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VALIDATING SAFEGUARDS INFORMATION

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PREPARED FOR

U.S. ARMS CONTROL AND DISARMAMENT AGENCY

PREPARED BY

PACIFIC NORTHWEST LABORATORIES
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by

Carl A. Bennett

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I. Introduction

The stated purpose of safeguards is "to detect, and so deter by the threat of detection, the diversion of nuclear materials to unauthorized uses". To accomplish this purpose every responsible safeguarding authority, from first line supervision in operating plants to an international agency, carries out certain prescribed activities designed to provide "assurance that significant diversion has not taken place". These activities may differ with "level"; i.e., as we proceed from first line supervision to plant management to national or regional authorities to international authorities the nature of the activities carried out to achieve the ultimate purpose of safeguards will differ. This difference is due not only to the nature of the restrictions, both political and practical, imposed at the various levels, but also to the varying nature of the threat presented at each succeeding level of responsibility.⁽¹⁾

Basically, all systems for deterring or detecting diversion are composed of some combination of activities designed to provide either physical security or accountability. We either attempt to prevent diversion directly through containment or surveillance, or we attempt to detect it after the fact through material accountancy. In practice it is difficult to dichotomize precisely which activities support each of these elements. For example, the containment afforded by placing seals on a reactor may be an essential part of proper item accountability at a reactor facility. Measurement, or at least detection, of contained nuclear materials may be required to establish physical security at entrances and exits to a facility. In any event, the basis for an effective system will be a combination of observation and monitoring of material movements (or the absence thereof) and the measurement of material flows and inventories. Research and development in the U.S. has been concentrated on the procedures and instrumentation necessary for effective containment and surveillance, the improvement of measurement techniques, and the effective allocation of available resources to these activities.⁽²⁾ Those responsible for implementing safeguards have placed particular stress on the need for an adequate measurement effort to ensure effective safeguards at the operating level.⁽³⁾

At the operating level the primary safeguards concern is to determine what constitutes a sufficient body of information to provide the required assurance. The balance is between the adequacy and timeliness of the information concerning the status of the nuclear material for which the facility is responsible and the expense of obtaining it. In addition to an adequate measurement effort, emphasis is on physical security, on improvements in

plant design and process which will lead to better and more timely measurements, and on statistical treatments and techniques which increase confidence in the conclusions reached.⁽⁴⁾ However, as the responsibility for safeguards becomes increasingly detached from plant operations, two approaches toward carrying out this higher level of responsibility for the determination of safeguards effectiveness are possible:

- 1) the safeguarding authority can perform all the steps necessary to assure that the plant operator and/or responsible management (a) has or provides the capability to safeguard effectively, and (b) is actually carrying out effective safeguards;
- 2) the safeguarding authority itself can carry out the necessary activities and perform the necessary measurements to reach a completely independent conclusion concerning the effectiveness of safeguards.

These approaches represent the two extremes. Even if feasible, a complete adherence to the second approach will be difficult, expensive, and unduly redundant. On the other hand, some degree of independence provided by the second approach is necessary in addition to the first to (a) check against any potential threat of systematic diversion at the immediately succeeding level of responsibility and (b) check the effectiveness of the safeguards performance at lower levels. Both approaches are responsive to the need not only to determine the adequacy of the measurement system and decision structure but also to establish the validity of the information on which the conclusions are to be based. This added requirement is in most instances combined with a necessary shift in emphasis from physical protection and surveillance to records and reports, and from continuous monitoring of the operation to reliance on verified measurements. It is difficult if not impossible, to validate an operational event after the fact.

II. Summary and Conclusions

There are three sources of information available to a national or international safeguards authority about the status of the nuclear material at any given facility. The first is validated facility information; that is, information obtained by the facility itself which the authority, through some process of verification, is willing to accept as a basis for reaching its own conclusion. The second source of information is independent measurements obtained directly by the authority through its own measurement and verification activities. The third source of information, which is in a sense unique to an over-viewing safeguards authority, is external information which may either confirm the validity

of other information or add directly to the information available to the authority.

It is this emphasis on the need to verify reported information and/or make independent measurements that makes methods based on the unique isotopic properties of nuclear materials so attractive and important to the International Atomic Energy Agency (IAEA). The safeguards system to meet Agency objectives proposes that "material accountancy should be adopted as the safeguards measure of fundamental importance, with containment and surveillance as important complementary measures." (16) Each of these traditional safeguards functions can be supported by identification or tracer techniques and by measurement methods and technical cross checks based on isotopic information. In some instances these methods provide the only practical means for carrying out needed verification, and the justification for, or at least the trade-offs involved in, requiring the recording and reporting of the necessary isotopic information can be relatively clearly defined. More generally, the availability of isotopic information adds to the "robustness" of the data base, enhances the deterrent effect by increasing the scope of reporting and the concomitant need for internal consistency in the reported data, and adds to the ability of the Agency to resolve the legitimate inconsistencies which will inevitably arise in its analysis of the reported data on material flows and inventories. Although the "value" of this more general requirement is more difficult to measure, it is suggested that some of the indirect "benefits" to both the agency and the signatory powers through an improved ability to resolve legitimate inconsistencies at an early stage are greater than generally realized, and may be well worth the "costs" involved.

III. Discussion

A. Sources of Valid Information

1. Facility Information

Every operating facility will for several reasons, including operating necessity, economic concern, or its own safeguard responsibilities as defined by the safeguarding authority, obtain information concerning the status of nuclear materials in that facility on a routine basis. One important function of the safeguards activities at higher levels (and a dominant aspect of U.S. domestic safeguards) is to insure that the plant or facility is actually carrying out its safeguards responsibilities to the required degree of effectiveness. Ideally this would include the requirement that facilities subject to safeguards demonstrate prior to operation that they are designed in such a fashion that the necessary information to carry out their

safeguards responsibilities can be obtained and, in addition, that where necessary this information can be verified and validated through inspection. It is the verified level of operational capability and effectiveness that determines the ability of the system to detect lower level diversions. The question being asked in this case is the following: If I am willing to assume that all of the information obtained by the plant is valid and acceptable information for reaching a decision, then what will be the effectiveness of the decision process at this level?

With respect to the basic decision required of a higher safeguards authority as to whether or not there is evidence of diversion, facility information becomes part of the authority's information base only if it can be appropriately validated, or verified. This has uniformly been accepted as one of the important parts of the verification process. Such topics as inventory verification, flow verification at strategic points and others which have been extensively dealt with in the safeguards literature are germane to this process of validating plant information so that it can be used for decisions by the authority. It is important to distinguish this validation from the problems associated with arriving at a conclusion, or assessing the effectiveness of decision procedures, assuming a valid data base. The trade-off involved is between the precision of the conclusions reached and their accuracy as reflected by the validity of the data on which they are based. It is also important to notice that at this stage of the game evidence of falsification of data, or even possibly evidence of lack of cooperation on the part of the facility in obtaining valid information, can in itself be considered as direct evidence that something untoward is taking place.

2. Independent Measurements by the Safeguarding Authority

The second source of information available to the authority is measurements arising from the authority's own actions and initiative. Since it is obtained by the safeguarding authority, it is presumed prima facie to be valid information. There are several reasons why an agency might require and obtain such independent information. One is that such independent measurement may be necessary in order to validate or confirm both the verity and reliability of the information reported or recorded by the facility. The second reason is that it may be needed in order to complement the measurements made by the facility in cases where an important piece of information or measurement was not made by the facility, or where it was made but could not be appropriately validated. The third reason is that it may be economically or tactically more effective (i.e., less costly or more valid) for the safeguarding authority to obtain an independent measurement rather than validate the facility measure-

ment. For example, given the inherent difficulties in validating a dissolver solution measurement, it may, in some instances, be easier and more economical for the agency to validate the plutonium input measurement of the plant by obtaining an independent measurement of plutonium content through the use of the Pu/U ratio method rather than to attempt to duplicate the volume-concentration measurements made by the reprocessing plant.

3. External Information

In addition to validated facility information and information obtained through its own independent measurements, the safeguarding authority has another source of information which can be important and which is in a sense uniquely available to it. Because of its overall responsibility it has available to it information throughout the nuclear cycle which may bear on the validity or the content of the information obtained from the facility. Such information can be used to validate, and possibly add to, the information which the agency can use to reach a decision. Since this information can be used to validate facility information, it will add to the authority's capability to obtain prima facie evidence of falsification.

4. Relationship of Data Source to Decision Processes

A schematic diagram of these information sources and the associated decision processes is shown in Figure I. This graphic portrayal emphasizes the central nature of the validation process. The two decision processes indicated, one at the operating level based on facility information and the other at the authority level based on authority information, may employ common methodology and involve a similar analytical treatment of the data. The difference lies primarily in the information used as input. Some of the decisions involved in the validation process are: (1) the decision as to the adequacy of the facility information, in terms of meeting its responsibility for detecting lower level diversion; (2) the decision as to whether facility information can be accepted as authority information; (3) a decision as to the adequacy of the validated plant information and the consequent need for additional independent measurement on the part of the authority either to complement or to substitute for plant information; (4) a decision as to the validity of concomitant information available from outside the facility and the degree to which it either validates facility information or provides valid independent information in its own right.

Given that the authority has established a valid information base it can now proceed to examine the adequacy of the final decision process, that is, the one concerning the status of the material to be safeguarded. There are two reasons why this

Figure I. Schematic Diagram of Information Sources and Decision Processes.

decision process based on the authority information base might fail to detect diversion. One of these is the inherent inadequacy or insensitivity of the information base itself, that is, the variance is simply too large. The second is that the authority may accept into its base information which is false, i.e., it may be bad data. Put in different terms we can err in two ways throughout the process of arriving at a conclusion: (1) due to the inherent insensitivity of our decision process or the lack of adequate data we can fail to recognize that diversion has taken place; (2) we can allow ourselves to reach an inferentially correct conclusion that no diversion has taken place on the basis of data which is invalid.

It can also be noted from Figure I that the information available to the authority is not necessarily a subset of that obtained by the facility, so that the sensitivity of the authority's decision process is not necessarily less than that of the facility. Both will be limited by the capability of measurement, in the sense that the sensitivity of the decision will always be limited by available measurement technology. In fact, if it were not for measurement uncertainty the decision process would be exact, and the whole system would reduce to a question of audit. Embezzlers are caught because auditors find evidence of falsified data, not because the accounts don't balance.

B. Requirements for Establishing a Valid Data Base

In many respects, the data acquisition problems of a safeguarding authority are more akin to those of the social scientist than the physical scientist. The production of the source data is not under its direct control. The data on which the safeguarding authority must base its decisions are obtained from questionnaires (reports) and validated through interviews (inspections), sometimes including the entire population but usually conducted on a sampling basis. While a safeguarding authority may alleviate some of the problems of "non-response" through its ability to require uniform reporting or periodic inspections, it will still face all of the problems associated with the determination of appropriate reporting procedures and the establishment of the reliability of the information reported. In the United States, inspectors or "survey teams" from the United States Atomic Energy Commission (USAEC) are given the responsibility of determining for each contractor or licensee the adequacy of the reporting process and validating both the precision and accuracy of the information reported.

It has long been recognized by social scientists that the problems of devising adequate scales of measurement and establishing reliable data bases are the controlling factors in reaching quanti-

tative conclusions. The sensitivity of the specific methodology used to treat these data, while also important, is of secondary concern. Rather than formal methods of hypothesis testing, their concern has been with the characterization of the population to be studied and the sampling frame to be used, the built-in redundancy of their questionnaires and interview schedules, and sampling strategies and biases. A particular concern has been the problem of multiple tests on the data obtained.⁽⁵⁾ Analogous concerns to these exist in establishing a valid data base for safeguards decisions, and some of these are discussed below.

1. Records and Reports

A sine qua non of the establishment of a valid data base on which a safeguarding authority can base its conclusions is the existence of an information base to be validated. Information concerning the status of the nuclear material to be safeguarded cannot be verified unless it has been reported, and it cannot be reported unless it has been measured and recorded. This need for records and reports as a basis for verification was stressed in the report of the IAEA consultants group on Records and Reports,⁽⁶⁾ and its importance is reflected in the major effort toward a comprehensive information system by the USAEC Division of Nuclear Materials Security.⁽⁷⁾ As mentioned in section A-1 above, provision for adequate and inexpensive safeguards measurements has been an increasingly important aspect of the recent emphasis on plant design for effective safeguarding and the provision for design reviews.

An interesting sidelight on the effectiveness of reporting was provided by a former Chief, Fraud Section, Criminal Division, U.S. Department of Justice, whose specialty is "white collar" crime. He made the point in a recent conversation that responsible officials (contractors, program administrators, etc.) have a very real reluctance to falsely certify to facts they know are untrue, or have reason to believe are untrue. There is apparently a strong inclination on the part of such people against officially exposing themselves to being directly confronted with their own demonstrably false statements, exposing themselves not only to civil liability but also to criminal liability.⁽⁸⁾ This tendency, in addition to the need to maintain the internal consistency of reported data to be discussed below, results in an appreciable degree of deterrence associated with the mere requirement of reporting. Since, as mentioned in section A-4 above, fraud or embezzlement is usually detected through evidence of falsification of data or reports, it is logical that the requirement to document a basis for such evidence and/or exposure should be a deterrent. Conversely, the existence of this deterrent emphasizes the importance of an ability to detect falsified data unless diversion can be

accomplished within the normal error of measurement associated with safeguards data.

2. Redundancy

As has been pointed out elsewhere, "verification is possible only through some degree of redundant effort."⁽⁹⁾ This redundancy can take the form of actual participation in the measurement process, the replication of all or part of the measurement process, and through checks of the internal consistency of reported data.

It should be pointed out that redundancy in the sense used here serves two purposes: (1) it helps to reinforce the signal, and (2) it helps to reduce the noise. In the former sense we need redundancy in the system to insure that the signal will get through in spite of the failure or deliberate distortion of some part of the system. This is the concept of redundancy built into process control mechanisms, flight control instrumentation, or alarm systems. In the latter sense redundancy may enable us to better distinguish the signal from the noise, in that the signal tends to be systematic and directly additive, while the noise tends to be random and hence only additive as a mean square. It is this latter redundancy that increases the detection capability of multidimensional multichannel analyzers, or enables us to distinguish signals of a specific frequency through spectral analysis.

Validation through redundancy has been standard practice in analytical labs and process control operations for decades. The practice of running a duplicate analysis is designed to validate the first result, not to improve the basic precision of the measurement. Internal cross checks of direct measures of concentration against stoichiometric concentrations adjusted for impurity content; against physical properties such as density and refractive index; and against associated data on waste losses and process efficiency have been commonplace in the nuclear and other chemical industries. A material balance can be considered as an index of the consistency of a body of facility information on flows and inventories. The redundant element is the physical inventory; it validates or fails to validate the book inventory and the associated information on transfers and receipts since the last physical inventory. An unacceptably large MUF simply implies inconsistencies in the data, and triggers further investigation of the source of these inconsistencies. Conversely, if each data element entering the balance has been individually or collectively validated, then some other source for the inconsistency, possibly diversion, is indicated.

This interpretation of the function of a material balance, coupled with the distinction between decision processes and data bases presented in section A-4 and Figure I, emphasizes that the material unaccounted for (MUF) is simply one index based on available information which can be used to test whether that information is inconsistent with the hypothesis that no diversion has taken place. The MUF has no meaning other than as a means of deciding whether a given body of information on flows and inventories contains evidence of diversion. The sensitivity and interpretation of the test are tied to the information base, not to the index itself. For many procedural reasons the MUF arrived at by the facility and the MUF arrived at by the authority could be identical. However, the interpretation of that MUF as a test statistic could be different depending on whether we were interpreting it in the light of the facility information base or the validated authority information base. If the latter were completely or partially independent of the facility information system we would not expect the MUF statistic computed by the authority to be identical with that computed by the facility. However, because of the operational fact that the basic source of information to the safeguard authority is frequently validated facility data these two computed statistics may be identical, differing only in the accepted validity of the information base from which they have been computed. The decision required is on the validity of the data, not the interpretation of the MUF in terms of its apparent precision and/or non-significance.

3. Sampling

It was stated previously that the most direct means of establishing a valid data base would be for the authority to perform the necessary observations and measurements. While instrumental methods and monitoring devices may ultimately make this possible, at the present time it is neither technically feasible nor economically acceptable. The verification through direct measurement of an appropriate random sample of facility source data provides one possible means of validating these data collectively, if not individually. Sampling inspection of records and source documents has been accepted auditing practice for some time, and the USAEC has routinely used sampling procedures in connection with period surveys and inventory verification for some time. A comprehensive treatment of the use of sampling methods in inventory verification has recently been completed.⁽¹⁰⁾ One point that should be emphasized in connection with the use of these methods is that they are designed to estimate characteristics of the population as a whole, not the individual members or parts thereof. Thus the results are tolerance statements as to the fraction of "defective" items in the sample, or an estimate of the total fissile content of the items in the population sampled.

A somewhat different approach to verification through sampling based on game theoretic models was initiated by Beirlein⁽¹¹⁾ and developed by Avenhaus, Beinhauer, and Höpfinger of the Institut für Angewandte Reaktorphysik at Kernforschungszentrum Karlsruhe. Two basic models are considered. One deals with the problem of detecting at least one case of falsification in connection with individual measurements or observations which would in itself constitute prima facie evidence of diversion, and is directly applicable to the validation of the data base. The second model deals with the decision problem associated with a single index of diversion, such as MUF, whose variability can be related to the number of measurements performed or validated. The relationship of these models to the distinction between the validation of the data base and the decision process assuming a valid data base is recognized by Avenhaus in a remark in a recent paper⁽¹²⁾:

Remark: It is assumed here, that the measurement errors are small compared to the batch-to-batch variation. In case there exist considerable measurement errors, the operator has to estimate if it is better for him to divert in the framework of measurement errors i.e. to falsify many batches within the range of the measurement standard deviation or to divert in the framework of the batch-to-batch variation. Furthermore, as stated above, it is considered here only one diversion strategy (falsification of information). One can extend these considerations by taking into account that diversion strategy which consists in diverting material without any falsification of information; such a diversion could be detected for example with the help of the material balance.

The practical problem with both the use of sampling inspection procedures and the proposed game theoretic approaches is that, as any lab chemist or chemical process supervisor will testify, "checking" a measurement is a decision process in itself. The problem of deciding when two duplicate measurements are discrepant is as old as analytical chemistry. The problem of false positives (errors of the first kind) is clearly recognized in the game theoretic treatment described above, and the usual assumption of zero error of the first kind is clearly stated. In their extensive treatment of the application of these methods to a nuclear fuel cycle, Avenhaus and Gupta⁽¹³⁾ justify this assumption on the basis that falsifications of the magnitude necessary to divert significant amounts are well outside the measurement errors involved. The multiple decision problem in the case of the material balance decision model over successive inventory periods or in multiple material balance areas is even

more complicated. Höpfinger's work on this problem⁽¹⁴⁾ is described by Avenhaus⁽¹²⁾ as follows (underlining supplied by author):

...a sequence of inventory periods is considered where measurement errors of the flow measurements as well as measurement errors of the physical inventory determination are taken into consideration. For a fixed error first kind for the total sequence of inventory periods considered the set of possible strategies of the inspection authority is given by the set of possibilities to choose the starting inventory and the significance thresholds for the difference between book and physical inventory (MUF) at the end of an inventory period. The set of possible strategies of the operator is given by the set of possibilities to distribute the total amount M of nuclear material to be diverted on the different inventory periods. The treatment of this model runs into very difficult analytical problems, an example is given in table 5 for the case of only two inventory periods and zero error first kind (which is possible if one deals with rectangular error distributions).

While the above approaches are theoretically sound, they are inherently conservative. If one accepts a fixed error of the first kind for each decision required, then in the course of a typical year's work a safeguarding authority will be faced with dozens of MUF's and hundreds of measurement discrepancies that exceed the, say, 5% significance level. Those of us who have spent appreciable portions of our lives trying to find out why material balances don't balance and why independent measurements don't agree face this prospect with some trepidation, envisioning an inspection force either spending a large fraction of its time and effort investigating legitimate inconsistencies or regularly accusing an appreciable portion of the world of diversion. On the other hand, the alternate decision to limit the probability of an error of the first kind in this multiple decision process to a given level for a series of tests or verifications can result in a large decrease in the probability of detecting a falsification or a diversion. For example, if we assume that:

- (1) the diversion of a fixed amount of material, M , is to be accomplished through k diversions of an amount M/k ,
- (2) the decision in each instance is to be based on a normally distributed test statistic with fixed variance, and

- (3) the error of the first kind is to be controlled to an overall level α by choosing the error of the first kind for each decision so that

$$\alpha = 1 - (1 - \alpha_k)^k$$

or

$$\alpha_k = 1 - (1 - \alpha)^{1/k}$$

then for cases of practical interest the probability that no one of the k diversions will be detected is a monotonically increasing function of k . For M/k large compared with the standard error of the test statistic the probability of non-detection may be small in absolute terms, but the relative increase may still be appreciable.

The inevitable conclusion to this discussion is that sampling strategies for validation and decision are heavily dependent on the degree to which each individual check can be made to approximate a go-no go decision. In different terms, we need to approximate as closely as possible a "rectangular" error structure. In this sense the use of concomitant information to bound the error becomes particularly important in order to maximize the effectiveness of the decision structure. The potential cost of these "second stage" decisions has again been recognized by Avenhaus⁽¹²⁾, but has apparently never been explicitly considered in systems applications. The routine collection of isotopic information may be a relatively cheap price to pay to avoid at least part of these potential "second-stage" investigations.

C. The Utilization of Isotopic Information

Having recognized both a heaven of orderly decision processes and well-defined strategic points and a hell of unbalanced material balances and unreconcilable measurement discrepancies, it is time to come back to earth and examine the practical consequences of these considerations. Actually, the situation is reasonably straightforward. After all is said and done, a safeguarding authority will proceed, within the constraints imposed by its charter and budget, to make the best decisions possible based on the information obtained through its reporting requirements and inspection activities. The problem then is to choose those reporting requirements and information gathering activities which represent the best feasible use of available resources. In solving this problem it is important that every potential source of information concerning the status of the nuclear material to be safeguarded, and the interpretation of the status, be considered.

Since late in 1967 the U.S. Arms Control and Disarmament Agency has sponsored a series of studies designed to investigate and demonstrate the usefulness of isotopic techniques, with particular emphasis on minor isotopes. These studies, combined with the prior information available throughout the nuclear industry on isotopic properties and their utilization in measurement and control, have confirmed that these techniques can enhance safeguards performance in two important ways: 1) the provision of a practical means of performing the measurements needed to provide the authority, either directly or through confirmation of existing measurements or observations, with an adequate data base; 2) the addition of a new dimension to existing data which permits additional cross-checks on their validity and enhances their utility as a basis for decision.

The general utility of isotopic techniques is based on the unique identification and measurement capabilities made available through the use of nuclear properties and isotopic composition. The application of these unique characteristics to the measurement of nuclear materials dates back to the beginning of the nuclear industry. This author owes his association with the industry to the fact that the "counting" of radioactive particles was a well-established, although by today's standards elementary, technique at the University of Chicago in 1944. Adjustments based on reactor predictions were used at Hanford as early as 1950 when the necessity for correcting the "counting" method for determining plutonium concentration in dissolver solution for the Americium-Curium contribution became apparent, and until such time as a suitable direct method became available it was necessary to predict the correction from exposure data. Modern non-destructive techniques and methods for continuous analysis of flows are either made feasible or improved by a knowledge of isotopic composition. Isotopic correlations developed by Schneider et al. (15) have been used to supplement instrumental methods for determining the nuclear material content of wastes developed by Los Alamos Scientific Laboratory. The specific utilities of the use of isotopic information to safeguards can be conveniently classified into three categories:

1. The provision of a feasible source of direct measurements by the safeguarding authority when replication or validation by conventional methods is intrusive, expensive, or impossible.
2. The confirmation of reported information on the identity and process history of nuclear materials.
3. The contribution to the overall robustness of the data base through the possibility of internal correlations and technical cross-checks.

Each of these potential uses can under appropriate circumstances support the requirements for improving the validity and extent of the data base available for safeguards decisions.

The usefulness of isotopic techniques to a safeguarding authority becomes most apparent when the use of these techniques makes it feasible to perform or validate measurements more economically or with less intrusiveness. In general, as mentioned above in section B-2, it has been recognized that there can be situations where it is possible, and even desirable, to validate measurements through indirect means rather than through exact replication. Within the constraints imposed on a safeguards authority, the practical ease of verifying ratios and isotopic compositions may be greater than that of verifying element concentrations, even though the latter were to be preferred by plant operators. Specific examples are the validation of reported reactor production data, the provision of independent measurements of dissolver solution by the ratio method, and dynamic inventory taking. A related but distinct use is the confirmation of the identity of discrete items.

The above uses of isotopic data are directly related to the fact that, in direct contrast to chemical compositions, isotopic compositions are affected in a predictable fashion by nuclear processing in reactors and separation processes in enrichment plants, but are not affected by chemical processes other than direct mixing. This stability under chemical changes simplifies sampling problems and makes possible the use of these stable characteristics to trace material through fuel fabrication and reprocessing plants. The relative difficulty of deliberately altering isotopic composition (particularly with respect to minor isotopes) makes isotopic information a particularly useful means of confirming data obtained by conventional methods.

The least quantifiable but, to some, the most important contribution of the measurement and reporting of isotopic information is to the "robustness" of the data base. Each element of interrelated information added to the reported information base assists in the interpretation of legitimate inconsistencies and adds to the difficulty of falsification, thereby increasing the validity of the data available and increasing their value as a basis for decision. The value of this type of interlocking validation of the data base is enhanced by the availability to the safeguarding authority of information from interlocking facilities throughout the fuel cycle. There is no question that this value is difficult to quantify, and is based largely on the perceived need by individuals who have studied and worked with similar data bases.

What we have been examining is really two different approaches toward justifying the need for isotopic data. In the first case the requirement, or "benefit", is clearly defined and it is proposed that isotopic methods represent a way of obtaining this "benefit" at less "cost". In the second case we are concerned with a less well defined "benefit", but on the other hand we may be dealing with information routinely available at a relatively low "cost". Actually, if one takes into account the potential costs associated with attempts to reconcile inconsistencies "after the fact" (see section B-3) the measurement and/or reporting of the isotopic information which can help alleviate this problem may be "cheap at half the price". From the point of view of the facility being safeguarded, the complete recording and reporting of available information may be preferable to the possibility of increased routine and/or special inspections.

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