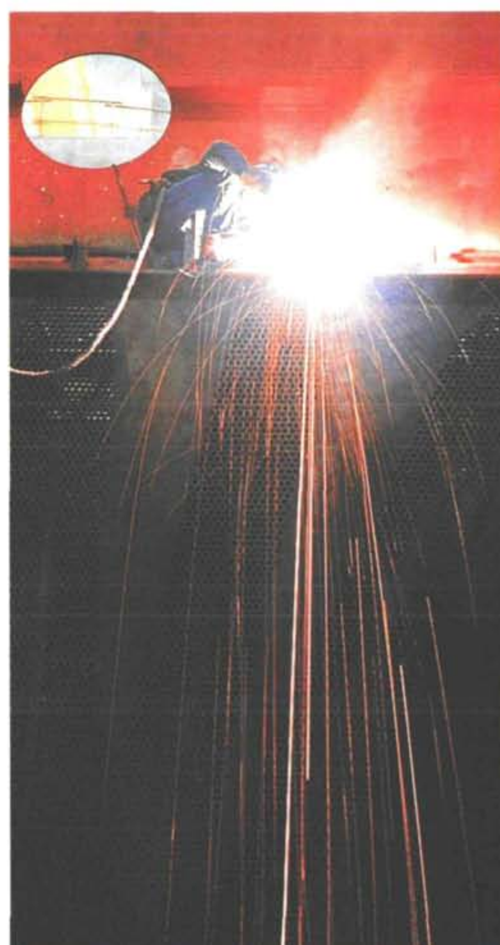
RADIATION AT WORK: In many ways, radiation technologies offer practical benefits to industries. Their use, for example, is helping (clockwise from top left) to determine the ash and mineral content of coal; sterilize medical products for hygienic safety; analyze the quality of welding processes; ensure 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.

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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

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.)*

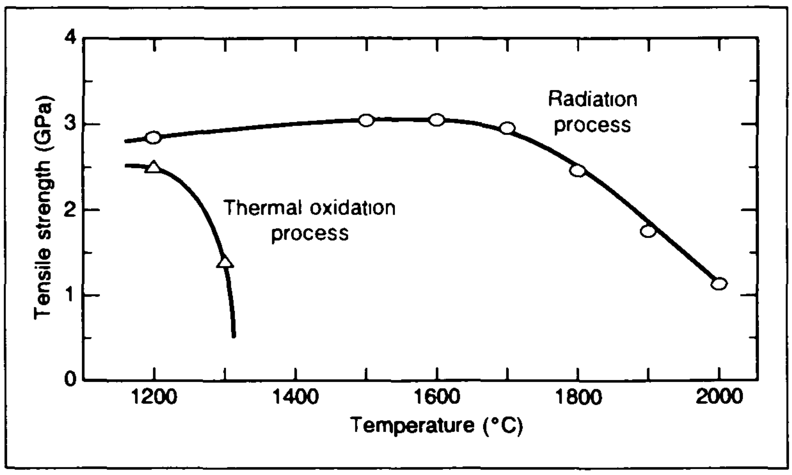
The dose requirement for cross-linking is 10 MGy by an electron beam accelerator. JAERI operates a pilot plant by which 4.5 kg of PCS is irradiated per batch in a vacuum. The project was initiated to develop the technology and to construct a commercial plant to produce one ton of SiC fiber per month.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