TECHNICAL REQUIREMENTS FOR NUCLEAR SAFEGUARDS

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The most important requirement for nuclear safeguards research and development is a clear definition of what nuclear safeguards are meant to do. I have been tempted to plan to make that statement and then sit down, but that isn't very constructive. So I shall try to tell you why I think this definition is needed, suggest some specific possible nuclear threats that should be taken into account in the definition, and briefly discuss a few things that I think ought to be done.

Let me use part of the IAEA Statute to illustrate some of the difficulty. It states that its safeguards are "designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose." One might use that, as a start, for a definition of safeguards. But immediately there are difficulties. The word "ensure" strongly implies, among other things, protection from theft. And yet people in the IAEA, Euratom, and the AEC disagree about the extent to which these agencies should provide or demand adequate physical security for special nuclear materials, especially those they do not own. "Ensure" also implies to me that the Agency should try to recover any lost plutonium, or at least try to find out where it is. But most people believe that the Agency safeguarding responsibility ends after detecting a loss and reporting it to the Board of Governors. I am strongly convinced that tritium, which one might include under "other nuclear materials," should be specifically under safeguards. Others strongly disagree. The word "any" in the phrase "further any military purpose" implies a degree of restriction that no one I have talked to says should be taken literally. How does one define a military purpose? I suggest that nuclear safeguards would be no more significant than safeguards of any other valuable materials if uranium or plutonium could not be used for making very powerful explosives or radiological warfare agents. I believe it would be better not to mix the IAEA's dedication to the development of peaceful uses of nuclear energy with the specific definitions of the purposes of nuclear safeguards.

Even greater difficulties appear when one tries to be quantitative about safeguards--to decide what surveillance accuracies to aim for, for example, or how much special nuclear material is an unreasonably large stockpile for a facility or for a country, or how far to go in insisting on physical protection of materials from theft. The Agency Statute uses the phrase "so far as it is able" at one point, but that does not help in planning for the future. The cumulative amount of plutonium produced by all the

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world's power reactors will exceed 100,000 kg in about five years, and the rate of production by the end of 1972 will exceed 30,000 kg/yr. Just one percent of either of these numbers potentially represents many bombs and a lot of money. Does this mean that surveillance accuracies must be very much better than one percent? Before one says obviously not, I suggest he think carefully about what the dangers are, and how they may be affected by the accuracy of the surveillance system.

Suppose that some safeguards system can detect, with 90% probability, the diversion of 10% or more of the special nuclear materials in a country, and, say, with 10% probability, 1% or more of the material. Such a system could, I believe, ensure that a non-nuclear power would not secretly build up a completed military nuclear stockpile. But it would not prevent or even necessarily strongly inhibit the undetected diversion of material for a few bombs by some non-national group of people. Neither would the system prevent stockpiling of large quantities of special nuclear materials that could quickly be incorporated into a prefabricated stockpile of nuclear explosive devices that have everything except the required special nuclear materials. Nor would the system, by itself, prevent the theft of large quantities of plutonium, uranium, or tritium by massive armed robbery.

All that is required to make a crude fission explosive that can be carried in an automobile is a few kilograms of plutonium or highly enriched uranium, a practical scientist or engineer who is familiar with the basic, unclassified properties of chain-reacting systems, and some other components that could easily be made and assembled in any city in the world. Devices of this kind, in the hands of unscrupulous revolutionary or criminal groups, could be used for severe threats against national governments or other very large groups of people, in forms for which a strategic deterrent force is useless. An unusually large assembly of national government leaders in the United States Capitol or the Kremlin, for example, could be killed by the explosion of such a device in a parking lot near the building. An organization that does not have to identify itself could try to force a government to take certain action, using the threat of detonating covertly assembled nuclear explosives in several of the nation's big cities, if the demanded action were not taken. The United States could be asked to pull military forces out of Viet Nam, for example. There are several quite different organizations that would like to see that happen.

One can think of many other examples of threats, using not only relatively low-yield, crude fission explosives, but also much larger-yield thermonuclear devices, that could make use of diverted or stolen special nuclear materials in the hands of groups or people that need not either represent any nation nor identify themselves. Furthermore, plutonium, highly enriched uranium, and tritium are all extremely valuable materials, worth much more than gold per unit weight, because of both their commercial and their military value. These materials are bound to become

temptations to unscrupulous criminal organizations that are now sustained by international illegal markets in gold, diamonds, dope, or arms. These are some of the other dangers, much less publicized than the dangers of further proliferation of national military nuclear stockpiles, in the development of large-scale industrial use of nuclear energy without an effective system of international nuclear safeguards.

I have discussed these matters that may seem out of place in a talk about the technical requirements for safeguards because I believe they have to be thought about very hard before we can be reasonably sure that we know what an effective system of safeguards should do. But even after all the important classes of dangers in an inadequately safeguarded nuclear energy system have been thought through, there are still some other constraints, often nontechnical, that should be taken into account in establishing a set of detailed requirements for a safeguards system. I haven't time here to do much more than mention some of these.

One constraint is the concern of many people that safeguards will interfere with the development of the nuclear power industry. Fortunately most, if not all of the information required for effective safeguards is also useful in the development and operation of the nuclear-energy industry. Some types of required physical security measures may, in some sense, interfere with the industry; in those cases I certainly believe that industry should yield, not the security measures.

Another constraint is cost. I strongly disagree with the idea that low costs for nuclear power should come first, effective safeguards, second. But, fortunately, it looks as though effective safeguards can be achieved at costs that would add one percent or less to the costs of nuclear power, and there is a good chance that even these costs would pay for themselves through the benefits that many safeguards measures hold for the industry.

A third constraint is the availability of adequately trained people as inspectors, especially within three or four years, when very large numbers of inspectors are likely to be required. This constraint tends to place emphasis on reliable, automatic data recording, transmittal, storage, and analysis techniques and on safeguards procedures that can be standardized.

Related to this is a fourth constraint that the safeguarding process has to be inspiring enough to make possible recruitment of good technical people to oversee inspections and research and development work.

A fifth constraint has to do with industrial secrecy. Of two otherwise equally effective safeguards measures, the one that requires the least detail in the description of components or processes used in the nuclear-energy industry is the more acceptable.

Finally, there are different types of political constraints, some of which are closely connected with ones I've mentioned, and many of which are extremely hard to define. Political constraints, if they are strong and persistent, usually have very important effects on the technical requirements for safeguards. A history of recent political instability in a country, for example, has a rather direct bearing on the quantities and physical forms of special nuclear materials that should be allowed to accumulate in that country. But other political considerations may make it impractical to take such a connection into account.

Having talked about dangers and difficulties and constraints, I want now to try to be more constructive and sketch very briefly a few concepts that I think would be useful and perhaps even necessary parts of the planning or operation of any effective safeguards system. I want to emphasize international nuclear safeguards, but I think that most of what I have to say also applies to national safeguards. This is by no means an attempt to summarize all the basic requirements for specific safeguards systems.

First, we need to develop and then use an information collection, storage, manipulation, and retrieval system that can keep track of all the important parameters that define the past, present, and future state of the world's nuclear-energy system. I do not believe that anyone now knows or can easily find out enough about the way the world's nuclear-energy system is developing to have a clear idea of what it is that we will want to safeguard in, say, three or four years. You all know how extremely fast things are now changing. This information system should make it possible to determine past, present, and future rates of production and consumption of special nuclear materials classified according to specific facilities, types of facilities, manufacturers, nuclear-energy complexes, countries, physical and chemical form of the material, etc.

Second, we need to develop suitable techniques for describing an international nuclear safeguards system on paper or in electronic data-storage units. These should provide general-purpose formats and programs that would be suitable for a wide variety of types of systems.

Third, we need systems-analysis techniques that are suitable for studies of the effectiveness of specific safeguards-system concepts. I believe the techniques should be suitable for deriving at least the following:

- a. The accuracy with which special nuclear materials are balanced, classified according to the type of material, the history of the material between inventories, geographical regions, types of facilities (e.g., fuel-element fabrication, transport, power plants, reprocessing plants), countries, international organizations, etc. The capability to make parameter sensitivity studies is essential.
- b. Operating costs of the system.
- c. Capital costs of the system.
- d. Numbers and types of safeguards personnel required.
- e. Effects of the safeguards system on the nuclear-energy system, in terms of cost increases or decreases, production delays, increases or decreases in safety parameters, for example.
- f. Levels at which diversion could take place without detection, organized by type of facility, energy system modules (combinations of fuel-element production, power plants, and chemical reprocessing plants, for example), industrial organizations, countries, international organizations, type of material and their physical and chemical form, etc. This implies that the analysis techniques include the ability to play diversion games on a machine.
- g. Changes in elements (components or procedures) of the nuclear-energy system that would increase the effectiveness of safeguards. The technique should also be suitable for deriving the effects of such changes (changes in costs, delays, or even improvements) on the energy-production system.
- h. Changes in parts of the safeguards system that would increase its effectiveness.
- i. Requirements for further safeguards research and development.
- j. Requirements for further R&D on elements of the nuclear-energy system to make it easier to safeguard effectively.

Fourth, an electronic information storage and retrieval system for use by the safeguards organization in its operations is needed. In summary, this should be capable of telling the safeguards personnel where and in what form all the special nuclear materials for which they are responsible were, are, and will be, as rapidly as is possible, by reasonable use of modern data acquisition, transfer, storage, processing, and display techniques.

Fifth, uniform reporting procedures and a hardware system that transmits data rapidly, in the right form, to the safeguards data bank are both required. In practice, provision should be made for reports from inspectors, facility operators, and automatic surveillance-recording equipment. The system will probably require several different types of data transmission links.

Sixth, there is a need for computing-machine programs for analysis of the implications of deviations from expected values of data reported through the safeguards information storage and retrieval system, and to test the data for internal consistency (comparisons between measurements and calculations, for example). Many of the sampling techniques will be based on statistical methods that are very complex, but that can greatly increase the effective accuracy of a surveillance system if the data are completely analyzed.

Finally, having so far talked mostly about information-system software, I want to give just one example of a specific class of measuring systems that I think looks very attractive, but which will require much theoretical and experimental work to develop. I call this a fuel-element isotopic-content scanning and tracking system. The heart of the system is any one of at least three possible techniques for nondestructively measurement of the relative and absolute amounts of fissionable isotopes in new or in irradiated reactor fuel elements. The techniques I have in mind use a zero-power critical assembly, a pulsed neutron source, or an electron linear accelerator. The first technique, which was examined in considerable detail at Westinghouse four or five years ago and, I believe, still looks promising, is based on measurements of the reactivity changes of portions of the fuel element as it is inserted into an annular-core critical assembly. The second, which Bob Keepin from Los Alamos will describe shortly, is based on observation of the delayed neutrons from fission products generated by an intense pulse of neutrons that strike the element. The third technique, which Bob Beyster from General Atomic will describe later today, is based on the observation of gamma rays or neutrons from fission of fuel-element isotopes by a short, intense pulse of gamma rays generated by impact of a pulse of electrons on the fuel element. All three techniques show some promise of working even in the gamma-ray background of irradiated fuel elements. All the techniques are suitable for use in a way that very accurately compares measurements of the properties of unknown elements with known standard elements, measurements of the same element before and after irradiation, and fuel-element measurements and prediction calculations.

One can imagine that the fuel-element scanning devices are permanently installed and used routinely near the point of output of elements from fuel-element-fabrication plants and near the point of input to chemical reprocessing plants. Each fuel element, defined as the smallest assembly into which fuel is separated between packaging for shipment from the

fabrication plant and destruction at the reprocessing plant, is somehow identified, kept under surveillance--either actively or by a system of seals and physical constraints--at all times during its life. Its whereabouts and detailed irradiation history are recorded in the safeguards-system data bank. Finally, a four-way comparison is made between measurements before irradiation, measurements after irradiation, measurements of a known standard set of fuel elements, and calculations that use the irradiation-history data on both the fuel-element positions in the reactor core and the reactor power level. By use of such techniques there is at least a chance of achieving very high precision in the overall material balance accounts between the input and output of fuel-fabrication plants and of chemical reprocessing plants, as well as preventing essentially any undetected diversion of material between the output of the fabrication plant and the input to the reprocessing plant, since the latter requires only counting and watching or constraining a finite number of specific items.

Just one comment about cost. The operating costs of the types of scanning facilities I have been suggesting could run as high as several hundred thousand dollars per year, and still represent 1% or less of the value of the annual throughput of U^{235} or plutonium in reasonably large plants. The write-off of capital costs, at first glance, looks comparable.

Careful study of this kind of a safeguards concept, if one accepts that it would be useful, will yield a large number of rather specific requirements for applied research into sources, measuring techniques, seals, shipment and packaging procedures, chemical analysis techniques, development of theoretical calculation techniques, and a lot of basic physics. In view of the time, I leave this as an exercise for the listener!

Many of you may think I have painted much too grandiose a picture of what an international nuclear safeguards system may become, that we cannot afford the costs and manpower to develop and operate them. To those I simply want to say two things. One is that the explosion in the middle of New York City of one large, dirty thermonuclear device, perhaps secretly assembled there, would kill several million people by fallout, would destroy many tens of billions of dollars of property, and would be very likely to start World War III. The other is that the nuclear-energy system is now a multibillion dollar a year enterprise, and increasing rapidly.