MOBILE INSTRUMENTATION FOR NUCLEAR MATERIAL CHARACTERIZATION

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ABSTRACT

Nuclear material consolidation and conversion of HEU to LEU is an essential element of the decommissioning process in Russia. Among other things, it is important to assure the receiver facility that the material it receives meets the acceptance criteria for proper operation of the re-packaging and down blending process. It is equally important for the shipper facility to check the shipments against the same criteria to be assured of acceptance at the receiver facility. Such measurements, however, present significant procedural challenges arising from calibration, operation, and sensitivity variations between different chemical and physical forms of the material. The most practical method to overcome these difficulties is to deploy a self-contained instrument van that is transported with the material shipment and is used to make the assays at the shipper site or, if required, at both the shipper and receiver sites. The measurement process as described also provides for detection of diversion. The same measurements can also ensure that the input material to the down blending operation meets the MPC&A contract terms and programmatic transparency objectives regarding the "attractiveness" of the HEU feed material. These terms make it essential that the material be measured for both total uranium concentration and for its U-235 enrichment.

This paper will describe the instrumentation required to meet the criteria described above and how they were installed into a transportable ISO container that was shipped to Russia at the beginning of this year.

INTRODUCTION

Since 1994, the Department of Energy has undertaken the mission of upgrading the safeguards and security of Russian nuclear facilities under the Material Protection, Control and Accounting (MPC&A) program.

In early 1999, the MPC&A program launched the Material Conversion and Consolidation (MCC) Project initiative with Russia. The mission of the MCC Project was to assist in consolidating special nuclear material (SNM) to fewer locations, and to down blend the material with natural or depleted uranium to reduce its attractiveness as a diversion target. The scope of these activities was to include Minatom facilities, and discussions and negotiations to solidify the processes and procedures were undertaken.

BACKGROUND

As negotiations proceeded, it was revealed that material for the MCC Project might be made available from Ministry of Defense (MOD), Minatom, GAN, and other Russian ministries. It quickly became apparent that the quantity of HEU that might be available for conversion was significantly larger than originally anticipated and that material configurations and storage container scenarios could be very different from what had been verified to date. Furthermore, the possibility was raised that quantities of plutonium (Pu) might become available for consolidation.

If these large quantities of attractive material could be rapidly consolidated and converted, the threat of diversion could be significantly reduced. However, at this point, the Project was faced with a dilemma.

- The available material would be mostly HEU, but could also be Pu.
- The "attractiveness" of the available material was unknown and must be verified prior to consolidation or down blending. (Specific criteria for enrichment and weight-percent would be available.)
- The quantity of available material was unknown, although thought to be large.

- Measurements must be made quickly in order to process and limit the exposure of the anticipated large quantities of material.
- The configuration and packaging of the material was expected to be significantly different from previous experience and highly variable, possibly including some relatively large items.
- There were many sites with material to be measured, each with limited or no measurement instruments available.
- Access to several sites would likely be restricted, but verification measurements might be made at a location outside the facility itself.
- Measurement capability must be made available very quickly (within a few months)

The real dilemma was, of course, how to even begin to address these issues. The Project was faced with more unknowns than knowns, with more Russian assertions than facts, with more variability than constancy; and all of this with pressure to move quickly to ensure that the material was properly identified and disposed.

Clearly, the need to verify the attractiveness of the material was of the highest priority. Until those measurements could be accomplished, no viable plan for material consolidation or conversion could be developed. This implied the need for a measurement capability at each donor facility and at the down blending facilities as well. But, what was to be measured - HEU, Pu, both? What was the configuration – homogeneous unirradiated fuel, odd components, liquid, other? What was the packaging – passport containers, 200-liter drums, something in between? How was the material to be measured – what techniques, accuracy, precision, etc.? Once again, the information available resulted in more questions than answers.

To begin attacking this complex problem, the Project used the following logic:

- The measurement instrument or instruments must directly measure both enrichment and concentration in order to determine the material's attractiveness. However, the accuracy and precision need be only sufficient to establish the material attractiveness in accordance with the enrichment and concentration criteria.
- The possibility of consolidating Pu cannot be overlooked; therefore, the measurement equipment must either be suitable for both HEU and Pu, or be easily modified to accommodate either.
- Because there may be large quantities of material to be measured, the measurement techniques must be very fast.
- Because the material may be in containers as large as 200-liter drums, the measurement instruments must be capable of accommodating large items and must be equipped with suitable sample-handling aids.

The Project Team estimated that if suitable MC&A measurement equipment were to be delivered to each site, the cost would be at least $6 million and could easily exceed that amount depending on material, quantity, packaging, configuration, and potential training requirements. This was unacceptably costly and contained too many unknowns. Therefore, an alternative concept was developed as follows:

- Many sites must be covered, but not necessarily permanently.
- Access to some sites will not be permitted, and the measurement facility must be off-site.
- Because the samples may be large, the instruments will also be large and must be housed in some kind of portable facility in any case.

From these considerations, the Canberra and Aquila instrumentation team suggested that a single transportable container that housed the requisite measurement equipment and material handling aids could be moved from site to site. This "Transportable Laboratory" would not have to be moved rapidly or frequently, and could contain a single set of instruments that would accommodate nearly any measurement situation that would be encountered. This approach would allow a comprehensive set of instruments to be deployed when and where needed without the need to replicate the measurement capability at every site. Furthermore, since there would be only one set of instruments, training, repair, calibration, and other logistics would be simplified. MCC concluded that with the large number of potential donors without any MC&A equipment present or verifiable that the cost savings could be up to $8 million by using a mobile measurement unit.

Finally, the MCC Project concluded that in order to meet the rapid deployment requirement, the transportable laboratory must be equipped using only readily-available commercial instruments. There simply was neither time nor sufficient funding to develop finely tuned custom instruments.

Combining all of the preceding factors, the MCC was finally able to arrive at the following specifications:

- All instruments are to be housed in a self-contained facility that can be transported by common carrier over land or water. Air transport is not required.
- The uranium and/or plutonium concentration of each item must be measured. The measurement technique need be sufficiently accurate only to ensure that the concentration exceeds the MPC&A program concentration limit.
- Uranium enrichment and the plutonium isotopics must be directly measured and not obtained from "process knowledge". The measurement technique need only be accurate enough to verify that the uranium enrichment exceeds the MPC&A program enrichment limit.
- Because the material is vulnerable, each item must be measured quickly (one hour or less).
- The transportable measurement system must be designed, built, and deployed within five months ARO. This requirement restricts the choice of instruments to those that are readily available within this timeframe.
- The material is packaged in containers that can be handled without remote manipulators; i.e. the containers are contact handled (small forklift).
- The items are generally of a size that fits into standard commercially available instruments (with minor modifications at most.)
- The items, including scrap HEU, are homogeneous enough that radiographic measurements to correct for inhomogenieties are not required.
- All of the uranium to be measured is at least six months old.
- The nuclear material matrix does not contain significant amounts of high Z material.
- The standard container wall is less than 1-cm stainless steel equivalent at 89 keV.
- The standard container size is equivalent to a 200-L drum, or smaller. E.g. the Russian “passport” container can also be used.
- The container does not include any polyethylene or other neutron moderator inserts.
- The use of liquid nitrogen (LN2) for instrument cooling is discouraged.

TECHNICAL APPROACH

In order to determine the total weight percent of uranium-235 in the material and its enrichment as required by the programmatic needs, the instrument design team determined that it was best to use two measuring techniques. A gamma spectroscopic measurement is required to establish the uranium enrichment. However, a gamma spectrometric technique typically cannot establish the total uranium mass, or weight percentage. Uranium is such a heavy material that the self-attenuation of the characteristic gamma rays prevents a gamma technique from seeing the entire sample. Hence trying to establish the concentration of uranium in the entire sample is unreliable. A neutron technique can produce a measurement result that is directly proportional to an effective mass, which however, is dependent on the uranium enrichment. Just a neutron measurement is sufficient to establish the total uranium mass, and hence the uranium concentration, only if the uranium enrichment is known from some other source.

Despite these difficulties, a single measurement technique was considered to see if the cost of the system could be reduced. However, an evaluation of the programmatic measurement requirements and the potential unknowns confirmed that it was necessary to measure both gamma and neutrons in order to cover all of the possible sample configurations. This was actually a low risk approach since the use of a combination of a neutron and a gamma system has been employed with good success in various safeguards and waste applications[1,2,3,4]. A two-technique approach is also fundamentally more flexible in case the instruments need to be modified for additional capabilities in the future. For example, both the neutron counter and the gamma measurement station are capable of measuring plutonium with minimal or no changes.

In order to meet the delivery schedule, it was also imperative that both the gamma and neutron equipment was chosen in such a way that it was either available from inventory or the components were available from inventory. Use of commercial instruments also permits installation of additional features that permit correcting for inhomogenieties, differences in overall sample densities, differences in the neutron multiplicities, etc., later, if the need arises.

Neutron System

Active neutron analysis is required for ^{235}U determination. A system favored by the IAEA for such measurements is the Active Well Coincidence Counter (AWCC)[5]. The AWCC uses a small Americium-Lithium (Am(Li)) source to interrogate the uranium material. Typically, AWCCs can also be operated in passive mode by removing the interrogating neutron source. However, standard AWCCs accommodate only smaller cans (typically less than 25 cm in diameter) and as such were not suited for this application. There are published designs of large multiplicity counters[6,7] that have been modified to include an excitation source, similar to the AWCC. Although there is no commercial off-the-shelf version of such a counter, neutron multiplicity counters are functionally very modular and it is common practice for the suppliers of neutron counters to produce them in an "as needed" form-factor (within sensitivity parameters). As it happened, Canberra had just designed a high efficiency neutron counter for a different customer that could be adopted for this project with the addition of the Am(Li) sources and a removal of one of the layers of ^{3}He tubes.

If the measurement needs change, the instrument was designed in such a way that it can be changed with minimal effort to provide it with additional capabilities. For example, the counter can easily be converted to a neutron shuffler. It is also possible to add the Add-a-Source correction method[8] to it, or to provide Am(Li) source inserts to accommodate smaller sample sizes.

The Am(Li) Sources

The Am(Li) sources for an active neutron counter could potentially have been a problem. We had them made in Russia from Russian materials. There was no schedule problem getting them shipped on time. Furthermore, since the sources were manufactured in Russia, there were no issues with export licenses from the United States. As a consequence, there were no problems importing the Am(Li) sources to Russia, since they were already there. An additional benefit of having the sources made in Russia was that it supports the sustainability of indigenous industry objectives of the MPC&A program overall.

Gamma System

We decided to use a simplified Segmented Gamma System (SGS) that only uses the MGAU[9] software for determining the uranium enrichment. The gamma system was also equipped with a scale to establish the weight of the item being measured. The gamma system can be converted to a traditional Segmented Gamma Scanner (SGS) for measuring canisters and drums[10,11] with the addition of a lift mechanism and, if desired, a transmission source and the appropriate software.

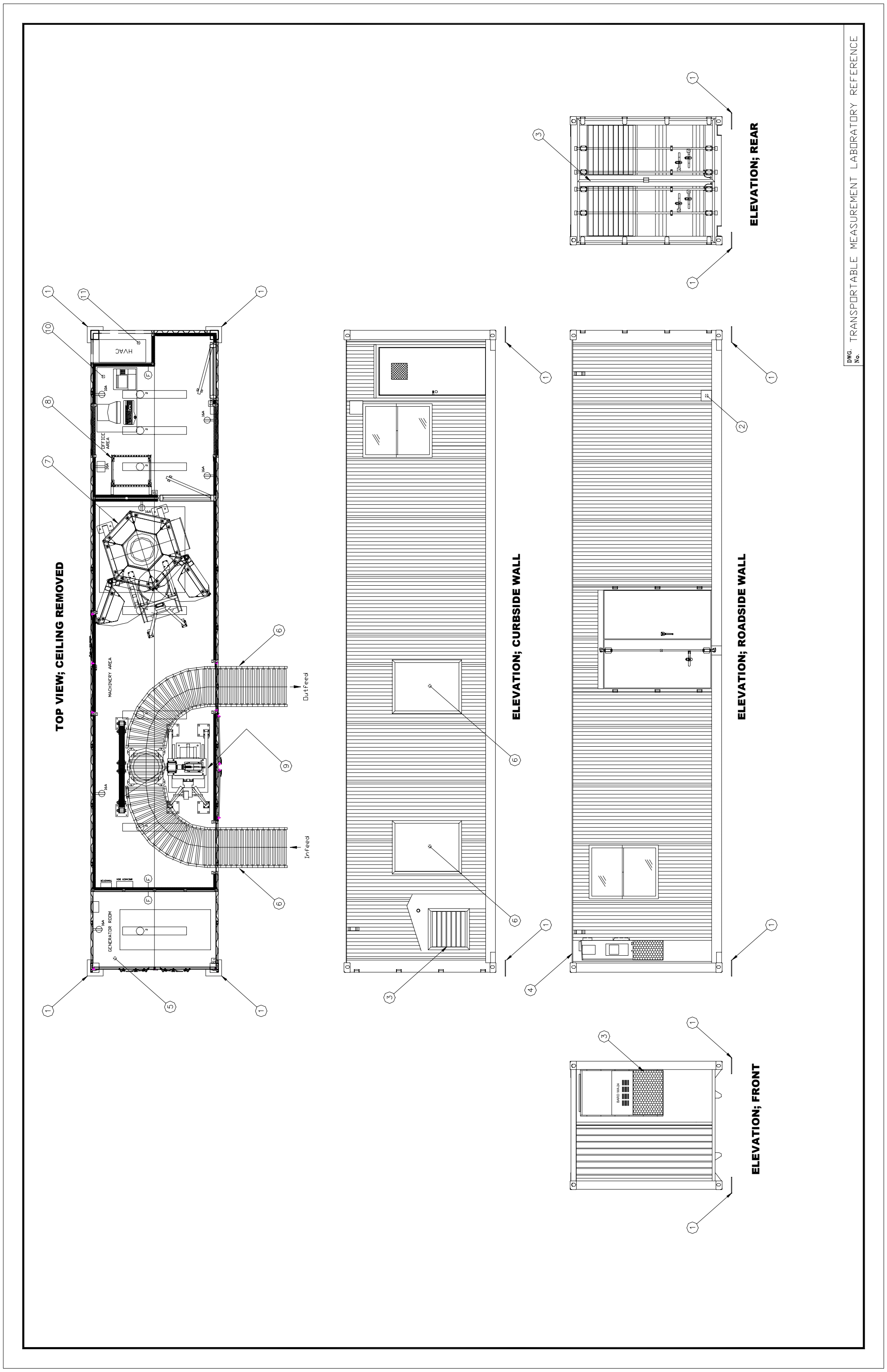
THE MOBILE PLATFORM CONFIGURATION

By far the most flexible and cost effective platform is to base the mobile laboratory on an ISO container. An ISO container was originally intended for long haul bulk hauling with the flexibility of being loaded onto rail cars, trucks or ships. Lately, such ISO containers have found increasing use as custom on-site command centers, offices, and instrumentation platforms. Thus, it was natural to consider an ISO container as the mobile platform for this project. ISO containers can be configured in a variety of sizes (20' - 40') to meet the needs of the project. Custom vans and other trucks are space restrictive. Trailers, 40' - 50', have the flexibility of the ISO container, but generally have higher costs, pose a number of regulation issues when considered for international use, and force the working platform to be several feet off the ground, complicating sample exchange. The ISO modules can be mated with suitable vehicles available in the destination country, which will conform to rules of that country. ISO modules are readily shipped by sea, rail, road or air and are adaptable to common methods of local transportation, either temporary (put on truck or trailer) or permanent (attach wheels to module). A variety of wheels, lifters, jacks and other accessories for ISO modules are available within the worldwide transportation network. Also, sitting flat on the ground simplifies material handling. No lifting mechanisms are needed for 200-L containers. Auxiliary requirements, such as heating and air conditioning, were designed to be provided by either a power generator, or by a direct connection to a local power grid. Additionally, the container was equipped with continuous alpha monitoring instruments to protect the workers in the case of an accidental release of airborne uranium (or plutonium) dust.

Diagram 1 shows the actual layout of the equipment in the container. There are two specific areas in the container: the measurement area and a separate office area. The measurement area is located on one end and consists of a gamma system and neutron counter, serviced by a conveyor system. Samples are placed on the conveyor and moved first to the gamma system, and hence inside the container. The gamma system performs measurements on the sample and when complete, the sample can be lifted with a simple hand-lift and transferred to the neutron counter. Once the neutron measurement has been completed, the sample can again be placed on the conveyor and moved out of the container.

A small, separate office area for the operator and the computer equipment completes the system. The office area is sufficiently shielded from the measurement area so as to not pose an unnecessary radiation exposure hazard to the operators.

Diagram 1: Transportable Measurement Laboratory Configuration



CONCLUSIONS

The transportable measurement unit was completed on schedule and is now being deployed. It is equipped as specified to meet all of the documented, identified and contingent requirements of the MCC Project as they were known at the time the mobile unit was designed. The assay instrumentation is commercially off the shelf equipment that will be versatile to meet the MCC Project requirements for measuring uranium and plutonium-bearing materials. This instrumentation includes a gamma spectroscopic measurement to establish uranium enrichment and a neutron measurement to determine uranium concentration, both of which will support measuring plutonium. These instruments can be changed with minimal effort to provide additional capabilities as needed by the Project. Additionally, the use of this equipped unit will likely save the Project up to $8 million dollars and preclude the need to place new or additional measurement instruments at all the sites offering up material. Measuring the material at the shipping site will also prevent sensitive political situations that would arise when the MCC Project would have to reject material that does not meet Project acceptance criteria for consolidation and conversion. The unit can be shipped and is adaptable to movement using common modes of transportation without causing damage to the instrumentation.

As might be expected, not all of the anticipated events where the mobile measurement unit can be used have come to fruition, but many are still in progress. The wide variation in material type and configuration that was originally anticipated is still anticipated. Nonetheless, as related issues are identified and resolved, the Project is now equipped and ready to respond in a cost-effective and efficient manner to virtually any measurement requirement that may arise.

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