and Budget "have been giving us a warmer reception lately." "It is possible," he concludes, that "there may be an earthquake program in the 1973 budget."

Certainly the argument for one never seemed more persuasive than it does now. The proposal writers have had little trouble estimating the costs. The potential benefits of such a program have always been couched in terms of the damage a major earthquake might be expected to inflict on a large urban area. But such estimates have necessarily been gross extrapolations from the San Francisco quake of 65 years ago, from a variety of foreign quakes of questionable relevance to this country, and from the Alaskan quake which occurred in an environment very different from a California megalopolis. Now, however, the $500 million in damage dealt by an earthquake of moderate magnitude on the fringe of a large metropolitan area suggests that an estimate of $20 billion in damage from a major quake under an urban center is not only reasonable but possibly conservative.

—ROBERT GILLETTE AND JOHN WALSH

Plutonium: Reactor Proliferation Threatens a Nuclear Black Market

The commonly accepted solution to national energy needs is sprinkling the landscape with plutonium-fueled nuclear power reactors. Environmental defenders have argued loudly that these pose health risks, but a less well known threat would arise from a vastly increased traffic in plutonium fuels. It has been predicted that these commercial reactors will cause civilian plutonium stores in the United States to rise from the present 600 to 720,000 kilograms or more in the next 29 years. Even Atomic Energy Commission (AEC) commissioners who are promoting the reactors admit that it is "likely" that this vast traffic will spring a leak onto a worldwide black market. Since plutonium is the stuff from which Nagasaki-type atomic bombs are made, such a black market could put the 5 kilograms of plutonium it takes to make an atomic bomb into the hands of anyone willing to pay.

But the prevention of just this sort of diversion has been a cornerstone of American diplomatic and strategic policy for two decades. It was the prime aim behind the nuclear Non-Proliferation Treaty (NPT) signed in 1968 by 63 nations and ratified last March by 48. (See box, page 144.)

In a speech titled "The Plutonium Economy of the Future,"* given in October 1970, Chairman Glenn T. Seaborg outlined a picture of the nation depending on plutonium for 15 percent of its electricity in 1980 and for 70 percent in 2000. By then the country's plutonium will total $18 billion in value and 720,000 kilograms in quantity. This fantastic rise in the scale of plutonium use will begin as early as 1973, when the present light water reactors (LWR) will convert to using recycled plutonium as their fuel instead of the expensive, enriched uranium they now use.

The LWR and other reactors being developed for use for the next 40 years produce plutonium. By the late 1980's a type which produces far more plutonium than any other, the liquid metal fast breeder reactor, will be most common, according to AEC plans. With plutonium as the product as well as the fuel for all these, an enormous commerical trade is inevitable, and, in fact, has already started with industry stockpiling of LWR-produced plutonium.

In perhaps the frankest speech on record on safeguarding these materials, AEC Commissioner Clarence E. Larson told a Los Alamos safeguards conference in 1969 about the "likely" nuclear black market of the future.

"Once special nuclear material is successfully stolen in small and possibly economically acceptable quantities, a supply-stimulated market for such illicit materials is bound to develop. And such a market can surely be expected to grow once a source of supply has been identified. As the market grows, the number and size of thefts can be expected to grow with it, and I fear such growth would be extremely rapid once it begins. Such a theft would quickly lead to serious economic burdens to the industry and a threat to national security."

Larson also quoted an "unavoidable" loss rate by industry of 1 to 2 percent: "We in the industry recognize this to be a fact." And later, he admitted, "from a practical point of view, we may never solve all the problems" of safeguarding materials.†

Practically everyone in and out of AEC agrees that there is a significant security threat associated with large-scale reactor use. At the Los Alamos conference, Don Povejsil, of Westinghouse's Nuclear Fuel Division, termed the plutonium-guarding problem the "dominant" one.‡ More recently, Ralph F. Lumb, chairman of a 1967 AEC advisory committee on safeguarding materials, specifically referred to the future plutonium problem "like any other business . . . the more you have of something, the more you're going to lose. It's something in the nature of risks." And Ralph Lapp, Washington writer and consultant on atomic matters, believes that the issue will "inevitably" become acute and that it is "a major unsolved problem of the nuclear future." Finally, John Gofman, of Livermore Laboratory and a severe critic of AEC, told *Science*, "We consider the question of loss a very serious matter and a chief condemnation of the nuclear reactor program."

At present, plutonium sells for about $10,000 per kilogram. It is thus five times as costly as heroin and ten times as expensive as gold. What its value would be on an illegal market is anybody's guess.

It takes only a very small bit of

* Delivered 5 October 1970 to the Fourth International Conference on Plutonium and Other Actinides, Santa Fe, N.M. (AEC S-33-70, Atomic Energy Commission, Washington, D.C.). See also "Potential Nuclear Growth Patterns," WASH 1098 (Government Printing Office, Washington, D.C., 1970) and "Cost-Benefit Analysis of the U.S. Breeder Reactor Program," WASH 1126 (Government Printing Office, Washington, D.C., 1969).

† Original text available through AEC, titled "Nuclear Materials Safeguards: A Joint Industry Government Mission." Also published in the proceedings of the AEC symposium on safeguards research and development held at the Los Alamos Scientific Laboratory, UCLA, 27 to 29 October 1969 (Clearing House for Federal Scientific and Technical Information, Springfield, Va., WASH 1147).

‡ *Ibid.*, WASH 1147, p. 173.

plutonium—about 5 kilograms or $50,000 worth—to make a bomb the size of the weapon that destroyed Nagasaki in August 1945. The technology and hardware are available—many sources recommend the *World Book* as a good text on atomic bomb–building. Finally, unlike the uranium now used in reactors, plutonium is relatively easily processed into weapons-ready condition. Hence the only real obstacle now stopping anyone from building a perfectly good bomb is the present scarcity of the materials and the tight security kept by the five nuclear powers over their uranium and plutonium.

To date, there have been a few reported losses of strategic material, although only one is said publicly to have involved an attempted theft. In late 1969, the experimental SEFOR reactor in Strickler, Arkansas, was found deficient in "a few kilograms" of plutonium. A Nuclear Materials Enrichment Corporation plant in Apollo, Pennsylvania, discovered that 6 percent of its materials had gone unaccounted for over a 6-year period. In both cases the AEC attributed the losses to normal processing. In Bradwell, England, however, two reactor plant workers dropped 20 fuel rods over the plant fence and left them, apparently to be picked up. The theft was intercepted, however.

Losses and Thefts

Those concerned with these materials envision two principal scenarios of plutonium or uranium theft. One is the smuggling of them bit by bit from the plant by one or a group of plant workers, who then become a steady source of supply to an illegal market. The other is outright holdup or hijacking of plants, trucks, or aircraft with these materials as cargo, just as other valuables have been stolen for centuries.

The smuggling scenario runs like this, according to Lapp: Plutonium fuel is cased in thimble-sized pellets containing 0.05 ounce of plutonium and weighing a third of an ounce each. A worker could extract a few pellets at a time from the 12-foot rods in which they are cased. If a worker carries out a handful of 20 pellets, containing a total of 1 ounce of plutonium, each day for 160 days, he will have passed out enough plutonium for one Nagasaki-type bomb.

The countermeasures to this scenario adopted by AEC's Office of Safeguards and Materials Management (OSMM) is to keep continuous audits on the materials themselves at each stage of processing and use. But such audits can never keep track of 100 percent of the material: inevitably, some is lost in normal chemical reactions, some sticks in pipes, in vents, to workers' uniforms and gloves, and some falls in among the scrap. The purpose of the audits is to determine what loss rates are tolerable so that any unusual losses will be known instantly. In that case, AEC can require a facility to shut down and clean itself inside out to find the lost material. According to Delmar L.

IAEA and Non-Proliferation of a Nuclear Black Market

Under the Nuclear Non-Proliferation Treaty (NPT), signed in 1968 and ratified in March 1970, The International Atomic Energy Agency (IAEA) was given the important role of international inspector, to see that the NPT nations do not divert the uranium and plutonium in civilian, peaceful use to military purposes.

But as both the United States and the rest of the world begin building plutonium-fueled, plutonium-producing nuclear reactors in increasingly large numbers, the international traffic in these weapons-grade materials will climb. And IAEA is described by many as too tiny in scale and too limited in powers to actually prevent the diversion of these valuable materials from the legitimate corridors of international commerce to an international black market.

Article III of the NPT—the section dealing with international materials safeguards—will formally go into effect in March 1972. Individual nations have until then to conclude formal agreements with IAEA. Under the NPT, only non-nuclear nations must be inspected, to see to it that they are not diverting enriched uranium or plutonium to military uses. But, as a sign of good faith, the United States and the United Kingdom (although not the third nuclear power in NPT—the Soviet Union) have voluntarily given IAEA permission to inspect their civilian facilities as well. All of these inspections will begin in 11 months.

Most recently, IAEA's principal safeguards work has been the hammering out of inspection guidelines for the 61 NPT nations by the Board of Governors' Safeguards Committee. While these negotiations are said to have won surprising cooperation among nations, and while IAEA inspectors are being readied for their tasks, critics say that these efforts have been mainly paperwork—albeit necessary paperwork—and that IAEA has yet to prove itself in the field as an effective international policeman.

IAEA's budget for 1970 was $12.2 million, while the amount for safeguards was $1.2 million. By comparison, the Atomic Energy Commission's (AEC) Division of Nuclear Materials Safeguards has an annual budget of $6 million—and even this does not include some activities that happen to fall under other budgetary headings.

But the most serious threat to keeping strategic nuclear materials out of the unlawful hands lies entirely outside the orbit of IAEA itself. Neither East Germany nor Red China, say AEC spokesmen, are IAEA members, and IAEA does not have the right of access to nonmember nations. Nor does it have the right of access to military facilities, even in member nations. Thus, a situation could arise in which IAEA would have no authority—for example, if Red China were to ship plutonium to Cuba (an IAEA member) for use in military plants. Even should IAEA detect diversions within its own ranks, it has no real police powers, only the force of censure by other nations. And how effective that will be, said one spokesman, "will depend entirely on the context of the incident."

Hence, the IAEA effort is only a step in the direction of deterring the growth of illegal trade in weapons-grade nuclear materials. But one scientist, readying the AEC to open its doors to inspection in 1972, defended it as "the best we can do for now."—D.S.

Crowson, head of OSMM, audits for plutonium-239 loss average within +0.18 to 0.51 percent, with 0.2 percent "not unusual."§

However, scientists working for AEC on this problem say that the above figures do not reflect the margins of uncertainty involved—which sometimes run as high as 1 percent or more. Current calculations, they say, are based on estimates, for example, of how much strategic material might be in a scrap heap—not on precise, actual measurement.

AEC is now working to revise its guidelines for industry so as much guesswork as possible will be eliminated. Thus, when the amount of material involved begins to climb, and IAEA begins its formal inspections in March 1972, AEC will have a more realistic tab on the materials.

But critics of AEC safeguards find the holdup or hijacking scenario more likely—and less well guarded against—than smuggling. Crowson told *Science* that the most likely point for materials theft is the fuel reprocessing plant. But critics, including Dr. Theodore Taylor, former safeguards consultant to the AEC, believe that loading, shipping, and transfer processes are most vulnerable. Dr. Taylor believes there is a good chance that the planes which carry the materials by commercial air freight could be hijacked.

There is not much chance for the public to examine the security measures now in force. But in early 1969, a *Wall Street Journal* reporter visited the one commercial reprocessing plant now in operation, of which four more are being built or planned.

Writing in *Esquire* magazine in May 1969, the reporter, Alan Adelson, reported that security seemed weak at Nuclear Fuel Services, Inc. (NFS), in West Valley, N.Y. He alleged that a third of the NFS employees have "the lowest level security clearances" and that the "room where the nearly bomb-ready plutonium solution" is prepared for shipment "is directly accessible to the outside through a glass-paned door." He said the drivers of the van which were to carry a shipment of plutonium equivalent to that needed for 12 atomic bombs across the country had "no escort, no radio transmitters, and no weapons."

NFS officials reply that the glass door is on the other side of the building from the room where the plutonium is prepared, and that all the plant employees are now in the process of being cleared by the government. They also say that in certain processes, materials unaccounted for can run as high as 1 percent.

Boffey to Head Nader Study

Philip M. Boffey, a member of the News and Comment staff for the past 3½ years, has resigned, effective 12 April, to conduct a study of the National Academy of Sciences–National Academy of Engineering–National Research Council under the sponsorship of Ralph Nader's Center for the Study of Responsive Law. The study is expected to take about 9 months and to focus on Academy activities that have an impact on public policy. Boffey can be reached at his home, 5511 Montgomery St., Chevy Chase, Md., 20015. Telephone: (301) 657-8129.

The Lumb Report

Taylor, citing, among other things, Commissioner Larsen's speech, told *Science* that AEC's posture on safeguards had in fact improved. "The pre-Lumb view of safeguards was that it was an accounting problem, that the government had to track the material because it was expensive. The post-Lumb view of safeguards is that AEC should be concerned about the possibility of removal."

The turning point, he said, was the report of a special advisory panel on safeguards chaired by Ralph Lumb, then at AEC, which was submitted in March 1967.

The panel was skeptical at first that a black market was a real possibility; but the Bradwell, England, and Apollo, Pennsylvania, incidents which occurred during their study apparently helped change their minds.||

The panel reported on a comprehensive series of safeguards actions, ranging from U.S. international responsibilities to criminal penalties.

To date, while some of the recommendations have been implemented, many have not. And Dr. Lumb, who is now a private consultant, told *Science* that although he had not kept close track of developments at the AEC, he did "not believe a great deal has changed since that report was issued."

The panel recommendations included the establishment of a single AEC safeguards office, safeguards research and development, design review of all proposed facilities, establishment of quantitative standard losses, U.S. support of the IAEA, and establishment of an international school of inspectors. All of these have been done.

But in two key areas, criminal penalties and security clearances, the Lumb panel has not borne fruit. The panel requested that personnel having access to "significant" quantities of unclassified special materials should have the lowest level security clearance. But as reporter Adelson learned at West Valley, N.Y., many people there were still not cleared.

The panel's first recommendation was that the Atomic Energy Act of 1954 and the Atomic Weapons Rewards Act of 1955 should be modified to provide severe penalties for diverting nuclear materials and to reward information about diversions.

The 1954 act has indeed been amended, but the penalties are still fairly light. Only if the lawyers can prove the difficult legal point of intent, that a suspect diverted materials "with intent to injure the United States or gain advantage to a foreign power," can he be given life imprisonment, or a $20,000 fine and jail sentence. Otherwise, he is subject to a fine of up to $10,000 and perhaps a sentence of 10 years or less.

But now, 4 years later, there is still no statute installing the much-recommended bounty system rewarding information on diversions, which both the Lumb panel and many others have urged.

Shipping: The Weakest Link

One of the anachronisms of AEC policy is that strategic nuclear materials which are to be used for military purposes are shipped under military rules. But, if the same materials are to be used for civilian purposes—although they too could fuel a bomb—they are usually shipped, in the words of Crowson, "like a special delivery letter."

Part of AEC's mandate is to promote private industry. In this case, it gives its business to commercial carriers. Sometimes the carriers, particularly railroads, have refused to ship

§ Reprint from Safeguards Techniques, "Progress and Prospects for Nuclear Materials Safeguards," by D. L. Crowson, IAEA SM 133/60, Vienna, 1970.

|| "Report to the Atomic Energy Commission by the Ad Hoc Advisory Panel on Safeguarding Special Nuclear Material" submitted 10 March 1967.

it on the grounds it was too dangerous. But the question of tighter controls on the truckers and freight companies is a touchy one. At the Los Alamos meeting which Commissioner Larsen addressed, one trucking consultant retorted that making security checks on shipping personnel, for example, was "retrogression, not progression. I was under the impression that the whole program of the AEC was to turn things over to industry. . . . I resent the implication that only the government is capable of doing anything correctively."

Sam Edlow, a transport consultant who has arranged shipments of fissionable materials internationally, said, "The carrier agrees to deliver a specific shipment between two specific points, at a published freight rate within a resonable period of time. . . . He doesn't promise you that he is going to follow your instructions at the transfer point of connecting carriers. . . . He won't guarantee to do it in a specific period of time. . . . If the Commission is serious—really serious—about establishing a real set of safeguards within the transportation cycle, the answer is probably (in addition to making the shipper act in a professional way) regulation of the transportation industry itself, because only in that way can authority be expressed on the industry."¶

But at the same time, the truckers agreed that organized crime could easily obtain nuclear materials if it wanted. "Anything that organized crime wants to lay its hands on, while it's in the transportation cycle, it's going to get."

AEC hired Wright, Long & Co. to make a study of the threat of hijacking by the Mafia and other organized groups. The study itself is classified, but Carmine Bellino of Wright, Long & Co. told the Los Alamos meeting that "on a list of 735 so-called Mafia members, 12 are or were owners of trucking firms, two are truck drivers, and at least nine were union officials." While interviews with police chiefs had revealed that the Mafia appeared more interested in cigarettes and television sets than in uranium and plutonium, he added: "It is possible, however, they would add, that some foreign tyrant might offer a deal of some kind to any racketeer who would divert enriched uranium or plutonium. . . . In such a situation a truck carrying uranium or plutonium could be easily hi-jacked or the theft could occur at warehouse or dockside." If such a threat exists already, the situation can only grow when, in 1974 and 1975, much greater quantities of plutonium will be shipped and stored.

Information Access

Although the black market problem is recognized by many at AEC as a grave question facing the nuclear reactor program and its plans for the future, to date there has apparently been little effort to make it public.

Naturally, details of losses, such as those at the Arkansas SEFOR reactor, are kept quiet for purposes of security. Congressional hearings dealing with security measures are also, generally, closed to the public. But the basic problem—the security aspect of AEC's future reactor program—is scattered through technical reports and documents, and it has rarely reached the public eye in coherent form.

When the head of the safeguards division first outlined the work of his group to *Science*, the problem of tracking great quantities of plutonium on a vast scale in the future was not even mentioned. (Later, when asked about the problem, he discussed it at some length and described his division's studies on the subject. The studies, however, are not public.)

The hazy line between withholding information on the problem and obfuscating it stretches into Commissioner Larson's speech on safeguards. There he repeated what many others in the field have said: that industry losses of strategic materials can run about 1 percent of the total. But when Larsen's speech was published with the other symposium proceedings, this admission had been reworded to say that "small process losses are unavoidable." The attitude at AEC seems to be to avoid telling the public much about this problem until the agency thinks it has a solution well in hand.

—DEBORAH SHAPLEY

¶ Los Alamos safeguards conference proceedings WASH 1147, pp. 21-38. See also summary of Oct. 2, 1969, Washington conference on transportation safeguards, AEC.

RECENT DEATHS

Charles V. Banks, 52; professor of chemistry, Iowa State University; 26 February.

Albert A. Bennett, 83; professor emeritus of mathematics, Brown University; 17 February.

Kenneth Berrien, 61; professor of psychology, Rutgers University; 9 February.

Paul W. Boutwell, 83; professor emeritus of chemistry, Beloit College; 22 February.

Robert E. Burns, 61; president, University of the Pacific; 13 February.

Toribio J. Castanera, 45; research radiobiologist, Armed Forces Radiobiology Research Institute, Bethesda, Md.; 27 January.

James R. Costello, 69; former professor of obstetrics and gynecology, Georgetown University; 24 February.

Herbert McL. Evans, 88; professor emeritus of anatomy, University of California's School of Medicine, Berkeley; 6 March.

Stevenson W. Fletcher, 95; former dean, College of Agriculture, Pennsylvania State University; 10 February.

Walter B. Ford, 96; former professor of mathematics, University of Michigan; 24 February.

Robert Getty, 54; chairman, veterinary anatomy department, Iowa State University; 18 February.

Herman Goodman, 76; retired clinical professor of dermatology, New York University Medical School; 9 February.

Amshel Gueft, 85; former clinical professor of prosthetics, College of Dentistry, New York University; 1 March.

William B. Hawkins, 70; professor of pathology, University of Rochester Medical Center; 4 February.

Charlotte Haywood, 74; professor emeritus of physiology, Mount Holyoke College; 6 February.

Arthur J. Heinicke, 78; former director, Cornell University's New York State Agricultural Experiment Station; 2 February.

Donnell F. Hewett, 90; research geologist, U.S. Geological Survey; 5 February.

Frank L. Horsfall, Jr., 64; president and director, Sloan-Kettering Institute for Cancer Research; 19 February.

Kenneth O. Hovet, 66; professor of education, University of Maryland; 1 February.

Donald Q. Kern, 56; chemical engineer and head, D. Q. Kern Associates a consulting firm; 2 March.

Derek J. Prowse, 40; chairman, physics department, University of Wyoming; 11 January.

George H. Roberts, Jr., 76; clinical professor emeritus of medicine, State University of New York; 25 February.