CONF-791117--8

MASTER

LA-UR-79-3205

TITLE: THE EVOLUTION OF SAFEGUARDS SYSTEMS DESIGN

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SUBMITTED TO: ANS-INMM Topical Conference on Measurement Technology for Safeguards and Materials Control, Kiawah Island, SC, November 26-29, 1979

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Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

The Evolution of Safeguards Systems Design

by

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ABSTRACT

Safeguards systems play a vital detection and deterrence role in current nonproliferation policy. These safeguards systems have developed over the past three decades through the evolution of three essential components: the safeguards/process interface, safeguards performance criteria, and the technology necessary to support effective safeguards. This paper discusses the background and history of this evolutionary process, its major developments and status, and the future direction of safeguards system design.

INTRODUCTION

The 1968 Treaty on the Non-Proliferation of Nuclear Weapons[1] emphasizes the need for effective safeguards systems. Articles I and II of the treaty prohibit signatories from transferring nuclear weapons or explosives devices, control, or assistance between nuclear weapons states and non-nuclear weapons states. Article III, paragraph 1 requires that each non-nuclear weapons state, according to the treaty, accept safeguards "for the exclusive purpose of verification of the fulfillment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices." Thus, the objective of safeguards, as an instrument of nonproliferation policy, is "the timely detection of diversion of significant quantities of nuclear material ... and deterrence of such diversion by the risk of early detection."[2]

For nearly 35 years since the first nuclear weapons explosion, three questions have been continuously debated: what effects do safeguards have on nuclear facilities, how well should safeguards perform, and how well can safeguards perform? We shall examine the background, history, and status of these three questions by considering three evolutionary aspects of safeguards systems: (1) the safeguards/process interface, (2) safeguards performance criteria, and (3) safeguards technology. Our point of view will be primarily that of materials accounting, recognizing that physical protection and containment/surveillance are vital parts of an effective, complete system.

THE SAFEGUARDS/PROCESS INTERFACE

A Historical Example

The following example, drawn from the early history of the nuclear age and the Los Alamos Scientific Laboratory, illustrates the evolving thinking of facility operators concerned about nuclear materials accounting. Beginning in 1943, the first work with plutonium was done on a small scale with a distinct flavor of experimentalism. Each experiment always led to quantitative analyses of feed, product, and sidestreams because of the chemist's desire for understanding. These comprehensive analyses were frequently used to draw materials balances, but the procedures were not called accountability.

As the quantity of plutonium increased, more detailed accounting systems became necessary. A bookkeeping system was established, and radioactive material was transferred from one area to another, from one person to another, as if the radioactive material were capable of being counted like pennies in a bank. But it wasn't. Discrete items or items amenable to precise chemical analyses were transferred without too much difficulty. Residues and

*Work performed under the auspices of the US Department of Energy, Office of Safeguards and Security.

wastes in a heterogeneous matrix were a different matter because of the impossibility of obtaining a representative sample. There were, of course, no instruments for quantitative nondestructive assay.

Because wastes could not be assayed, it was always possible that some significant amount of plutonium might go out in a box of waste or trash. Consequently, in 1949 LASL designed, built, and installed a neutron counter using BF_3 tubes to detect neutrons emanating from each box and container leaving the plant. Although the measurement wasn't quantitative, it did give assurance that only small amounts (less than 0.5 gm) were in the containers. In addition, no portable, quantitative gamma survey instruments were available, so that the guards had to rely on visual examination of people and items leaving the facility.

The plutonium content of process residues was another matter of great concern because of accounting requirements imposed by LASL and the USAEC. The plutonium content of heterogeneous residues was difficult to measure; consequently, it was decided early in 1949 to keep residues segregated according to generator. The residues were stored in segregated groups until a process unit could be dedicated to processing a block of these residues. Each group of residues was designated as a "receipt area" so that data could be properly credited to the group by referring to that receipt area number.

The process data were recorded in log books, and transfers of plutonium were recorded on receipts. It was a slow and laborious process to make the final evaluation and to calculate inventory differences, and there was no practical way to obtain interim numbers.

In 1958 and 1959 as a result of a study of the data gathering and analysis process, several conclusions were reached: (1) Accountability data and process data were often the same. (2) The shipper and receiver were documenting the transfer by each recording the same data. (3) Compilation and evaluation of hand-logged data was slow and subject to error. (4) Good process data, criticality control data, and accountability data could not exist independently. It was then decided to design and establish an automated data processing system to address the above considerations. The data necessary to document each transfer were selected. The number of fields had to be restricted so that all the data would fit the 80-column format normally available at that time on punched cards. After many iterations, a format was chosen and a system was put into operation in 1960. The initial printouts are described in LA-2662.[3] This system was used as a recording document virtually unchanged for more than 17 years. There were, however, the development and use of an increased number of sorting programs and printouts that served many coincident process and accountability needs.

As interest in safeguards increased, it was realized that quick recall and analyses of data were necessary for the timely review of inventory differences. The main drawback was that data recall had to await the bi-weekly printout, although special printouts could be obtained on 4 hours notice, but at the expense of accumulating huge stacks of paper. Timely access and review was also the desire of process accountability and criticality managers.

The desire for timeliness led to the dedication of a computer to data acquisition and handling, with remote terminals in the plant connected to the computer. The result was a dynamic materials accounting system that collected process and accountability data and immediately updated the inventory file. The system would be invaluable to process people, and when NDA equipment could be developed and installed between materials balance areas, it would be invaluable for improved safeguards. Such a system is now being installed, tested, and improved at TA-55, the new plutonium processing facility at Los Alamos.[4,5]

From this example, we can see four main reasons, other than for safeguards, why facility operators are keenly interested in materials accounting: (1) production control, (2) supplier/customer interactions, (3) safety, including criticality control, and (4) regulatory requirements imposed to meet externally generated criteria. Thus, materials accounting is intimately related to both process control and safeguards, and both sets of considerations must be taken into account in any cogent safeguards systems design.

Integrating Materials Accounting and Process Design

Good materials accounting depends on the ability to draw materials balances having acceptably low uncertainties. That is, the nuclear material must be <u>measurable</u>, which has important implications for process design. For example, process equipment must be constructed so that significant amounts of material are not "hidden" in locations inaccessible for measurements. In the past, equipment was often not designed with this constraint in mind and instrumentation for measuring material residing inside process vessels was unavailable. These limitations have forced the materials accounting system to rely on cleaning out the process, i.e., doing a physical inventory, before a materials balance could be drawn.

Oftentimes, process operating procedures have significant impacts on the performance on the materials accounting system. For example, buffer tanks occasionally have input and output transfers that occur simultaneously, which severely limits the ability to infer the transfers from level and concentration measurements made on the tank. On the other hand, if input and output transfers do not occur simultaneously (e.g., if the tank is "batched"), then obtaining the transfer measurements is relatively straightforward.

The examples show that a great deal of thought must be given to designing the process for improved safeguards and process operations, two compatible and mutually supportive requirements. This is a relatively simple matter at the design stage of the process, but much more difficult and costly after the facility has been built. It is imperative, therefore, that the safeguards and process viewpoints be integrated at the earliest stages of facility design. Furthermore, it is often true that featu[illegible] important to materials accounting are the "designer's choice" with respect to the process and could have been changed had safeguards been a factor.

International Safeguards Considerations

The implementation of international safeguards contributes additional complexities to the safeguards/process interface. By statute, the IAEA performs independent verification activities to arrive at a technical conclusion on "the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."[2] These activities are based on the "use of material accountancy as a safeguards measure of fundamental importance, with containment and surveillance as important complementary measures."[2] Thus all the process design features relevant to safeguards discussed above are important, and there are several additional factors, such as proprietary information and questions of national sovereignty.

To fulfill its verification responsibilities, the IAEA is both allowed and required to take samples, make independent measurements, check standards, and examine records and reports. These activities require that the IAEA have access to the so-called strategic points, which include key measurement points used by the Agency for drawing materials balances and points where containment/surveillance measures may be executed. That is, the IAEA's activities may be considered, by some at least, to be intrusive. The degree of intrusiveness to a large extent will depend upon the capability of the facility's materials accounting system and on the inspector's confidence that he can ascertain whether or not the facility is being operated as declared. Both of these criteria depend heavily on the process design and must be incorporated early in the design stage.

PERFORMANCE CRITERIA

Performance criteria for materials accounting systems have also evolved. We will consider first the US domestic requirements and then discuss the proposed IAEA goals.

US Domestic Requirements

In recognition of the limitations of materials accounting, regulatory requirements in the US have specified that materials balances should be drawn immediately following a shutdown-cleanout physical inventory. A minimum physical inventory frequency has also been specified depending on the type of facility. For example, reprocessing plants must take a physical inventory and draw a materials balance at least once every six months. In addition, the uncertainty associated with the materials balance is also specified. In the reprocessing plant example, the materials balance uncertainty (the limit of error of the material unaccounted for) must be less than 1% of throughput.[6] Although these requirements have been deemed adequate in the past, the advent of large, high-throughput facilities requires that new criteria be considered.

Clearly, the current regulations have limitations in timeliness and sensitivity. In a 1500-metric ton/year reprocessing plant, a diversion of 75 kg of plutonium is the nominal amount that should be detected, and that only after 6 months. In addition, the merits of specifying detection sensitivity as a fraction of throughput are still being debated. On the one hand, a relative criterion seems inappropriate if the diversion quantity of interest is in absolute terms. On the other hand, an absolute criterion appears to favor small facilities, which are economically less attractive.

These changing perceptions have indeed resulted in increasing reconsideration of both the forms and the values of performance criteria. It is a continuing struggle to formulate performance requirements that both meet our perceived needs and are achievable with reasonable extrapolations of current technology.

IAEA Requirements

At the current time, performance criteria for IAEA safeguards are still being developed. However, criteria have been proposed for "timely detection" and "significant quantities" and have been authorized by the Director General of the IAEA for use by the Agency in its safeguards system.[7] The definition of significant quantity is related to the quantity of special fissionable material required for a single nuclear explosive device. For example, a significant quantity of plutonium is generally taken to be eight kilograms.[7,8] Timely detection depends on the "conversion time" for a particular material and has been defined as the minimum time required to convert different forms of nuclear material to metallic components of a nuclear explosive device. Thus, for plutonium oxide, nitrate or other pure compounds, the estimated conversion time is on the order of one to three weeks.[7,8]

The IAEA assumes that proliferation occurs when a single nuclear explosive is acquired. Therefore, to counter the range of possible diversion scenarios the proposed IAEA criteria have been set at detecting 8 kg of plutonium diverted over any period of time from one to three weeks up to one year.[7,8] That is, the Agency must treat both abrupt and protracted diversion scenarios, and the time allotted to detect these diversion scenarios is one to three weeks following completion of the diversion.

Given the current capabilities of the IAEA safeguards system and the facilities it has to safeguard, which currently are all low-throughput facilities, these are reasonable and achievable criteria. However, the large-throughput facilities on the horizon require continued attention to technology development.

TECHNOLOGICAL DEVELOPMENTS

Improved Instrumentation

We have seen that in the early days very little instrumentation, particularly NDA, was available. However, tremendous strides have been made in recent years.* New NDA instruments routinely make measurements of much better than 1% precision and accuracy on many types and forms of nuclear materials.[9,10] Large improvements have been made in the ability to assay such difficult items as waste containers and spent fuel.[11,12] In addition, these measurements can be made in a timely fashion and on the spot.[13] To satisfy the needs of IAEA inspectors, portable versions of these instruments have been developed, such as a high-level neutron coincidence counter that folds up into a suitcase.[14,15]

At the same time measurement capabilities are being improved, the instruments are being tested, evaluated, and demonstrated in operating environments. For example, an absorption-edge densitometer is being installed at the Japanese reprocessing plant at Tokai, and IAEA inspectors routinely use a multitude of portable hand-held units in their inspection activities.

Near-Real-Time Accounting

To meet the changing performance criteria discussed above, near-real-time accounting concepts and systems are being developed in preparation for the construction of new high-throughput facilities.[16-19] The essential feature of near-real-time accounting is the ability to obtain an estimate of the inventory of nuclear material in the process without having to resort to a physical inventory. This ability is desirable because it greatly improves timeliness and sensitivity, and it is made possible by the ongoing instrumentation development work discussed previously. In conjunction with near-real-time accounting, sophisticated data analysis methods, which we call decision analysis,[20-23] make most effective use of the vast amount of new information that will be available. The decision analysis techniques treat the data as an aggregation rather than as individual materials

*The references cited in this section are only examples of those available. A complete list would be much too long for this paper. See the cited works for additional references.

balances to provide the best achievable sensitivity to diversion in any scenario. The decision analysis techniques also provide quantifiable measures of systems performance and a defensible basis for action.

The costs of these improvements, surprising though it may seem, are not large. It is often true that near-real-time materials accounting can be accomplished with very few additional instruments, including upgrades of process control measurements, added to that instrumentation already necessary for properly performing conventional materials accounting. Likewise, the advanced data analysis techniques merely make better use of the information that should already be available for the more traditional analysis methods.

Systems Design Approach

All these technological developments must be folded together to form a coherent safeguards system. That is, we must have a systematic approach to safeguards and facility design. This approach has been developed through numerous interactions with the safeguards community and the process designers, and has been reported in several documents.[16-19,24,25] Although many steps must occur in a successful system design, one step stands out as both the most difficult and the most useful: computerized modeling and simulation of the facilities and safeguards systems. This is true for a host of reasons, including cost, time, and unavailability and inflexibility of operating facilities. This approach allows the investigation of ideas that would be impossible to try in actual facilities. We must constantly keep in mind that the results are only as good as the information we put in. For this reason, any modeling and simulation activity must be based on a specific reference process and must, of necessity, involve the cooperation and participation of the process designers.

For materials accounting, the modeling and simulation approach requires a detailed dynamic model of the process based on actual process design data. Design concepts are evolved by identifying key measurement points and appropriate measurement techniques, comparing possible materials accounting strategies, developing and testing appropriate data analysis algorithms, and quantitatively evaluating the capability of the proposed materials accounting system to detect losses. By using modeling and simulation techniques the effects of process and measurement variations over long operating periods and for various operating modes can be studied in a short time.

CONCLUSION

Examination of these three aspects of safeguards makes evident their dynamic, evolutionary, and interrelated natures. Facility operators are always interested in making the best use of available materials accounting capability. Performance criteria are changing to provide better protection against perceived threats and to make the most effective use of current technology. Both these aspects have spurred the development of the third: technological advances in safeguards. All three aspects must play a major role in safeguards system designs for future high-throughput facilities.

At the conceptual level, future activities will be aimed at international safeguards. The implementation of these concepts in the international context, however, must await demonstration and evaluation of advanced safeguards systems in a benign but realistic environment.

REFERENCES

1. "Treaty on the Non-Proliferation of Nuclear Weapons," reproduced in International Atomic Energy Agency document INFCIRC/140 (April 1970).

2. "The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," International Atomic Energy Agency document INFCIRC/153 (corrected) (June 1972).

3. E. L. Christensen, J. A. Leary, J. P. Devine, and W. J. Maraman, "A Punched-Card Machine Method for Management of Nuclear Materials," Los Alamos Scientific Laboratory report LA-2662 (January 1962).

4. G. R. Keepin and W. J. Maraman, "Nondestructive Assay Technology and In-Plant Dynamic Materials Control--DYMAC," in Safeguarding Nuclear Materials, Proc. Symp., Vienna, October 1975 (International Atomic Energy Agency, Vienna, 1976) Paper IAEA-SM-201/32, Vol. I, pp. 304-320.

5. R. H. Augustson, N. Baron, R. F. Ford, W. Ford, J. Hagen, T. K. Li, R. S. Marshall, V. S. Reams, W. R. Severe, and D. G. Shirk, "A Development and Demonstration Program for Dynamic Nuclear Materials Control," Proc. Safeguards Symp., Vienna, Austria, October 2-6, 1978 (International Atomic Energy Agency, Vienna, in press), IAEA-SM-231-110.

6. Title 10 Code of Federal Regulations, Part 70.51.

7. C. G. Hough, T. Shea, and D. Tolchenkov, "Technical Criteria for the Application of IAEA Safeguards," Proc. Safeguards Symp., Vienna, Austria, October 2-6, 1978 (International Atomic Energy Agency, Vienna, in press), IAEA-SM-231/112.

8. IAEA Safeguards Technical Manual, Part A, International Atomic Energy Agency technical document IAEA-174 (Vienna, 1976).

9. R. H. Augustson and T. D. Reilly, "Fundamentals of Passive Nondestructive Assay of Fissionable Material," Los Alamos Scientific Laboratory report LA-5651-M (September 1974).

10. T. D. Reilly and M. L. Evans, "Measurement Reliability for Nuclear Material Assay," Los Alamos Scientific Laboratory report LA-6574 (January 1977).

11. D. F. Jones, L. R. Cowder, and E. R. Martin, "Computerized Low-Level Waste Assay System Operating Manual," Los Alamos Scientific Laboratory report LA-6202-M (February 1976).

12. S. T. Hsue, T. W. Crane, W. L. Talbert, Jr., and J. C. Lee, "Nondestructive Assay Methods for Irradiated Nuclear Fuels," Los Alamos Scientific Laboratory report LA-6923 (January 1978).

13. T. R. Canada, S. T. Hsue, D. G. Langner, E. R. Martin, J. L. Parker, T. D. Reilly, and J. W. Tape, "Applications of the Absorption-Edge Densitometry NDA Technique to Solutions and Solids," Nucl. Mater. Manage. VI(III), 702-710 (1977).

14. M. S. Krick and H. O. Menlove, "The High-Level Neutron Coincidence Counter (HLNCC): Users' Manual," Los Alamos Scientific Laboratory report LA-7779-M (June 1979).

15. J. E. Foley, "Field Manual for the High-Level Neutron Coincidence Counter (HLNCC)," Los Alamos Scientific Laboratory report LA-7729-M (to be published).

16. J. P. Shipley, D. D. Cobb, R. J. Dietz, M. L. Evans, E. P. Schelonka, D. B. Smith, and R. B. Walton, "Coordinated Safeguards for Materials Management in a Mixed-Oxide Fuel Facility," Los Alamos Scientific Laboratory report LA-6536 (February 1977).

17. E. A. Hakkila, D. D. Cobb, H. A. Dayem, R. J. Dietz, E. A. Kern, E. P. Schelonka, J. P. Shipley, D. B. Smith, R. H. Augustson, and J. W. Barnes, "Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant," Los Alamos Scientific Laboratory report LA-6881 (September 1977).

18. H. A. Dayem, D. D. Cobb, R. J. Dietz, E. A. Hakkila, E. A. Kern, J. P. Shipley, D. B. Smith, and D. F. Bowersox, "Coordinated Safeguards for Materials Management in a Nitrate to Oxide Conversion Facility," Los Alamos Scientific Laboratory report LA-7011 (April 1978).

19. H. A. Dayem, D. D. Cobb, R. J. Dietz, E. A. Hakkila, E. A. Kern, E. P. Schelonka, J. P. Shipley, and D. B. Smith, "Coordinated Safeguards for Materials Management in a Uranium-Plutonium Nitrate-to-Oxide Coconversion Facility: Coprecal," Los Alamos Scientific Laboratory report LA-7521 (February 1979).

20. J. P. Shipley, "Decision Analysis in Safeguarding Special Nuclear Material," invited paper, Trans. Am. Nucl. Soc. 27, 178 (1977).

21. J. P. Shipley, "Decision Analysis for Nuclear Safeguards," invited paper presented at the Spring Meeting of the American Chemical Society, March 12-17, 1978; in Nuclear Safeguards Analysis, Nondestructive and Analytical Chemical Techniques, E. A. Hakkila, Ed. (American Chemical Society, Washington, DC, 1978).

22. James P. Shipley, "Decision Analysis for Dynamic Accounting of Nuclear Material," in Analytical Methods for Safeguards and Accountability Measurement of Special Nuclear Material, H. T. Yolken and J. E. Bullard, Eds., NBS Special Publication 528 (November 1978), pp. 83-97.

23. J. P. Shipley, "Efficient Analysis of Dynamic Materials Accounting Data," Nucl. Mater. Manage. VII, 355-366 (1978).

24. J. P. Shipley, "Conceptual Design of Integrated Safeguards Systems," Nucl. Mater. Manage. VI(III), 111-124 (1977).

25. H. A. Dayem, "Modeling and Simulation for Safeguards Systems Design," ESARDA Symposium on Safeguards and Nuclear Materials Management, Brussels, Belgium, April 25-26, 1979.