system into a very competitive range with other combined technologies. Work will continue on reducing the system's energy requirements.

Existing electron beam test facilities and demonstration plants have been built in a number of countries, and four test facilities remain in operation. They are being operated by the Japanese Atomic Energy Research Institute (JAERI) in Takasaki, Japan; the Institute of Chemistry and Nuclear Technology in Warsaw; KFK in Karlsruhe, Germany; and Ebara in Fujisawa, Japan. These test facilities are conducting programmes to improve the process and reduce energy requirements.

Many noteworthy accomplishments have been made in the past few years at the various research facilities and pilot plants:

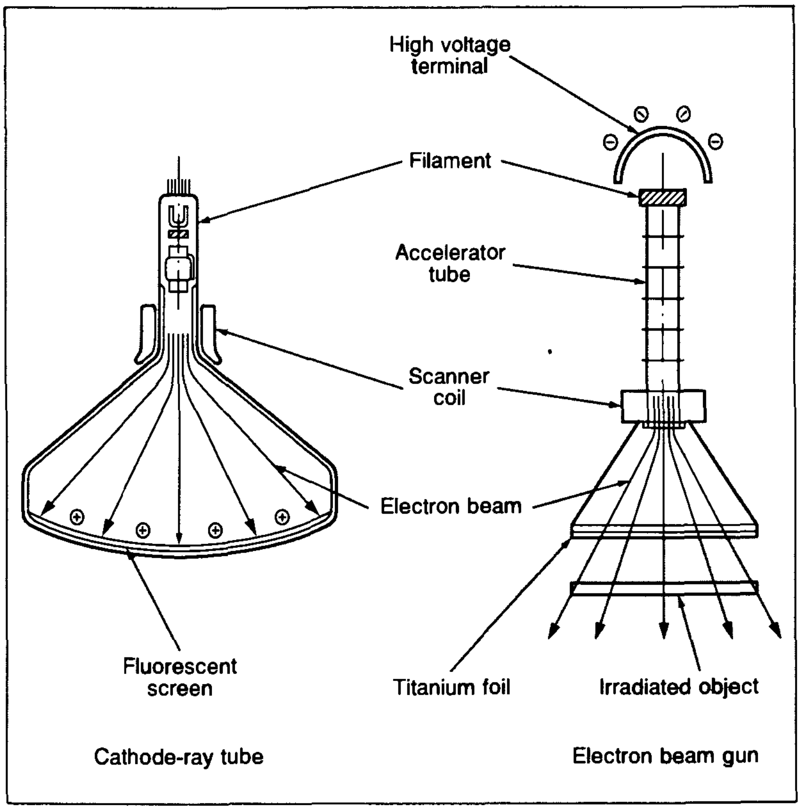
- The mass balances of both nitrogen and sulfur have been confirmed with the finding that about 22% of the nitrogen is released as N_2O.
- Duct configurations have been studied and tested so that different ones are available to suit the conditions.
- Zone irradiation has been tested and confirmed as a significant reducer of energy requirements.
- Different methods for avoiding the buildup of byproducts and duct clogging were analyzed and tested which will allow long-term operation of the process.
- Low NO_x concentrations in gases have been tested with good results.
- Testing is continuing on the removal of volatile organic compounds.
- Testing is continuing on incinerator gases; this is providing valuable information concerning the removal of other pollutants, such as hydrogen chloride (HCL).
- A recent report by the Electric Power Research Institute (EPRI) in the United States has shown that the electron beam process is being considered as one of the future simultaneous removal systems for SO_2 and NO_x.
- Existing electron beam accelerators have progressed to larger sizes (300-400 kilowatts) with good reliability for immediate use.
- The United States Defense Nuclear Agency is developing an accelerator in the size range of



The EB process: No NO_x or SO_2

The electron beam process, which is essentially a dry scrubbing process, removes two pollutants — SO_2 and NO_x — from combustion flue gases at the same time. Before entering the spray cooler, the flue gas is cleaned of fly ash by a standard technique. The gas then passes through the spray cooler where the gas temperature is lowered and the humidity is increased by the process water. The gas then passes through the process vessel where it is irradiated by beams of high-energy electrons in the presence of a near stoichiometric amount of ammonia which has been added to the flue gas prior to the irradiation zone. The SO_2 and NO_x are converted into their respective acids, and these acids are subsequently converted into ammonium sulfate and ammonium sulfate-nitrate. These are then recovered by an electrostatic precipitator. The byproduct is a useful fertilizer and can be used for agricultural purposes. The clean gases are then released to the atmosphere.

At right: The accelerator which creates the electron beam is a very well known piece of equipment to many people. One model of it, for example, is used throughout the world — a television set. An accelerator is only a more powerful cathode ray tube.



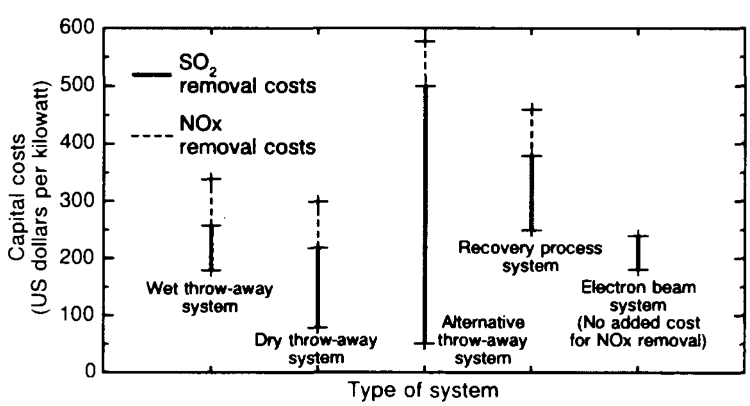
0.8 to 1.8 megawatts for use in air pollution control.

The economics of the process have been studied for various kinds of fuels which have different SO_2 and NO_x concentrations. It looks promising that the system will be available in the range of US $200 per kilowatt for the installed cost. From the tabulation of costs for existing conventional FGD systems, it can be seen that the electron beam process is competitive with all existing SO_2 removal systems. When factoring in the cost of an SCR removal system for NO_x, which is approximately US $80 per kilowatt, it can be seen that the installed costs for the projected electron beam process make it one of the most economical systems to install and operate in a power station. *(See graph, page 10.)*

More importantly, the system has been proven to be very effective with high-sulfur fuels. Countries that have high-sulfur crude oil,

Electron beam pilot and demonstration facilities for flue gas processing

Institution/Year	Volume flow rate	Accelerator	SO_2/NO_x raw gas concentration (ppm)	Temperature (°C)
JAERI 1981	900 l/h	1.5 MeV 20 MA	1000/5000	80-150
Institute of Nuclear Chemistry & Technology, Warsaw 1989	400 m^3/h Oil-fired	775 KeV 5.4 kW	0-1200 0-400	60-150
Karlsruhe Agate II 1989	1000 m^3/h Crude oil	500 keV 50 kW	400-1000 300-1000	60-120
Ebara Fujisawa 1991	1500 m^3/h Oil-fired and incineration gas	500 keV 15 kW	0-1000 0-200	65
INCT/Kaweczyn power plant 1992	20 000 m^3/h Coal-fired	500-700 keV 2-50 kW	200-600 250	60-120
NKK-JAERI Matsudo City 1992	Incineration gas 1000 m^3/h	900 keV 15 kW	SO_2-100 NO_x-100 HCL-1000	150
Ebara-JAERI Chubu 1992	12 000 m^3/h Coal-fired	800 keV 36 kW x 3 heads (= 108 kW)	800-1000 150-300	65
Ebara-Tokyo-EPA 1992	Auto-tunnel exhaust gas 50 000 m^3/h	500 keV 12.5 KW x 2 heads (= 25 kW)	NO_x 0 - 5	Ambient (20)



Note: Based on 300 megawatt system and 2.5% sulfur fuel.

Comparison of capital costs for flue gas processing

coal, or lignite can effectively use this system when generating electricity and still maintain an export market for the higher quality fuels. This could have a significant impact on both the environmental and economic conditions of several countries. It has already been shown that the higher the SO_2 content, the more economical the electron beam process becomes with respect to removing both the SO_2 and NO_x from the gases that will be emitted to the atmosphere.

Electron beam accelerators have progressed in reliability and efficiency throughout the years and many are currently in use in many other radiation processing applications. The power of today's accelerators for applications can go to 400 kilowatts per machine. It is anticipated that a conventional transformer-type accelerator of approximately 800 kilowatts will be available in the future. At the same time, pulse-type accelerators up to approximately 2 megawatts in size are being developed that could be utilized. The potential advantages of this type of accelerator would be its more compact size and its modular design, factors which would reduce the installation costs and shielding.

Using accelerators for radiation processing technologies such as cleaning up flue gases is reliable and simple. The systems are easy to install, use, and control and they are safe for operating personnel and the environment. There is no radioactivity produced during the operation, and when the system is switched off, there is no residual radiation.

With the growing interest in environmental preservation and remediation, the electron beam process for the treatment of combustion flue gases is creating interest worldwide, since it has numerous advantages over conventional systems and is a futuristic process. Moreover, the pollutants are converted into a useful agricultural fertilizer instead of a waste that requires additional disposal.

The process is ready for use now for removing SO_2 and NO_x from combustion flue gases. It is anticipated that its use will become widespread in years ahead. Current research and development programmes are producing many new improvements and innovations, for flue gas treatment as well as for other environmental applications. ❒

Radiation technologies for waste treatment: A global perspective

Countries are studying irradiation systems for disinfection and decontamination of liquid and solid hazardous wastes

by
J.F. Swinwood, T.D. Waite, P. Kruger, and S.M. Rao

Pollution of water, land, and air is a widespread and growing concern of global proportions. Media reports of diseases and contamination caused by the improper treatment and disposal of waste products occur on a regular basis. This heightened awareness of potential health hazards from insufficient or inappropriate waste handling methods has stimulated the search for effective waste treatment alternatives. In many countries, recycling initiatives are being seen at the individual, community, city, and state levels.

Of particular concern are wastes that present problems in two areas: those containing potentially infectious microorganisms (sewage sludge, biomedical wastes, wastewater) and those contaminated with toxic chemicals. Basic types of irradiation systems which are currently being used in waste treatment operations, or are being studied for this purpose, include gamma, electron-beam, ultraviolet, and X-ray.

Gamma irradiators, typically installed with an energy source of radioactive cobalt-60, have been widely used since the early 1960s in the sterilization of medical products and consumer goods. Their use in the disinfection of sewage sludge has been demonstrated on a full-scale basis at a plant near Munich, Germany; and at a biomedical waste sterilizer in Arkansas, USA, for the treatment of hospital wastes. Their use for degradation of toxics in soils currently is under investigation.

Similarly, electron-beam machines have seen decades of use in industrial processes. This technology has been proven effective in the disinfection of drinking water and wastewater. More recently, it has been used in pilot-scale studies to break down contaminants in soils and industrial waste slurries.

Ultraviolet irradiation systems have regained popularity at wastewater treatment plants as an alternative to chlorine. First used many years ago, these systems have undergone improvements that resulted in more robust equipment and more reliable operation.

Finally, the possible application of X-rays — whose use is well established for medical diagnosis and cancer therapy — for the treatment of wastes has been investigated. However, the technology has not yet been applied for this purpose.

A history of worldwide activities

For irradiation treatment in large-scale applications, several types of radiation sources are generally considered. A review of the state-of-the-art of the technology for irradiation treatment of water, wastewater, and sludge by four types of radiation was published by the American Society of Civil Engineers in 1992.* It summarizes the development status for the four types of radiation technologies investigated: ultraviolet, radioactive isotopes (primarily cobalt-60), linear accelerators or electron-beam machines, and X-ray machines.

Irradiation facilities for treatment of water have been constructed in many countries of the world. *(See table on page 12.)* The first large-scale plant was the Geiselbullach Gamma Sludge Irradiator, constructed in Germany in 1973. Another commercial application, also in

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**Radiation Treatment of Water, Wastewater and Sludge*, Task Committee on Radiation Energy Treatment, American Society of Civil Engineers, New York, (1992).

Irradiation facilities for treatment of water, wastewater, and sludge that have been or are operating

	Irradiator type	Waste type processed	Reason for treatment
Austria	Electron-beam	Drinking water	Reduction of chemical contaminants
	Cobalt-60	Wastewater	Reduction of phenols
Canada	Cobalt-60	Sludge	Disinfection prior to fertilizer use
Czech Republic	Cobalt-60	Drinking water	Disinfection
Germany	Cobalt-60	Sludge	Disinfection prior to land use
	Cobalt-60	Well water	To prevent biological fouling
India	Cobalt-60	Sludge	Disinfection
Japan	Cobalt-60	Sludge	Disinfection prior to composting
	Cobalt-60	Landfill leachate	Destruction of toxics
Norway	Cobalt-60	Sludge	Disinfection
	Electron-beam	Effluent	Disinfection
South Africa	Electron-beam	Sludge	Disinfection
United States	Electron-beam	Wastewater, sludge	Disinfection

Source: Adapted from Radiation Treatment of Water, Wastewater, and Sludge, a report by the American Society of Civil Engineers (1992). This listing includes pilot and full-scale facilities that have operated or are currently operating. More detailed descriptions and references are available in that report.

Germany, is the use of irradiation to reduce biological fouling of drinking water wells. Several electron-beam facilities are in operation to explore the commercial feasibility for water, wastewater, and sludge treatment.

Liquid sludge irradiator system in India

India's Sludge Hygienization Research Irradiator (SHRI) is the second such plant in the world. It was formally commissioned in the city of Baroda in early 1992. SHRI forms part of the programme of the Bhabha Atomic Research Centre, Bombay, in the application of radiation technology for public health and environmental protection. The irradiator was built in co-operation with the Government of the State of Gujarat, the Baroda Municipal Corporation, and the M.S. University of Baroda. The final objective is to treat the entire sludge output of about 110 cubic meters per day from the Gajerawadi Sewage Treatment Plant and use the hygienized sludge as a safe fertilizer.

SHRI has two separate identical irradiation circuits, each comprised of a silo, irradiation chamber, and recycling systems. Presently only one circuit is operated at a time. Each irradiation chamber has a maximum cobalt-60 loading capacity of about 500 kilocuries. At a dose of 4 kilogray (kGy), each irradiation circuit can handle up to about 100 to 120 cubic meters per day of sludge. *(See schematic on page 13.)*

The digested/undigested sludge is first passed into a silo and a measured volume of 3 cubic meters is fed by gravity into the irradiation vessel. The sludge is then circulated by a pump for a predetermined duration to prevent settling and to impart the desired dose. At the end of this operation, the sludge is drained into a storage tank from where it is pumped to drying beds. With the present cobalt-60 loading, a batch operation of two to three hours results in a nearly complete elimination of the microbial load, depending on the initial count. Three batches are disinfected each day.

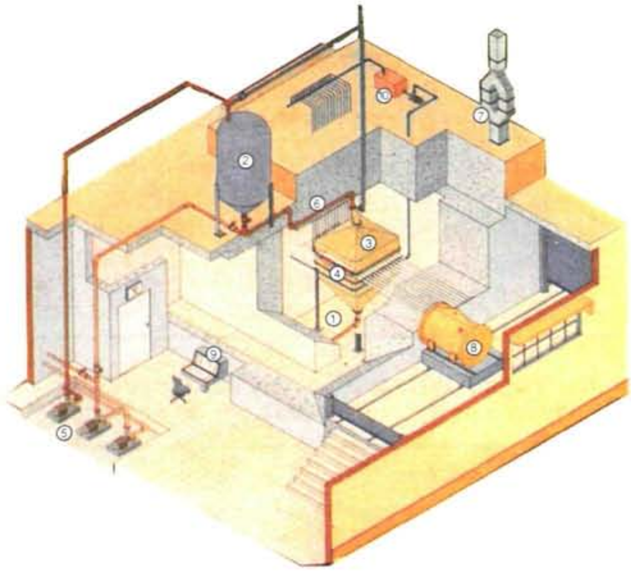
The disinfected and dried sludge has been used as a fertilizer in the SHRI facility's garden. Efforts are being made to supply the treated sludge to farmers in the region.

The facility, though originally designed for sludge hygienization, has been used to assess the technology's suitability for the treatment of effluent from sewage treatment plants. India's Ministry of Environment has expressed interest in radiation technology for large-scale treatment of municipal sewage effluent in cities along the Ganga river in northern India.

Destruction of toxic contaminants: Research in the United States

For the last 6 years, an interdisciplinary team of scientists and engineers has studied the effect of high-energy electron irradiation on the removal (ultimate destruction) of toxic organic chemicals in aqueous solutions and the factors that have been identified as important in efficiently destroying the chemicals. The results of these studies are applicable to waste treatment and the remediation of hazardous waste sites. The studies have been conducted at the Electron Beam Research Facility (EBRF) in Miami, Florida.

EBRF is located at the Miami-Dade Central District Wastewater Treatment Plant on Virginia Key, Miami, Florida. It features a horizontal 1.5 million electron volt (MeV) electron accelerator. The accelerator is an insulated-core transformer (ICT) type, capable of delivering up to 50 mA beam current. Varying the beam current changes the absorbed dose in a linear fashion, allowing for experimentation at doses from 0 to 8 kGy. The electron beam is scanned to 200 Hz to give a coverage of 1.2 meters wide and 5 centimeters high.



Above: India's sludge irradiation research facility in Baroda. As shown in the schematic, the facility includes the irradiation cell (1); storage silo (2); irradiation vessel (3); source assembly (4); pump house (5); recirculation lines (6); obnoxious gas exhaust (7); transport container (8); control console (9); and source coolant system (10).
Below: In Canada, lettuce is being grown in land fertilized with irradiated sludge at the Ontario Agricultural College as part of research activities. *(Credits: Bhabha ARC, India; Prof. Thomas Bates, Land Resource Science Dept., Univ. of Guelph, Canada.)*

Summary of the average dose to remove 99% of trichloroethylene from aqueous solution in the presence and absence of clay

No Clay		3% Clay	
Initial concentration range (micro-M)*	**Average dose (kGy) required to remove 99%**	**Initial concentration range (micro-M)**	**Average dose (kGy) required to remove 99%**
0.61 - 0 88	0.57	0 58 - 0.72	0.58
6 2 - 8.9	0.64	6.2 - 7 2	0 64
40 - 58	1.07	45 - 59	1.06

*1 micro-M = 0.131 mg per liter

Summary of the average dose needed to remove 99% of benzene from aqueous solution in the presence and absence of clay

No Clay		3% Clay	
Initial concentration range (micro-M)*	**Average dose (kGy) required to remove 99%**	**Initial concentration range (micro-M)**	**Average dose (kGy) required to remove 99%**
1.1 -2.1	0.56	1.1 - 1.3	0.49
17 - 24	0.72	16 - 19	0.96
23 - 87	2.00	25 - 76	1 81

*1micro-M = 0.078 mg per liter

At the design flow of 0.45 cubic meters per minute, influent streams at the EBRF are presented to the scanned beam in a falling stream approximately 4 millimeters thick. Since the maximum penetration in water is approximately 7 millimeters for 1.5 MeV electrons, some electrons pass through the stream. Thus not all of the beam energy is transferred to the water. By over-scanning the waste stream to ensure that the edges of the stream are irradiated, more energy is lost. The result is that the efficiency of energy transfer is approximately 60% to 85%. Thus, at 50 mA (75 kW), doses of between 6.5 and 8 kGy have been recorded. Total power consumption including pumps, chillers, and other auxiliary equipment is about 120 kW.

Removal of toxic and hazardous organic chemicals: Summary of results

Numerous studies have been conducted on organic chemicals that may be of interest in contaminated soils treatment, groundwater remediation, industrial waste treatment, and hazardous waste leachates. Results for two compounds are summarized below.

The data for the removal efficiency was obtained at several irradiation doses, at three initial solute concentrations, three different pHs, and in the presence and absence of 3% clay. The solutes were either prepared in concentrated stock solutions in the laboratory or injected into tank trucks as the trucks were being filled up with water. *(See tables.)*

Reaction byproducts for all of the compounds studied are highly oxidized in nature. For example, formaldehyde and formic acid, at micro-M concentrations, were the only reaction byproducts identified for trichloroethylene. The remainder of the parent compound was completely mineralized to CO_2 H_2O and HCI.

It has been shown, therefore, that high energy electron-beam irradiation is effective and efficient in destroying organic chemicals from aqueous streams. The examples shown here are typical of organic chemicals found in waste streams and at remediation sites for hazardous waste.

The Canadian sludge recycling facility: Marketing irradiated sludge

Municipal sewage sludge is the solid matter removed during wastewater treatment processes at sewage treatment plants. Sludge typically contains potentially harmful components such as infectious organisms (viruses, bacteria, parasites), heavy metals, and chemicals. It also contains nitrogen, phosphorus, and other nutrients beneficial to plant growth.

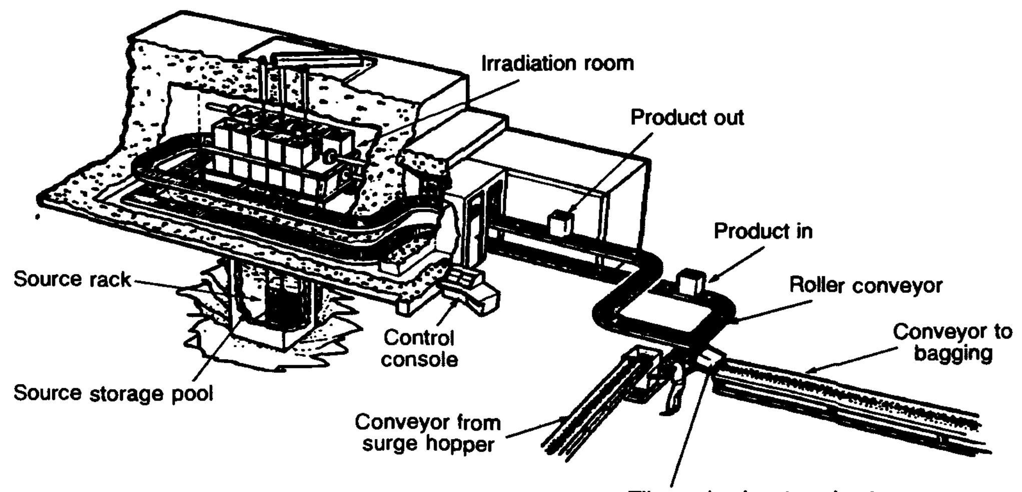
In several countries (Germany, India, Italy) the use of irradiation systems to disinfect liquid sludges prior to application on farm land has been successfully adopted. In Canada, a 4-year trial programme has led to a proposal to create a Sludge Recycling Facility, incorporating a cobalt-60-sourced sludge irradiator. If approved, the facility will convert sludge into a dry, soil-like product ready for bagging and marketing to horticultural firms.

Sludge irradiation systems

Irradiation disinfection of sludge would typically be carried out in a gamma irradiator with a cobalt-60 source. There are more than 160 of these full-scale industrial irradiators operating around the world to sterilize syringes, sutures, surgeons' gowns, heart valves, ointments, talcs, and a multitude of medical and consumer products.

A sludge irradiation disinfection system consists of three main components :

- a concrete-walled disinfection room which houses the irradiator and cobalt-60;
- a product handling mechanism which moves the sludge into and out of the room; and
- a cobalt-60 energy source for disinfection.



Schematic of a municipal sludge irradiator

The cobalt-60 sources are an important part of the irradiator. Cobalt-60 is a deliberately produced radioactive isotope, the same as is used in the treatment of cancer patients in hospitals. Naturally occurring non-radioactive cobalt-59 is fashioned into pencil-like rods. These "pencils" are bombarded with neutrons in a nuclear reactor for one or more years, after which time about 10% of the cobalt-59 has been transformed into cobalt-60. The pencils are then removed from the reactor for further processing and preparation for shipment to users of industrial irradiation systems.

The cobalt-60 emits gamma rays as it decays to nickel. These gamma rays pass through sludge, killing microorganisms and parasites. They do not leave any residue in or on the sludge, and they do not make the sludge "radioactive". The irradiation process will not change moisture content, or the levels of nutrients and heavy metals — its sole function is to eliminate pathogenic organisms.

Irradiated sludge as a fertilizer product

Disinfected sludge can be safely recycled for use as a fertilizer, soil conditioner, or as an ingredient in a wide range of specialty fertilizer products. Sludge products compete well with soil amendment and animal manure products typically available in the marketplace.

Because it is organically based, sludge products offer long-term soil improvement, unlike chemical fertilizers which provide nutrients but have few soil-enhancement properties. The natural components of sludge-based products make it ideal for use around shrubs and flowers. It can also be integrated into new or existing lawns.

Future challenges and opportunities

This article has provided a very brief overview of the types of waste management problems for which various radiation technologies can provide solutions. In some cases, more research and testing is required before the technology can be used on a commercial basis; in other instances the technology is already being used, or is ready for use, on a full-scale basis.

Looking to the future, ongoing research in scientific centres points the way to new roles for the safe, reliable, and economic application of radiation technologies for waste treatment. Among these are electron-beam machines to rid flue gases of environmental pollutants such as nitrogen oxide and sulphur dioxide; machines using cobalt-60 to sterilize hospital and laboratory wastes for safe disposal; and the increasing use of ultraviolet in place of chlorine chemicals to disinfect wastewater.

As each year passes, citizens in all countries are confronted with a growing list of seemingly insurmountable environmental problems. To meet these challenges, high-technology solutions are being sought which will provide answers now, as well as in the future. Radiation technology provides a viable alternative in this ongoing search. ❐

Monitoring wear and corrosion in industrial machines and systems: A radiation tool

Under an IAEA-supported project, countries are studying applications of a technique known as thin layer activation

by I.O. Konstantinov and B.V. Zatolokin

It is well known that the reliability of industrial equipment and machines, transport systems, nuclear and conventional power plants, pipelines, and other materials is substantially influenced by degradation processes such as wear and corrosion. For safety and economic reasons, appropriately monitoring the damage could prevent dangerous accidents during operation of industrial installations or vehicles and avoid production losses from the breakdown of machinery.

When the surfaces of machine parts under investigation are not easy to reach or are concealed by overlying structures, nuclear methods have become powerful tools for examination. They include X-ray radiography, neutron radiography, and a technique known as thin layer activation (TLA).

TLA is one of the most effective methods for monitoring wear and corrosion. By remote measurement, critical parts in a machine or a processing plant can be examined under real operating conditions, and the rate of wear and corrosion determined. TLA's main feature is the creation of a thin radioactive layer under the investigated surface, commonly by irradiating the object under study in an accelerator (cyclotron).

The methods for activating machine parts using an accelerator are sufficiently developed. They now enable highly sensitive measurements of the rate of surface destruction within a range of 0.0001 to 1 millimeters per year. TLA has been used as a tool for measuring the wear rate of a variety of components. These include bearings, camshafts, vehicle brake disks, as well as piston rings and cylinder housings of an internal combustion engine. More recent applications include the evaluation of corrosion and erosion phenomena in pipelines, vapor and gas turbine blades, off-shore platforms, and nuclear power plants. Its benefits to industry significantly exceed the costs of irradiating machine parts at accelerators and purchasing adequate radiometric equipment.

In response to interest among its Member States, the IAEA in 1991 initiated a co-ordinated research programme on nuclear methods for monitoring wear and corrosion in industry. Its scope includes the further development of irradiation technology employing charged particle accelerators, and various technical studies on practical applications of TLA in different industries. Six institutes from China, Hungary, India, Romania, and Russia participate in the programme. Their efforts are being concentrated on the development of new irradiation devices, measuring systems, and practical monitoring of wear and corrosion, among other areas. This article presents a brief technical overview of TLA, including reports of several case studies.

TLA: Modified tracer technology

TLA should be considered as one modification of radioactive tracer technology. In this method, radioactive tracers are created by irradiation of investigated objects in an accelerator. Due to the limited range of the charged particles in the condensed matter, the thickness of the activated layer usually is considerably smaller than the thickness of the machine part. Generally speaking, the radioactive tracer's depth distribution is not uniform and must be

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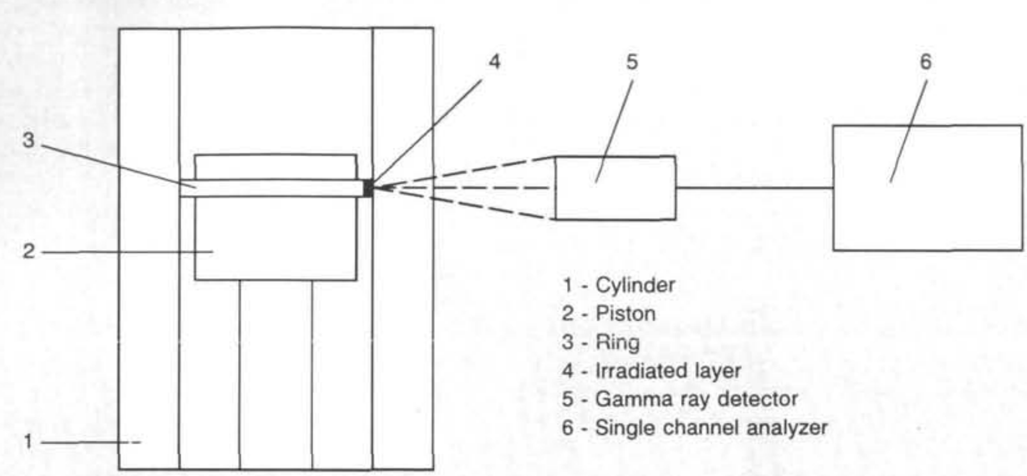
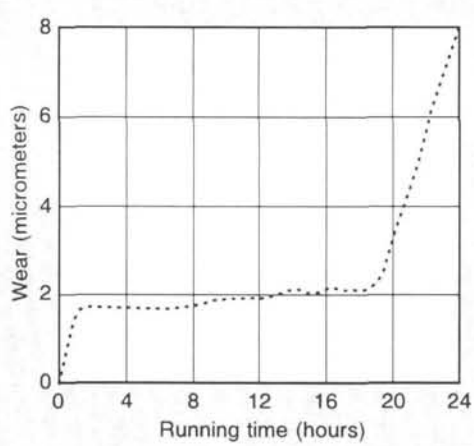
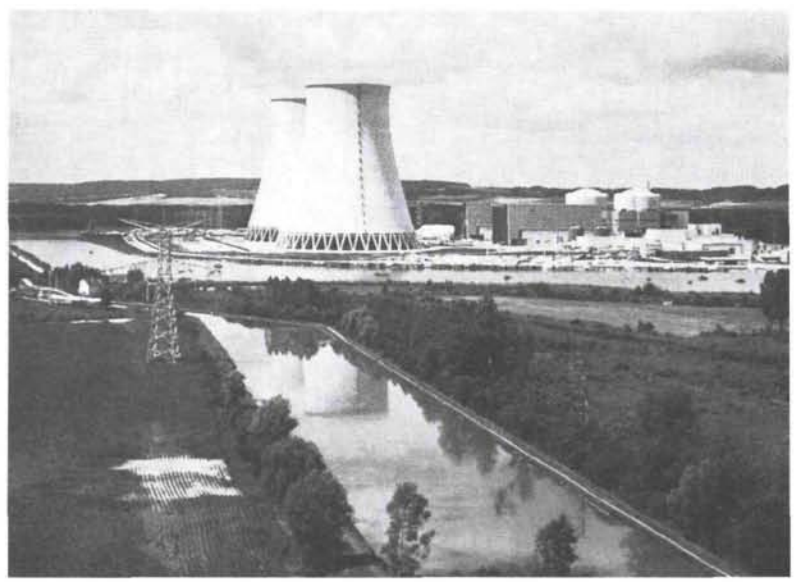
Typical experimental set-up for monitoring of wear and corrosion by TLA



Wear of piston ring in internal combustion engine





Thin layer activation (TLA) studies are done in industry for measuring and monitoring processes that degrade machinery and parts. Recent applications include evaluation of corrosion and erosion phenomena in pipelines, turbine blades, off-shore oil platforms, and at nuclear power plants.

determined in a separate experiment using special techniques.

The irradiated machine part is then assembled into the machine and the activity of the radioactive tracer is measured by an appropriate gamma spectrometry system. In the case of wear processes (corrosion or erosion) the tracer's activity decreases at a higher rate than the rate of its natural decay. The activity of the radioactive tracer usually does not exceed about 10 microcuries, and in most cases there is no need for special shielding against radiation. *(See graph and table.)*

Case studies from research activities

Internal combustion engines. TLA today is extensively used for wear monitoring of internal combustion engine parts, including such important friction pairs as the piston ring and cylinder.

Researchers in Russia have investigated the wear rate of a piston ring under various operating conditions. In one experiment, the ring's chrome-plated surface was irradiated by alpha-particles with 28 mega-electron volts (MeV) of energy at an angle of 30° to the surface. The thickness of the activated layer, which contained the radionuclide manganese-54, was equal to 25 micrometers. Results indicated that the rate of wear increases dramatically after about 18 hours of running time. *(See graph.)*

Interesting results also have been obtained using TLA at the Institute of Physics and Nuclear Engineering in Bucharest, Romania.The outer part of a piston ring was activated by energy deuterons of 8.5 MeV, which produced the radionuclide cobalt-57 that served as the radioactive label. The results of monitoring demonstrated that the wear rate was not uniform over the circumference of the piston ring but had two maximum points.

Other aspects of transport processes also are being examined. At China's Institute of Atomic Energy in Beijing, for example, researchers are investigating the influence of the quality of diesel fuel on the wear rate of diesel locomotives.

Pressure vessels. In the United States, TLA has been used to monitor erosion and corrosion occurring on the inner carbon steel wall of a pulp digester at a paper mill. Representative samples of the same steel as that used in the digester wall were irradiated and tested. Subsequent weight-loss measurements and comparison with ultrasonic thickness measurements established that the corrosion rate measured by TLA gave accurate results over a much shorter time scale.

Machine tools. In Hungary, scientists at the Institute of Nuclear Research of the Academy of Sciences have developed on-line wear measurements of the cutting edge of superhard turning tools made of polycrystal artificial diamond and cubic boron-nitride. Researchers irradiated the tools by protons at a cyclotron and then tested them under laboratory conditions using a grinding machine.

Other materials. Research also is being done using TLA for monitoring degradation processes of engine cam nose, knitting machines in the textile industry, artificial hip joints, gun barrels, compressors, materials for nuclear power plants, bearings, rails and railway wheels, gears, and pipeline equipment, for example.

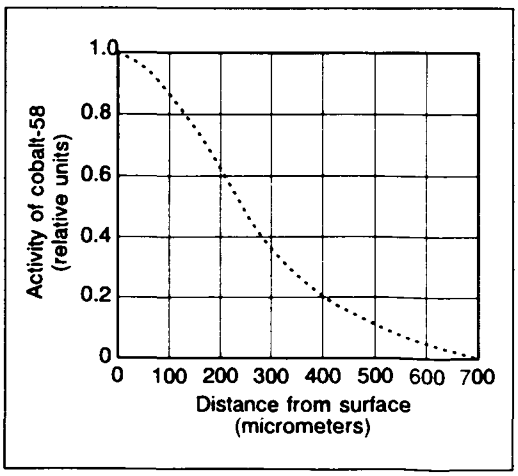
Depth distribution of cobalt-58 in irradiated iron

Distance from surface (micrometers)	Activity of cobalt-58 (relative unit)
0	1.000
40.6	0.992
82.3	0.982
120	0.970
159	0.957
197	0.940
234	0.916
270	0.896
306	0.874
341	0.842
376	0.806
409	0.779
442	0.748
473	0.705
505	0.657
535	0.605
565	0.551
593	0.491
622	0.432
648	0.378
675	0.323
693	0.272
726	0.229
749	0.183
773	0.143
795	0.107
816	0.074
837	0.050
856	0.026
875	0.014
893	0.004
910	0.001

Note: Irradiation by protons at initial energy of 22 MeV

A deployable technology

Based on its practical applications, chiefly in industrialized countries, and ongoing research, TLA could be readily deployed in more developing countries, given the appropriate infrastructure. It should be underlined that the availability of the appropriate accelerator (for example, a cyclotron or tandem accelerator) in the country is not a prerequisite for using TLA. The irradiation of machine parts could be carried out in those countries that already have an appropriate accelerator. Such an approach would obviate the need for a large capital investment to construct an accelerator facility, and it would speed up the technology's transfer to the developing world.❒



Radiation technology in surgery and the pharmaceutical industry: An overview of applications

Drugs, tissues, and other medical materials sterilized by gamma rays are being used for health care in many countries

by Glyn O. Phillips

Although drugs such as antibiotics can attack and destroy bacteria within the human body, they are not self-sterilizing. Pharmaceuticals, and/or their associated adjuvants (materials used to aid the delivery of drugs) can harbour bacteria, either from a primary source of origin or introduced during the production process. Their sterilization can present a problem since many such substances react with ethylene oxide to produce toxic chemicals and are unstable to heat.

The alternative — to manufacture in a sterile environment — is expensive. Radiation, therefore, has long offered an imaginative alternative, and it was initially pursued indiscriminately. Consequently, those expecting radiation treatment to be a panacea, applicable to all states and mixtures, were disappointed. The best results have since been obtained when the established principles of radiation chemistry were applied.

Like all chemicals, pharmaceuticals, and adjuvants, can undergo chemical changes under the influence of radiation. Thus each system must first be rigorously studied to examine the chemical changes induced and to establish the maximum tolerated dose. Further trials may then be necessary to endure long-term stability, and to demonstrate that there is no loss of potency or harmful pharmacological change produced by the selected dose. Fortunately, there is now extensive scientific literature documenting the effects of radiation on pharmaceutical systems. The main lesson is that irradiation should be carried out in the dry, solid state within an inert atmosphere to minimize damage. The presence of water and oxygen lead to reactive free radicals which promote secondary chemical changes.

Whichever sterilization or processing procedure is selected, the final product must conform to standards of safety, quality, and efficacy set by national regulatory bodies. Generally, this means that the producer must convince the regulatory authority that the treatment has not changed the potency of the drug, nor introduced harmful degradation products. Despite the inevitable prejudice against radiation, steady progress has been made in the use of radiation to sterilize pharmaceuticals, often because no alternative was available, or the alternatives were too costly.

Although some drugs are administered topically in the pure, dry form, formulations generally are devised for administering or delivery of the active ingredient. For this purpose, oils or ointments in a paraffin or polyethylene glycol base, for example, are frequently used. Thus, the radiation stability of such adjuvant materials must be considered as well.

Pharmaceuticals, raw materials, and wound dressings

Most solid pharmaceuticals that are irradiated dry show no significant loss of potency when irradiated to 25 kGy, which must be the starting point for any evaluation of the technology's applicability. *(See table on page 21.)* It has, therefore, proved possible to use gamma radiation to sterilize commercially parenteral antibiotic preparations. Heat can exercise adverse effects on vegetable oils, but preparations such as testosterone propionate, tetracycline ophthalmic oil suspensions, and physostiginine salicylate in an oil base are stable

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Patients at the Leprosarium, Sitanala Hospital, in Tangerang. Radiation sterilized amnion membrane has been used to heal their wounds. *(Credit: Newtech)*

Pharmaceutical products approved for sterilization by radiation

Regulatory bodies in a number of countries permit radiation sterilization of various pharmaceutical products. Below is a listing of approved products.

AUSTRALIA: Gaviscon; ispaghuyla husk; lubricating cream; lyophillized reagent kits of calcium-glucanate and DTPA for preparing technetium-99m radiopharmaceuticals; neomycin, polymixin, and bacitracin (separately or combined as a dusting powder); normal saline (for perfusing kidney transplants); opthalmic oil suspension of physostigmine salicylate; opthalmic ointment of mercuric oxide and sodium sulphacetamide; sutures.

INDIA: Absorbable gelatin sponge; catalin sodium tablets; fluorescein sodium strips; normal saline (for kidney perfusion); ophthalmic ointment in paraffin base in collapsible aluminium tubes (atropine sulphate; chloramphenicol; gentamycine sulphate; hydrocortisone and neomycin; tetracycline hydrochloride) and in soft gelatin capsules (chloramphenicol; gentamycine sulphate); prickly heat powder (antifungal containing boric and salicylic acids); raw materials (bella donna dry extract; ergot powder; papain; Rauwolfia serpentina powder); Ringer's lactate sodium; silver sulphadiazine; skin ointment in PEG base (neomycin sulphate; hydrocortisone acetate; alpha-chymotrypsin); sutures; veterinary products (quinapyramine prosalt).

INDONESIA: Herbal medicines; medicated dressings containing framycetin sulphate.

ISRAEL: Tetracycline hydrochloride ophthalmic ointment.

NORWAY: Chloramphenicol ointment.

UNITED KINGDOM: Atropine sulphate eye ointment 6%; chloramphenicol eye ointment; chloramphenicol ear ointment; chlorhexidine burn dressing; chlortetracycline eye ointment 1%; contact lens saline aerosol; corticosteroid ophthalmic ointment; Debrisan; neomycin ophthalmic ointment; sulphacetamide sodium eye ointment 6% tetracycline eye ointment 1%; tetracycline ophthalmic oily suspension 1%; tetracycline powder for i.m injection; tetracycline powder for i.v. injection; tetracycline topical ointment 3%; veterinary products.

UNITED STATES: Antibiotics; botanicals; chlortetracycline opthalmic ointment 1%; eye drops; eye ointments; injectables; pigments; steroids; Sutilains ointment USP; talc; tetracycline ophthalmic ointment 1%; veterinary products.

Source: Dr. Brian Read, Nordion International Inc., Canada

to radiation. Various types of ophthalmic ointments have long been routinely sterilized by radiation. *(See box.)*

Raw materials. Radiation also is extensively used for the decontamination of naturally occurring excipient materials. Gum Arabic, a natural gum exudate from the African Acacia senegal tree is widely used as a tableting, coating, and encapsulating agent for the active ingredient. The natural product, as delivered to the processor, inevitably has a high microbial load. Radiation has been shown to be an excellent method to decontaminate Gum Arabic, without degradation, loss of functionality, or viscosity. For this gum, radiation is now favoured by the pharmaceutical industry, though not completely by the food industry where Gum Arabic is widely used as an ingredient and additive. Such upgrading to acceptable microbial levels of bulk natural commodities is now an increasing application of radiation. (The European Commission is now poised to accept this process for food.)

A variety of other materials or thickeners can be sterilized without significant induced chemical change, if suitable irradiation conditions are selected. These include sodium carboximethyl cellulose, gelatin, starch, liquid paraffin, lanolin, and white soft paraffin.

Wound dressings. Wound-healing materials having a carbohydrate base also are regularly sterilized by radiation. One of the most well-known is Debrisan, a cross-linked dextran. It is produced as dry porous beads with highly hydrophilic properties. When poured on the secreting wound, Debrisan swells and seals the wound. The wound exudate with its associated bacteria is drawn into the three-dimensional macromolecular network, thus cleansing the wound. It reduces inflammation and edema, prevents crust formation, and keeps the surface soft and pliable. Debrisan can also be prepared as a paste with organic alcohols which are stable to radiation.The merit of the sterilization process is that the final dry product or paste can be processed in the packaged form. For packaged chemical wound and burn dressings, radiation is a valuable method of sterilization.

	Dose (kGy)	Loss of potency (%)
Chlortetracyline	17.9-100	0
Oxytetracyline	17.9-100	0
Chloramphenicol	17.9	0
Tetracyline hydrochloride	80	0
Streptomycin hydrochloride	25	0
Sodium benzyl penicillin	25	0
Phenoxymethyl penicillin	25	0
Benzathine penicillin	25	0
Dihydrostreptomycin	25	0
Potassium benzyl penicillin	17.9	0
Polymyxin sulphate	25	0
Polymyxin	up to 80	0
Colimycin	up to 80	0
Nystatin	up to 80	0
Mycerin	up to 80	0
Sulphapyridine	25	0
Sulphathiazole	25	0
Streptomycin sulphate	25	3
Dihydrostreptomycin	250	5
Neomycin sulphate	25	4
Sodium benzyl penicillin	250	~3
Benzathine penicillin	250	~3
Phenoxymethyl penicillin	250	~3
Zinc bacitracin	25	7.1
Zinc bacitracin	250	26.7

Loss of potency of solid irradiated pharmaceuticals

Radiation technology in surgery

Experience with tissue transplantation dates back some 2500 years to the Indian surgical empirics, who used a skin flap from the forehead to repair noses damaged in battle. The modern era started with the classical work of the Bologna surgeon Gaspare Tagliacozzi (1549-1599) entitled "The Surgery of Mutilation by Grafting". He described attaching a skin flap from the forearm to the nose, and when the repair had been effected after several weeks, severing the connection. Such a graft from the person to himself is referred to as an *autograft.* Tagliacozzi recognized the problems of transferring a graft from one person to another (termed an *allograft*). He rejected the idea because of "the force and power of the individual". It showed a remarkable prediction of what we now scientifically recognize as immunological rejection.

Surgery has passed through many conflicting phases since Tagliacozzi's time. John Hunter was the first to use the word "transplant", identifying the technique with "grafting" in the plant kingdom. There was a period at the end of the last century when allograft skin and parts of organs were used indiscriminately, and the consensus was that they worked. Reverdin (1842-1929) even reported success using animal graft skin *(xenograft).* In fact, they were confusing true grafting with in-growth of new skin. The period since has been dominated by the newly emerging immunological knowledge, and the conviction grew that only autografts would work. The most influential experiment was when Medawar and Gibson in the Medical Research Council's Burns Unit in Glasgow showed that a second set of skin grafts in a burn patient were rejected quicker than the first set. This seemed the final proof that allografts were of no clinical value.

Not so, however. The judgement was premature. Now more than 500 000 allografts are used surgically every year in the United States alone. The use of ionizing radiation for sterilizing tissue allografts has contributed significantly to this spectacular reversal of fortunes. The IAEA's programme on radiation sterilization of tissues has led to the establishment of multi-tissue banks in 13 countries in the Asia and Pacific region, and other banks now are emerging in Africa and South America.

To further promote progress, especially in developing countries, the IAEA has harnessed the support of major world associations which promote this technology. These include the

American Association of Tissue Banks; European Association of Tissue Banks; and the Asia and Pacific Surgical Tissue Bank Association. International meetings also are frequently convened at which the application of radiation in tissue sterilization and other areas of health care is evaluated.

Origin of the tissues

It is important to recognize that we are dealing here with the transplantation of non-viable (dead) tissues, not live organs. It is, therefore, low technology and extremely inexpensive. The IAEA's programme is concentrated on those tissues which are of maximum benefit to developing countries, and which reduce their dependence on expensive, imported prosthetic devices, artificial skin coverings, and wound dressings. These materials include bone, skin, amniotic membranes, tendons, and cartilage.

Both live and cadaveric human donors contribute to the supply of tissues. Throughout the world, total hip replacement (arthroplasty) surgery is practiced, which requires removal of the head of the femur. This bone from the live donors is retained for processing and future surgical use. When death occurs, donation by consent can provide the tissues within 24 hours after death. There are medical contra-indications which must be strictly observed. Malignancy, infectious diseases, prolonged drug therapy, or poisoning or drowning before death would preclude the use of the tissues.

With live donors, the blood is tested for all transmittable diseases. It further must be quarantined for 6 months, when a second blood test is carried out on the donor. This is because there can be a period of several weeks to 6 months between HIV infection and the appearance of the HIV-antibody.

It must be stressed that extreme sensitivity is maintained in the discussions with relatives to obtain permission for tissue donation. Great dignity is observed with the body and care is taken to reconstitute the limbs after procurement. All removed bones are replaced with identical structures made of wood or plastic so that finally there is no external damage observable on the body.

Processing and sterilization

Processing methodologies have been developed to reduce the level of contamination at each step, and provide the tissue in the form which is safe and useful to the surgeon. For bone in the Clwyd and Oswestry Research Tissue Bank, it has been found that an effective method is as follows:

Initially the bone is pasteurized at 56°C for 3 hours. HIV is inactivated in 20 minutes at this temperature. This treatment also inactivates heat labile enzymes, which might digest components, and kills heat sensitive organisms. At this temperature Bone Morphogenic Protein (BMP), which assists new bone to grow after implantation, is not inactivated. Soft tissues attached to the bone are excised. For femoral heads the cartilage is removed. The bones are then frozen overnight (-20°C) and cut using a motorized band saw. Bone pieces are continuously washed alternately in cold and hot (50°C) jets of water, when marrow and fats are removed. After freezing at -20°C for 4 to 5 days the bone is freeze-dried. The various shapes, sizes, and types of bone are double-packed in radiation resistant polyester/polyethylene film and grid-lacquered medical kraft paper. A third layer of polyethylene is applied at this stage and heat sealed. The package is finally sterilized by gamma radiation. All grafts are labelled, which accesses full details of the donor, and all operations to which the bone has been subjected.

A total quality system which encompasses good manufacturing practice governs all management and operations of the tissue bank. The processing reduces the antigenic properties and improves graft incorporation after transplantation. The cleaning and freeze-drying, followed by gamma radiation, applies equally to the processing of other tissues.

Programmes under the IAEA's Regional Co-operative Agreement for Asia and the Pacific now centre on introducing total quality systems and associated training. This is to ensure that all tissue banks have access to the best practices and full information about the most effective processing procedures. Open learning methods also are being introduced. When uniform systems are in operation, it is anticipated that individual tissue banks can be validated and sterile tissue allografts exchanged throughout the region.

For bone, sterilization by radiation is undoubtedly now the method of choice if only for its complete penetration of the most massive bone allograft. Additionally, toxic effects of freeze-dried bone allografts sterilized by ethylene oxide have recently been reported. In the irradiation process, the freeze-drying step reduces the water content to less than 5%, which reduces secondary effects from water-derived free radicals. The tissues most stable to radiation are those containing the highest proportion of collagen. The glycosaminoglycan is the most radiation-labile component of connective tissue. Excessive irradiation doses can, therefore, influence the mechanical behaviour of the tissue. Dose selection, therefore, is important. (A full account of this subject is available in the IAEA's 1986 Technical Document-454, *Technical and Economic Comparisons of Irradiation and Conventional Methods.*) The Agency's Coordinated Research Programme has enabled the optimum conditions to be established for minimal damage to the tissues on irradiation.

Surgical utilization

When bone is lost by disease or trauma, it must be replaced if the limb is to function. Prosthetic devices have been ingeniously produced from metal and synthetic polymers to support the body's mechanical structures. Once implanted, these must remain in the body throughout the person's lifetime. On the other hand when radiation sterilized allograft bone is used to replace the missing bone, it acts as a biocompatible scaffold. If the necessary criteria are followed, the patient's own bone, often in a matter of weeks, will grow into and incorporate the allograft. The structure is, therefore, all the patient's own bone. The dead bone has been transformed into new living bone. Hence, the motto of the USA's Bethesda Tissue Bank, *Et Mortua Vita* (The Dead Lives). Now, knowledge about the role of BMP, addition of the patient's own autologous marrow during transplantation, and good surgical fixation can greatly assist the growth of new bone by osteoconduction and osteoinduction.

Smaller allografts. The IAEA programme has not yet addressed the production and use of massive allografts for replacing sections of complete limbs when amputation may be the only other option. In general orthopaedics, the smaller allografts have a wider range of successful uses. Examples are:

- filling a cavity after removal of a cyst or benign tumours. The packed bone rapidly incorporates, promoting healing and re-modelling.
- acting as a buttress for skeletal structures. Here it is an osteoconductive scaffold for fractures involving articular surfaces.
- augmenting the amount of autograft which is necessary for promoting union ("biological weld") as in spinal fusion for scoliosis.
- in revision hip arthroplasty resulting from bone loss due to wear caused by the implanted prosthetic, resulting in loose hip and knee metal implants. This use will dramatically increase particularly for the younger, higher demand patient.
- in a wide range of oral surgery to fill cavities, repair trauma bone loss, and tumours of the mandible.

Allografts have many advantages over autografts. They can be stockpiled, and are available in quantity and in various sizes and shapes. In developing countries, they also help surgeons avoid taking the autograft from the patient, a process which extends surgical theatre time, consumes expert manpower, anaesthetics, and blood, for example, and is a potential new site of infection.

Membraneous tissues

Open wounds caused by either burn or ulcerations are the site of infection and fluid loss. The resulting metabolic dearrangements can prove fatal. In such circumstances, therefore, it is necessary to convert an open, potentially contaminated wound into a closed, clean wound as soon as possible. Radiation-sterilized, freeze-dried allograft skin or amnion can serve as a lifesaving bandage. With amnion, the angiogenic factors remaining in the processed membrane which sustained the baby in the womb also can assist when it is used as a bandage to promote granulation of the tissue and the development of new skin.

The IAEA programme has placed great emphasis on production of radiation-sterilized freeze-dried amnion dressings since many Moslem countries cannot readily obtain cadaver tissue. Treatment of burns in this way considerably lessens the pain and is extremely cost-effective when compared with the commercial alternatives. In Pakistan, for example, amnion is being produced at a fraction of a rupee per square inch, compared with 80 rupees for commercial skin/dressing.

The surgeon's approach to the use of allografts has, therefore, gone full circle. First misplaced confidence, then disenchantment, and now a realistic appraisal of the value. Radiation-sterilized allografts are now a part of the armoury of all up-to-date orthopaedic surgeons. Burn treatment can be greatly assisted by the use of allograft skin and amnion, which in developing countries can reduce the dependence on costly commercial synthetic alternatives.

Compared with the Creator, the chemist is still a novice in fabricating tissues. ❐

Accelerators in science and industry: Focus on the Middle East & Europe

Many countries are applying advanced technologies using low-energy accelerators, but not all are able to reap benefits

by
Vlado Valkovic
and Wiktor
Zyszkowski

Originally developed as tools for frontier physics, machines commonly known as particle accelerators today are routinely applied in science, industry, medicine, environmental protection, and other fields. While they come in a range of sizes and types, accelerators that produce relatively low energy beams have become some of the most powerful nuclear analytical tools. Among the practical applications of such low-energy accelerators are highly sensitive scientific analyses of trace elements in studies of air pollution, for example, or in health care and treatment.

Despite the range of practical applications, this high-level technology has not yet made significant inroads in most developing countries, in stark contrast to the situation in the industrialized world. In the interests of narrowing this technological gap, and in light of health and economic benefits derived from applications of low-energy accelerators, the IAEA initiated a regional project in 1993 through its technical assistance and co-operation programmes. The project on low-energy accelerators in science and industry is keyed to co-ordinating efforts among interested countries in the Middle East and European region, and it complements a number of separate national projects in this field.

This article presents a brief overview of common applications of low-energy accelerators and describes work being done within the framework of the IAEA's national and regional projects involving countries in the Middle East and Europe. More than 20 countries intend to take part in the regional project.

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The regional project addresses some fundamental problems regarding the interconnections between the effective transfer of technologies and scientific and industrial development. In industrialized countries, the link between scientific institutes and industries typically is a strong one, and developmental policies are firmly in place. In the developing world, on the other hand, this most often is not the case, a weakness that can prevent countries from reaping practical benefits of advanced technologies. The regional project seeks to help countries build such necessary links and establish effective policies. In this regard, it is important to keep in mind that today's emerging technologies are tomorrow's conventional ones, and countries must carefully and selectively build up their scientific and industrial capabilities in areas that can give them a competitive edge.

Applications of accelerators

Accelerators and their products are used in almost all branches of high technology and modern medicine. Some typical applications of low-energy accelerators — most of them being cyclotrons, electrostatic generators (Van de Graaff or similar), and linear accelerators ("LINACs") — are briefly described below.

Accelerators as analytical tools. In many areas, several powerful analytical techniques based on accelerator technology have made impressive impacts. *(See figure.)* The list includes particle induced X-ray emission (PIXE); Rutherford backscattering (RBS); nuclear reaction analysis (NRA); particle elastic scattering (PESA); particle induced gamma emission (PIGE); channeling microscopy (CM); scanning transmission ion microscopy (STIM); and secondary electron microscopy (SEM).

By the proper combination of the detected reaction products, one can obtain information on the total elemental composition related to the morphology of the sample. Scanning by spot-size ion beams has transformed these techniques from analytical tools into an imaging device. They thus map the distribution of elements and become a veritable nuclear "microscope".

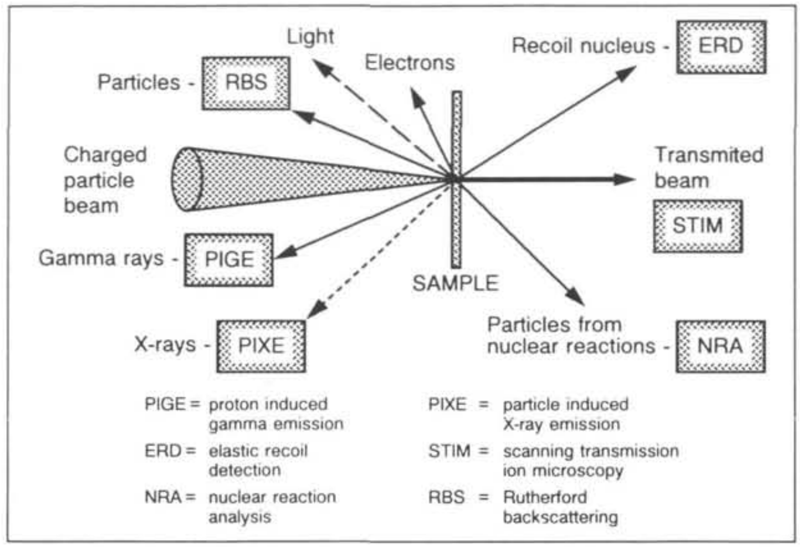
Another technique — accelerator mass spectrometry (AMS) — uses an accelerator and its beam transport system as an ultra-sensitive tool. It is capable of detecting isotopic abundances of long-lived radioisotopes (beryllium-10, carbon-14, aluminum-26, chlorine-36, calcium-41, iodine-129) in the range 10^{-15} to 10^{-16} in small (mg) samples. AMS has been accepted for use in more than 30 laboratories worldwide.

Applications are abundant — for example, in areas of archeology, art, paleo-anthropology, geology, paleo-climatology, extraterrestrial mineralogy, and biology. AMS is used in the majority of radiocarbon dating measurements, for instance, giving a much greater sensitivity than the more traditional method of counting the beta decays of carbon-14.

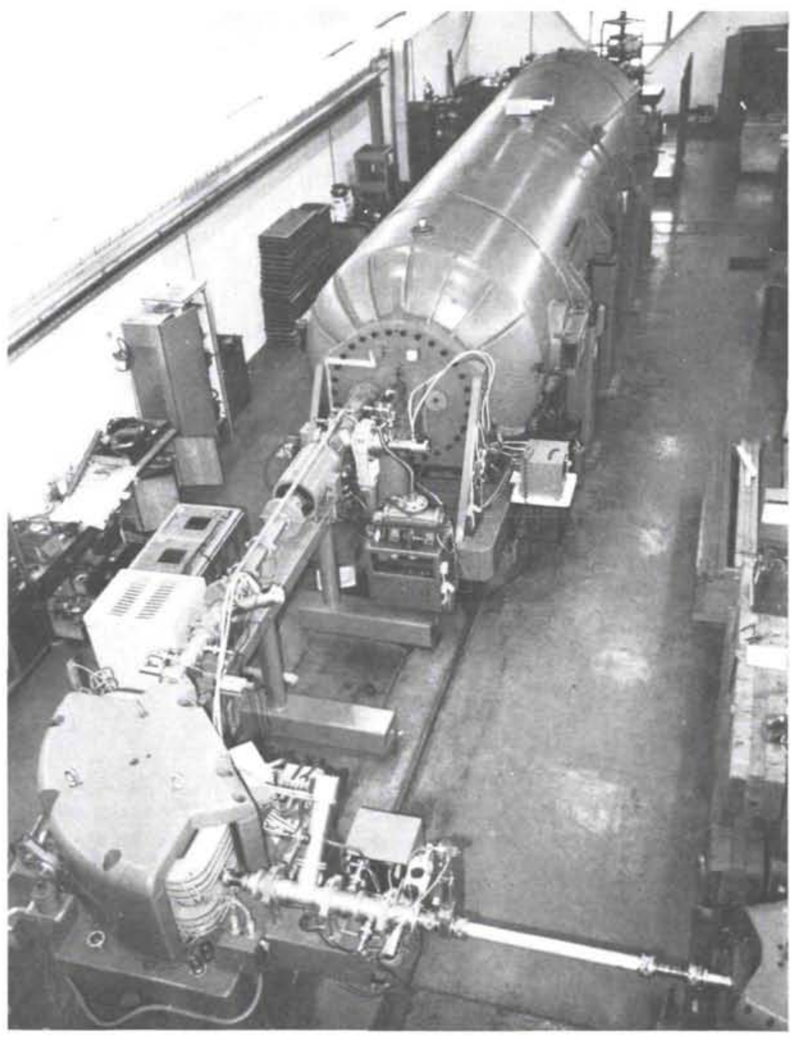
Accelerators in life science and medicine. Particle beams produced by accelerators can be used in medical institutions for both diagnostic and therapeutic applications. Diagnostic applications include the use of nuclear analytical techniques for element analysis, the use of different radioisotopes, and especially the use of positron emitters. Therapeutic applications are not limited to radiotherapy. They also include a broad spectrum of other activities ranging from the use of special materials to surgical applications.

Analyses of the concentration levels of trace elements in body fluids and tissues hold much promise as a clinical test. Techniques based on accelerators offer a very interesting approach to these problems because of their abilities to detect simultaneously several trace elements in very small samples (biopsy, hair, blood, etc.). Perhaps as in no other area, the development of accelerators has had a marked impact in medicine — specifically in the field of nuclear medicine and in radiation therapy. A range of radioisotopes for medical application which are not available from a nuclear reactor is produced by a cyclotron. These radioisotopes can provide a better understanding of the processes through which human diseases develop. Some radioisotopes have very short half-lives, measured in minutes and they must therefore be produced close to where they will be used. The most often needed radionuclides used in positron emission tomography (PET) are carbon-11, nitrogen-13, oxygen-15, and fluorine-18.

In addition to conventional radiation like gamma or X-rays produced by electron linear accelerators, several centres have been using



When a sample is bombarded with beams of charged particles, a number of processes take place. All of them can be used to obtain analytical information about a sample under investigation, and a number of them have been developed into accepted nuclear analytical techniques. *Photo:* The EN Tandem Van de Graaff accelerator that was donated by Rice University in Houston, Texas, to the Ruder Boskovic Institute in Zagreb, Croatia.



neutron and proton radiation therapies. Superior results are reported for the control of selected diseases by a dozen facilities which are currently investigating proton radiation therapy. In addition, facilities for heavy-ion treatment will soon be available at several locations. Heavy-ion beams exhibit a favourable depth/dose distribution and give the possibility of neurosurgical applications.

Accelerators in material science. The use of accelerators in material modification and subsequent analysis has been a fast-growing area of accelerator-based technologies. Numerous applications of ion implantation technology have been transferred from the research laboratory to industry. One outstanding example is the development of ion implantation for improving the wear resistance of artificial protheses.

It is an accepted view that a new industrial revolution will be brought about by the establishment of advanced material processing and machining technologies that can create new materials down to an atomic and molecular level. This could be accomplished by accelerator-based technologies through the development of high-energy ion beams that are focused, clustered, and wide-ranging.

Modifications and analyses of different materials employing ion beams in the range of mega-electron volts (MeV) are being done with an increasing number of charged particle accelerators. Some of the tasks performed include: ion implantation and processing; synthesis of thin films and surface modifications; fabrication of bio-materials; study of corrosion-erosion phenomena; concentration profile measurements; and diffusion phenomena studies.

Currently at least five companies worldwide have high-energy ion implantation systems available. All are designated to accelerate singly or doubly charged heavy ions such as boron, nitrogen, phosphorus, arsenic, and antimony. By controlling the beam's energy, the systems can be used to treat materials at desired surface depths. In this way, for example, extremely high quality multi-layers or modified surface layers having numerous functions can be formed on ordinary materials.

Accelerators in environmental protection. Accelerator-based analytical techniques are used in monitoring environmental pollution and for identifying the pollution sources. Because of their multi-elemental capabilities, and the possibility of measuring concentration profiles, they have been extensively used for air pollution studies. *(See graphs.)*

One of the major sources of air pollution is coal burning for electrical power generation and heating, despite improvements in combustion operations and the use of gas cleaning devices such as electrostatic precipitators (and electron accelerators). Moreover, electrical precipitators may show minimal collection efficiency for particles in the 0.1 - 1.0 micrometer size range. Such particles have longer atmospheric residence times and greater effects on health and air quality than would an equal mass of larger particles. They contain unusually large surface concentrations of potentially toxic trace elements which increase with decreasing particle size, owing to mechanisms of fly ash formation.

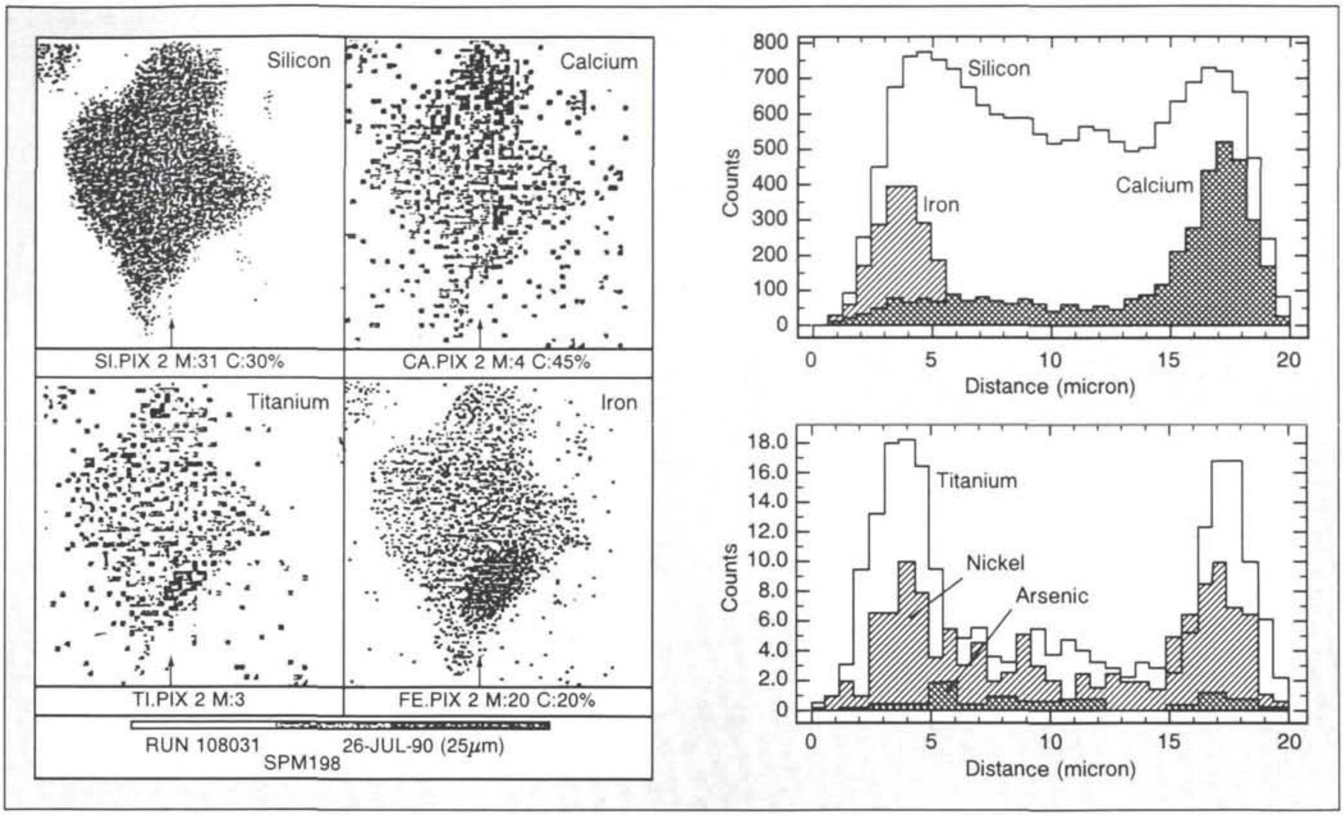
Accelerators in industry. Another noteworthy application is ion projection lithography. The microelectronics industry requires the development of lithography capabilities below 0.3 micrometers for advanced silicon devices and capabilities below 0.1 micrometers for hetero-structure and quantum coupled devices. Ion projection lithography may meet these strict requirements, surmounting the limits of optical and X-ray lithographic methods.

Industrially developed countries are aware of the potential of accelerator-based technologies. For example, Germany has 23 electrostatic accelerators, nine of them being tandems with experimental set-ups for hydrogen profile determination, RBS, ion implementation, channelling, microprobe, and AMS. Many of these facilities devote more than 50% of their operating time to applied research. In addition, there are 16 cyclotrons, some designed exclusively for isotope production, at least three with PET capabilities, and 11 synchrotron and linear accelerators mainly used for heavy ion acceleration. In Japan, medical applications of accelerators alone include 13 cyclotrons with PET capabilities, heavy-ion accelerators, and more than 500 linear accelerators used for therapeutic applications.

IAEA-supported national projects

For the past 15 years, the IAEA's technical assistance programme for the Middle East and Europe region has included a number of projects involving accelerator technologies. Several laboratories in Albania, Bulgaria, Croatia, Greece, Hungary, Iran, Jordan, Poland, Portugal, and Romania, among other countries, have been assisted under national projects having objectives to upgrade or establish accelerator laboratories. Using large amounts of non-convertible currency funds in the late 1970s and early 1980s, the IAEA provided accelerators of Soviet origin to Bulgaria, Hungary, Poland, and Portugal, for example.

In Hungary, a national laboratory in Debrecen received a cyclotron which was put



In air pollution studies, accelerator technologies (namely PIXE and RBS) can be used to characterize fly ash particles by measuring element concentrations, and providing element concentration profiles. Shown here are results of areal and line scans of the aluminosilicate fly ash particle.

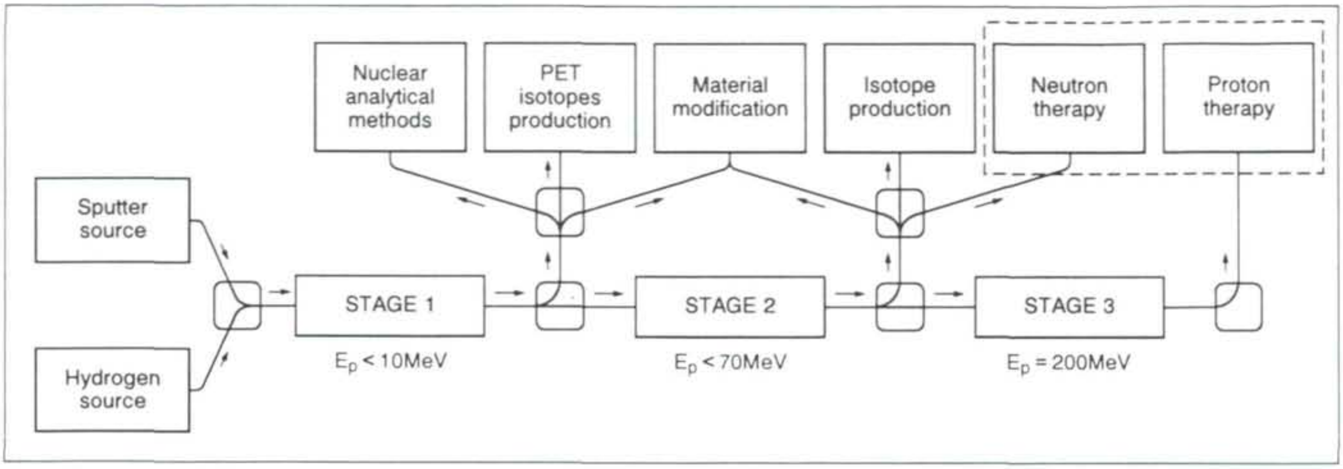
into operation in 1985. Extensive use is being made of it today for fundamental research in atomic and nuclear physics, and for applications in industry, agriculture, and medicine, including isotope production. The laboratory has become one of the leading ones in the region and is active in providing expertise, and in organizing meetings, seminars, and group and individual training sessions.

In Bulgaria, IAEA assistance has been provided since 1984 toward establishment of an accelerator laboratory at the Higher Institute of Chemical Technology in Burgas. The objective is to support applications in the petrochemical and cable industries. An electron accelerator was installed in 1991. It is expected that the project will lead to Bulgarian production of more heat-resistant wire insulation and new packaging materials, thereby reducing the need for imports of such products.

In Poland, the Institute of Nuclear Chemistry and Technology in Warsaw has been assisted by the IAEA for the last 10 years. Early on, a pilot electron accelerator and some auxiliary equipment from the former Soviet Union was provided. Today it is being used for the pilot production of heat shrinkable tubes and tapes, among other applications.

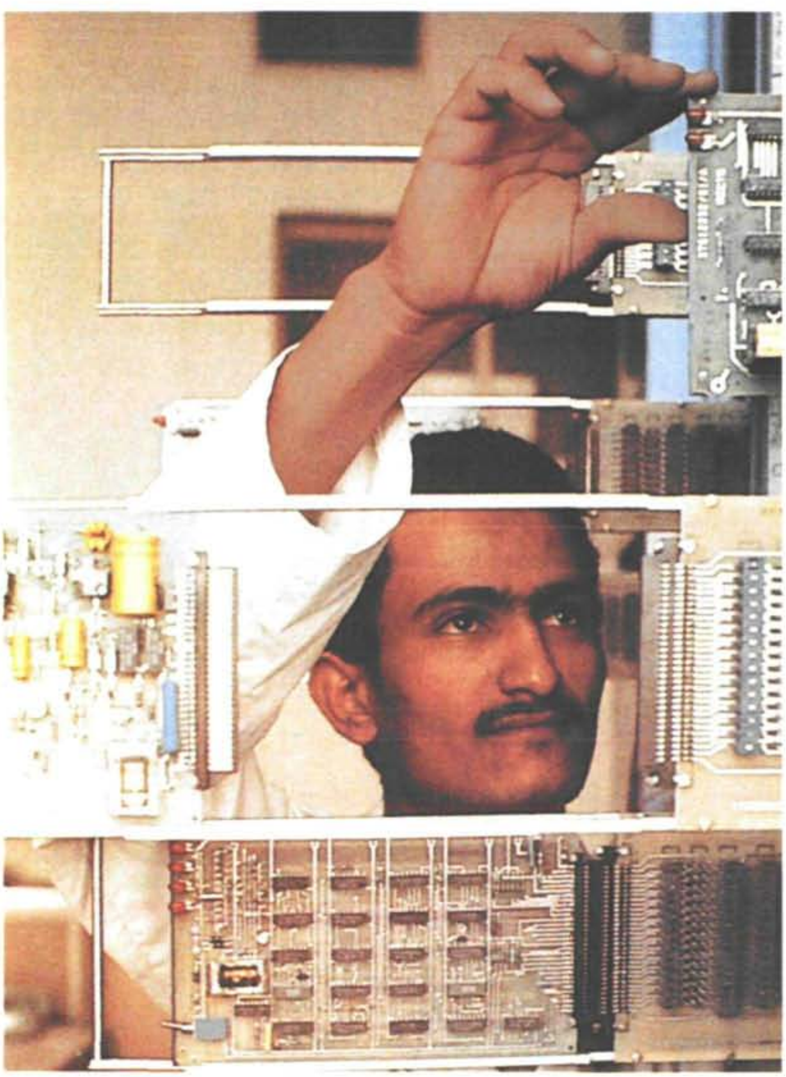
One highly visible project in Poland was initiated in 1987 with the same Institute in Warsaw. It involves the use of electron beam technology for the purification of flue gases in Polish coal-fired power stations. Based on two accelerators of Soviet origin, a demonstration facility was constructed in Warsaw and the concept is now being extended on a larger scale in the Szczecin area. Positive impacts on the environment are expected through the effective, simultaneous removal of pollutants, namely SO_2 and NO_x gases. The project is being generously supported by contributions from the United States and Japan, and in many respects has become a model one. A number of other countries in and outside the region have expressed their interest in the technology, and continued support will be required.

In Albania, Croatia, Greece, Iran, Portugal, and Romania, the IAEA's assistance has helped to upgrade the experimental capabilities of laboratories equipped with Van de Graaff accelerators. At the Ruder Boskovic Institute in Zagreb, current efforts under the project are directed at upgrading a previously installed accelerator to enable microanalytical work. Present applications of the accelerator include development of nuclear analytical techniques;



Above: **A schematic of a three stage accelerator facility in a typical hospital environment.**

Below: **Industrial applications of accelerators include research and development of materials for microelectronics.**



studies of trace elements in coal, bio-medical samples, and other materials; and research involving nuclear reactions and dosimetry.

In Greece, an accelerator laboratory at the Demokritos centre in Athens is being provided with a goniometer under a US-funded project. This will open new possibilities for applications in material science and other areas. Similarly, in Portugal, the existing Van de Graaff accelerator has been equipped with facilities to carry out research in the fields of atomic and solid state physics. Essential items included a computer, a multichannel analyzer, a semi-conductor detector, and vacuum equipment. Using the PIXE and RBS techniques, among other analytical methods, studies have been undertaken involving biological samples, aerosols, and silicon devices.

In a number of countries in the region, there is increasing interest in cyclotron applications for modern radiation therapy. In Iran, a cyclotron laboratory is under construction and the IAEA is providing guidance, expertise, training, and some equipment. The facility is designed for medical applications (including production of radioisotopes such as thallium-201, gallium-67, and iodine-123; and the future use of PET) and research in nuclear physics. A similar project is contemplated by Turkey and the IAEA is helping authorities there with a feasibility study.

Use of linear accelerators also has been supported. In Portugal, for instance, the Laboratorio de Engenharia e Tecnologia Industrial was equipped with an electron beam accelerator of Soviet origin to support research and development of promising radiation-induced processes. They include the curing of surface coatings and inducing cross-linking or polymerization in plastics such as those used in cable sheathing.

At the Ruder Boskovic Institute in Zagreb, the IAEA is supporting installation of a linear accelerator donated by Germany, while in

Poland, the IAEA has provided equipment to the Institute of Applied Radiation and Chemistry of the Technical University in Lodz, which houses a linear accelerator. The Institute's work embraces applied research in polymer chemistry, synthesis of labelled compounds, studies of biological and bio-active materials, and industrial sterilization of medical products.

Additionally, nearly all countries in the region have been interested in electron beam technology for food irradiation under a separate IAEA regional project. However, only Poland has decided to construct a facility, and the IAEA has supported the construction of an accelerator there.

Regional needs and initiatives

Despite the range of national technical assistance projects, not all countries have been able to realize practical applications of accelerator-based technologies. The most successful projects have been those for which the necessary infrastructure and local support already exist. Cases in point are projects in Hungary and Poland. At the other extreme are a number of other countries, including Turkey, Syria, and Cyprus, for example, who have had little or no experience with accelerator technologies. The situation illustrates the inherent difficulties in instituting effective multi-year projects and the importance of a solid preparatory phase, including decisions on the allocation of funding, as preconditions for effective broad-based projects.

One practical need with respect to both planning accelerator-based projects and promoting effective co-operation among participants is the development of a database. Unlike the case of nuclear power or research reactors, for example, full information about accelerators and their applications is lacking, on a regional as well as worldwide basis. The IAEA has started work on compiling a database for low-energy accelerators (100 keV to 100 MeV energy interval). Although planned as a worldwide survey, the first step is a pilot study for the Middle East and Europe, and a questionnaire has been mailed to IAEA Member States in the region.

In January 1993, the IAEA further initiated a regional project for the Middle East and Europe on low-energy accelerators and their applications in science and industry. It has two overriding objectives:

- to promote the use of low-energy ion accelerators for industrial applications by regional co-operation and transfer of newly developed methodologies and techniques from advanced countries to developing ones;
- to promote the use of accelerator-based analytical techniques in environmental and biomedical studies by regional co-operation and to familiarize more specialists with the techniques used by advanced countries in the region.

The project's work plan includes three basic tasks: The first one involves data collection and processing about the accelerators available in the region. This would cover information on the location, type, and parameters of the facility, among other data. This work further would identify the available expertise in the region, fields of common interest, and training needs.

The second task concerns improving scientific capabilities through a series of workshops that address specific subjects. These would cover, for example, sample preparation for accelerator-based analytical techniques; use of accelerator-based techniques in mineral prospecting and exploration; software required for X-ray, gamma ray, and charged particle spectra evaluation; and inter-calibration exercises among participating laboratories. Workshops on other subjects also are contemplated.

The third task relates to promotion among industries of accelerator-based techniques for specific applications. Workshops for scientists, accelerator specialists, industrial managers and policy makers are planned. Toward this end, the experience and know-how of advanced laboratories in the region — such as the Laboratori Nazionali di Legnaro in Padua, Italy — will be drawn upon, in the interests of promoting the transfer of technologies. As guidance for detailed feasibility studies that countries may desire to do, the IAEA also is considering the preparation of a manual on the subject.

In summary, the IAEA's new regional project should stimulate greater awareness of accelerator-based technologies and closer collaboration among countries interested in applying them. A number of IAEA-supported national projects in this field already have had a positive impact in the region, including those seeking to establish new centres equipped with an accelerator (cyclotron) for medicine and science. It is hoped that these initiatives will help strengthen the links between scientific institutes and industries and help developing countries formulate required policies that take into account the interconnections of basic science, research and development, and the transfer of technologies. In this way, more possibilities may open for countries in the Middle East and Europe to effectively apply advanced technologies for their social and economic development. ❐

Food irradiation in developing countries: A practical alternative

Health and economic benefits are major reasons why more countries are looking closely at the technology's commercial uses

by Paisan Loaharanu

Among existing technologies for food preservation, irradiation of food is recognized as a safe and effective method for a range of specific applications. Through its use, food losses and food-borne diseases can be reduced, and wider trade of many food items can be facilitated.

A worldwide standard on food irradiation was adopted in 1983 by the Codex Alimentarius Commission of the Joint Food Standard Programme of the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO). Such a standard provides an assurance to governments and consumers of the safety and effectiveness of the technology. As a result, 38 countries have approved the use of irradiation for treating one or more food items, and the number is increasing. Currently 27 countries — half of which are from the developing world — are using the technology for treating food for commercial purposes. *(See table.)*

In light of such developments, the IAEA has developed an action plan directed at the practical utilization of food irradiation in developing countries. The plan was developed in response to an initiative from the Ambassador of India in 1992. It now includes a detailed project proposal for the introduction of commercial-scale food irradiation in developing countries through appropriate technical co-operation channels, and in collaboration with other United Nations organizations, including the FAO, WHO, and International Trade Centre. The proposal was approved by the IAEA Board of Governors and subsequently endorsed by the IAEA General Conference in September 1993.

It included the outcomes of several economic feasibility studies. Four countries — Chile, China, Mexico, and Morocco — were invited to collaborate with the IAEA to conduct the studies, and all but Chile's has been completed.

Based on its study, the Chinese government decided to allocate approximately US $1.1 million toward the design and construction of a commercial food irradiator in Beijing for treating mainly rice, garlic, and a few other food items for the domestic market. The IAEA was requested to provide a cobalt-60 source, expert services, quality control equipment, and fellowship training of their personnel.

Mexico's feasibility study reported that several commercial food irradiators may be considered both for the domestic market and for export. The first such commercial plant was recommended to be built in the central region of Mexico for treating spices, dried food, fruits and vegetables, and medical products; a potentially high profit was foreseen.

In Morocco, on the other hand, the study found that the infrastructure required for introducing commercial-scale food irradiation appeared to be premature. An IAEA expert mission recommended strengthening research and development efforts prior to embarking on commercial-scale application.

This article looks at some of the major reasons why more countries, particularly those from the developing world, are interested in commercial applications of food irradiation technology.

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Health and economic considerations

Post-harvest food losses. Despite the availability of many food processing technologies, developing countries are still experiencing high post-harvest losses of food. Up to 50% of perishable food — such as fish and seafood, fruits and vegetables, meat and poultry — is lost during production through various spoilage agents before reaching the consumer. Post-harvest losses in countries of the Asian region, for example, are estimated at 30% for grains, 20% to 40% for fruits and vegetables, and up to 50% for fish. In Africa, a conservative estimate shows that a minimum of 20% of total food production is lost after harvest. Losses of perishable items such as fruits, vegetables, and fish, for example, are even higher than 50%. The US National Academy of Sciences has estimated that the minimum post-harvest food losses in developing countries amounted to more than 100 million tonnes at a value surpassing US $10 billion in 1985.

Many of the losses are attributed to insect infestation. To combat the problem for cereals, pulses, and other stored products, developing countries often fumigate them with chemicals such as ethylene dibromide, methyl bromide, or ethylene oxide which have to be imported from advanced countries. Their use has created problems relating to health, environment, and worker safety. For these reasons, ethylene dibromide has been prohibited for fumigating food since the mid-1980s. Recently, methyl bromide — the most widely used chemical for fumigating food against insect infestation — has been reported to have strong ozone-depleting properties. Under terms of the Montreal Protocol — which was adopted in 1989 by most nations to protect the environment — chemical substances which damage the ozone layer will have to be phased out by the year 2000.

Food-borne diseases. Food-borne diseases continue to affect adversely the health and productivity of populations in most countries, especially in developing ones. Contamination of food — especially of animal origin — with microorganisms, particularly pathogenic non-spore-forming bacteria, as well as infection with parasitic helminths and protozoa, are important public health problems and causes of human suffering and malnutrition. According to WHO, infectious and parasitic diseases represented the most frequent cause of death (35%) worldwide in 1990, with the majority of deaths occurring in developing countries. These diseases include malaria, diarrhoea, tuberculosis, measles, pertussis, and schistosomiasis. Diarrhoeal disease caused about 25% of deaths in developing countries. It is estimated that in possibly up to 70% of cases food is the vehicle for transmission of diarrhoeal diseases.

Moreover, during the past 2 years, 15 countries in Latin America have reported some 400 000 cases of cholera and more than 4000 deaths. The most important cause of transmission of the disease was the consumption of contaminated water and food.

In a number of countries, consumers have had the choice of buying foods processed by irradiation. *(Credit: CEA)*

Elsewhere, 7 million people in the north-eastern provinces of Thailand, 3 million in the Republic of Korea, and millions more in China are infected by liver fluke parasites from consumption of raw freshwater fish. The economic losses caused by these diseases in these countries are estimated to be hundreds of millions of US dollars annually.

Food trade. Besides having to compete among themselves for food export markets, developing countries also have to satisfy the increasingly strict standards of quality and quarantine in major importing countries. They are accustomed to exporting raw agricultural and food commodities, such as spices and condiments, fruits and vegetables, cereals and pulses, as well as beverage crops such as coffee beans and cocoa beans, which are prone to contamination by microorganisms and infestation by insects. Large quantities of such products are rejected by importing countries each year on the grounds of poor quality and hygiene. The economic losses from rejections can be enormous.

Many fruits produced in developing countries are not allowed to enter lucrative markets in the United States, Japan, Australia, and other countries because of insect infestation, especially by fruit flies of the *Tephritidae* family. Such commodities have to be treated either by chemical fumigation, hot water or vapour heat, or refrigeration near 0° C before importation by these countries. The problem is compounded by the fact that most tropical fruits and vegetables cannot tolerate drastic temperature treatments. Considering the volume and value of fruits and vegetables exported to countries having strict quarantine regulations, developing countries could suffer seriously if there were no effective alternative treatments available.

The impending ban of methyl bromide could create enormous economic losses for both advanced and developing countries. For example, some 300 000 tonnes of fruits and vegetables imported annually into the United States require methyl bromide fumigation for insect control. The bulk of these imports consists of grapes from Chile (close to 200 000 tonnes per annum). Irradiation is probably the best alternative treatment method available. Its use on four selected commodities being imported by the United States can yield an economic benefit ranging from US $650 million to $1100 million over a 5-year period, based on an analysis by the US Department of Agriculture (USDA).

Currently, developing countries can export their fresh fruits and vegetables to most countries of the European Community without any restrictions. As some of the European and Mediterranean countries have started growing commercial quantities of tropical fruits (such as mangoes and papayas), the European and Mediterranean Plant Protection Organization (EPPO) is evaluating phytosanitary regulations in line with the free movement of goods within the European Community. This is being done to protect these countries from exotic quarantine pests. This action of EPPO is going to seriously affect trade in food and agricultural products from developing countries. Regional plant protection organizations including EPPO have recognized food irradiation as an effective quarantine treatment to overcome such a problem.

Trade in food products which are contaminated by disease-causing microorganisms (for example, *Salmonella*) could create a liability problem for manufacturers, especially of ready-to-eat food. A recent incident in Germany in late 1993 concerning a snack food flavoured by paprika contaminated by *Salmonella* has cost its manufacturer between 30 to 40 million Deutschmark due to product recall and destruction. The paprika was imported from a developing country. It was not known whether the paprika was treated in any way prior to its use in the snack food. Proper irradiation of paprika would overcome the problem of such contamination.

Interest in food irradiation

Food losses. Depending on the absorbed doses, irradiation is effective as a method for reducing post-harvest losses of a range of foods. Low-dose irradiation (0.05 to 0.15 kGy) is effective for inhibiting sprouting, which is the most important cause of deterioration of crops such as potatoes, onion, garlic, and yam. Irradiation provides an important alternative to chemical sprout inhibitors which are not always effective under tropical conditions. For example, it is the only effective method to control storage loss of yams due to sprouting. It also reduces the use of refrigeration for storing these crops, as irradiated products may either be stored at ambient or chilled (10° to 15° C) conditions, instead of at low temperatures (0° to 2° C) to reduce losses caused by spoilage microorganisms.

Food spoilage. Ripening and maturity of fruits and vegetables — such as mangoes, papayas, mushrooms and asparagus — may be delayed by low-dose irradiation of approximately 1 kGy, thereby extending their shelf-lives. By combining irradiation with mild heat treatment, e.g., hot water dip (50° C for 5 minutes), both a delay in ripening and in disease control of fruits such as mangoes and papayas can be achieved.

Most spoilage microorganisms of meat, fish, and seafood are relatively sensitive to low-dose irradiation. Thus, irradiating these products with doses between 1 and 5 kGy after proper packaging results in significant reduction of spoilage microorganisms. Together with proper storage under refrigeration, the shelf-lives of these products may be extended significantly.

Disinfestation. For insect disinfestation, irradiation offers an attractive alternative to chemicals for grains, dried fish , dried fruits, and tree nuts. A dose between 0.25 and 0.5 kGy is effective for controlling infestation by practically all species of insects in stored products. Irradiation is economically attractive as demonstrated by the two large electron irradiators situated at Port Odessa, Ukraine. They process approximately 400 000 tonnes of grain per annum.

Cured and dried fish provides important sources of animal protein for populations in many developing countries in Africa and Asia. These products are normally infested by several species of insects during sun drying and storage. In several countries, the use of insecticides to control insect infestation of these products is still practiced. Irradiation of properly packaged dried fish with a dose of 0.5 kGy is an attractive and residue-free alternative to chemical control of insects in these products.

Safety and hygiene. Spices and dried vegetable seasonings have to be processed to meet the microbiological specifications of food manufacturers before their incorporation in processed food such as sausages, canned meat, soups, sauces, and salad dressings.

Irradiation facilities around the world

Twenty-seven countries worldwide have irradiation facilities available for commercial applications of food irradiation; six others are either building or planning such facilities. A listing by country follows. *Countries in italics are irradiating food products for commercial use.*

ALGERIA: a facility at Mascara is under construction for processing potatoes.

ARGENTINA: a facility in Buenos Aires started irradiating spices, spinach, and cocoa powder in 1986.

BANGLADESH: a facility at Chittagong started irradiating potatoes, onions, dried fish, and pulses in 1986.

BELGIUM: a facility at Fleurus started irradiating spices, dehydrated vegetables, and deep frozen foods in 1981.

BRAZIL: a facility in Saõ Paulo started irradiating spices and dehydrated vegetables in 1985.

CANADA: a facility at Laval started irradiating spices in 1989.

CHILE: a facility in Santiago started irradiating spices, dehydrated vegetables, onions, potatoes, and poultry meat in 1983.

CHINA: facilities at Chengdu (since 1978) started irradiating spices, vegetable seasonings, Chinese sausage, and garlic; at Shanghai (since 1986) apples, potatoes, onions, garlic, dehydrated vegetables; at Zhengzhou (since 1986) garlic, seasonings, and sauces; at Nanjing (since 1987) tomatoes; and at Jinan (since 1987), Lanzhou (since 1988), Beijing (since 1988), Tienjin (since 1988), Daqing (since 1988), and Jianou (since 1991) unspecified products.

CÔTE D'IVOIRE: a facility is being built at Abidjan for irradiating yams, cocoa, and beans.

CROATIA: a facility at Zagreb started irradiating spices, rice, and food ingredients in 1985.

CUBA: a facility in Havana started irradiating potatoes, onions, beans, and cocoa powder in 1987.

DENMARK: a facility at Riso started irradiating spices in 1986.

FINLAND: a facility at Ilomantsi started irradiating spices in 1986.

FRANCE: facilities at Lyon (since 1982) started irradiating spices; Paris (since 1982) spices and vegetable seasonings; Nice (since 1986) spices; Vannes (since 1987) poultry (frozen deboned chicken); Marseille (since 1989) spices, vegetable seasonings, dried fruit, frozen frog legs, and shrimp; Pousauges and Osmanville (since 1991) unspecified products; and Sablé-sur-Sarthe (since 1992) Camembert.

HUNGARY: a facility at Budapest started irradiating spices, onions, wine cork, and enzymes in 1982.

INDIA: facilities are planned in Bombay for irradiating spices and in Nasik for onions.

INDONESIA: facilities at Pasr Jumat (since 1988) and Cibitung (since 1992) started irradiating spices.

IRAN: a facility in Tehran started irradiating spices in 1991.

ISRAEL: a facility at Yavne started irradiating spices, condiments, and dry ingredients in 1986.

JAPAN: a facility at Hokkaido started irradiating potatoes in 1973.

KOREA, REPUBLIC OF: a facility at Seoul started irradiating garlic powder, spices, condiments, and food ingredients in 1986.

MEXICO: a facility in Mexico City started irradiating spices and dry food ingredients in 1988.

NETHERLANDS: a facility at Ede started irradiating spices, frozen products, poultry, dehydrated vegetables, rice, egg powder, and packaging material in 1981.

NORWAY: a facility at Kjeller started irradiating spices in 1982.

PHILIPPINES: a facility in Quezon City started irradiating unspecified products in 1989.

POLAND: facilities started irradiating products at Warsaw (since 1984); Wlochy (since 1991); and Lodz (since 1984).

SOUTH AFRICA: facilities at Pretoria (since 1971, 1978, 1980, respectively) started irradiating potatoes, onions, fruits, spices, meat, fish, and chicken; at Tzaneen (since 1981) onions, potatoes, and processed products; at Kempton Park (since 1981) fruits, spices, and potatoes; and at Milnerton (since 1986) fruits and spices.

THAILAND: facilities at Bangkok started irradiating onions in 1971; and at Patumthani fermented pork sausages, enzymes, and spices in 1989.

UKRAINE: a facility at Odessa started irradiating grain in 1983.

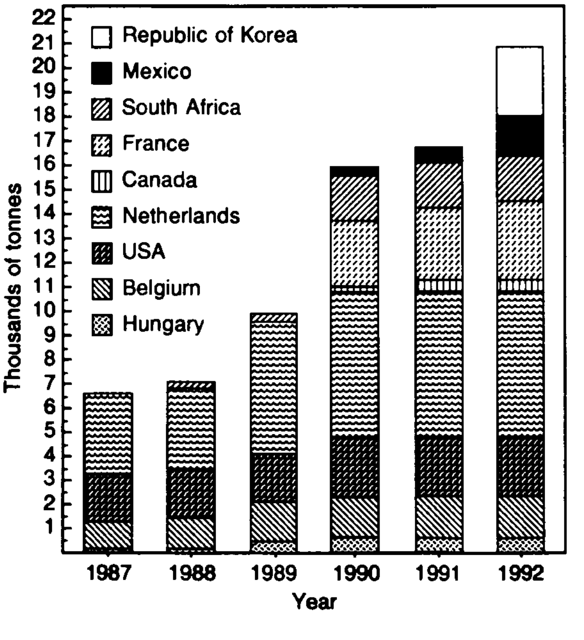
UNITED KINGDOM: a facility at Swindon started irradiating spices in 1991.

UNITED STATES: facilities at Rockaway, New Jersey (since 1984), Whippany, New Jersey (1984), and Irvine, California (since 1984) started irradiating spices; at Ames, Iowa (since 1993) unspecified products; and at Mulberry, Florida (since 1992) fruits and vegetables; a facility at Gainsville, Florida, is under construction.

VIET NAM: a facility at Hanoi started irradiating onions, potatoes, seafood, spices, rice, and dried tobacco leaves in 1991.

YUGOSLAVIA: a facility at Belgrade started irradiating spices in 1986.

Commercial irradiation of spices and vegetable seasonings in different countries



Country	Irradiated food items	Date of testing	Remarks
Argentina	onions, garlic, garlic powder	1985-1988	Consumers positive to irradiated foods. 95% like to buy irradiated onions
Bangladesh	potatoes, onions, dried fish, pulses	1984-1992	Consumers preferred irradiated foods
China	spirit from sweet potatoes, sausages, apples, potatoes, hot pepper products, oranges, pears	1984-1993	Consumers positive to irradiated products
Cuba	potatoes, onions, garlic	1988-1992	Consumers positive to irradiated products.
France	strawberries, Camembert	1987-1988 1991-1992	Consumers positive to irradiated products
Indonesia	dried fish	1986-1988	Consumers positive to irradiated products
Pakistan	potatoes, onions, dried fruits	1984-1992	Consumers positive to irradiated products
Philippines	onions, garlic	1984-1987	Consumers positive to irradiated products
Poland	onions, potatoes	1986-1988	90-95% of the consumers preferred irradiated foods
Thailand	nham (fermented pork sausage), onions, garlic	1986-1992	95% consumers preferred irradiated nham. Consumers positive to irradiated onions and garlic
USA	mangoes, papaya, apples	1986-1988	Consumers preferred irradiated mangoes and apples. Irradiated papayas sold at a ratio of 11:1 over non-irradiated papayas
	strawberries, oranges, grape fruits, tomatoes, onions and mushrooms	1992-1993	Irradiated strawberries sold at a ratio of 20:1 over non-irradiated ones. Consumers positive to others.
Yugoslavia	herbal extracts	1984-1985	Consumers positive to irradiated products

Market trials of Irradiated foods (1984-1993)

The once widespread use of ethylene oxide fumigation is being challenged, however, for health and safety reasons. Irradiation is slowly replacing it, especially in the European Community (where ethylene oxide fumigation was prohibited in 1991) and in its trading partners. The use of irradiation to ensure that the hygienic quality of spices is acceptable has increased significantly in recent years, i.e. from under 10 000 tonnes before 1990 to above 20 000 in 1993. *(See box.)* Most commercial irradiation of spices and vegetable seasonings is done in advanced countries, such as the Netherlands, France, Belgium, USA, and South Africa. Developing countries that produce and export these products would stand to gain if they would start processing them by irradiation.

Food trade. Despite the wide variety and large quantities of fruits and vegetables produced in developing countries, only a few tropical fruits (such as mangoes, papayas, and star fruit) are traded with advanced countries. Certain advanced countries, including the USA, Australia, Japan, and New Zealand, have strict plant protection and quarantine regulations which prohibit entry of fruits and vegetables from countries endemic with quarantine pests, especially fruit flies of the *Tephritidae* family. Fresh commodities from these countries have to be given approved treatments prior to importation.

Irradiation (0.15 kGy minimum) offers the most effective treatment to satisfy quarantine regulations. A low dose effectively provides quarantine security against any species of fruit fly without damaging the quality of most fruits and vegetables. Irradiation as a quarantine treatment for fresh fruits and vegetables has been endorsed by regional plant protection organizations. They include the North American Plant Protection Organization, European Plant Protection Organization, and the Asia and the Pacific Plant Protection Commission.

Refrigeration costs. Modern freezing technology not only facilitates wide trade in perishable foods (especially those of animal origin) but also enables foods to retain most of their freshlike properties. Because of the Montreal Protocol, the most widely used refrigerants, chlorofluorohydrocarbons (CFCs), will no longer be available for the refrigeration industry by the year 2000. Although alternative refrigerants exist, the ban on CFCs could result in higher costs of refrigeration which most developing countries would find increasingly difficult to afford.

Developing countries will have to consider suitable alternatives, as well as technologies that reduce dependance on refrigeration in general. Irradiation offers a strong possibility to reduce the use of refrigeration for a range of food items, if used in combination with other food preservation technologies. Some semi-dried fruit products have been developed with excellent sensory properties and successfully marketed in France in recent years. Irradiated dried fish has been market tested in some Asian countries with success. Radiation-sterilized meat, poultry, and seafood have been developed by the US Army Natick Laboratories and they have been widely used by astronauts since the early 1970s.

The use of shelf-stable products, including those developed through irradiation processing, will be highly valuable to developing countries, especially those which could not afford to invest in the cold chain for food distribution.

Consumer acceptance of irradiated food

There appears to be a perception by the food industry, consumer organizations, and even governments that consumers would be reluctant to purchase and consume irradiated food. Indeed, a number of consumer surveys conducted by organizations, especially during the 1980s when several Western countries were introducing regulations allowing the use of food irradiation, appear to support such perceptions.

It should be noted, however, that consumers have been exposed to misleading information during the past decade by some self-appointed "consumer groups" to oppose the introduction of food irradiation. Their sensationalized claims of "negative effects" from irradiated food were often highlighted through media reports. Following the Chernobyl accident in 1986, the public was further confused by the contamination of food by radionuclides in the food chain as compared with irradiation of food for preservation purposes.

Fortunately, starting in the mid-1980s, market tests of irradiated food were carried out in both advanced and developing countries. Such tests, together with correct dissemination of information about irradiated food, has helped to create a much better understanding among consumers of the safety, benefits, and limitations of this technology. A variety of irradiated food — including onions, potatoes, garlic, mangoes, papayas, strawberries, dried fish, and fermented pork sausages — were put on sale with labels indicating irradiation treatment, often alongside non-irradiated counterparts.

The positive outcome of the market tests was impressive; consumers were not only willing to purchase irradiated food but often bought them with overwhelming preference over the non-irradiated ones. The main factors which influenced consumers to purchase more irradiated food appear to be quality or safety. Thus, when consumers are offered irradiated food with proper information, they are willing to purchase it. *(See table.)*

Commercial applications

The number of countries which use irradiation for processing food for commercial purposes has been increasing steadily from 19 in 1987 to 27 today. Most of this increase in recent years has been in developing countries, which either need the irradiated products for their domestic market or see an opportunity to develop markets overseas.

The most significant event creating an awareness among governments, the food industry, and the media was the opening of the first commercial food irradiator in the USA in 1992. It is located at Mulberry, near Tampa, Florida. The facility has treated strawberries, other fruits, and some vegetables for spoilage control and marketed the products in the Miami and Chicago areas with great success. Irradiated strawberries outsold non-irradiated ones by a margin ranging from 10 to 1 to 20 to 1 depending on the time of sale. Apparently, consumers were attracted by the premium quality of "natural field ripe" irradiated products as compared with "nearly" ripe non-irradiated strawberries normally available to them. The sale of other irradiated produce, such as onions, mushrooms, and citrus, registered similar success to the sale of strawberries. Retail stores which carried out the sales also reported significant savings. Spoilage losses were reduced considerably, to about 2% for irradiated strawberries, compared to about 10% for non-irradiated ones.

Since September 1993, limited quantities of irradiated poultry also have been on sale in the United States with success. Over the past 5 years, irradiated food with proper labelling has been successfully sold at the retail level elsewhere as well, including China, France, South Africa, and Thailand.

A practical choice

The technology of food irradiation can provide developing countries with an additional weapon to combat high food losses and food-borne diseases, and to broaden trade markets for various food commodities. Increasing commercial applications in advanced countries are positive signs for the greater practical utilization of food irradiation in developing countries.

As the world's population grows and additional demands are placed on our agricultural resources, all available technologies to safely process and preserve food will have vital roles to play, both in health and economic terms. In many cases, irradiation could be a practical choice for developing countries. ❒

Radiation applications and waste management: Taking the final steps

Countries are receiving practical guidance and support for safely managing radioactive sources after their beneficial use

by C. Bergman and B.G. Pettersson

Reported radiation accidents have caused about 20 fatalities among innocent members of the public due to improper handling and storage of spent radiation sources. Against this background, the IAEA has developed a range of services for assisting countries interested in building effective systems for the safe control, management, and disposal of these sources.

This article focuses on nuclear applications that involve the use of sealed radiation sources. It highlights common applications of sealed sources and discusses principles and techniques for safely managing them after use.

Applications of sealed radiation sources

Sealed radiation sources of various types and activities are in widespread use in virtually all IAEA Member States and the use is increasing. The largest diversity of radionuclides and activity is found in industrial applications.

In the medical field, both the number of nuclides and the activity range is more limited. Research applications can involve almost any radionuclide, the activity of which is usually in the lower range. The notable exception is radiation sources in irradiators for research related to biology.

Radiation sources in industry. A large proportion of radiation sources are used for process or quality control. Typical examples are industrial radiography and industrial gauges.

The purpose of radiography is to detect any imperfection, voids, or alien material in the sample being investigated. Radiography techniques are used in the construction industry, mainly for checking the quality of welds, and in the steel industry for verifying the quality of manufactured items such as piping and cast iron. The principal nuclides used are cobalt-60 and iridium-192.

Radiography units comprise a housing for shielding purposes and a mechanism to bring the source into the exposure position. Units used in the construction industry are portable, while those used in the steel industry are of fixed types, often installed in specially built enclosures.

Industrial gauges broadly include units for determining the thickness, density, or moisture content of a particular material during or immediately after production or for monitoring levels in vessels or tanks. Beta sources (strontium-90 and krypton-85) are used for thickness/density measurements of paper, plastics, and thin, light metals. Gamma sources (caesium-137 and iridium-192) are needed for the more dense materials such as steel plates. Caesium-137 and cobalt-60 are commonly used in level gauges.

More specialized gauges for determining the density, porosity, and moisture or hydrocarbon content of geological structures or building material use americium-241/beryllium and caesium-137.

High-activity cobalt-60 and caesium-137 sources are used in specially designed facilities for sterilization of gloves, syringes, and similar medical products. They also have applications in the preservation of foodstuffs.

Radiation sources in medicine. The two principal applications of radiation sources in medicine are brachytherapy and teletherapy. Brachytherapy is a term used to describe the interstitial or intracavitary application of radioactive sources by placing them directly in, or very near, the tumour. The application may be done manually or by remote control.

When brachytherapy started, only radium-226 was in use. Replacement programmes have made the vast majority of the radium sources redundant, but limited use of radium still occurs. Current applications mainly involve the use of

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caesium-137, cobalt-60, and iridium-192. Additional applications include superficial treatment of skin and ophthalmic lesions (strontium-90).

In teletherapy, high-activity cobalt-60 or caesium-137 sources are used. The sources are invariably mounted in specially designed shielded housings and used in shielded enclosures.

Radiation sources in research. Applications of sealed radiation sources in research are highly varied. Almost any radionuclide can find a use in research work. Many of the radiation sources are of low activity and/or of short half-life.

The notable exceptions include high-activity sources for biological research. Cobalt-60 and caesium-137 sources are used for irradiation or sterilization of materials and plants, and americium241/beryllium or caesium-137 sources are used for density and moisture measurements in agricultural research. Additionally, radium-226 and radium-226/beryllium sources may still be in use for instrument calibration purposes or in university training programmes. *(See tables.)*

Waste management principles

The primary reason for the hazards of radioactive material is its inherent characteristic of emitting ionizing radiation. That characteristic is independent of whether the material, the radiation sources, is in use or not. A radiation source, no longer to be used and for that reason considered as radioactive waste, is therefore as potentially dangerous as the corresponding source still in use. The fact that a radiation source in use is often considered as a valuable resource makes the owner more apt to exercise control of it than if the source is spent and thus represents a negative resource (cost for disposal). This fact, and that there is no interest to save it for future use, often makes a spent radiation source more dangerous than one in use.

The primary objective of radioactive waste management is to implement an effective control, management, and disposal system that ensures the safety of people and of the environment. The control, which must have a firm base in a national regulation and enforcement system, needs to cover every source of significant risk from cradle to grave.

To meet requests from Member States on this subject, the IAEA's Waste Management Section is finalizing a radiation source database package. It consists of a database which can be operated on modern personal computers and includes an operating manual. After proper testing, the package will be offered to all Member States as a tool for keeping track of their sealed radiation sources. The prime target group is national regulatory bodies. It also can be used by individual organizations, such as a national waste management body, which have a large number of radiation sources.

Radiation sources in industry

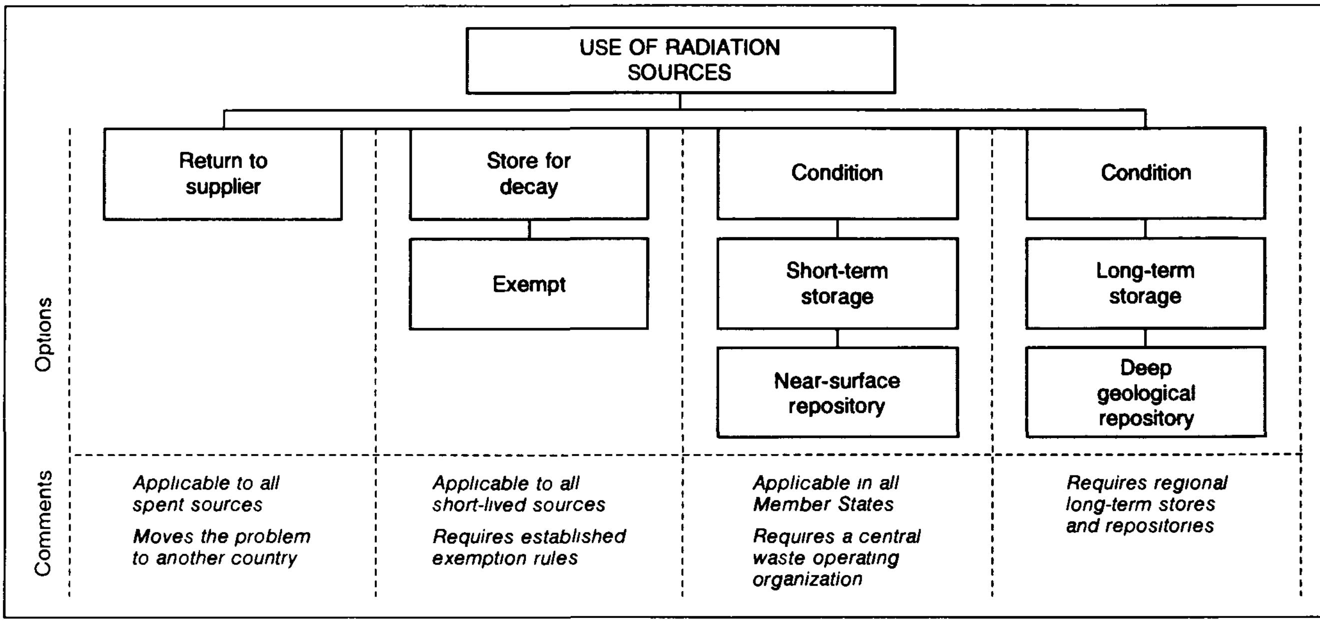
Application	Radionuclide	Source activity
Industrial radiography	Iridium-192	0.1 - 5 TBq
	Cobalt-60	0.1 - 5 TBq
Well logging	Americium-241/Beryllium	1 - 800 GBq
	Caesium-137	1 - 100 GBq
Moisture detector	Americium-241/Beryllium	0.1 - 2 GBq
Conveyor gauge	Caesium-137	0.1 - 40 GBq
Density gauge	Caesium-137	1 - 20 GBq
	Americium-241	1 - 10 GBq
Level gauge	Caesium-137	0.1 - 20 GBq
	Cobalt-60	0.1 - 10 GBq
Thickness gauge	Krypton-85	0.1 - 50 GBq
	Strontium-90	0.1 - 4 GBq
Static eliminators	Americium-241	1 - 4 GBq
	Polonium-210	1 - 4 GBq
Lightning preventers	Americium-241	50 - 500 MBq
Sterilization and food preservation	Cobalt-60 Caesium-137	0.1 - 400 PBq 0.1 - 400 PBq
Calibration facilities	Cobalt-60	1 - 100 TBq
	Caesium-137	1 - 100 TBq

Radiation sources in medicine

Application	Radionuclide	Source activity
Manual brachytherapy	Caesium-137	50 - 500 MBq
	Radium-226	30 - 300 MBq
	Cobalt-60	50 - 500 MBq
	Strontium-90	50 - 1500 MBq
Remote after-loading brachytherapy	Cobalt-60 Caesium-137	about 10 GBq 0.03-10 MBq
	Iridium-192	about 400 GBq
Teletherapy	Cobalt-60	50 - 1000 TBq
	Caesium-137	500 TBq

Radiation sources in research

Application	Radionuclide	Source activity
Calibration sources	Many different ones	less than 0.1 GBq
Calibration facilities	Caesium-137	less than 100 TBq
	Cobalt-60	less than 100 TBq
	Californium-252	less than 10 GBq
Irradiators	Cobalt-60	less than 1000 TBq
	Caesium-137	less than 1000 TBq



Options for waste management of radiation sources

To meet the waste management objective, it is necessary to have a complete system for collection, transport, treatment, conditioning, storage, and final disposal of radiation sources that is adapted to national needs. It is outside the scope of this article to go into the technical details on how the different steps can be implemented, but the different approaches for the final steps will be elaborated.

There are four ways in which the final step in waste management can be taken. *(See figure.)* These are (1) return of the spent radiation source to the supplier; (2) storage to allow time for decay and subsequent exemption from regulatory control; (3) conditioning, storage, and disposal in a near surface repository; and (4) conditioning, storage for a long period of time, and disposal in a deep geological repository.

Return to supplier. A simplified procedure may be described as follows: *The waste producer sends the sealed source back to the supplier as soon as it is no longer to be used. Information is given to the regulatory body. Approval and/or a license might be required for the transport and export based on national legislation.*

Sealed radiation sources represent a special problem because of their small sizes and often high dose rates on the surface. Additionally, they frequently appear in countries which do not have a waste management infrastructure suitable for managing the disposal of the sources. The producer of a radiation source often has the best possibilities to safely store the radiation sources it produces. Furthermore, the producer may have the possibility to refurbish a spent source by re-encapsulation of the source for reuse. (Such operations can normally not be done by the user).

Through the IAEA's Waste Management Advisory Programme (WAMAP), advice on the return-to-supplier option is provided to national authorities which do not have full waste management capabilities, especially in developing countries. As a result, national legislation today often requires a clause in every purchase contract for sealed radiation sources that permits the buyer to return it to the supplier when it no longer is of any use.

The option to return a spent radiation source to the supplier should, however, only be used when it is the optimal solution; it is no final solution since it only moves the problem from one country to another. In countries having excellent possibilities for final disposal of spent sources, there is no need to use the option since in these cases it will increase rather than decrease the total risk from the radioactive waste.

Exemption from regulatory control after storage for decay. A simplified procedure may be: *The waste producer places the waste in a suitable decay store and keeps it there under proper surveillance until it has reached levels for exemption (clearance), at which time it is removed and disposed of as if it were not radioactive.*

The inherent characteristics of radionuclides to decay, and eventually to result in stable nuclides, makes it attractive to store radioactive waste until the established exemption level has been reached. Although a very useful option, there are prerequisites to be met and limitations to its applicability.

Half-lives of the radionuclides in the waste must be short to allow the exemption level to be reached in a reasonable time, at most a few years. In practice, the half-life must thus not exceed one or at most a few months. For example, with a half-life of one month, the activity will be reduced by a factor of 4000 in one year and 16 million in 2 years.

In order to be able to practice this option, it is necessary to have exemption levels established by the national regulatory body. There are no international derived exemption levels. However, there has been agreement on the basic principles for exemption, and the IAEA is now preparing appropriate guidance.

The main advantage with this option is that it can be done by every waste producer, avoiding unnecessary transport of radioactive materials. If properly applied, the option also prevents storage of unnecessarily large quantities of radioactive waste, since the wastes which have reached exemption levels can be removed.

To implement the option successfully, there needs to be an operational system of waste segregation to ensure that the short-lived waste is properly separated from the long-lived wastes. Radionuclides having the longest half-lives in a waste package will determine the storage time required for decay.

Although suitable for almost all radioactive waste generated in diagnostic nuclear medicine, this option has only limited application for sealed radiation sources.

Short-term storage followed by near surface disposal. A simplified procedure may be: *The waste producer transports (before or after conditioning) the waste to a national central waste processing and storage facility for subsequent disposal in a near-surface repository.*

Radioactive wastes with half-lives below the order of 30 years can normally, after being properly conditioned, be disposed of in a shallow land repository. Establishment and operation of these repositories is technically mature and there is no major disagreement among experts on the acceptability of the concept, provided that proper limitations and conditions are given for the waste and the repository. There might still be disagreement among politicians, people requiring "no risks" and those who, for whatever reasons, are against nuclear energy.

Almost every country can, in principle, establish a near-surface repository on its territory for disposing of short-lived waste generated in the country. Since the quantities would be small, it is normally not justified to have more than one, or very few, repositories in a country. The cost for a repository for small quantities of short-lived waste is not unacceptable even for small countries, since simple solutions will be adequate for a small waste producer.

Radioactive waste for such storage or disposal needs to be properly conditioned. These operations often can not be done by every waste producer, but rather by a central waste operating organization. The IAEA has developed a generic description of a waste treatment and storage facility, intended for a country having a nuclear research centre with a research reactor. The package includes detailed descriptions of the facility and the equipment used, lay-out drawings, and a generic safety assessment of the facility. The package was recently made available to IAEA Member States, and has already been used for new central waste management and storage facilities. A similar design package for conditioning and interim storage of spent radiation sources has recently been completed and will be made available to Member States in 1994.

To implement the option, a country has to establish a central waste processing and storage facility at which the waste can be stored until disposal in a near-surface repository. The country will, sooner or later, have to establish such a repository for its short-lived radioactive wastes.

Long-term storage followed by deep geological disposal. A simplified procedure may be: *The waste producer transports (before or after conditioning) the waste to a national central waste processing and storage facility. If required, the waste is later transported to a regional store for long-term storage awaiting deep geological disposal.*

There is waste from nuclear applications which is not suitable for near-surface disposal owing to its long half-life and activity. These wastes notably include sealed sources containing radium-226 and americium-241. As discussed in the IAEA's 1991 report *The Nature and Magnitude of the Problem of Spent Radiation Sources* (IAEA TECDOC-620), it is expected that those radiation sources should be disposed of in deep geological repositories.

Establishment of a deep geological repository is extremely expensive. The cost can not be borne by countries having only sealed radiation sources for deep geological disposal. A country having nuclear power must, on the other hand, establish such a repository. Since the activity of the sealed radiation sources is negligible in comparison to what exists in spent fuel or high-level waste, one suggested solution is to dispose of the long-lived sealed sources, including those from foreign countries, along with the high-level waste from the nuclear power reactors.

The co-disposal of sealed sources from one country with high-level wastes in another country will require international or bilateral agreements. Although there is no urgency in having such agreements, considering that deep geological repositories will not be established until well into the next century, it might still be wise to initiate the process, which most likely will be both difficult and time consuming.

Until the availability of deep geological repositories, interim stores for the conditioned waste are needed which can be safely operated for many decades. Considering that the volumes are very small and the requirements for interim stores are high, it is also desirable to find regional solutions for the long-term storage of conditioned long-lived sealed sources. The IAEA has initiated a process for establishing such a regional approach.

Much national legislation today prohibits import of radioactive waste for disposal and there are political statements to the effect that "all countries shall take care of and dispose of their own waste". The background of those requirements and statements, however, is the fear of having the large quantities of radioactive waste from the nuclear power plants and not the small quantities of radioactive waste from, for example, medical applications.

The final steps in managing long-lived spent radiation sources are not yet at hand. Before they can be taken, decisions will be required on the need for regional long-term stores and international or bilateral agreements on the co-disposal of sealed sources and high-level wastes from nuclear power reactors.

The range of radiation applications includes radiography, typically used in the airline and steel industries for reasons of safety and quality control. *(Credits: Tech/Ops; Dahlström, Bildhuset Sweden)*

Challenges ahead

It is possible today to manage, on a national basis, all radioactive waste generated from nuclear applications with the exception of a few long-lived sealed radiation sources which require international solutions. If it actually can be accomplished in a country is a question of the availability of national expertise and resources. The IAEA is assisting its Member States to give them that possibility. However, there is still a long way to go before most Member States will have been able to establish an appropriate national waste management infrastructure. ❐

The "second nuclear era": A perspective from Russia

As are many other countries, Russia is working on the development of new nuclear power plants that incorporate enhanced safety features. At the same time, it is realized that over the next 20 years the expansion of nuclear power can hardly be expected in a country suffering a deep crisis, with a low standard of living yet with *per capita* energy production higher than in Germany or France. Even doubling the nuclear capacity would influence less than 3% of Russia's fuel balance, making it incommensurate with the extent of problems now facing the country and its fuel and energy economy.

The main goals of nuclear power and arguments in favour of its development — in Russia as in most other countries with nuclear programmes — are lying ahead in the century to come. The objectives of the next stage — the "second nuclear era"— should be to provide a radical solution to the looming problems of environment, resources, and transportation, as well as social and international problems associated with the inevitable growth of energy demands.

Need for a new concept

Today, however, nuclear experts do not venture to come out with a definite concept of large-scale nuclear power development, for various reasons. The absence of such a concept is detrimental not only to nuclear power's future development but also to its current development, stripping it of a clear perspective. It is worth looking at some of the reasons for this.

Conventional nuclear technologies basically were shaped 30 to 40 years ago, proceeding from notions prevalent then. The generally favourable experience with military nuclear engineering and with the first nuclear power plants gave rise to a certain "engineering philosophy" of safety, a belief in the omnipotence of engineered means for its assurance.

The accidents at Three Mile Island in 1979 and at Chernobyl in 1986 shook this conviction and brought about a new nuclear philosophy whose key words —"inherent safety"— were introduced into the nuclear vocabulary by Alvin Weinberg. New nuclear designs were substantially improved, to the extent that there now is hardly a single reactor type which would not be described as "inherently safe", with the resultant devaluation of the term. However, the potential risks of accidents with sudden criticality excursions, loss of coolant, fires, and explosions are not eliminated for the conventional reactor concepts. They are intrinsic in the basic conceptual features of these designs. They do rely on some elements of inherent safety, but a decrease in the probability of dangerous accidents calls for building up engineered systems and barriers, and for imposing extraordinary requirements on the quality of equipment and skills of operating personnel. This makes reactors more complicated and expensive, which in turn impairs their competitiveness and narrows the applications in developing countries where the need for energy production is the greatest.

The safety improvements incorporated in reactors, and their resultant good service record, during this "post-accident period" does enable the prolongation of the "first nuclear era" by using traditional nuclear technologies. However, the validation of reactor safety by probabilistic means, and by deterministic means for a certain class of accidents, is ultimately limited and not sufficiently convincing. Such validation is not convincing for the public, especially since it rests on knowledge of the probability theory. People will hardly be reconciled to the possibility of even one new major accident at a nuclear power plant, no matter how much the nuclear industry talks about the casualties from traffic accidents or chemical releases. They demand that any new technology, nuclear or non-nuclear, should improve the quality of life, and primarily the safety of life.

This imperfection in the validation of reactor safety, which actually results from the imperfection of the modern nuclear technologies themselves, makes it risky to espouse a new concept. The situation may doom nuclear power to sluggish evolution based on conventional technologies that are improved on the basis of slowly accumulating experience and do not allow extrapolation over long periods of time.

A way out of this state, which borders on stagnation, lies in developing and demonstrating to the public a new nuclear technology that offers consistent implementation of inherent, to wit deterministic, safety. Without a new deterministically safe technology, the "second nuclear era" may well remain just a fine-sounding phrase. The nuclear industry needs practical action to find and develop a new technology, comparable to the effort to ensure safe operation of existing nuclear power plants and to provide improved facilities over the near term.

Initiatives in Russia

In Russia, attempts already have been made to work out the new requirements for such a technology. They formed the basis for a new line of research and development, known as "unconventional concepts of inherently safe nuclear power plants", included in the State energy programme for which a competition of projects was announced.

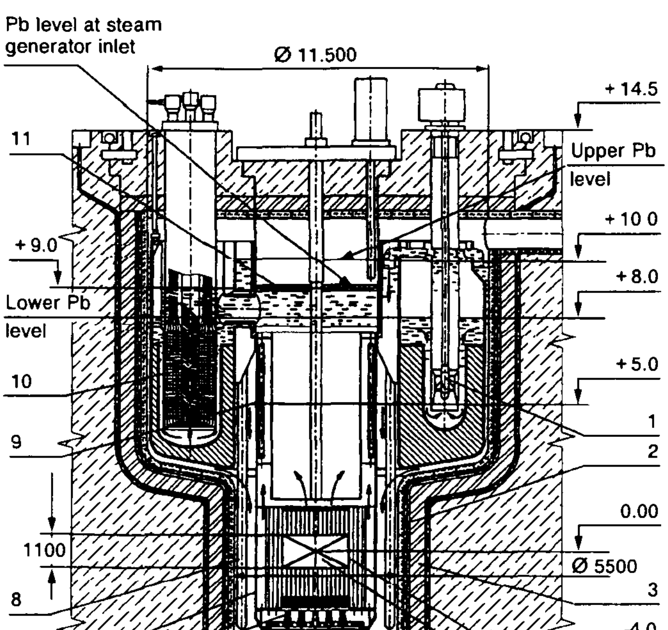
Put in the most general form, the goal of the new development is to achieve harmony between safety, fuel breeding, and economy, using their deep inner relationship. It is inherent safety that is a key to attaining this harmony. The basic requirements of the new technology, which are going to be refined and particularized, include:

- the exclusion of fuel failures and major radioactive releases into the environment during any accidents that can occur within the laws of nature and technical possibilities. Some sequences of events, whose probability can be reliably assessed at a maximum and will be acceptable to society, are perhaps the only exceptions;
- the reduction in specific consumption of natural uranium by at least five to ten times compared to consumption levels in modern light-water reactors;
- the provision for the disposal of radioactive wastes without disturbing the natural radiation equilibrium, that is at levels equivalent to the radioactivity of the natural uranium and its decay products extracted from the Earth;
- the minimization of long-distance transportation of fissile and radioactive materials, and the exclusion of the use of uranium and plutonium for nuclear weapons, in conjunction with international and national safeguards;
- the retention of the cost of nuclear energy production at the level of modern light-water reactors.

Undoubtedly, efforts to develop a deterministically safe nuclear technology will lead to a number of new reactor concepts, and to a long-term development programme. It is important, however, to make sure that there is at least one concept capable of meeting the specified requirements that does not go too far beyond today's technological capabilities and thus allows implementation in the foreseeable future.

The quest in Russia, spurred by Chernobyl, has shown that such a concept can be produced by combining the technologies that are well established in civilian and military nuclear engineering. Liquid metal cooled fast reactors that work on the uranium-plutonium cycle appear to come closest to the ideal of deterministic safety, and they are preferable for centralized electricity production at large stations in terms of safety and economy. This does not preclude limited use of thermal reactors and the thorium-uranium cycle, which is preferable for supplying local demands for heat and electricity in remote regions, which are vast in Russia.

To utilize the potential of fast reactors for ensuring the highest safety levels and economic efficiency, the Russian concept considers replacing sodium with lead, which is nonreactive and has an extremely high boiling point. This is akin to the lead-bismuth eutectic employed in Russian submarine reactors for more than 30 years. The choice of sodium then was largely dictated by criteria that no longer are imperatives.



Schematic of the Russian concept for a new reactor: 1) pump; 2) thermal shielding; 3) heat resistant concrete; 4) control elements; 5) core; 6)support posts; 7)separating shell; 8) air-cooled channel with fission products; 9) fuel storage; 10) steam generator; 11) rotary plug.

The concept overall draws upon many ideas and technologies available in the development of current fast reactors, owing much in particular to achievements with the integral fast reactor at the Argonne National Laboratory in the United States. Consideration further is being given to the option of locating the reactor underground, so as to prevent external impacts, and to the long-term use of nuclear plant sites through renovation of reactors. Plans also are being made for storage of fission products in the reactor vault for up to 200 years and for their ultimate disposal at radioactivity levels equivalent to that of natural uranium and its decay products extracted from the Earth.

The calculations, design, and experimental studies performed for such reactors, at power levels of 300, 600, and 1000 megawatts, testify to the feasibility of their creation within reasonable timespans. The results of conceptual studies, including calculations, design work, and experiments on lead circuits and critical assemblies, are being prepared for publication shortly.

The development of a deterministically safe nuclear power technology that promises a radical solution to energy problems facing the world is a universal challenge, which can bring international nuclear co-operation to a new height. It is a goal worth considering seriously, primarily by the world's nuclear communities.— **by E. O. Adamov and V.V. Orlov, Research and Development Institute of Power Engineering, Moscow.** *Full details are available from the authors at the Research and Development Institute of Power Engineering, P.O. Box 788, Moscow 101000, Russian Federation.*

IAEA safeguards inspections resume in DPRK

A team of IAEA safeguards inspectors carried out inspection activities in March 1994 at declared nuclear facilities in the Democratic People's Republic of Korea (DPRK).

The mission followed a series of developments in late 1993 and early 1994 concerning *inter alia* the resumption of IAEA safeguards inspections in the DPRK. They include an agreement reached by the IAEA and DPRK on 15 February 1994 on the scope of the inspection now under way, and the IAEA Board of Governors consideration of DPRK safeguards implementation at its meetings 21-23 February.

The aim of the inspection was to verify that nuclear material in the DPRK's seven declared facilities has not been diverted since the IAEA's earlier inspections. Inspectors additionally undertook certain measures, such as reloading of cameras and changing of seals, to facilitate future verification.

At its February 1994 meetings, the IAEA Board, following its consideration of a report by Director General Hans Blix, expressed its "continuing, deep concern at the seriousness of the situation" and urged the DPRK to co-operate fully with the IAEA. In reaffirming its support of the IAEA's continuing efforts, the Board particularly noted that the agreement on inspection of seven declared sites was "only a first step toward resolution of all the nuclear issues", including the DPRK's full compliance with its obligations under the safeguards agreement that entered into force in April 1992.

The report to the Board by Dr. Blix reviewed and placed into context the Agency's extensive contacts with DPRK authorities over the past two months, since the Board last considered the matter at its meeting in December 1993.

As he had informed the Board in December, Dr. Blix in his February Board statement once again noted that the absence of periodic inspections and related activities has damaged the "continuity of knowledge" about the DPRK's declared nuclear activities. As a result, he said, the safeguards system now in place "can no longer be said to provide any meaningful assurance of non-diversion of nuclear material and of the peaceful use of the declared installations in the DPRK".

Results from the forthcoming inspection (since conducted in March) can "at least partly compensate for the loss of knowledge that has occurred", he told the Board in February. He underlined, however, that the agreed inspection activities deal only with material in declared facilities which the IAEA has visited before. They do not include visits to additional sites and access to information needed to clarify inconsistencies which exist between the DPRK's initial declaration of nuclear material and IAEA findings.

"Without visits to additional sites and access to additional information, there would be no way to verify the correctness and assess the completeness of the initial declaration," he said.

He expressed the hope that consultations on the resolution of this matter would be possible following the inspection activities at declared facilities.

Conference on nuclear safety convention in June

A working group of legal and technical experts has finalized a draft international nuclear safety convention for adoption at a diplomatic conference being convened in June 1994 under IAEA auspices in Vienna.

The draft text reflects the broad agreement reached by the experts and has the overall support of the group, which was formed in February 1992. Experts from more than 50 countries, as well as the Commission of the European Communities, Nuclear Energy Agency of the Organization for Co-operation and Development, International Labour Organization, and the IAEA took part in the work. The group's seventh and final meeting took place 31 January to 4 February 1994 at IAEA headquarters.

As finalized, the draft convention's scope of application applies to nuclear installations defined as land-based civil nuclear power plants. The safety-related obligations it places upon parties are based to a large extent on fundamental principles. They include in particular the obligation to establish and maintain a legislative and regulatory framework for nuclear installations and the obligation to implement a number of measures based on general safety considerations regarding, for example, the availability of financial and human resources, the assessment and verification of safety, quality assurance, and emergency preparedness.

Other obligations concern technical aspects of nuclear plant safety, including siting, design, construction, and operation. Contracting parties also are required to provide reports on the implementation of the Convention. The IAEA is identified as the Secretariat of the Convention and the Director General its Depositary.

The convention is an outgrowth of recommendations issued in early September 1991 by an international conference on the safety of nuclear power organized by the IAEA. That conference urged consideration of an integrated international approach to all aspects of safety, referring to the potential value of step-by-step approach to a framework convention on nuclear safety. The recommendation subsequently was embodied in a resolution of the IAEA General Conference, which requested additional preparations toward a possible convention. In February 1992, the IAEA Board of Governors authorized the formation of the group of experts who prepared and finalized the draft nuclear safety convention.

Nuclear inspections in Iraq

Under the close supervision of IAEA inspectors, the second and final consignment of highly enriched uranium (HEU) in the form of irradiated nuclear fuel has been removed from Iraq. The action completed the removal of declared stocks of nuclear-weapons-grade material from Iraq.

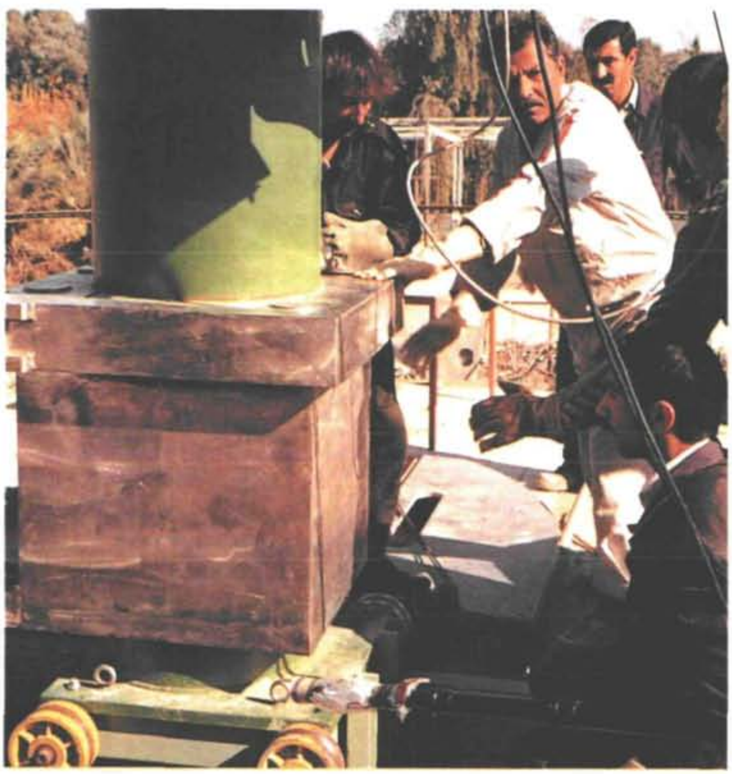
The irradiated fuel was removed under a contract with the Russian Ministry of Atomic Energy and a United States subcontractor which supplied specially designed transport casks capable of withstanding severe accident conditions. The Iraqi Atomic Energy Commission provided all necessary assistance. Substantial technical problems had to be overcome to remove the irradiated fuel, some of which was buried under the rubble of a research reactor destroyed during the Gulf War.

The irradiated fuel was removed in two shipments under the IAEA's close supervision; the first shipment took place on 4 December 1993 and the second on 12 February 1994. In both cases, the material was transported from the Iraqi nuclear centre at Tuwaitha by road to Habbaniya airfield west of Baghdad, and then flown out of Iraq in an Antonov 124 directly to Yekaterinburg in Russia for onward transport to a reprocessing facility at Chelyabinsk. After the dilution to lower enrichment at the Chelyabinsk facility, the residual material will be available for sale under IAEA supervision for use in peaceful nuclear activities. Reprocessing of the fuel is expected to take six months.

The removal of Iraq's nuclear-weapons-usable material, namely HEU and plutonium, stands among operations undertaken by the IAEA since 1991 with the co-operation and assistance of the United Nations Special Commission on Iraq under terms of UN Security Council resolutions. In 1991, following inspections in Iraq, IAEA inspection teams removed gram quantities of plutonium that Iraq was found to have separated, and they supervised the removal of nuclear material, including fresh nuclear fuel, that was part of Iraq's declared inventory under IAEA safeguards.

Ongoing activities in Iraq include the verification of information provided by Iraqi authorities about foreign technical advice and suppliers, quantities, and locations of materials and equipment. Technical talks also continue with Iraqi authorities regarding the satisfactory implementation of the IAEA's ongoing monitoring and verification plan which now is gradually being put into effect. The plan includes, *inter alia*, periodic radiometric surveys of Iraqi surface waters to provide added assurance about the country's nuclear activities.

Irradiated fuel transported from Iraq.
(Credit: V. Mouchkin, IAEA)



Strengthening the safeguards system

The IAEA is evaluating a number of measures and recommendations for improving the cost effectiveness of its safeguards system. The measures under evaluation, through a 2-year-development programme known as "93+2", were recommended by the Standing Advisory Group on Safeguards Implementation (SAGSI). SAGSI is comprised of experts appointed in consultation with governments to advise the Director General on effectiveness and efficiency in the safeguards system.

The IAEA programme is designed to further assess, develop, and test SAGSI's recommendations and related measures, including evaluations of their technical, legal, and financial implications. Six areas are being evaluated: cost analysis of present safeguards implementation; assessment of potential cost-saving measures; environmental monitoring techniques for safeguards application; increased co-operation with State Systems of Accounting and Control and other measures for improving the cost-effectiveness of safeguards; improved analysis of information on a State's nuclear activities; and enhanced safeguards training.

The results from evaluations will be integrated into proposals for more effective and efficient safeguards that are expected to be made to the IAEA Board of Governors in early 1995.

An integral part of the programme is the active participation of a number of countries in technical areas, including environmental monitoring field trials. Countries that have offered assistance include Argentina, Finland, France, Germany, Hungary, Indonesia, Republic of Korea, Russia, South Africa, and Sweden. Two field trials of environmental monitoring already have taken place, one in Sweden which collected samples at 35 locations around five nuclear facilites, and the other in Hungary, which sampled the Danube River near the Paks power station and in the vicinity of Budapest.

Overall, the programme builds upon actions already taken to strengthen the IAEA's safeguards system. These include Board decisions in late 1991 and early 1992 regarding the early provision and use of design information, and a voluntary reporting scheme on imports and exports of nuclear material, and exports of specified equipment and non-nuclear material.

Ban on sea dumping of radioactive waste

A ban on the dumping of low-level radioactive wastes at sea took effect in late February 1994, in the process modifying the IAEA's technical advisory role under the governing international convention. The ban was imposed in November 1993 when Contracting Parties to the London Convention — officially called the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter — adopted an amendment to the Convention. The amendment entered into force as of 20 February 1994, according to the London-based International Maritime Organization (IMO), which administers the Convention. The IMO noted that the Russian Federation has announced it will not accept the amendment although it will "endeavour to avoid pollution of the sea by dumping of wastes and other matter".

As amended, the London Convention effectively prohibits the dumping of all types of radioactive wastes at sea. Previously only sea dumping of high-level wastes was prohibited, while sea disposal of low-level radioactive wastes was temporarily suspended under a voluntary moratorium adopted in 1983. The IAEA was charged with defining high-level wastes and other high-level radioactive matter unsuitable for dumping at sea, and with providing guidance to national authorities in issuing special permits for sea disposal of low-level radioactive wastes.

Now that a total ban has taken effect, the IAEA's new technical role will be to define radioactivity levels below which material may be considered "non-radioactive" (known as "de-minimis" or "exempt" levels) for purposes of the Convention. The IAEA also will continue to consider requests from countries for assistance with special problems relating to the safe disposal of radioactive wastes, so as to help them meet their international obligations under the Convention. Toward this end, the IAEA is expected to participate in an expert group formed under the Convention to evaluate the need for supporting Russia to complete facilities for safely managing low-level liquid radioactive wastes so as to avoid future sea dumping.

The IAEA also will continue to administer the International Arctic Seas Assessment Project (IASAP). Its aim is to evaluate the health and environmental risks posed by the dumping of radioactive wastes in the Arctic Seas, and in developing and maintaining an inventory of radioactive materials entering the marine environment.

The London Convention has been adopted by more than 70 countries. It generally bans the dumping into the sea of certain substances and permits the dumping of other materials only if certain criteria are met.

More information on the IAEA's role under the Convention may be obtained from the IAEA Division of Nuclear Fuel Cycle and Waste Management. Information about the Convention itself is available from the IMO, 4 Albert Embankment, London SE1 7SR, United Kingdom.

The DECADES project

As countries define their energy programmes will evolve over the coming decades, interest is growing in the application of improved data, analytical tools, and methods for comparatively assessing different options for the generation of electricity, particularly their health, environmental, and economic aspects.

As a means to address the issues, the IAEA and eight other organzations are carrying out an inter-agency project on databases and methodologies for comparative assessment of different energy sources for electricity. Called DECADES, the project was initiated in 1992. Other participating organizations are the United Nations Industrial Development Organization; Organization of Petroleum Exporting Countries; International Institute for Applied Systems Analysis; Commission of the European Communities; Economic and Social Commission for Asia and the Pacific; International Bank for Reconstruction and Development (World Bank); Nuclear Energy Agency of the Organization for Economic Co-operation and Development; and World Meteorological Organization.

As part of the project, the IAEA launched a co-ordinated research programme (CRP) in December 1993. It focuses on case studies to assess and compare the potential role of nuclear power and other options reducing the emissions and residuals from electricity generation. The purpose of the case studies is to demonstrate the use of available databases and computer tools, including some being developed by DECADES, in studies to support decision-making in the electricity sector. Some 15 countries already have submitted proposals for their participation in the CRP, which will run through 1995. Results from the CRP, as well as from additional case studies being done by organizations participating in DECADES-related activities, are scheduled for presentation in September 1995 at an international symposium on electricity, health, and the environment being planned in Vienna.

The DECADES project is part of the global response to energy and environmental concerns of the 1990s. Agenda 21 adopted by the United Nations Conference on Environment and Development in June 1992 particularly notes the role of energy in sustainable development and the importance of global co-operation to help developing countries build environmentally benign energy strategies. Since there is no single worldwide intergovernmental organization that comprehensively covers these and other global issues of energy and electricity generation, the DECADES project provides a useful means to combine the expertise of various international and regional organizations.

Transport of radioactive waste

More than 80 experts from IAEA Member States and international organizations attended a seminar on the transport of radioactive waste in Vienna 21-25 February 1994. The meeting provided information for the revision of the IAEA's *Regulations for the Safe Transport of Radioactive Waste* (IAEA Safety Series No. 6) and promoted dialogue between national operators and regulators in both the transportation and waste management fields.

Papers presented during the seven scientific sessions covered the following areas: IAEA activities in radioactive waste transport; national experiences and recommendations for international transport regulations; waste transport and handling; waste generation volumes, characteristics, and disposal requirements; risk assessment; and transport and waste packages. Participants discussed proposed amendments related to the transport of materials having a low specific activity and surface-contaminated objects. They expressed support for efforts to ensure compatibility between requirements for waste management and those for transportation, especially with regard to the packaging of materials.

The IAEA is heavily involved in the review and revision process of its transport regulations for radioactive waste. In 1996, it plans to issue a new revised edition reflecting the latest scientific and technological developments, taking into account factors such as the new regulations of the International Commission on Radiological Protection; more stringent packaging requirements for the shipment of large quantitites of radioactive material by air; and other changes approved for adoption under the IAEA's continuous review and revision process. Information presented during the seminar will be used for the next meeting of the revision panel for Safety Series No. 6 scheduled in Vienna 10-14 October 1994.

International safeguards symposium

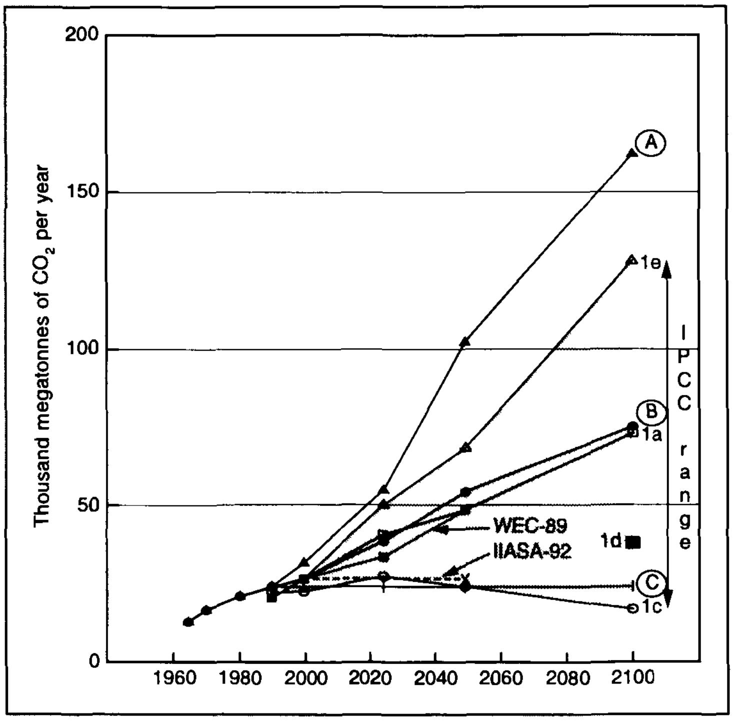
Measures being taken to strengthen safeguards on nuclear materials and facilities were among the featured topics at an international safeguards symposium in Vienna 14-18 March 1994.

The IAEA organized the meeting in cooperation with four other organizations: the American Nuclear Society, European Safeguards Research and Development Association, Institute of Nuclear Materials Management, and Nuclear Society International, based in Moscow. Safeguards specialists and governmental representatives from more than 50 countries attended the symposium.

Topics for discussion included strengthened and more cost-effective safeguards; experience in special verification situations; safeguards for plutonium, uranium enrichment, fuel fabrication, and spent fuel storage facilities; containment and surveillance technologies; safeguards approaches and evaluation; and regional and national systems for accounting and control of nuclear materials.

Corrections

Some copies of the English language edition of the December 1993 edition of the *IAEA Bulletin* (Vol. 35, No. 4) contained editorial errors.



On page 54, in the second paragraph, and on page 55 in the photo caption, the correct spelling of the IAEA General Conference President's name is Mr. Saleh Abdul-rahman Al-Athel. On page 54, in the item on the IAEA Board of Governors, the correct spelling of the name of the Governor from Indonesia is Mr. Argus Tarmidzi.

On page 25, in the graph, the correct quantities of CO_2 emissions should be stated in thousand megatonnes, and the IIASA projection should appear as a broken line; the corrected graph appears at left. Also on page 25, in the second column, paragraphs two and three, the emission quantities should be stated in thousand megatonnes.

On page 29, in the table, the correct entry for C1 wastes from reprocessing in the low range is 3.5; the correct entry for wastes from fabrication in the high range is 30.

On pages 31 and 32, the bar graphs and their titles were inadvertently transposed. The graph on page 31 should be titled "Comparison of levelized costs: Nuclear waste management" and it should appear on page 32. The graph on page 32 should be titled "Comparison of levelized costs: Fossil fuel waste management" and should appear on page 31.

The editor regrets the errors and any inconvenience they may have caused readers.

Lithuania, Marshall Islands, Uzbekistan: New members

Lithuania, the Marshall Islands, and Uzbekistan have become members of the IAEA. Lithuania deposited the necessary legal instruments on 18 November 1993, while the Marshall Islands and Uzbekistan did so on on 26 January 1994. As of 1 March 1994, the IAEA had 120 Member States.

Latvia & Uzbekistan: IAEA safeguards

Comprehensive IAEA safeguards agreements have been concluded with Latvia and Uzbekistan pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

The IAEA Board of Governors approved the agreement with Latvia in December 1993, and the one with Uzbekistan in February 1994. Latvia and Uzbekistan became parties to the NPT in January and May 1992, respectively.

Bulgaria: Nuclear communications

Bulgaria is hosting a public information seminar in mid-May 1994 being organized by the IAEA in co-operation with the country's atomic energy authority. The meeting will focus on public communication and educational approaches in the field of nuclear energy, with educators, journalists, and government communicators invited to participate. Topics for discussion address economic, environmental, and safety aspects of nuclear power; media attitudes; and public information strategies and approaches in various countries. The seminar is being organized by the IAEA Division of Public Information within the framework of an extrabudgetary programme being financed by Japan.

Bangladesh: New research centre

Bangladesh — one of the world's most heavily populated countries — is building an international research centre dedicated to issues of science and technology relative to densely populated regions, reports the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. The centre is being built in Dhaka and research is expected to be supported by the United Nations Industrial Development Organization (UNIDO) and World Bank.

The new International Centre of Science, Technology and Environment for Densely Populated Regions initially will conduct research on environment and natural disaster protection; population control and biotechnology; computer software development; and materials science, which will include development of natural products like jute and also semiconductors and other solid-state technology. A research staff of about 150 people is envisaged. More information may be obtained from the ICTP, P.O. Box 586, 34100 Trieste, Italy.

Zambia: Regional co-operation

Zambia has become the 17th IAEA Member State to accept the African Regional Co-operative Agreement for Research, Development, and Training related to Nuclear Science and Technology (AFRA). The country notified the IAEA of its acceptance on 20 December 1993.

AFRA is one of three regional co-operative programmes of the IAEA for transferring nuclear techniques and applications for peaceful uses in fields of medicine, agriculture, industry, and science. Other programmes are in place for Latin America and the Asia and Pacific region. Members of AFRA now include Tunisia, Egypt, Algeria, Nigeria, Madagascar, Libyan Arab Jamahiriya, Morocco, Kenya, Sudan, Ghana, Tanzania, Mauritius, Cameroon, South Africa, Zaire, Ethiopia, and Zambia.

Algeria: NPT declaration

On 21 December 1993, Algeria's Minister of Foreign Affairs declared that his country "resolves to adhere to the Non-Proliferation Treaty". The Minister also said Algeria was "absolutely dedicated to the peaceful use of the atom" and "confidently and unequivocally affirms its commitment to the non-proliferation regime". The statement — which was welcomed by IAEA Director General Hans Blix and communicated to the Agency's Board of Governors — was made on the occasion of the inauguration of the "Es Salam" research reactor, which is under IAEA safeguards.

Latin America: Atoms for peace

Further steps have been taken to bring closer the entry into force of the Treaty of Tlatelolco, which would establish a nuclear-weapon-free-zone in Latin America. On 18 January 1994, the Treaty entered into force for Argentina, which deposited the necessary legal instruments with Mexico, the Treaty's Depositary. Additionally, at the Chilean government's request, the IAEA is preparing a proposed comprehensive safeguards agreement with Chile, which also has become a Contracting Party to the Treaty.

Quadripartite safeguards agreement. Comprehensive IAEA safeguards are expected to take place soon in Argentina and Brazil. The expectation follows, *inter alia,* constructive discussions at the IAEA last December, and the Brazilian Senate's approval on 9 February 1994 of the quadripartite agreement between Argentina, Brazil, the IAEA, and the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC).

Africa: Treaty progress

A group of experts designated by the United Nations in co-operation with the Organization of African Unity is expected to finalize the draft of a treaty on a nuclear-weapon-free-zone in Africa later this year. Meetings of the group in 1994 are scheduled in Windhoek and Addis Ababa. The final draft text is expected to be submitted to the UN General Assembly at its 49th session later this year.

During its 48th session in 1993, the UN General Assembly strongly renewed its call upon all States to consider and respect Africa and its surrounding areas as a nuclear-weapon-free-zone. The IAEA General Conference, in October 1993, adopted a resolution commending the efforts of African States to establish such a zone in the region.

Russia & United States: IAEA support

As announced recently by the Presidents of the United States and Russia, a joint US-Russian working group is to be established to consider "steps to ensure the transparency and irreversibility of the process of reduction of nuclear weapons, including the possibility of putting a portion of fissionable material under IAEA safeguards".

Consultations already have started between the United States and the IAEA concerning the US initiative to place some of the excess nuclear material released from weapon programmes under IAEA safeguards.

In their joint statement of 14 January 1994, Presidents Clinton and Yeltsin made the following other points concerning the IAEA:

- They expressed their support for the IAEA in its efforts to carry out its safeguards responsibilities. They also expressed their intention to provide assistance to the Agency in the safeguards field, including through joint efforts of their relevant laboratories to improve safeguards.
- They supported the Nuclear Suppliers Group (a body outside the auspices of the IAEA) and agreed with the need for effective implementation of the principle of full-scope IAEA safeguards as a condition for nuclear exports, and with the need for export controls on dual-use materials and technology in the nuclear field.
- They called upon the DPRK to honor fully its obligation under the Treaty on the Non-Proliferation of Nuclear Weapons and its safeguards agreement with the IAEA in connection with the Treaty, and to resolve the problems of safeguards implementation, *inter alia*, through dialogue between the IAEA and DPRK.
- They firmly supported the efforts of the UN Special Commission and the IAEA to put into operation a long-term monitoring system of the military potential of Iraq, and called upon Iraq to comply with all UN Security Council resolutions.

Possible new verification tasks. Steps also are being taken under auspices of the Conference on Disarmament (CD) to negotiate a Nuclear Test Ban Treaty. Also in prospect is negotiation of a convention on the cut-off of production of fissile material for nuclear weapons or other nuclear explosive devices. The CD recently invited the Agency's views on matters related to possible verification arrangements and to the Nuclear Test Ban Treaty.

Colombia: Reactor fuel

The further transfer of nuclear fuel for a research reactor under safeguards in Bogotá has been approved by the IAEA Board of Governors.

Colombia had requested the IAEA's assistance in securing the transfer from the United States of a further quantity of up to eight kilograms of low-enriched uranium (LEU) to fuel the continued operation of the IAN-R1 research reactor at the Institute of Nuclear Science and Alternative Energy in Bogota. The reactor is being converted for operation with low-enriched fuels. For conversion to the fuel and to meet the needs for operation at an increased power level of 1000 kilowatts, about 18 kilograms of LEU will be required for about 5 years. The first transfer of fuel for the reactor, of about 7.8 kilograms of low-enriched uranium, had been approved by the IAEA Board in February 1993.

Japan: Nuclear conferences

IAEA Director General Hans Blix is scheduled to address the 27th annual conference of the Japanese Atomic Industrial Forum (JAIF) in Hiroshima 13-15 April 1994. The meeting, which typically attracts more than 1000 participants, has become a major international gathering covering key issues in the peaceful development of nuclear energy.

This year's topics focus on the ultimate abolition of nuclear weapons; promotion of peaceful uses of nuclear energy; problems encountered in nuclear fuel recycling; and evaluation of radiation exposure effects, in light of surveys carried out in Hiroshima and Nagasaki, which suffered from atomic bombing.

Conference activities include a number of technical tours, including ones to Shimane nuclear power plant and Yanai power plant, which uses liquid natural gas for fuel.

In February 1994, Japan held its 21st conference on radiation and radioisotopes, especially commemorating the 100th anniversary of the discovery of X-rays. The meeting featured sessions on radiation applications in food processing, archeology, medicine, environmental convervation, and aerospace industries, as well as national reports of radiation technologies and their use in China, Japan, Russia, and Thailand. The meeting was co-sponsored by JAIF, the Japan Radioisotope Association, and the Atomic Energy Society of Japan.

United States: Nuclear consolidation

Leading utility executives have approved the consolidation of nuclear industry associations and organizations into a single body known as the Nuclear Energy Institute (NEI). NEI combines the functions of four previous groups — the American Nuclear Energy Council, the Nuclear Management and Resources Council, the US Council for Energy Awareness, and the Edison Electric Institute's nuclear-related functions.

The goals of NEI are to achieve broad public and policymaker recognition of nuclear energy as a vital, safe, and environmentally sound component of the US electric energy supply; and to achieve an effective, objective, and highly credible regulatory and political environment that supports and enhances the primary responsibility of nuclear utility management in ensuring the safe, dependable, and economic generation of nuclear energy. Expected to head the new organization is Mr. Phillip Bayne, president of the US Council for Energy Awareness.

Kazakhstan: NPT ratification

On 13 December 1993, the parliament of Kazakhstan ratified the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Adherence takes effect once the required legal instruments are deposited. Kazakhstan — one of four former Soviet Republics, along with Belarus, Russia, and Ukraine, having strategic nuclear weapons on its territory — thus would become the eighth State emerging from the former Soviet Union to adhere to the NPT. Others that have become parties since September 1991 are Lithuania, Estonia, Latvia, Uzbekistan, Azerbaijan, Armenia, and Belarus.

Viet Nam: Radiation processing

Preliminary results from studies at the Viet Nam Atomic Energy Commission (VINATOM) under an IAEA-supported project are opening up prospects for radiation processing of products.

According to Dr. Dang Duc Nhan of VINATOM's Institute for Nuclear Science and Technology, studies are being done on radiation processing of polymers using a semi-commercial irradiation facility placed into operation with the IAEA's assistance. Based on research so far, it is possible that small-scale production can be set up using the facility to produce heat-shrinkable tubes and bags for packaging products such as drugs, beverages, and foodstuffs.

Latin America: More kilowatts

Countries in Latin America and the Caribbean are planning to increase their installed electric capacity by about 40% — or 66 000 megawatts — over the next 10 to 15 years, projects the US-based Utility Data Institute (UDI).

In a report entitled *Directory of Power Plants in Latin America and the Caribbean*, UDI reports that most of the new capacity is being installed in Brazil, Mexico, Argentina, and Venezuela, closely followed by six other countries including Colombia, Peru, Chile, Ecuador, Panama, and Cuba. About 66% of the projected new capacity is hydroelectric, 11% oil-fired, 8% coal-fired, 7% nuclear, and 3% natural gas, with the remainder supplied by geothermal energy. Most of the new plants already are under construction. The UDI report includes regional and country discussions, as well as detailed lists of 3900 electric generating units in each of the 40 countries of the region. More information is available from UDI, 1200 G Street NW, Suite 250, Washington, DC 20005.

Malaysia: Honouring Dr. Novak

In honour of Dr. F.J. Novak, a senior IAEA staff member who passed away in 1993, Malaysia is releasing a new variety of banana to be known as "Novaria". The crop was developed by Dr. Novak and his team along with scientists in Malaysia using radiation mutation breeding techniques. Dr. Novak was the Head of the Plant Breeding Unit at the IAEA's Seibersdorf Laboratories in Austria.

"Novaria" is among more than 1500 cultivars of crop plants and ornamentals that have been developed and released over the past quarter century, many of them with the support of scientists at the IAEA's Seibersdorf Laboratories.

Romania: Energy strategies

The city of Neptun on Romania's Black Sea coast is the site of the country's second national energy conference — CNE'94 — from 13-16 June 1994. The meeting will address both problems and opportunities in the country's energy sector during the transition toward a market economy. Sessions are planned covering energy policies and environmental requirements; electricity planning; nuclear power and safety; advanced technologies for electricity generation; and the development and management of human resources, among other subjects.

The country's first national energy conference, held in 1992, brought together nearly 1000 energy specialists and experts from more than 20 countries. More information may be obtained from the Energy Research and Modernizing Institute (ICEMENERG), 8 Energeticienilor Blvd., 79619 Bucharest 3, Romania.

Sixteen countries request IAEA nuclear plant safety reviews

Under two IAEA programmes, international teams of experts are scheduled to conduct on-site safety reviews at nuclear plants in 16 countries in 1994.

Twenty missions are scheduled in 1994 under the Assessment for Safety Significant Events Team (ASSET) services. They include two at Age-Croft (24-28 January) and one at Cliff-Quay (31 January - 2 February) in the United Kingdom; Kalinin (15-17 February and 4-15 July), Smolensk (6-10 June) and Balakovo (4-14 September) in Russia; Zaporozhe (7-11 February and 13-24 June), South Ukraine (21-25 March and 3-14 October), and Chernobyl (11-22 April) in Ukraine; Bohunice (26-28 April) in the Slovak Republic; Krsko (2-6 May) in Slovenia; Athens, Greece (a seminar, 16-20 May); Tehran, Iran (a seminar, 30 May-8June) Koeberg (5-16 September) in South Africa; Kozloduy (14-25 November) in Bulgaria; Madrid, Spain (a seminar, 3-21 October); and Paks (5-9 December) in Hungary.

Thirteen missions and follow-up visits are scheduled in 1994 under the Operational Safety Review Team (OSART) services. They include those to Grand Gulf (14-18 February) in the United States; Sizewell B (14-18 February) and Hunterston B (11-29 April) in the United Kingdom; Chernobyl (7-18 March) and Zaporozhe (9-27 May) in Ukraine; Cattenom (14 March - 1 April) and Gravelines (7-11 November) in France; Ulchin (6-24 June) in the Republic of Korea; Kola (6-10 June) in Russia; Bohunice (5-16 September) in the Slovak Republic; Embalse (September/October) in Argentina; Krsko (24-28 October) in Slovenia; and Leibstadt (21 November - 10 December) in Switzerland.

Both the ASSET and OSART programmes — which are among a range of IAEA services in areas of nuclear safety and radiological protection — include specific types of services that are performed at the request of individual countries. OSART services address operational safety practices in specific areas of nuclear plant safety regulation. ASSET services focus on the review and analysis of operational safety experience from the standpoint of events that have occurred.

IAEA APPOINTMENTS. Mr. Richard Hooper, from the United States, has been appointed Director of the IAEA's Division of Concepts and Planning, Department of Safeguards; he succeeds Mr. Raymond Parsick from the United States. Mr. Poong-Eil Juhn, from the Republic of Korea, has been appointed Director of the IAEA's Division of Nuclear Power, Department of Nuclear Energy and Safety; he succeeds Mr. Pranab Dastidar from India.

NPT CONFERENCE PREPARATIONS. Three senior IAEA officials recently gave presentations on the IAEA's safeguards and technical co-operation programmes to the Preparatory Committee for the 1995 Conference of Parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which concluded its second session in New York on 21 January 1994. The officials were Mr. Mohamed ElBaradei, Assistant Director-General for External Relations; Mr. Richard Hooper, newly appointed Director in the IAEA Department of Safeguards; and Mr. Paulo Barretto, Director of IAEA Technical Co-operation Programmes. During its session, the Committee invited the Director General of the IAEA to prepare comprehensive background documentation on the Agency's activities relevant to the NPT. Two other sessions of the Preparatory Committee are scheduled from 12-16 September 1994 in Geneva and 23-27 January 1995 in New York. The NPT Conference will be held for four weeks from 17 April to 12 May 1995.

NON-PROLIFERATION REFERENCES. The IAEA is among more than 30 organizations profiled in the latest edition of the *Inventory of International Non-Proliferation Organizations and Regimes.* The inventory is issued by the Monterey Institute of International Studies (MIIS) under a project of its programme for non-proliferation studies. It compiles information on international, regional, and bilateral organizations, international treaties, and international non-governmental organizations connected with the non-proliferation of weapons of mass destruction and their means of delivery. It thus provides a comprehensive base of information for scholars, analysts, policymakers, and others interested in furthering their knowledge and understanding of international organizations having responsibilities for preventing the further spread of nuclear, chemical, biological, and other weapons of mass destruction. More information about the reference booklet, which is available for a fee of US $10 to cover printing and shipping costs, may be obtained from MIIS, Programme for Non-Proliferation Studies, 425 Van Buren Street, Monterey, California 93940 USA.

DECOMMISSIONING SYMPOSIUM. The World's Fair Convention Center in Knoxville, Tennessee is the site of an international symposium on decommissioning being organized by the US Department of Energy (DOE) in co-operation with the IAEA 24-29 April 1994. The meeting features technical presentations, tours of DOE's Oak Ridge national laboratories, a trade show, and an exhibition. With the transition of many of DOE's facilities from nuclear-weapons production missions to environmental restoration, the symposium will address many of the technical challenges and alternatives for maintaining facilities in safe condition and for their ultimate decontamination and decommissioning. More information may be obtained from DOE, Office of the Press Secretary, Washington, DC 20585.

INSTRUMENTATION IN DEVELOPING COUNTRIES. Contributions are invited to the *MMSZ Notebook,* an information sheet about instrumentation in developing countries. It is issued under the auspices of the Hungarian Academy of Sciences and features items on technical instrumentation and related development and training programmes and meetings. More information may be obtained from Dr. Gy. Stokum, MTA-MMSZ. Kft., P.O. Box 58, H-1502 Budapest, Hungary.

IN MEMORIAM. The international community noted with sadness the passing in the United States of Ms. Dixy Lee Ray in early January 1994, at the age of 79. Ms. Ray, the former chairwoman of the US Atomic Energy Commission and Governor of the State of Washington, was recognized by numerous scientific and civic organizations during her distinguished career. Among the awards she received was the United Nations Peace Medal in 1973. Ms. Ray's recent book, *Trashing the Planet,* includes an article which the *IAEA Bulletin* featured in 1990 (Vol. 32, No. 2) under the title "Who Speaks for Science?".

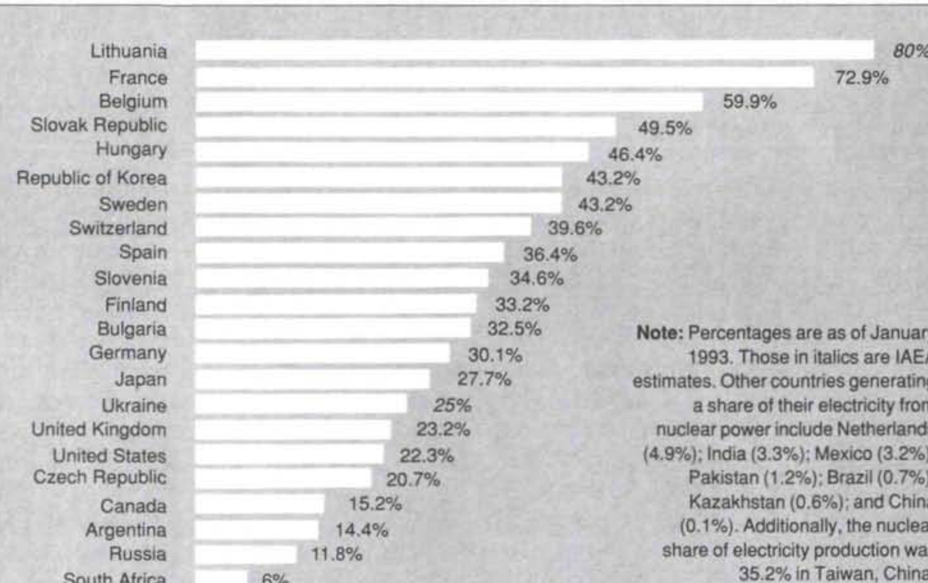
Nuclear power status around the world

	In operation		Under construction	
	No. of units	Total net MWe	No. of units	Total net MWe
Argentina	2	935	1	692
Belgium	7	5 484		
Brazil	1	626	1	1245
Bulgaria	6	3 538		
Canada	22	15 755		
China	2	1 194	1	906
Cuba			2	816
Czech Republic	4	1 632	2	1 784
Finland	4	2 310		
France	57	59 033	4	5 815
Germany	21	22 559		
Hungary	4	1 729		
India	9	1 593	5	1 010
Iran			2	2 392
Japan	47	36 970	6	5 397
Kazakhstan	1	135		
Korea, Rep. of	9	7 220	7	5 770
Lithuania	2	2 370		
Mexico	1	654	1	654
Netherlands	2	504		
Pakistan	1	125		
Romania			5	3 155
Russian Federation	29	19 843	17	13 225
South Africa	2	1 842		
Slovak Republic	4	1 632	4	1 552
Slovenia	1	632		
Spain	9	7 101		
Sweden	12	10 002		
Switzerland	5	2 985		
United Kingdom	35	11 901	1	1 188
Ukraine	15	13 020	6	5 700
USA	109	98 784	2	2 330
World total*	429	336 998	67	53 631

* The total includesTaiwan, China where six reactors totalling 4890 MWe are in operation.

Note: The data, reflecting the status at the end of 1993 as reported to the IAEA, are preliminary and subject to change.

Nuclear share of electricity generation in selected countries



Note: Percentages are as of January 1993. Those in italics are IAEA estimates. Other countries generating a share of their electricity from nuclear power include Netherlands (4.9%); India (3.3%); Mexico (3.2%); Pakistan (1.2%); Brazil (0.7%); Kazakhstan (0.6%); and China (0.1%). Additionally, the nuclear share of electricity production was 35.2% in Taiwan, China.

NUCLEAR POWER PLANT ENGINEER (94-006), Department of Nuclear Energy and Safety. This P-4 post requires a Master of Science or equivalent degree in nuclear or mechanical engineering, and at least 10 years of professional experience in nuclear power projects, preferably in project management and infrastructure development. *Closing date: 26 May 1994.*

SAFEGUARDS DATA ANALYST (94-004), Department of Safeguards. This P-4 post requires a university degree in chemistry or physics and at least 10 years of experience with various nuclear properties measurement systems and the analysis of the resulting data; some experience/training in the use of statistical methods is required. *Closing date: 26 May 1994*

COMPUTER INFORMATION SYSTEMS SPECIALIST (94-001), Department of Nuclear Energy and Safety. This P-2 post requires an advanced degree in information science or related discipline and 2 years of practical experience in the field of data processing; excellent communication skills, both written and verbal, familiarity and experience in the area of customer support; and solid knowledge of technical development in information technology. *Closing date: 19 May 1994.*

HEAD, PRINTING SECTION (94-002), Department of Administration. This P-4/P-5 post requires a university degree in business administration or engineering, or equivalent qualification specific to the printing and publishing industry, and at least 10 years of relevant experience in a national and/or international organization or in the private printing sector, and demonstrated administrative and supervisory experience. *Closing date: 19 April 1994.*

HEAD, RADIATION SAFETY SERVICES SECTION (94-003), Department of Nuclear Energy and Safety. This P-5 post requires a university degree or equivalent in physics or chemistry, and at least 15 years of experience in measurement aspects of radiation protection, of which 10 have been in a senior supervisory capacity. *Closing date: 19 May 1994.*

RUSSIAN TRANSLATOR (93-082), Department of Administration. This P-3 post requires a university degree or equivalent, at least 3 years of relevant experience with a demonstrated aptitude for translation work, and the ability to handle difficult technical material. *Closing date: 15 April 1994.*

RADIATION PROTECTION SPECIALIST (93-083), Department of Nuclear Energy and Safety. This P-4 post requires a university degree in medicine, at least 10 years of experience at the national level, at least 5 of which have been in medical aspects of radiation protection, including international basic standards and regulation, and at least 2 of which have been at the international level. *Closing date: 15 April 1994.*

HEAD, PROGRAMME CO-ORDINATION SECTION (94-005), Department of Technical Co-operation. This P-5 post requires an advanced university degree or equivalent in nuclear science, technology, or business administration. At least 15 years of professional work experience, 5 years of which should be at the international level in the following areas: project management, including project design, field implementation, monitoring and evaluation; technical co-operation administration at both field and headquarters level; sound knowledge of techniques of management, programme, statistical and quality analysis; practical acquaintance with multilateral and bilateral development agencies, especially their project management systems and procedures. *Closing date: 25 March 1994.*
Note. This is a re-advertisement of the post.

RESEARCH ENTOMOLOGIST (94-007), Department of Research and Isotopes. This P-2 post requires academic qualifications equivalent to an advanced university degree in medical and/or veterinary entomology. At least 2 years of experience in research and in rearing large numbers of insects, and knowledge and experience with the Sterile Insect Technique (SIT). *Closing date: 14 June 1994.*

EVALUATION OFFICER (94-008), Department of Technical Co-operation. This P-3 post requires a university degree or equivalent in science and technology. At least 6 years of overall experience with project management and technical co-operation at the national and/or international level, effective communication and excellent English drafting capabilities. *Closing date: 19 May 1994.*

HEAD, INIS CLEARING HOUSE (94-009), Department of Nuclear Safety. This P-4 post requires an advanced university degree in information science, computer science or related field, 10 years of relevant working experience, including the provision of document delivery services, knowledge in the use of micrographic and related technology, familiarity in the use of CD-ROM or Optical Disk technology, PC and mainframe applications. *Closing date: 14 June 1994.*

HEAD, STATISTICAL ANALYSIS SECTION (94-010), Department of Safeguards. This P-5 post requires an advanced university degree in statistics, physics, nuclear engineering or equivalent, coupled with 15 years of practical experience in the statistical analysis of data and quality control of measurement systems, including at least 5 years of which have been in nuclear material safeguards. Also required are a sound knowledge of the nuclear fuel cycle and demonstrated experience in progressively responsible positions of a supervisory/managerial nature. *Closing date: 14 June 1994.*

READER'S NOTE:

The ***IAEA Bulletin*** publishes short summaries of vacancy notices as a service to readers interested in the types of professional positions required by the IAEA. They are ***not*** the official notices and remain subject to change. On a frequent basis, the IAEA sends vacancy notices to governmental bodies and organizations in the Agency's Member States (typically the foreign ministry and atomic energy authority), as well as to United Nations offices and information centres. Prospective applicants are advised to maintain contact with them. Applications are invited from suitable qualified women as well as men. More specific information about employment opportunities at the IAEA may be obtained by writing the Division of Personnel, Box 100, A-1400 Vienna, Austria.

ON-LINE COMPUTER SERVICES IAEA vacancy notices for professional positions, as well as application forms, now are available through a global computerized network that can be accessed directly. Access is through the Internet Services. The vacancy notices are located in a public directory accessible via the normal Internet file transfer services. To use the service, connect to the IAEA's Internet address NESIRS01.IAEA.OR.AT (161.5.64.10), and then log on using the identification *anonymous* and your user password. The vacancy notices are in the directory called *pub/vacancy_posts*. A *README* file contains general information, and an *INDEX* file contains a short description of each vacancy notice. Other information, in the form of files that may be copied, includes an application form and conditions of employment. Please note that applications for posts cannot be forwarded through the computerized network, since they must be received in writing by the IAEA Division of Personnel.

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Strengthening Radiation and Nuclear Safety Infrastructures in Countries of the Former USSR, *300 Austrian schillings, ISBN 92-0-102793-1*

Nuclear Power, Nuclear Fuel Cycle and Waste Management: Status and Trends 1993, *(Part C of the IAEA Yearbook 1993), 200 Austrian schillings, ISBN 92-0-102593-9*

Nuclear Safety Review 1993, *(Part D of the IAEA Yearbook 1993), 200 Austrian schillings, ISBN 92-0-102693-5*

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IAEA Yearbook 1993, *500 Austrian schillings, ISBN 92-0-102493-2*

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(Vol. 35, Nos. 1-4)

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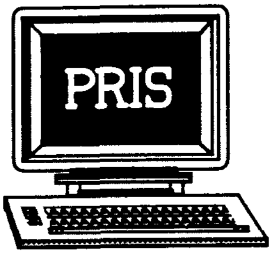


Database name
Power Reactor Information System (PRIS)

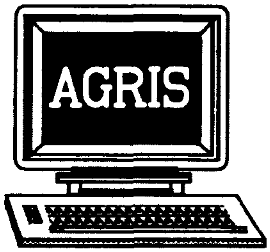
Type of database
Factual

Producer
International Atomic Energy Agency in co-operation with 29 IAEA Member States

IAEA contact
IAEA, Nuclear Power Engineering Section, P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via BITNET/INTERNET to ID:
NES@IAEA1.IAEA.OR.AT

Scope
Worldwide information on power reactors in operation, under construction, planned or shutdown, and data on operating experience with nuclear power plants in IAEA Member States.

Coverage
Reactor status, name, location, type, supplier, turbine generator supplier, plant owner and operator, thermal power, gross and net electrical power, date of construction start, date of first criticality, date of first synchronization to grid, date of commercial operation, date of shutdown, and data on reactor core characteristics and plant systems; energy produced; planned and unplanned energy losses; energy availability and unavailability factors; operating factor, and load factor.



Database name
International Information System for the Agricultural Sciences and Technology (AGRIS)

Type of database
Bibliographic

Producer
Food and Agriculture Organization of the United Nations (FAO) in co-operation with 172 national, regional, and international AGRIS centres

IAEA contact
AGRIS Processing Unit
c/o IAEA, P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via BITNET/INTERNET to ID:
FAS@IAEA1.IAEA.OR.AT

Number of records on line from January 1993 to date
more than 130 000

Scope
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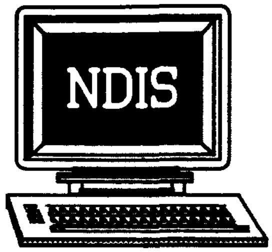
Coverage
Agriculture in general; geography and history; education, extension, and information; administration and legislation; agricultural economics; development and rural sociology; plant and animal science and production; plant protection; post-harvest technology; fisheries and aquaculture; agricultural machinery and engineering; natural resources; processing of agricultural products; human nutrition; pollution; methodology.



Database name
Nuclear Data Information System (NDIS)

Type of database
Numerical and bibliographic

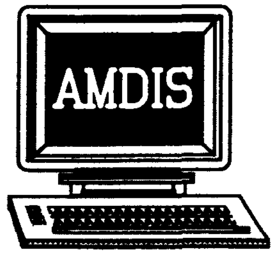
Producer
International Atomic Energy Agency in co-operation with the United States National Nuclear Data Centre at the Brookhaven National Laboratory, the Nuclear Data Bank of the Nuclear Energy Agency, Organisation for Economic Co-operation and Development in Paris, France, and a network of 22 other nuclear data centres worldwide

IAEA contact
IAEA Nuclear Data Section,
P.O. Box 100
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via BITNET/INTERNET to ID:
RNDS@IAEA1.IAEA.OR.AT

Scope
Numerical nuclear physics data files describing the interaction of radiation with matter, and related bibliographic data.

Data types
Evaluated neutron reaction data in ENDF format; experimental nuclear reaction data in EXFOR format, for reactions induced by neutrons, charged particles, or photons; nuclear half-lives and radioactive decay data in the systems NUDAT and ENSDF; related bibliographic information from the IAEA databases CINDA and NSR; various other types of data.

Note: Off-line data retrievals from NDIS also may be obtained from the producer on magnetic tape



Database name
Atomic and Molecular Data Information System (AMDIS)

Type of database
Numerical and bibliographic

Producer
International Atomic Energy Agency in co-operation with the International Atomic and Molecular Data Centre network, a group of 16 national data centres from several countries.

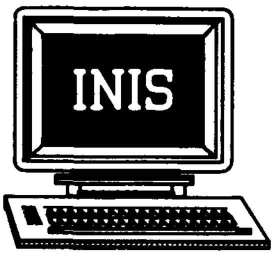
IAEA contact
IAEA Atomic and Molecular Data Unit, Nuclear Data Section
Electronic mail via BITNET to: RNDS@IAEA1;
via INTERNET to ID:
PSM@RIPCRS01.IAEA.OR.AT

Scope
Data on atomic, molecular, plasma-surface interaction, and material properties of interest to fusion research and technology

Coverage
Includes ALADDIN formatted data on atomic structure and spectra (energy levels, wave lengths, and transition probabilities); electron and heavy particle collisions with atoms, ions, and molecules (cross sections and/or rate coefficients, including, in most cases, analytic fit to the data); sputtering of surfaces by impact of main plasma constituents and self sputtering; particle reflection from surfaces; thermophysical and thermomechanical properties of beryllium and pyrolytic graphites.

Note: Off-line data and bibliographic retrievals, as well as ALADDIN software and manual, also may be ob-tained from the producer on diskettes, magnetic tape, or hard copy.

For access to these databases, please contact the producers.
Information from these databases also may be purchased from the producer in printed form
INIS and AGRIS additionally are available on CD-ROM



Database name
International Nuclear Information System (INIS)

Type of database
Bibliographic

Producer
International Atomic Energy Agency in co-operation with 86 IAEA Member States and 16 other international member organizations

IAEA contact
IAEA, INIS Section, P.O. Box 100,
A-1400 Vienna, Austria
Telephone (43) (1) 2360
Telex (1)-12645
Facsimile +43 1 234564
Electronic mail via
BITNET/INTERNET to ID:
ATIEH@IAEA1.IAEA.OR.AT

Number of records on line from January 1976 to date
more than 1.5 million

Scope
Worldwide information on the peaceful uses of nuclear science and technology; economic and environmental aspects of other energy sources.

Coverage
The central areas of coverage are nuclear reactors, reactor safety, nuclear fusion, applications of radiation or isotopes in medicine, agriculture, industry, and pest control, as well as related fields such as nuclear chemistry, nuclear physics, and materials science. Special emphasis is placed on the environmental, economic, and health effects of nuclear energy, as well as, from 1992, the economic and environmental aspects of non-nuclear energy sources. Legal and social aspects associated with nuclear energy also are covered.

IAEA UPCOMING CO-ORDINATED RESEARCH PROGRAMMES

The standardization of iodine-131 treatment for hyperthyroidism with an intent to optimize radiation dose and treatment response
To standardize iodine-131 treatment for hyperthyroidism (diffuse toxic goitre) with the objective of optimizing radiation dose and treatment response, and identifying important factors which influence the outcome of the treatment.

Nuclear techniques for diagnosis of bacterial and viral infections (African region)
To develop expertise in the African region in the use of DNA probe hybridization and polymerase chain reaction amplification methods in diagnosis of diseases such as AIDS, viral hepatitis, and tuberculosis and evaluate different primers and probes which work best for the pathogen strains in the region.

Clinical application of radiosensitizers in cancer radiotherapy
To enhance radiation-induced therapeutic gain by introducing the effective hypoxic cell radiosensitizer in treatment management.

Development of reference input parameter library for nuclear model calculations of nuclear data (Phase I: Starter file)
To develop a starter file of the input parameter library. The file is designed to provide necessary input for nuclear reaction model calculations of nuclear data for incident energies up to about 30 MeV.

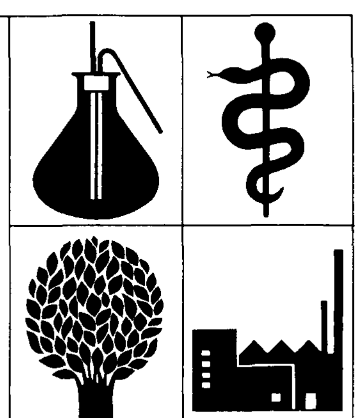
Radiative cooling rates of fusion plasma impurities
To establish a comprehensive recommended database for the radiative power losses of the most important plasma impurities in the range of plasma parameters relevant for presently operating and next generation fusion devices.

Validation of accident and safety analysis methodology
To promote research and the exchange of information on validation of accident and safety analysis methodology covering the aspects of DBAs and beyond DBAs (so-called severe accidents).

Irradiation as a public health measure to control food-borne diseases in Latin America and the Caribbean
To foster research and development including pilot-scale studies on the use of irradiation to control infectivity of cysticercosis/taeniasia from pork consumption and Vibrio infection from consumption of seafood. The CRP is co-sponsored by the Pan-American Health Organization (PAHO).

Research and certification of quality control and preventive maintenance of instruments in nuclear medicine centres (Asia and Pacific)
To apply new hardware and software phantoms in interlaboratory comparisons and studies for improvement of quality control and preventive maintenance practice in nuclear medicine centres in Asian developing countries and to carry out methodological studies on certification for good performance of nuclear medical instruments.

These are selected listings, subject to change. More complete information about IAEA meetings can be obtained from the IAEA Conference Service Section at the Agency's headquarters in Vienna, or by referring to the IAEA quarterly publication ***Meetings on Atomic Energy*** (See the *Keep Abreast* section for ordering information.) More detailed information about the IAEA's co-ordinated research programmes may be obtained from the Research Contracts Administration Section at IAEA headquarters The programmes are designed to facilitate global co-operation on scientific and technical subjects in various fields, ranging from radiation applications in medicine, agriculture, and industry to nuclear power technology and safety



IAEA SYMPOSIA & SEMINARS

MARCH 1994

IAEA Symposium on International Safeguards, ***Vienna, Austria*** (14-18 March)

JUNE 1994

Diplomatic Conference for Adoption of the Nuclear Safety Convention, ***Vienna, Austria*** (14-17 June)

AUGUST 1994

Interregional Seminar on Isotope Techniques in Arid and Semi-Arid Land Hydrology, ***Vienna, Austria*** (15-26 August)

Interregional Seminar on Radiotherapy Dosimetry: Radiation Dose in Radiotherapy from Prescription to Delivery, ***Brazil*** (27-30 August)

SEPTEMBER 1994

Conference on Nuclear Power Option, ***Vienna, Austria*** (5-9 September)

15th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, ***Madrid, Spain*** (26 September-1 October)

OCTOBER 1994

Seminar on Radioactive Waste Management Practices and Issues in Developing Countries, ***Beijing, China*** (10-14 October)

International Symposium on Spent Fuel Storage — Safety, Engineering and Environmental Aspects, ***Vienna, Austria*** (10-14 October)

FAO/IAEA International Symposium on Nuclear and Related Techniques in Soil/Plant Studies on Sustainable Agriculture and Environmental Preservation, ***Vienna, Austria*** (17-21 October)

NOVEMBER 1994

International Conference on Radiation, Health and Society: Comprehending Radiation Risks, ***Paris, France*** (7-12 November)

Revision Conference of the Vienna Convention on Civil Liability for Nuclear Damage, ***Vienna, Austria*** (Preliminary)

GENERAL CONFERENCE

IAEA General Conference, Thirty-eighth Regular Session, ***Vienna, Austria***, (19-23 September 1994)

IAEA BULLETIN

Published quarterly by the Division of Public Information of the International Atomic Energy Agency, P.O. Box 100, A-1400 Vienna, Austria.
Tel: (43-1) 2360-1270
Facsimile: (43-1) 234564

IAEA MEMBER STATES

1957
Afghanistan
Albania
Argentina
Australia
Austria
Belarus
Brazil
Bulgaria
Canada
Cuba
Denmark
Dominican Republic
Egypt
El Salvador
Ethiopia
France
Germany
Greece
Guatemala
Haiti
Holy See
Hungary
Iceland
India
Indonesia
Israel
Italy
Japan
Korea, Republic of
Monaco
Morocco
Myanmar
Netherlands
New Zealand
Norway
Pakistan
Paraguay
Peru
Poland
Portugal
Romania
Russian Federation
South Africa
Spain
Sri Lanka
Sweden
Switzerland
Thailand
Tunisia
Turkey
Ukraine
United Kingdom of Great Britain and Northern Ireland
United States of America
Venezuela
Viet Nam
Yugoslavia

1958
Belgium
Cambodia
Ecuador
Finland
Iran, Islamic Republic of
Luxembourg
Mexico
Philippines
Sudan

1959
Iraq

1960
Chile
Colombia
Ghana
Senegal

1961
Lebanon
Mali
Zaire

1962
Liberia
Saudi Arabia

1963
Algeria
Bolivia
Côte d'Ivoire
Libyan Arab Jamahiriya
Syrian Arab Republic
Uruguay

1964
Cameroon
Gabon
Kuwait
Nigeria

1965
Costa Rica
Cyprus
Jamaica
Kenya
Madagascar

1966
Jordan
Panama

1967
Sierra Leone
Singapore
Uganda

1968
Liechtenstein

1969
Malaysia
Niger
Zambia

1970
Ireland

1972
Bangladesh

1973
Mongolia

1974
Democratic People's Republic of Korea
Mauritius

1976
Qatar
United Arab Emirates
United Republic of Tanzania

1977
Nicaragua

1983
Namibia

1984
China

1986
Zimbabwe

1991
Latvia
Lithuania
Yemen, Republic of

1992
Croatia
Estonia
Slovenia
Uzbekistan

1993
Armenia
Czech Republic
Kazakhstan
Marshall Islands
Slovak Republic
Former Yugoslav Republic of Macedonia

Eighteen ratifications were required to bring the IAEA's Statute into force. By 29 July 1957, the States in bold face had ratified the Statute.

Year denotes year of membership. Names of the States are not necessarily their historical designations.

For States in italic, membership has been approved by the IAEA General Conference and will take effect once the required legal instruments have been deposited.

The International Atomic Energy Agency, which came into being on 29 July 1957, is an independent intergovernmental organization within the United Nations System. Headquartered in Vienna, Austria, the Agency has more than 100 Member States who together work to carry out the main objectives of IAEA's Statute: To accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world and to ensure so far as it is able that assistance provided by it, or at its request or under its supervision or control, is not used in such a way as to further any military purpose.

IAEA headquarters, at the Vienna International Centre.

Until now, one of the biggest problems with reading personal exposure doses has been the size of the monitoring equipment. Which is precisely why we're introducing the Electronic Pocket Dosimeter (EPD) "MY DOSE mini™" PDM-Series.

These high-performance dosimeters combine an easy-to-read digital display with a wide measuring range suiting a wide range of needs.

But the big news is how very small and lightweight they've become. Able to fit into any pocket and weighing just 50~90 grams, the Aloka EPDs can go anywhere you go. Which may prove to be quite a sizable improvement, indeed.

Model	Energy	Range	Application
PDM-101	60 keV ~	0.01 ~ 99.99 μSv	High sensitivity, photon
PDM-102	40 keV ~	1 ~ 9,999 μSv	General use, photon
PDM-173	40 keV ~	0.01 ~ 99.99 mSv	General use, photon
PDM-107	20 keV ~	1 ~ 9,999 μSv	Low energy, photon
PDM-303	thermal ~ fast	0.01 ~ 99.99 mSv	Neutron
ADM-102	40 keV ~	0.001 ~ 99.99 mSv	With vibration & sound alarm, photon

SCIENCE AND HUMANITY

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