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Attributes and Thresholds in Measurements for Transparency Initiatives

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Abstract

The collection of programs broadly termed "Transparency Initiatives" frequently involves physics measurements that are applied to items with sensitive or classified properties. The inability or reluctance to perform quantitative measurements, in the safeguards tradition, to such items, and then to expose the results to international examination, has impelled development of an "attributes" approach to measurements, following the philosophy "if it looks like a duck, walks like a duck and quacks like a duck, call it a duck." This approach avoids certain of the classification issues that would otherwise be associated with such measurements. Use of the attributes approach, however, continues to pose problems of interpretation, in light of the need to establish numerical thresholds whereby data obtained from the measurements can be evaluated to determine whether the attribute is present. In this paper we examine the foundations of the attributes approach and the steps used to determine appropriate attributes and thresholds, using examples from contemporary threat-reduction initiatives where possible. Implications for the detector technologies used in the measurements will be discussed, as will the characteristics of so-called "information barriers" intended to prevent inadvertent release of sensitive information during attributes measurements.

INTRODUCTION

The development and application of nuclear instrumentation in traditional nuclear safeguards, as called for by the Nonproliferation Treaty (NPT) and other initiatives as well as domestic safeguards requirements, has generally (though not universally) had a goal of improving regulator knowledge of the quantitative properties of the nuclear materials being safeguarded, such as the mass of material present in a storage container; detecting and quantifying holdup in a process stream; determining enrichment of the isotope ^{235}U in uranium; and so on. In the large majority of such measurements, the quantitative information obtained by performing the measurements is readily exchangeable among the parties with a stake in the measurements, be they regulatory agencies, signatories to a treaty, or the facility housing the nuclear materials being inspected. Even the measurements that must be performed qualitatively rather than quantitatively (for example, examination of spent fuel rods) are generally based on techniques that allow open exchange of the results. The literature of quantitative measurement methods is extensive and will not be summarized here; the standard summary manuals on passive[1] and active[2] nondestructive assay of nuclear materials describe not only the measurement methods but also the circumstances under which they may be applied.

The advent of threat-reduction initiatives such as the START treaty, the "Trilateral Initiative" for the securing of excess fissile materials in the United States and Russia,[3] and the agreement between the United States and the Russian Federation covering purchase of excess Russian enriched uranium, however, has brought to light situations in which the full ensemble of information obtainable with nuclear instrumentation might *not* be exchangeable within the context of the initiatives. The fundamental reason is that these threat-reduction initiatives, unlike the NPT and other earlier treaties and agreements, apply directly to nuclear materials derived from the weapons programs of avowed nuclear-weapons states – materials that, by dint of their origin, possess some of the most highly classified and sensitive properties of any of the assets of the affected states. Quantitative information on such materials tends to be "born classified" under national laws, and may easily remain classified even after the materials themselves are converted to forms no longer directly usable in nuclear weapons.

Accordingly, much effort has been dedicated, during the preparations for and implementation of these initiatives, to the development of an "attributes" approach to radiation measurements, in which instruments report whether the measured item has any or all of a set of properties that items of the same general *type* would be expected to have. The operational philosophy can be summarized succinctly (if non-technically!) thus: "If it looks like a duck, walks like a duck, and quacks like a duck, we'll call it a duck." The instruments used may be intrinsically capable of more complete measurements, but they are modified so that only information bearing on the attributes of interest is reported; these modifications and the procedures for implementing them are known as "information barriers" and are discussed in a separate paper in this conference.

The present paper explores the circumstances under which the attributes approach is feasible and appropriate, and examines the technical ramifications of implementing such an approach. The concept of a restricted set of measurements applied to sensitive nuclear materials is not entirely new; the safeguards approach developed for gas-centrifuge enrichment plants set a precedent for such measurements as long ago as 1983.[4] However, the growing body of contemporary initiatives where attributes might be measured offers both lessons and challenges that will be developed in this paper.

ATTRIBUTES

The fundamental task in developing an attributes regime and the instruments to implement it is the selection of attributes that the regime will exploit. To be useful, an attribute should possess certain general properties:

1. First, the attribute should be *relevant*; that is, it should provide some useful distinction between items admissible under the initiative where the regime is being applied, and items that the regime seeks to exclude. The distinction need not be absolute, as a later example will show, but it should contribute to the confidence building that the regime is intended to provide.
2. Second, the attribute should be *measurable*; some means should exist for making a yes/no decision on the presence of the attribute that can be quantified and used in an analysis algorithm, even if the quantitative data are

never displayed to an inspector. Furthermore, the measurements should be *practical*, i.e., achievable under realistic conditions in acceptably short periods of time.

3. Less obviously, the attribute should be *amenable to negotiation*. If the attribute deals with a property of the inspected items such that the mere *existence* of the property is classified, then discussing the attribute with a partner in negotiation will be difficult, if not impossible.
4. Finally, the attribute should be *limited*, or perhaps more accurately, the means for *measuring* the attribute should be limited, to minimize the risk that sensitive information might be divulged during a measurement.

Examples of the challenges of selecting attributes can be found in connection with the Fissile Materials Transparency Technology Demonstration (FMTTD) currently being prepared as groundwork for an eventual US/Russian program connected with excess fissile materials of weapons origin. Suppose, for purposes of argument, that the task is to provide confidence that a piece of fissile material came from a dismantled nuclear weapon. Suppose further, again for the sake of argument, that the specific goal is to provide confidence that the piece of material had at one time been an actual *component* within a weapon – that is, an "intact" piece. The purpose of FMTTD is to demonstrate that the necessary attributes measurements in support of this supposition can be performed without compromising sensitive information. The paper in this conference by Rutherford and McNeilly provides additional information on FMTTD and its underpinnings, describing in broad outline the Attribute Measurement System with Information Barrier (AMS/IB), the instrument developed to apply the attributes approach in the demonstration. Key components of the AMS/IB are γ-ray spectrometers and a neutron multiplicity counter; other papers in this conference provide additional technical information on the instrument.

The logic shown in Figure 1 has governed the choice of attributes used in FMTTD and the AMS/IB. A weapon component (specifically, one containing plutonium, the focus of FMTTD) is a highly specialized piece of nuclear material with certain general properties:

- The plutonium is of "weapons grade" rather than "reactor grade," although the exact isotopics may vary from component to component and from country to country.
- The amount of plutonium present is relatively large, although it is obviously impossible, for reasons of classification, to say exactly what that amount is.
- The plutonium is present in metallic form, rather than as oxide.
- The plutonium is in a definite configuration (geometry) rather than a changeable form such as bits of scrap or oxide might have.
- The plutonium is "old" – produced prior to entry into force of the Plutonium Production Reactor Agreement (PPRA), which has sequestered all plutonium created in the participating countries since the beginning of 1997 so that it is unavailable for fabrication into a weapon component.

An intact weapon component should possess all of these properties, and an appropriate measurement performed on the component should confirm this. However, other pieces of plutonium exist that possess *some* of the properties. For example, material being produced by the Pit Disassembly and Conversion Facility[5] (PDCF) would satisfy the weapons-grade, large amount, and "old" criteria, and possibly the criterion that the material be metal. Consequently, if a regime called for distinguishing between pre- and post-PDCF material, only the configuration criterion of the ones listed would provide the necessary partition.* Similar considerations would apply to other types of material resident in the countries interested in FMTTD.

The correspondence between attribute and measurement is not always exact. An example from FMTTD involves the metal/oxide property. No radiation measurement provides direct proof that a piece of plutonium of unknown geometry is of metallic form. However, it is possible to look for evidence that the piece is *not* oxide, by searching for excess (α,n) neutrons and/or lines in the γ-ray spectrum associated with α particles impinging on oxygen or contaminants. Accordingly, in FMTTD the relevant attribute is couched as "absence of oxide" rather than "presence of metal" – a distinction with certain implications in terms of the types of material that might be admissible in a regime based on FMTTD, but one that allows practical implementation in a demonstration designed to show that sensitive information can be adequately protected.

Not every imaginable attribute of a weapon component will be exploited in FMTTD. It was at one time thought desirable to include in FMTTD provisions for demonstrating that the material being measured contained gallium, based on the unclassified fact that gallium is added to metallic plutonium to improve phase stability. At that time it was hoped that interactions between radioactive emissions of the plutonium (either alpha particles or neutrons from spontaneous fission) might lead to observables in the γ-ray spectrum, i.e., neutron capture lines, inelastic-scattering lines, or lines from the decay of radioactive ^{70}Ga or ^{72}Ga created by neutron capture. However, trials with the radiation-detection equipment used in the AMS/IB have not found any of these indicators unambiguously in spectra from unclassified Pu pieces known to contain gallium. Therefore this attribute was abandoned as unsuited to measurement with the AMS/IB apparatus.

THRESHOLDS

To implement an attributes approach, it is necessary not only to identify the key attributes that will be exploited, but also to define criteria by which a measurement can determine whether the attribute is present in the measured item or not: "thresholds." These must be couched in terms amenable to use in an algorithm, preferably a simple one, that is embedded in an analysis instrument that prevents disclosure of raw, unprocessed data; in other words, the thresholds must be numerical and concrete. Most of the remarks above, pertaining to selection of attributes and the criteria that a suitable attribute should possess, are equally applicable to the identification of thresholds.

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* It should be kept in mind that the initial impetus for FMTTD resided in transparency requirements in the purely *unilateral* case of the Fissile Material Storage Facility (FMSF), being constructed in Russia, and related initiatives. Invoking the PDCF here is for illustrative purposes only and does not bear on transparency requirements at FMSF.

In some cases it is relatively straightforward to specify a threshold from first principles. The AMS/IB includes a test with the simple goal of showing that plutonium is present, drawing on the obvious tautology that a plutonium weapon component should contain some plutonium(!). To claim the presence of plutonium, it is considered sufficient that lines at characteristic energies, unique (in ensemble) to plutonium, be present in the γ-ray spectrum. The lines chosen, at energies near 345, 645, and 658 keV, are all prominent in the spectra of γ rays emitted by bulk plutonium, so that a simple statistical test, to determine whether the lines are all present at the 5σ level, is not only easy to define but equally easy to implement in an analysis routine.

Most thresholds, however, are considerably more troublesome to define, both for physics reasons and because of interplay between the measurements and national classification policy. The AMS/IB approach to the "absence of oxide" attribute is an example of physics difficulties complicating the threshold. The AMS/IB measurements associated with this attribute, as noted above, involve analysis of both neutron and γ-ray data – the former derived from excess singles events recorded with a neutron multiplicity counter (NMC), the latter from searching a γ-ray spectrum for the 871-keV peak from the first excited state of ^{17}O. Practical implementation of both of these measurements poses unexpected difficulties. While the theoretical magnitude of excess singles neutrons from pure plutonium oxide is well known[1] and is indeed reflected in measurements of very pure oxide, almost *any* light element in contact or admixed with an alpha emitter might lead to production of excess singles neutrons, even if that alpha emitter is predominantly metallic. Furthermore, (α,n) neutrons from oxide may be either more or less abundant than the theoretical value depending on impurities in the oxide, particle size, moisture content (not all oxide is purged of water when it is produced), etc. Consequently, in the preparations for FMTTD, it was necessary to obtain a threshold value empirically (in this particular case, chosen such that material with an excess of singles neutrons less than 0.5 is declared non-oxide) after measuring various samples of oxide and metal, rather than from first principles. In the case of the 871-keV γ ray, there is a long-standing difficulty in relating abundance of the γ ray quantitatively to amount of oxide present. Recent research[6] conducted in preparation for FMTTD reveals an important reason for this difficulty, namely that the line may result not only from the reaction $^{17}O(\alpha,\alpha')$ as generally believed, but also from the reaction $^{14}N(\alpha,p\gamma)$ on nitrogen entrained in the oxide from the surrounding air or as plutonium nitrate present as an impurity in the oxide. Accordingly, specification of a threshold for FMTTD (again, presence of the key line at the 5σ level) had to be validated through experimental measurements on oxide and metal samples, rather than decreed from first principles.

An example of classification issues arises with regard to plutonium isotopics. An unclassified definition of weapons-grade plutonium exists for material originating in the United States, and it may be referenced in the AMS/IB as long as quantitative information on certain specified items is not revealed – a constraint well within the capabilities of the instrument's "information barrier." However, the corresponding definition relevant to Russian plutonium (which need not be of the same isotopic composition as that produced in the United States) is considered sensitive by the Russian

Federation, and accordingly may *not* be referenced in the AMS/IB without a risk of complicating eventual Russian acceptance of the AMS/IB or a follow-on instrument. For FMTTD purposes, it has been decided to use a threshold for the ratio M(240)/M(239) of amount of ^{240}Pu and ^{239}Pu present that does not refer directly to the weapons-grade definition, out of respect for Russian sensitivities. The value incorporated in the AMS/IB for M(240)/M(239) is 0.1; i.e., material with less than 1/10 as much ^{240}Pu as ^{239}Pu is deemed to have appropriate isotopics for weapons origin, while material with a higher proportion of ^{240}Pu is not.

The isotopics measurement in the AMS/IB also affords another example of a constraint placed upon choice of thresholds: measurement robustness and appropriate balance between false negatives and false positives. As discussed in other papers in this conference, the AMS/IB isotopics measurement exploits the region of the γ-ray spectrum of energies between 630 and 670 keV (Fig. 2). Using this restricted part of the spectrum, rather than the entire spectrum exploited by such traditional safeguards codes as FRAM,[7] conforms to the information-barrier principle of minimizing the information processed to mitigate the consequences of inadvertent release of information, and in addition turns out to simplify the analysis, in that differential-attenuation corrections can generally be ignored over this limited range of the spectrum. However, the γ rays producing peaks in this part of the spectrum are weak, and adequate statistics for determination of an isotopic ratio accurate to 1% or better can only be acquired through prohibitively long counting times. Consequently, for FMTTD, in which counting time is limited for operational reasons, it is necessary to accept the possibility that a given measurement might deduce an isotopic ratio differing by perhaps ±10% from that truly characteristic of the material. In the FMTTD situation, this possibility is of little practical significance, as the threshold M(240)/M(239) of 0.1 mandated by classification concerns, as described above, is not only far from the range characteristic of US weapons-grade material as used in the demonstration, but also far from the value M(240)/M(239) ~ 0.25 characteristic of "reactor-grade" material. However, a threshold chosen closer to the nominal weapons- or reactor-grade compositions might occasionally lead to misanalyses giving false negatives or positives, respectively, and a real-world inspection regime would have to deal with such difficulties. In general, a threshold chosen to reduce the incidence of false negatives (legitimate items being rejected) increases the incidence of false positives (the number of *non*-acceptable items that would be erroneously found to possess the attribute). The decision as to whether to err on the side of suppressing false positives or false negatives involves a number of difficult operational and political tradeoffs that exceed the scope of this paper and must be dealt with on a case-by-case basis.

CONCLUSION

The FMTTD example provides some insights into the difficulties of dealing with an attributes regime under the practical limitations within which a measurement scheme must operate. The challenges are as follows:

- First, devise an appropriate set of attributes that provide the desired confidence (by distinguishing among acceptable and unacceptable items) without falling afoul of national-security concerns.

- Second, devise a measurement scheme that can measure a piece of nuclear material presented for inspection and provide an answer as to whether the attributes are present, in operationally acceptable lengths of time, with realistic equipment, and with all sensitive information being concealed by an information barrier.
- And finally, negotiate thresholds against which the measurements may be evaluated (by the analysis system, invisible to the inspector) and a report generated as to whether the attributes are present.

The technical challenges of this program are considerable, even though the underlying physics is in general well understood, precisely because the historical trend in developing analysis systems is *toward* greater rigor and precision in measurements. It is necessary for the developer of such a measurement system to be fully aware of real-world constraints such as classification, operational impact on the facility where the measurement system would be housed, and the need to negotiate use of the system under international agreements that may not have anticipated some of the technical difficulties involved. Similarly, the negotiator pursuing such agreements is well advised to be fully aware of the technical capabilities and limitations of the instruments to be used in the implementation phase. This interplay between technology and policy is one of the characteristics of contemporary arms-reduction activities.

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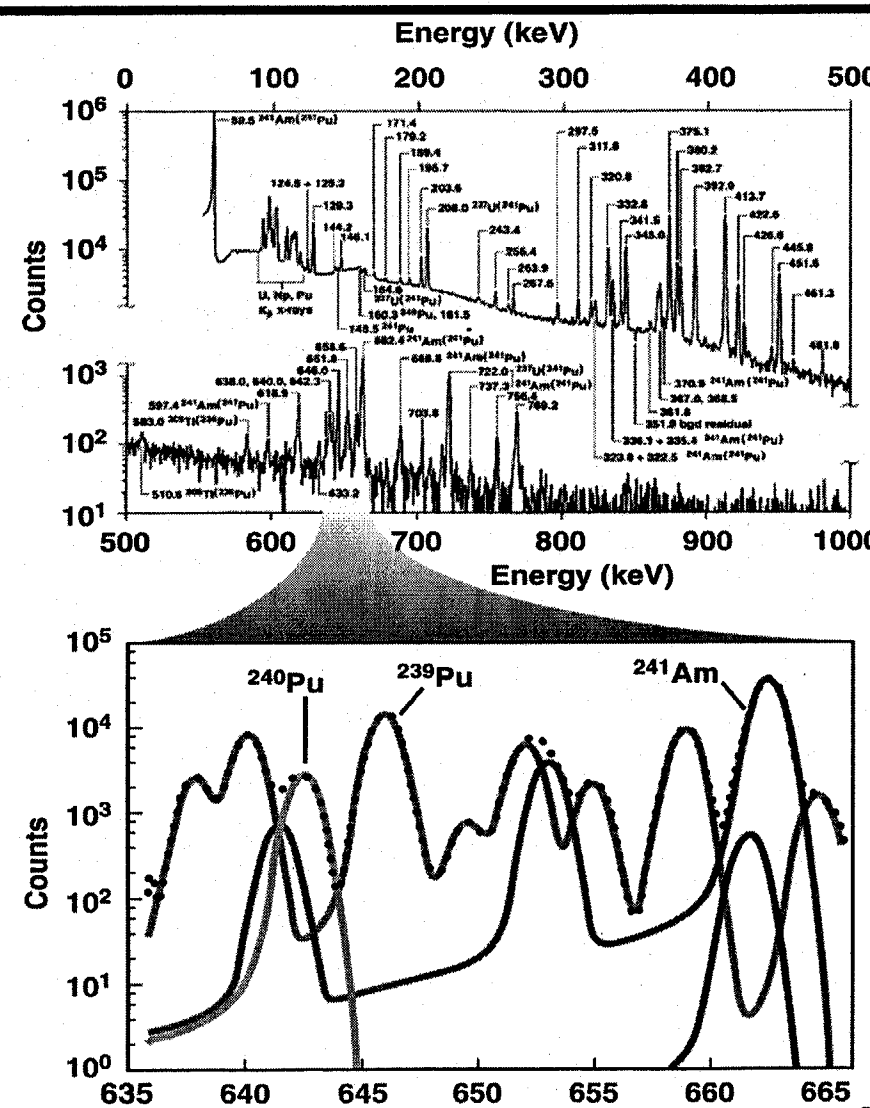
REFERENCES

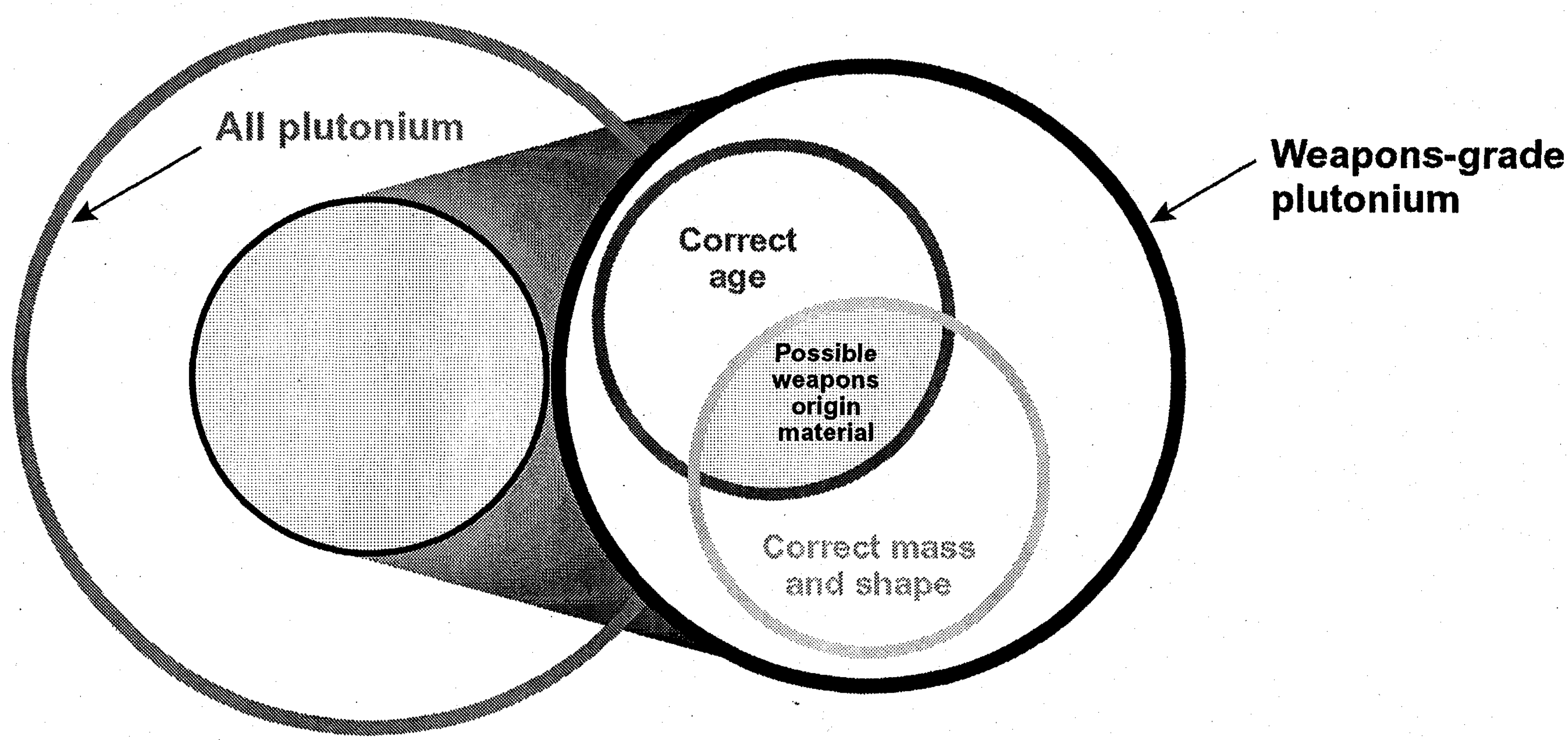
1. Doug Reilly, Norbert Ensslin, Hastings Smith, Jr., and Sarah Kreiner, *Passive Nondestructive Assay of Nuclear Materials*, NUREG/CR-5550, March 1991.
2. T. Gozani, *Active Nondestructive Assay of Nuclear Materials: Principles and Applications*, NUREG/CR-0602, January 1981.
3. R. Whiteson, R. P. Landry, D. G. Langner, D. W. MacArthur, and J. Wolford, "A Prototype Inspection System with Information Barrier for the Trilateral Initiative," *40th Annual Meeting of the Institute of Nuclear Materials Management*, Phoenix, AZ, July 27-29, 1999; Los Alamos National Laboratory document LA-UR-99-3609 (July 1999).

4. Hexapartite Safeguards Project (J. H. Menzel, Ed.), Nuclear Materials Management 12, 30 (1983).
5. S. Zygmunt, L. Christensen and C. Richardson, "Design-only Conceptual Design Report for Pit Disassembly and Conversion Facility," Los Alamos National Laboratory report LA-13398-MS, December 1997.
6. Anthony Peurrung, Richard Arthur, Bruce Geelhood, Randy Scheele, Robert Elovich, Sharon Pratt, Richard Kouzes, "The 871-keV Gamma Ray From Oxygen-17 And the Misidentification Of Plutonium Oxide", Pacific Northwest National Laboratories report PNNL-SA-33134, May 2000.

Pu-600—Weapons-Grade Pu / Presence of Pu

- **Weapons-grade plutonium:**
  - For weapons-grade plutonium: $^{239}Pu + ^{240}Pu \approx$ Total Pu.
  - Therefore, if the ratio $^{240}Pu/^{239}Pu$ is low, the material is weapons-grade.
  - This value is also used in conjunction with the neutron multiplicity data to determine the plutonium mass.
- **Presence of plutonium:**
  - 646 and 659 keV peaks.
  - Determination of presence requires *both* the 345 keV peak from Pu-300 and the 646 and 659 keV peaks from Pu-600.





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