NUCLEAR SAFEGUARDS: 2. THE US PROGRAM

Protection of fissionable materials becomes increasingly a problem as private nuclear industry grows. Physicists can help the safeguards program by developing improved materials-analysis methods.

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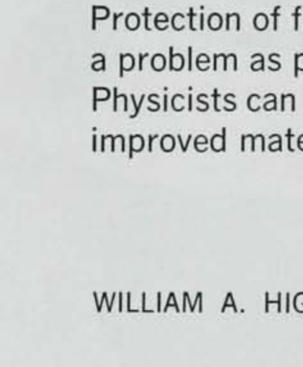
THE DOMESTIC PROBLEM of nuclear safeguards is that of ensuring, so far as possible, that significant amounts of nuclear materials do not become lost, strayed or stolen, and to do so without interfering unnecessarily with free enterprise and at a price that the nation can reasonably afford. In the US responsibility lies largely with the Atomic Energy Commission, in its Office of Safeguards and Materials Management (OSMM) and its Division of Nuclear Materials Safeguards (DNMS). Physicists are contributing to the safeguards program by perfecting the technical means to carry out policy.



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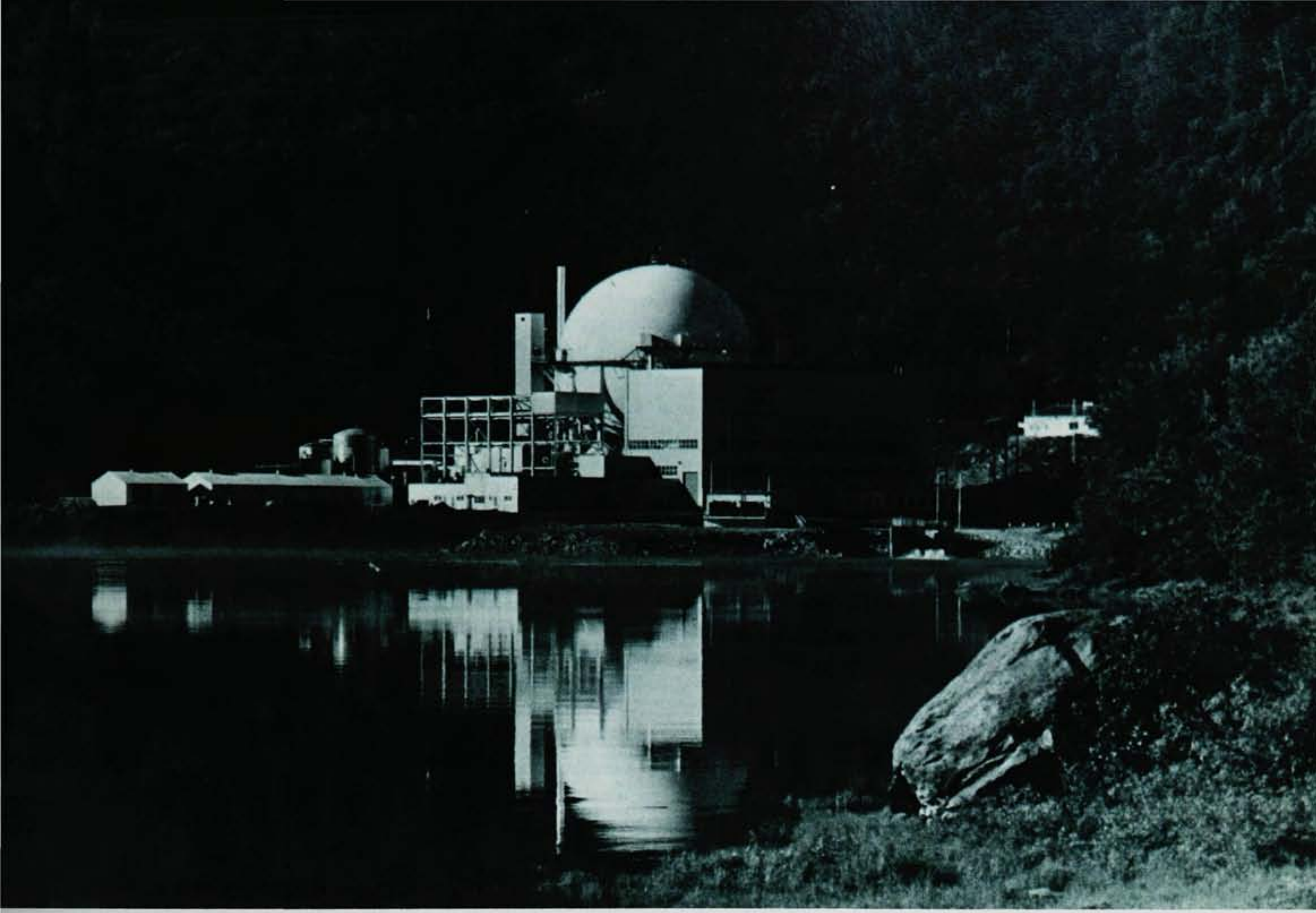
Protection of nuclear materials has been a concern of the US government since the days of the World War 2 Manhattan Project. In early years activities were conducted by personnel with security clearances in government-owned installations, under guard. The Atomic Energy Act was amended in 1954 to permit the use of nuclear materials by private industry under license and the transfer of these materials to other nations subject to certain "safeguards" requirements. Although most appropriations were still for military applications, there were research reactors in universities and national laboratories. Emphasis was increasingly on developments related to nuclear power.

Widespread research and development stemmed from the International Conference on the Peaceful Uses of Atomic Energy, held in Geneva, Switzerland in 1955. There the major nuclear powers vied with each other in declassifying information and offering assistance to other nations. At the same time in the US, private industry was encouraged to join with AEC in developing peaceful applications; this effort began to bear fruit in the early 1960's.

Nuclear power has now become competitive with fossil fuels in many parts of the world. Anticipated growth of the nuclear electric-power industry is shown in figure 1; numbers represent present commitments. Although later growth may be affected by technical and political developments, the nuclear power industry will, in any case, expand rapidly in many parts of the world. Plutonium produced in nuclear power plants (approximately 1 gram per megawatt day, electric) could in the absence of effective safeguards become a serious threat to world political stability.

Figure 1 suggests that, for some time at least, the US nuclear industry will be about equal to that of all the nonweapons countries combined, and that the UK will have a proportionately large program. Figures for the USSR are low; massive reserves of oil and gas offer keen competition in that region. It is clear that the US will have



a major problem to ensure that its domestic safeguards system is adequate.

Trend to private sector

From the beginning, AEC has conducted its operations through contracts with private corporations. Thus the University of California operates Los Alamos Scientific Laboratory and Western Electric runs Sandia Laboratory in Albuquerque. These are, in effect, government installations where materials are under guard and access is restricted. Substantial amounts of highly enriched uranium for naval reactors and plutonium fuels for research reactors are, however, processed under contract in commercial plants. Rapid growth at present is in development of boiling-water and pressurized-water power reactors and related fuel-fabrication and reprocessing plants, all in the private sector.

Uranium enriched to 2–4% in U^{235} by AEC diffusion plants is the fuel for these reactors. This uranium would require substantial further enrichment to be useful for weapons. The amount of plutonium produced in these reactors, however, is already impressive. (See figure 2.) There are strong incentives for recycling at least some of this plutonium, and development of breeders in the next few years will produce even greater amounts of plutonium and U^{233} for general use.

It is generally assumed that primary attention should be paid to those materials that could be made into nuclear explosives with relatively little effort; such as the highly enriched uranium used in research reactors and mixed uranium-plutonium fuels. Substantially further down the scale are low-enriched uranium fuels; below them come natural uranium, depleted uranium and uranium ores.

An alternative way to look at the problem is to consider accessibility. Significant diversion at a mine involves transporting hundreds of tons of ore. Fuel elements inside an operating reactor are securely confined. Discharged fuel elements are intensely radioactive and release a good deal of heat as well. Thus the effort needed to safeguard a reactor may be considerably less than that required to safeguard an isotope-separation plant, a fuel-fabrication plant or a chemical reprocessing plant. This situation is fortunate because there will be a large number of power reactors and relatively few of the other installations will be required to support them.

A safeguards program consists of some combination of three general classes of activity: containment or physical security, material accountability and surveillance. The particular combination depends on the operation or the facility involved. The AEC can be somewhat arbitrary in the requirements it imposes on its contractors, but with private industrial operations it must operate through regulations that are acceptable and reasonably fair.

A few years ago, when private nuclear industry was smaller, emphasis was placed on the high monetary value of the materials involved. (Enriched uranium and plutonium are worth ten times their weight in gold.) But the nuclear industry has grown up, and it is unlike other businesses in at least one important respect: A company can take out insurance against theft, but insurance cannot compensate for losing control of a nuclear weapon.

Lumb panel report

As the news media have reported, unexpectedly large losses of materials did occur, and in 1966 AEC set up a panel headed by Ralph Lumb[1] to take a fresh look at the nuclear-safeguards problem. At the same time negotiations for a nuclear nonproliferation treaty began to show promise, and it was clear that the US had to develop consistent domestic and international safeguards policies.

After it had received the Lumb Panel report, AEC placed the responsibility for research and for development of policy in the new OSMM, headed by General Delmar L. Crowson. This office is also responsible for the application of safeguards to license-exempt contractors. In the regulatory arm of AEC, DNMS was established to apply safeguards to licensees, that is to the private sector of the domestic nuclear industry. It may help to explain that AEC is in large part a development and promotion agency, and that its contractors participate in these activities. AEC is also charged with regulation of the private sector on behalf of health and safety and national security. This regulatory branch is not responsible to the AEC general manager, but reports directly to the Commission as evidence of its separation from promotional activities. To confuse the issue further, Crowson not only reports to the general manager, but also directly advises the Commission on safeguards policy matters.

The OSMM research and development program is in two parts; systems studies and development of measurement techniques. There are presently systems-studies contracts with Battelle Memorial Institute (Hanford) and the National Bureau of Standards, and technical contracts, mostly for research on nondestructive measurement instrumentation, with other groups. A Technical Support Organization has been established at Brookhaven National Laboratory to review the research and development program and to perform field exercises. Other aspects of safeguards procedure, such as transportation, the proper use of inspectors, computerized data processing and physical security of plants, are being investigated by OSMM and DNMS, and the present system of materials accounting and inspection is being carefully studied.

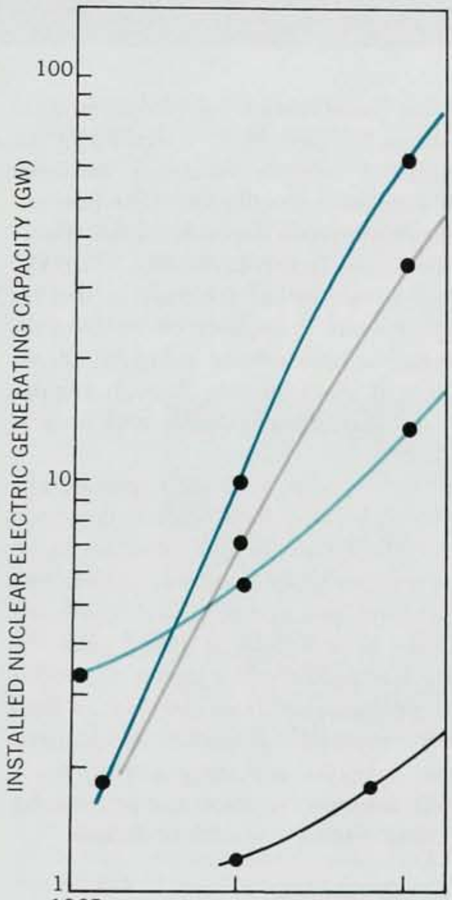
How can physicists help?

Physicists can probably help most by developing the technical means to monitor fissionable materials. The system of materials accounting at present is roughly the following: A plant or other installation, contractor or licensee, is required to keep records of its receipts and shipments and to take inventory at specified intervals.

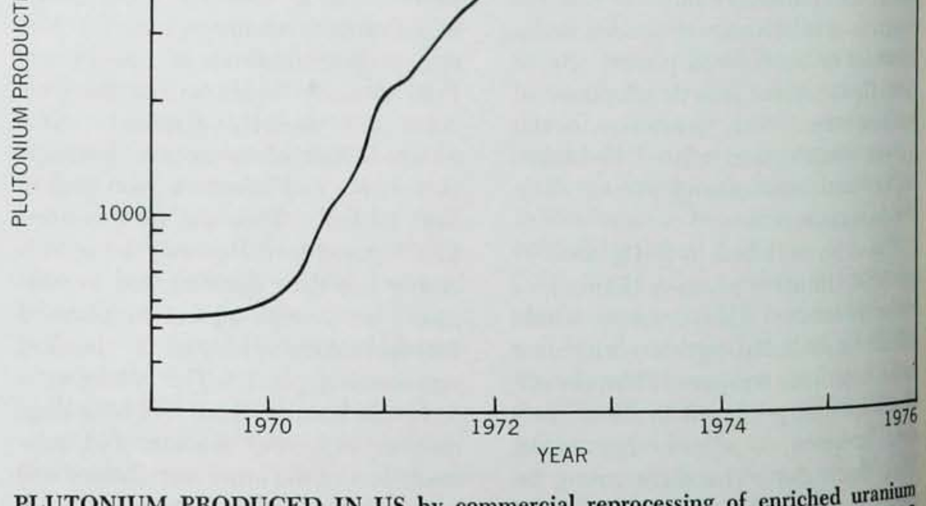
As an example, consider a plant that gets highly enriched uranium hexafluoride and converts it to uranium metal. Input consists of 25-kg cylinders of uranium hexafluoride that have been carefully measured at Oak Ridge National Laboratory. These cylinders are weighed and heated, and the contents are transferred into the system. The UF_6 is converted into UF_4, a powder, and the UF_4 is heated in a crucible and reduced to metal. Crust is scraped off the metal billets, and they are further cleaned in acid. Scrap includes slag, broken crucibles, cleaning acid, dust and airfilters. The clean product is weighed, sampled and shipped. Scrap may be recovered within the plant or sent to another facility.

Shipper–receiver reports are made to AEC for each transfer. Every six months a status report lists the initial inventory, receipts and shipments, losses, final inventory and "material unaccounted for." At least once a year, the company takes a physical inventory that is observed and verified by AEC inspectors, and company books are audited by AEC.

In this case, as elsewhere in the industry, most measurements consist of weighing, taking samples and chemical analysis. In some cases (for example nonhomogeneous scrap and fin-



NUCLEAR ELECTRIC-POWER capabilities to 1975, estimated from present commitments, show US dominance. US curve is dark color, UK light color, and USSR is black. Gray curve is for IAEA nonnuclear weapons states. —FIG. 1



PLUTONIUM PRODUCED IN US by commercial reprocessing of enriched uranium will increase substantially during the next six years. —FIG. 2

ished fuel elements) it is difficult or impossible to obtain representative samples. If it were possible to supplement these techniques with nondestructive measurements, a number of advantages would accrue both from the point of view of safeguards and of general production control.

In many cases it should be possible to measure whole items, avoiding problems associated with obtaining representative samples. For some materials and process lines it should be possible to keep up with the process flow so that information is current rather than days or months behind. Alternatively some combination of sampling and physical measurement may permit more extensive measurement or substantially reduce cost. For these obvious reasons AEC, the US Arms Control and Disarmament Agency, the International Atomic Energy Agency (IAEA) and a number of institutions in other countries are conducting research on safeguards techniques.

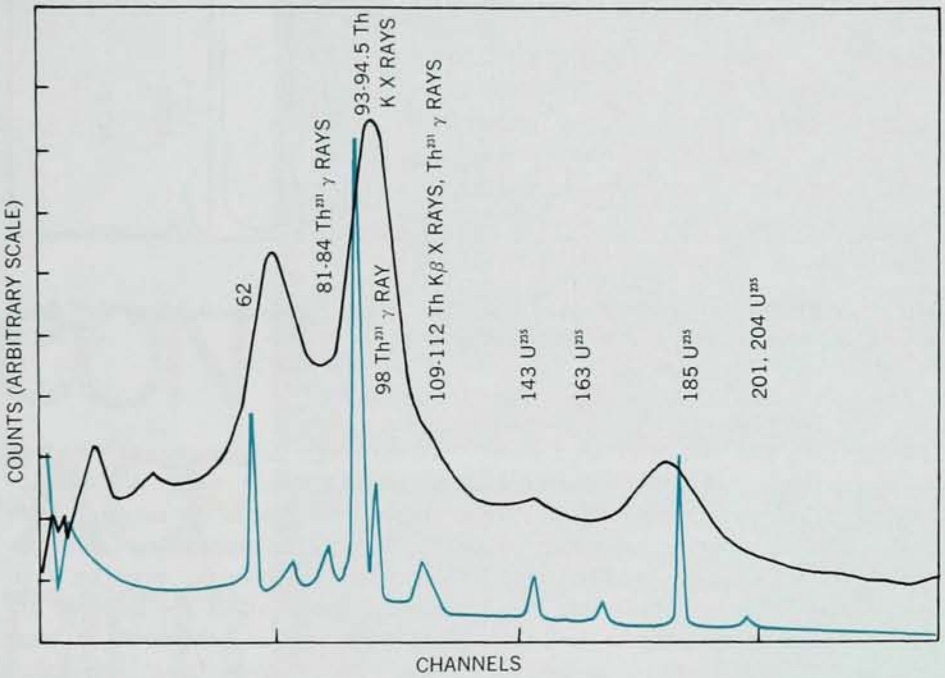
The nuclear nonproliferation treaty will, we hope, come into existence in the not too distant future, and many nations, including the US, will submit their nonmilitary nuclear programs to control by the IAEA safeguards system. (See page 33, this issue.) It is clear that development of nondestructive assay techniques will help to make IAEA safeguards more acceptable and effective. For those concerned about proprietary information, automated nondestructive measurements could be less intrusive. Such measurements depend less on the skills of particular analysts, and provide data on the spot, promptly and directly, for all to see.

At first blush, these techniques may seem easy. Isotopes of interest are naturally radioactive and react characteristically to neutrons. Chemical analysis, however, is still the basic method; this fact indicates that physical measurements are not that easy and brings us to the current effort in research and development.

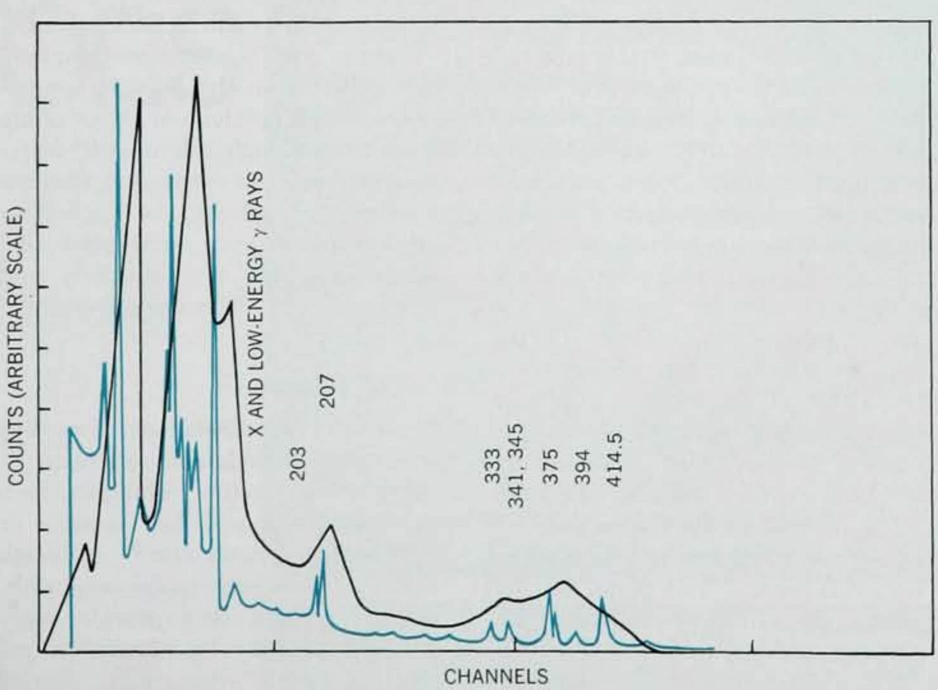
Current research

First there are the passive gamma-ray and neutron measurements. The one nondestructive technique that has had widespread use is monitoring of the 185-keV gamma-ray line of U^{235}. The apparatus consists of a sodium-iodide scintillation detector, a single-channel analyzer and an electronic counter. The procedure involves plotting a spectrum, setting the single channel on the line of interest and comparing the counting rate of a reference sample with that of the unknown. The method is particularly useful for the measurement of highly enriched uranium. For example, accuracies of 0.25% have been obtained for highly enriched samples that are thin, so that there is little self-absorption of the relatively soft gamma rays.

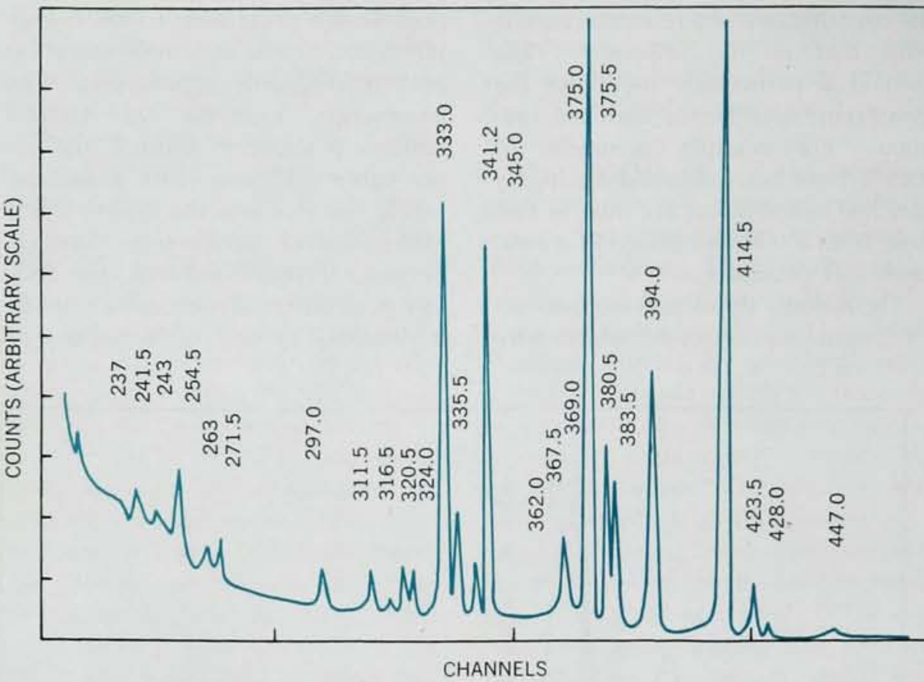
The recently developed semiconductor gamma-ray detectors, which have been such a great boon to low-energy physicists, can be extremely useful for nuclear-safeguards applications. The low-energy spectrum of natural uranium is shown in figure 3; the upper curve was taken with a sodium-iodide detector and the lower with a lithium-drifted germanium detector. Because of poor resolution, the 185-keV peak observed with sodium iodide is distorted by tails of higher-energy



GAMMA-RAY SPECTRUM OF NATURAL URANIUM with sodium-iodide (black) and lithium-drifted germanium (color) detectors shows the increased resolution due to the germanium detector. The source of major emission lines is identified, and their energies in kilovolts are indicated. —FIG. 3



GAMMA-RAY SPECTRUM OF PLUTONIUM SAMPLE shows greater resolution with germanium detector (color) than with sodium iodide (black). —FIG. 4



HIGH-RESOLUTION SPECTRUM of plutonium sample clearly shows many Pu^{239} lines as well as lines from Pu^{241} and Am^{241} impurities. —FIG. 5

gamma rays and not well separated from the cluster of x rays that are slightly lower in energy. With the high-resolution detector, however, the 185-keV line is clearly resolved, and many other lines are observable. In fact, the relative intensities of the 143-, 163- and 201-keV lines may be used to estimate the degree of self-absorption.

Sodium-iodide and germanium spectra of plutonium are shown in figure 4. Sodium iodide is the more efficient detector, but poor resolution leaves uncertainty about the exact nature of the sample. With germanium (see figure 5) many Pu^{239} lines are clearly resolved, as are lines from Pu^{241} and Am^{241}. A group at Argonne National Laboratory[2] has built an automatic scanning system with a germanium detector and computer-controlled stage to measure the plutonium content of several thousand plutonium-uranium alloy plates for the zero-power plutonium experimental reactor (ZPPR). Because self-absorption was appreciable (70% of the higher-energy plutonium gamma rays were absorbed in 2 mm of the alloy) plates were scanned on both sides. Results ultimately achieved were comparable in accuracy to the chemical analysis of samples from cast ingots. Two plates that fell outside the specifications were easily detected.

Most of the plutonium gamma rays are from the 239 and 241 isotopes. Because isotopic composition varies over a wide range, gamma-ray analyses may not tell the whole story. Another approach is to look at the neutrons from Pu^{240} spontaneous fission. The interpretation, however, may be confused because all of the isotopes are alpha emitters, and there will, in most cases, be neutrons from the alpha–neutron reaction with oxygen or with other light elements in the sample. Both Los Alamos and the Naval Research Laboratory have developed neutron-coincidence circuits that can distinguish multiple-neutron fission events from the alpha–neutron background.

Calorimetry is another technique applicable when the isotopic composition of the plutonium is precisely known. Although calorimetric determinations are time consuming, they are very precise and may be applied to large samples, even to massive fuel assemblies that are presently not amenable to other nondestructive methods.

Active techniques

Because of the limitations of passive techniques considerable attention is being given to active techniques, such as interrogation with fast neutrons or high-energy gamma rays.[3] Although such measurements involve more elaborate apparatus, they provide many handles that may be adjusted to extract the desired information. Among the signatures that may be exploited are: ratio of prompt to delayed neutron emission as a function of interrogation-beam energy; time distribution of delayed neutrons; prompt and delayed gamma rays; fission and gamma-neutron thresholds. Many measurements of these properties have been made in the last 20 years, but it is not possible to sit down with the tables and design a device; one must make many basic measurements of special relevance to the particular materials and mixtures.

Each of these methods has advantages and shortcomings. None of them have yet been fully tested against the many types of material that must be measured today, and undoubtedly there will be more difficult forms and combinations, shapes and sizes (not to mention greatly increased amounts) in the near future. General research on methods is undoubtedly useful, but now the need is for more emphasis on practical application of existing techniques: correction for absorption of gamma rays or multiplication of neutrons within the sample; accounting for variations in geometry; measurement of samples that contain fission products, and development of fast, precise measurement to provide data in a useful form.

My emphasis here has been on activities supported by AEC. The US Arms Control and Disarmament Agency is also supporting research on instruments, techniques and tamper-resistant components. IAEA, Euratom, and a number of individual nations have programs similar to those described here. An up to date summary of all of this activity was recently prepared by OSMM.[4]

Domestic problems are formidable if one takes into account the political, economic and managerial aspects as well as the technical ones. Internationally there are additional considerations that are political, social and strategic in nature. Yet the clock can not be turned back; so solutions must be found.

References

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