6.0 The Evolution of Technical Verification Methods in International Safeguards

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Participants:

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1. INTRODUCTION

Tom: Every IAEA Safeguards Agreement includes a paragraph in which the stipulation is made in which nuclear material accountancy would be a fundamental measure of the safeguards system. Today that's the topic of our discussion. We have a distinguished panel of six people who have had extensive experience in the application of nuclear material accountancy in relation to IAEA safeguards.

We'll begin with a discussion of the analytical procedures that are at the basis of these procedures. Yusuke, if you would take this on and discuss uranium and plutonium and their pure forms and materials that have some complications in association with them.

Yusuke: Growth and partial defects can be predicted by NDA but bias defect or protracted divergence cannot be detected by NDA. That's why Destructive Assay is there. Which includes some very accurate measurements. IAEA inspectors cannot measure all the samples. That's why the system is to verify operator measurements, that is, if the operator cannot measure properly, IAEA has to take the entire sample. But if the operator side is fostered to get a higher level of measurement system, then we can check with IAEA and we can take some of the sample so both sides must develop high levels of accuracy in their measurement system. For instance, plutonium - we are employing a system called IDMS, Isotopic dilution mass spectrometry, this is a typical system - and there are some other titrations.

Tom: Is that pretty much the world standard now or is that a practice that you emphasize in your own laboratories (referring to IDMS)?

Yusuke: No, Seibersdorf is using it, and some other facilities use this technique. For instance, coulometry - this is a very accurate measurement that can be used for the calibration of plutonium measurements, but can also be used for other measurements. Some discussion here but I used to use for 10 years for measurements in facilities providing all but about point one percent accuracy.

Tom: point one percent?

Yusuke: Yes. And not so many, but gravimetry can be used - because if you are given purified plutonium, gravimetry is a technique just to get the weight and after changing the chemistry to oxidize at a very high temperature then you can weigh the very simply. Of course, you have to mind how much you put in there. This is a simple and very accurate way. K-edge densitometer, this would be part of the NDA or in the DA or NDA, but we use the K-edge densitometer in the analytical lab because also provides good accuracy.

Tom: So the K-edge densitometer is used on some occasions as an inline application but often times it requires that a sample is taken and introduced into the equipment. So it is a non-destructive measurement because nothing happens to the sample that alters its chemistry. Erwin, you're having a reaction here.

2. DESTRUCTIVE ASSAY METHODS – AN OVERVIEW

Erwin: We had endless discussions on what is the difference between destructive analysis and non destructive analysis. We had this discussion on the European Working group (ESARDA) on NDA and we finally agreed upon the definition that any measurement which is done on a item without destroying the integrity of the item or on a sample taken from an item but the sample is returned to the item; this is called non-destructive. Anything which involves a sample taken but the material does not go back to the item, it becomes waste, this is destructive analysis. So hybrid K edge, because it involves taking a sample which is not going back to the process, is by definition a destructive analytical measurement.

Yusuke: IDMS, this is the typical DA measurement tool. The operator and the inspector should take the sample very accurately and there has to be a so called tracer, we call it spike. Spike has to be prepared very accurately, and mix it together, and you can imagine Plutonium 242 or 244, those are not so much important to the sample, or U-233. The sample includes Plutonium 239 or Uranium 235 or 238, so what happens after mixing, you can compare this type of tracer and the sample's isotope and you can find the ratio of the different isotopes. That makes your analytical result. So an important decision point is how to take a sample accurately. How to prepare a spike accurately. This is the key point.

After that, even the dissolver solution reprocessing, which includes a lot of fission products, if you do this mixture in the hot cell for instance, you don't have to mind so much about the preparation because all of it is mixed in the hot cell to separate the plutonium - there is no need to recover 100%, just to take the plutonium from the other elements.

Shirley: As an inspector, the introduction of a large spike, the LDS (Large Dried Spike) spike, was really a great contribution to our preparation of samples at the Tokyo Reprocessing plant, you as the operator, and Erwin as our representative at the agency. It really was a noteworthy contribution.

Erwin: The tradition IDMS, before introducing the large size, dried spike, involved taking a sample from an accountability tank, making a one to 150 dilution and then taking an aliquot and adding in the spike. This was a small spike. But then the spiking material was mainly plutonium 242, for the Uranium it was 233. These are rare isotopes that are not available in large quantities. As an alternative technique, because of the advances in mass spectrometry, it was not necessary to use plutonium 242 anymore, one could even use low burn up plutonium 239 as a spike. Still the difference between the plutonium 239 in the spike which was 97%, 55% high burn up in the sample, this was sufficient with the new mass spectrometry to get a good measurement. Now, we thought okay, if this is possible, there is much more low burn up plutonium around, why not spike directly the concentrated sample? So we prepared these large size dry spikes and the answer to your question, it contains 2 milligrams of plutonium for one spike and about 40 milligrams of 20% enriched uranium. These spikes are prepared and from the concentrated sample there is just one milliliter taken, added to it and dissolved, and after this everything can be volumetric.

Tom: So in this dry spike then, the high grade plutonium is the diluent for the plutonium sample?

Erwin: Right.

Tom: And does the uranium then include Uranium 233 as a matter of course?

Erwin: No, the uranium spike in the large size dry spike will use.

Tom: That's a separate spike?

Erwin: No. It's mixed.

Tom: Okay, so every spike includes…

Erwin: 2 milligram of low burn up plutonium 242 and 40 milligram of 19.9% enriched uranium.

Shirley: And from a practical point of view this results in the inspectors having more confidence in observing the operator prepare that sample, but also doing a larger dilution on the fission products you could not do that because the spike was added right at the beginning. But also because the capability of doing a larger dilution on the fission products so that our samples were not so radioactively hot for shipping. It was a great contribution.

Erwin: If I could just add. If you look at measurement quality, the measurement quality is achieved with these large sized dry spikes, of course it's .1% of the plutonium measurement in a high active spent fuel solution.

Tom: Before we talked about the controlled potential coulometry by a tenth of a percent and the impression I had, that was pretty pure material that you're starting off with in your sample. In this case you're saying, it contains fission products and everything else that happens to be included in that uranium and the minor actinides that are present but the capability overwhelms that and still performs a tenth of a percent measurement accuracy on the plutonium concentration. So that is the long term improvement.

Erwin: But the controlled potential coulometry still has a role. You shouldn't depend on just one technique. So it is for the certification of the validation of the spikes. You use an independent technique for the calibration of the working reference material and you send this to routine analysis.

Yusuke: So the initial argument over IDMS was just before the input [tank] version. This is designed for the analysis but it was extended to the plutonium and uranium measurement.

Tom: I understand mixed oxide in fuel fabrication plants well, so this basic technique has become a universal standard for plutonium assay.

Yusuke: I would say it happened by chance because plutonium can be made very accurate by potential coulometry, but this instrument is developed by a very small company and it is not enough worldwide. For instance, Tokyo reprocessing plant uses one instrument for 10 years, but after that it is aged and this program is already gone and no other nice instrument is available. If there is some sort of historical reason we change to IDMS, but if we are given pure plutonium, you have to pay attention how to do it. No titrations should be applied because IDMS is a time consuming, costly and long process.

Erwin: But, Yusuke, I would say that in the selection of analytical techniques, many laboratories went away from the titration techniques and switched to IDMS because it generates less complicated waste. The titration procedures will generate liquid waste which contains chromium 6 or Iron or Silver, antimony, and this is a type of waste which is difficult to get rid of. In the case of reprocessing facility what you are talking about, the situation is different because you have a lot of liquid waste anyway and you may just add this waste to it. But for a plutonium fuel fabrication facility it is a problem to have large volumes of complicated liquid waste.

Tom: Chemists can extract anything given money. So you're saying that the problem with the purification and extraction of plutonium from an accumulated inventory of samples is not something that is reasonable to do, the cost of such is still a waste material that would require a disposition of that waste.

Erwin: I would fully agree, it's the cost of the waste handling.

3. URANIUM CONCENTRATION MEASUREMENTS

Tom: What about Uranium, to come back to this particular case? We talked about gravimetric methods and that's also suitable for pure uranium forms but there are analytical procedures used for uranium as well. Davies Gray as we know and presumably IDMS can be used for any uranium sample as well.

Yusuke: As Erwin suggest Davies Gray is a technique for the uranium from reprocessing and the toxic waste solution, this is a problem.

Tom: So it's good but it's messy?

Yusuke: Good and bad. So the reason that an operator tries to use gravimetric rather than titration is because the product is purified, you don't have to titrate it. Because titrate gives you very accurate results but even the gravimetric with its combination of impurity you can still get final results that are very accurate. So I think that after a period the world change the technique from titration to gravimetry if possible – it depends on the operator or purity of the product. The importance of the analysis is much different for the plutonium, the significant quantity is 8 kg, and on the other hand, as you know, the SQ of low enriched uranium is 75 kilogram. Big difference. We don't have to care as much about the accuracy [for uranium].

Shirley: However, not just talking about material balance, the uranium-plutonium ratio it is important to be sure that the process is operating as declared. Going on beyond the uranium requirements, in the last few years, we now have the requirement for alternate nuclear materials, neptunium and potentially americium in the future. It is becoming more of a demand than just uranium and plutonium, the streams and that, able to fingerprint them to have indications that the facility is operating as declared. So although we may have developed some fine analysis in the past, it is going to be expanding in the future.

Takeshi: In my experience, you're talking about the purity of the uranium analysis, but however during the fuel fabrication process, the facilities' amount of material can amount to enrichment because for example, boiling water reactor fuel. Five, six different enrichments are in the process, therefore the uranium concentration measurement accuracy is getting higher but the uranium 235 accuracy still is not acceptable. What do you think?

4. CAUSES OF UNCERTAINTY IN MEASUREMENTS

Tom: As I understand it, what we've been talking about is making the best measurements you can possibly make to the accountancy procedures on the main flows of inventory. When we get to the questions on off-specification materials, heterogeneous materials, then we have a different situation and we need to cope with them. Takeshi's point is that in a practical production environment, particularly in facilities that make BWR fuel, the enrichment varies axially and radially in every fuel bundle and the presence of poison is also something that varies. Here we have great complications and a practical day to day thing, making a mistake can and has caused one entire core to be brought back and scrapped. This is obviously a very expensive mistake to make and one wouldn't want to do that.

Erwin: Back to the uranium concentration measurement again before we talk about U235. For the uranium concentration measurement it's clear that the facility operators - for the main product - which is pure material- either pure UO2 that comes in and the pure pellets that go out. They need to do impurity measurements anyhow as part of the product specifications, and therefore, gravimetry is the right technique because at a certain temperature profile, weigh and weigh, and then subtract the impurities.

Tom: How do you determine the impurities to subtract?

Erwin: In the past it was done with emission spectrometry but now most facilities use ICPMS (Inductively Coupled Plasma Mass Spectrometry).

Tom: In any case it requires that a sample is prepared and introduced into a measurement system depending on how well you keep it in calibration.

Erwin: Right, now Davies Gray method we mentioned and that's a procedure that generates terrible waste – sulfuric acid, iron, chromium, and I don't know what else from the analytical process, however, it has the advantage that it is basically free of interferences and that's why for the safeguards laboratory it is still a very good technique. You dissolve, do titration, measure. Initial Davies Gray and NBL modified D-G procedure, generated many liters of waste. For years, every titration produced 200 milliliters of waste, and now most of the laboratories have reduced the volume. They are now working at 20 milliliters maximum 50 milliliters volume in order to minimize the waste. The advantage is that it is basically free of interferences and it gives very good results, better than 0.1 percent.

Tom: All of these are analytical techniques that reach that technical ability.

Shirley: Maybe one more technical ability that we touched on but didn't really bring forward that has been a great contribution for onsite analysis is the K-edge for product material and then later the hybrid k-edge for solutions. This allowed the inspector to do some analysis themselves onsite because it doesn't require any sample preparation. Although it doesn't have the accuracy and sensitivity as IDMS, it certainly provides some good analysis.

Erwin: K-edge densitometry is a very good technique because samples taken at the facility can be measured directly or indirectly by the inspectors, however since this mostly operator-owned equipment you need to have authentication procedures in place. I know examples where products of facilities are measured extensively by K-edge densitometry and a fraction of these samples is sent in parallel to the analytical laboratory for destructive analysis and quality control but also for authentication. The sample selection to go to the safeguards laboratory is only announced after the operator has made his declaration. That's part of the authentication measures.

Tom: Before we move over into non-destructive assay, there were questions about U-235 assay and uranium and the methods that are used for that mass spec; would you comment on that?

Yusuke: This includes a program based on the homogeneity of a sample and the measurement. Regarding measurement, there is no problem if you use mass spectrometry. You can easily find very accurate result in the U-235 and 238. So the measurement doesn't have any problem.

Tom: Tenth of a percent? Or better?

Erwin: Low enriched Uranium - 0.1, 0.2 (percent accuracy). Mass spectrometry is certainly the easiest technique and it gives you good results but I must say that most of the facilities use gamma spectrometry because it's a simple technique, it's easier to set up, and the investment is cheaper. Mass spectrometry nowadays costs 1 million US.

Shirley: $800,000

Takashi: That is true and fuel fabrication facilities use gamma spectrometry not mass spectrometry because it is too expensive.

5. NDA METHODS

Tom: It used to be the case that there would be a range of measurement performances and all you need is a rough indication, sometimes you need a finer indication, and sometimes you need the best measurement you can possibly make. We've focused so far on the chemical analysis methods that are used in analytical laboratories which on occasion include gamma ray analysis or hybrid K-edge or K-edge densitometry which in and of themselves don't alter the physical characteristics of a sample. In that case there is the question of what happens to the sample after the measurement is finished. Generally these samples are small and pure in form. This is not the case in the real world where we encounter a variety of containers and materials in heterogeneous and pure forms, sometimes in containers that cannot be opened like fuel rods or fuel assemblies. Sometimes they are too hazardous to take apart, and in those cases the application of NDA provides a basic measure for safeguards accountancy practices. Howard Menlove is going to give us a general flare for NDA and then focus a bit on uranium and plutonium.

Howard: As the IAEA took on the challenge of verifying nuclear material worldwide there was new challenge in that items that were inaccessible for sampling and chemical analysis such as rods, fuel assemblies, needed to be verified and also a new aspect was added to nm measurement and that is the operator and owner of the material needed to be checked in terms of – you could no longer check and count an item and assume its contents were as declared - because the declaration itself needs to be verified. This required new technology and entire groups were formed at LANL and other labs to take on this challenge. The basic signatures that were available for NDA had been used in the nuclear industry since the nuclear age began and that was the gamma rays, neutrons, and heat being emitted from nuclear material – this could all be used to quantify how much material was present. The IAEA inspection brought in added complexity because the inspector needed to complete his work in a small time scale because he needed to come in, verify material, and leave. He could not have continuous access to the material in the beginning so many NDA techniques were developed that gave the inspector portable mode equipment often carried in suitcases or on rolling cargo cases. Both neutron and gamma ray technology were put in to these portable type containers. The nuclear material intrinsically, well the primary focus is on enriched uranium and plutonium. Enriched uranium is especially difficult because it doesn't give off very useful neutron signatures where plutonium does.

Tom: And the difference in this case is that the neutrons penetrate so it is possible to get a better result from an entire container as opposed to a situation where gamma rays might not be so penetrating.

Howard: That's true and typically the bulk containers the gamma rays were limited to a few millimeters into the surface so historically the gamma ray technique developed as a spectroscopy ratio technique to give isotopic ratios of the surface material with some assumption that the inner material was the same as the surface material. So the enrichment meter principal was developed for U235 enrichment and it is still in use today on plants that handle uranium and UF_6, but going deeper into the material was a challenge so in the uranium area, NDA brought along both the gamma ratios of isotopic peaks as well as active neutrons was introduced to penetrate bulk uranium samples to show what was on the interior. Various NDA equipment was developed and provided to the IAEA that used neutron interrogation to supplement the gamma ray isotopic work. The equipment such as the neutron collar and the active well coincident counters were developed for this purpose and are still used today. Commercial neutron sources have been developed. As an interesting side line – active well coincidence counters measure bulk U-235 in high enrichment uranium samples and about 15 years ago that had a resurgence of activity as the weapons states such as Russia and the United States started to dismantle nuclear weapons that were in the form of bulk HEU and move it from weapons configuration to powder stable storage configuration and verifying how much HEU was moving through that process required quite a few active well counters – they were procured for that program and used both in Russia and the US.

Tom: And these were driven by a neutron source, such as an alpha N?

Howard: To give a little information on the active neutron for uranium: an isotopic neutron source is fabricated at a commercial company where it is made of americium lithium and the americium alpha decays into the lithium and makes purely alpha neutrons that then fissions the U235 in the sample, and the fission neutrons are born in coincidence – 2 or 3 neutrons per fission, so the equipment looks for neutrons coming out and then it's directly proportional to the number of u235 atoms in the container. That is being used in 3 or 4 standard equipment types now and is being deployed worldwide for this particular problem. Currently there is a lot of interest in how to do NDA of large containers of UF6 and the cylinders that contain UF6 should, with safeguards treaty agreements, be below 20% enrichment. When there is a cylinder of many tons of uranium in a plant the IAEA needs a rapid way to determine if the material in the plant is meeting that criteria, and in an adversarial situation the grab sample that goes to chemistry has a question – was the entire weight of the cylinder in the grab sample or what there a heterogeneous material in the sample that was concealing HEU. So that is an up to date IAEA question that is being addressed both with collaboration and NDA for the bulk sample and DA for the grab sample that you can get access to. The IAEA makes use of both technologies to draw conclusions so there is a lot of interface and cooperation especially in the IAEA evaluation of the information between NDA and DA where the large bulk is in the NDA arena and the accurate analysis is in the DA arena and you need both to get you to your final answer.

Tom: Howard we are talking about neutron sources. The isotopic sources have special characteristics which make it complicated, they have to be procured, there are safety issues associated with handling these sources, transportation, so it is attractive to have a source that is an accelerator of some sort because it is not radioactive until it's on, and the other would be the question of the longer life sources versus the shorter life ones. Cf has a short half life compared to Am for example. Maybe you could comment on that dimension of this NDA application.

Howard: The IAEA has wrestled with the question of how to both procure and transport and license into the facility any radioactive material and the americium-lithium for neutron interrogation - they have gone though those steps on many of the uranium facilities – they're now licensed - and they know how to ship it out without too much delay to nuclear facilities back and forth from Vienna. Another isotopic source widely used by the IAEA is Californium 252 because it puts out so many neutrons with such a small mass - with nanogram quantities - so the IAEA makes extensive use of Cf 252 in the mode of calibration normalization activity. And that normally ends up in the plutonium facilities where they need a known neutron source. So the movement of radioactive sources is difficult and has been dealt with at some level by the IAEA. Moving on to the forms that NDA has addressed - a major form is complete fuel assemblies and pins that show up as both uranium and plutonium in that form. Its normally done w/ NDA, both gamma ray and neutron techniques have been developed. As we move into fuel assemblies, there are many being fabricated that have plutonium rods and full assemblies that add an additional importance to IAEA safeguards because there are so many kg of fresh plutonium in that form. So the recycled mixed oxide plutonium called MOX is quite important. The large fabrication plants that process plutonium, that's the primary verification methodology in the facilities is to check the passive neutron rate. One advantage of passive neutron is that it avoids the radioactive source shipment that is there for uranium in some cases. Any fabrication plant of MOX has powder going in the input and fuel assemblies coming out - the output of the plant - and as the material moves through the plant the verification activity is primarily based on neutron yield that is the same for any gram of plutonium anywhere in the plant. When Tom mentioned earlier that there was well over 100 NDA systems approved by the IAEA for use, probably 30% of them are based on neutron time correlation counting based on this physical principle that a fission event, both spontaneous and induced, gives off a small burst of neutrons.

Tom: When you have a collection of Plutonium, the neutron emission will depend on multiplication, which in turn depends on presence of moisture or other scattering materials that will allow moderation and change the fission characteristics of the collection of material.

Howard: In the last 15 years the neutron counting technologies advanced in singles counting and then coincident counting is the next level, and then multiplicity counting in the next level. Multiplicity counting means you look for not only when there is a little fission burst of neutrons but also you determine if the burst had 1, 2, 3, or 4 neutrons in the burst - the number in the burst is the so called multiplicity. If you have measured the multiplicity you can correct for impurities and moisture that make the answer less accurate if you're not doing that. So multiplicity counting was mainly developed for IAEA verification of impure and moist materials. You need a pretty big counter to count these neutrons.

Tom: Before when we were talking about destructive analysis, at least the chemical procedures, now when we are talking let's say about a container of relatively pure formed plutonium dioxide or controlled moisture and a substantial amount 100g or kg or whatever. What kind of measurement performance is attainable with a gross count, coincident count, and a multiplicity count? Any idea off hand?

Howard: Yes, it is an informative question because if you gross count that container you can probably get the right answer with 10-20% accuracy absolute, and if conditions are good you can do better than that.

Tom: And this is with relatively cheap equipment and a relatively short amount of time?

Howard: Yeah, like seconds. Maybe 5 to 20 % would be a range for a gross count.

Tom: Equipment maybe like $1,000 or something like that?

Howard: Well you can't get anything for $1,000 now. The electronics all run above $5,000. And the electronics cost is the same whether you're doing a simple count or a multiplicity count because the cost is all in the packaging and marketing and commercializing it. Back to your question, if you do a simple coincidence count with no moisture you get down to 1 or 2 %. And in a time of like 10 – 15 minutes. If you then move into the multiplicity counting technology, the count time might be 10 minutes to an hour then the accuracy pushes down to below a percent and we're pushing to below a half a percent based on calibration standards. I think Erwin had a contribution here.

Erwin: Which is - what you measure is plutonium 240 effective. Now, what we should verify is the total mass of plutonium element. How do you convert the 240 effective amount to total mass of plutonium and what impact has this on the measurement quality?

Howard: It is a very good question. It's been there for the 30 year period, the passive plutonium counting comes from the Pu 240 isotope effective, with even isotopes of plutonium (242, 244…). And to get to the total Pu you need isotopic ratios. In the NDA world those isotopic ratios have been measured with gamma high resolution spectroscopy for the 30 year period. But it introduces both extra time and more uncertainty in the answer, so the IAEA has worked around this problem with methodology where they'll generally do both neutron and gamma measurement in the plant at the time of the bulk sample. Then the final amount of plutonium, the accuracy is sitting on top of the uncertainty due to the gamma isotopic measurement, and in the total safeguards procedure for the plant there are also samples going to the chemistry lab and those samples are generally getting mass spectrometry isotopic ratios performed for chemistry reasons. Those ratios go into the IAEA data file and at some point they bring together the isotopic from mass spec with the neutron measurement to push the uncertainty down and so as the time increases and the mass spec data comes in, the uncertainty gets better on what was done earlier. And so the NDA has a role of timeliness that sometimes, especially for NRTA (near real time accountancy), something we will get to later, needs very timely information.

NDA in the future

Tom: NRTA is near real time accounting.

Howard: Yes, thank you. So time is a factor and NDA has always played a role with the agency because it gives rapid time turn around. Projecting into the future a little bit, as you're doing real time continuous measurements, the IAEA ability to know what's in a plant is becoming more timely than it was in the past and that's improving safeguards overall.

Tom: I want to take us in the direction of installed instruments but before going there, this neutron coincidence of neutron multiplicity measurements are such a fundamental part of nuclear material accountancy practices today. Most of the neutrons are detected by helium 3 neutron tubes and that is because this particular type of detector has certain characteristics which make it a very attractive substance and design. There are other ways to detect neutrons but they don't seem to have made it into the marketplace the way that the helium 3 tubes have. Maybe you can comment on the supply prospects of Helium 3.

Howard: There is a supply shortage on Helium 3. But first the helium 3 technology and tube fabrication with the preferred vendor is such that you have a stability in performance that has never been there available to even the physics community in the past. We have systems that have been running continuously for 20 years where the absolute efficiency and performance of the system has changed by less than a percent over the 20 year period. The stability when count rates are high drop down to much better than a tenth of a percent or a one hundredth of a percent. So the stability and performance of these tubes make them an invaluable asset to the IAEA. IAEA needs robustness in equipment and helium 3 tubes - there's thousands of them in use continuously by the IAEA and the meantime between failure is more than a thousand years – so reliability and stability is a great success story. As the IAEA's specifying new equipment to go in new facilities, they say we need this capability to keep this success a reality.

The helium 3 supply historically has been from the decay of tritium. Tritium has a half life where 5% of it turns into helium 3 each year. So if you have a large amount of tritium it is automatically making helium 3. And historically, both Russia and the US and other countries produce tritium for thermonuclear weapons but the thermonuclear weapons are going down by orders of magnitude in the past decade or more, and so the tritium supply and helium three has been disappearing as the weapons supply is dropping worldwide and in the Russia and the US. In parallel, the need for Helium 3 has been going up by a factor of 10. IAEA safeguards has had more or less a constant need for the past 3 decades. But portal monitors and large neutron scattering centers are requiring helium 3 in quantities that are an order of magnitude bigger than what the IAEA uses. So it has put a shortage on the supply. So we are trying to make sure of the quantity it needs going into the future.

Tom: We were talking about helium 3 and its importance – the question of sources and the adequacy of supply, and the present and future situation.

Howard: The main reason helium 3 is in short supply is the large increase in demand in the portal monitors in the US and other countries. The portal monitors in the US and overseas are using amounts of helium three that are 10 times bigger than what IAEA has used in the past. The people involved in the problem are looking at alternative supplies and there is a lot of helium three being produced in CANDU reactors worldwide that is not being presently harvested. In the future the helium 3 will have a continuing supply and it is a matter of the economics of harvesting it. In domestic safeguards the heat signature from plutonium is used a great deal for material verification and accountancy. IAEA has not been able to use the heat signature very well because it takes longer to do the measurement than IAEA usually has available. We mentioned briefly, K-edge densitometers and hybrid densitometers where its gamma ray transmission is the methodology involved. Radiography gamma ray has found some application. But the great bulk of the IAEA NDA equipment focuses on gamma isotopic ratios and neutron bulk measurements, both active and passive.

Tom: And the gamma ray isotopics depends upon the performance of the measurement detector itself and in that case there's again a spectrum of capabilities, some of which are cheap and easy to use but don't perform all that well and others that are high performance. Could you talk for a moment about sodium iodide and cadmium telluride and other solid state room temperature detectors and the king of the hill, intrinsic germanium?

Howard: The detectors in the gamma ray world keep improving. There are solid state detectors that make the whole package very small and portable, but in general the resolution of the gamma ray peaks (the full width at half max) is still best with the high purity geranium detectors that have the disadvantage from IAEA standpoint in that they need to be cooled to a temperature that is close to liquid nitrogen temperatures. There are mechanical systems to approach that and different packages. But in the commercial world you can get a high purity germanium system that's about this big and this long and has a handle that lets inspectors go out in the field and do a high purity germanium measurement reasonably well. Both the electronics and the detector head itself have improved over the years, so it's becoming a much more attractive package for inspection. There has been tremendous improvement in electronics over the period in question, all to the benefit of the IAEA and many countries have contributed to improvements both the electronics and NDA technology in general.

Erwin: Well Howard, you had mentioned heat measurements and that means calorimetry that is widely used in this country but not used in the IAEA. Isn't this mainly because the isotopic composition is different? Here you are dealing with military or weapons grade plutonium but what is subject to IAEA verification is mainly industrial type plutonium, where the heat generated or almost entirely comes from plutonium 238.

Howard: It's a combination of those two reasons but the primary reason is that it takes 4-8 hours to come to equilibrium with the calorimeter and the IAEA needs to get answers faster than that. The secondary reason is that in the US, weapons type plutonium - most of the heat is coming from Pu fissile content that is of interest. Whereas with reactor grade plutonium in the commercial cycle that is under IAEA safeguards, most of the heat comes from pu 238 and americium 231, that are not items of safeguard interest. As you try to relate the heat measurement to the Pu of interest, there is a sizeable error increase, so the calorimeters are mainly used in U.S. domestic accountability.

Tom: As we move away from discussion of NDA, there are two-three topics to take into account. One would be the question of hold up. Instead of having a very tightly confined sample in which you have complete control over the counting sample, you have a distributed source in a manufacturing plant in particular and trying to estimate the amounts of plutonium without taking the plant apart is a real problem.

Howard: Hold up is a very important item for the IAEA. You try to do a mass balance about a plant that has hold up and waste you've got to include the amount of nuclear material in the form of hold up and waste, and those forms are generally difficult to get into the tradition DA accountancy scheme. You can't take a sample.

Tom: Or if you could it wouldn't mean anything.

Howard: It's not uniform enough for sampling. So technology was developed for the IAEA in the holdup arena for uranium and plutonium. The plutonium is the more important of the two and the plutonium is all processed inside of glove boxes and the plutonium hold up ends up on the equipment and the walls and the floor. So it's all in these atmospheric sealed glove boxes but the plutonium mass is increasing in the holdup form and if you're doing a plutonium mass balance for the facility you're deciding how much you're going to assign for hold up. So NDA was developed to measure hold up in situ, while it's still in the glove boxes, over the past 2 decades and is widely deployed now. The basic measurement principle was to place temporary or installed portable large size neutron counters on both sides of the outside of the glove box and sequentially scan to get the total box. They have been used for 20 years to quantify the plutonium mass in the box to approximately 10%. On that topic, going into the higher volume process plants of MOX, the number of glove boxes is increasing and the size is increasing. The time it would take to measure with portable equipment scanning gets to be too large so new technology is being introduced with IAEA participation on installing neutron counters in the shielded wall of the glove box, roughly at 1 meter layers – a tube and then a meter later another tube - to cover the entire geometry and if you collect counts in that system you get thousands of counts a second in the singles mode. But again, the accuracy of this mode is degraded by cross talk and other material in the plant. You don't know if it came from the hold up or somewhere else. So the time correlation coincidence counting is being deployed and the efficiency is very low so statistically you have to count 8 hours. Since it is continuous measurements, there are 8 hours of hold up every night waiting to be measured so it doesn't use any inspection time to collect the 8 hours of data. It is done every night and you get not only the hold up in the box but also the process movement of plutonium during the day and that's information that's never been available to the IAEA before and it probably has more safeguards significance than the holdup number itself.

Shirley: I might expand on that, actually. I think the system that's installed in MOX conversion plant in Rokkasho shows movement and pattern recognition is being used on that, the same as you would use on a solution flow-type system. If that's similar to what you're referring to.

Howard: Yes and the process flow can be measured in the singles mode because it's relative- did something come or go, was there any change, was it one percent or 10 percent? That type of measurement the best data is in the singles mode that is being done in the conversion area already.

Tom: So we see a historical trend here in which the measurement methods have been evolving, the deployment of measurement system, the arrangements for acquisition of data is continuous in effect. The density of instrumentation is becoming rather extensive. You were talking about how in one facility that the number of helium tubes necessary to instrument a facility is getting close to 1,000?

Howard: Yes 1,000 in JMOX (the Japanese MOX fuel fabrication plant at Rokkasho). And the facility Shirley mentioned?

Shirley: 148, yeah. That has smaller lines though.

Tom: So all of these systems acquire data in real time, sometimes this data is captured at the facility with the redundant use of components that are likely to fail - the system performance has become remarkably stable and long lasting. Another great success story.

Howard: As the IAEA plans for future facilities they're very resistant to change from a helium 3 detector to an unknown because if you have a component failure in an installed system the time and the cost to deal with it would equal 100 detectors purchasing. So the actual detector cost becomes small compared to dealing with a failure so reliability and sustainability with the IAEA means that they are going to keep using the high reliability system. The systems will become available for that one way or the other.

Tom: And of course once this data is captured it becomes data, it can be stored or it can be exported to other location around the world so that the ability to monitor an activity can be done in essence in real time from any location anywhere else. It is necessary to secure the data so it is not tampered with in any way, but the application of accountancy has evolved from being an infrequent intensive time experience to something which is a built-in part of operations of facility and keeping track in that kind of time frame.

Howard: That process monitoring aspect is an improvement and increases in IAEA information. As you change from a reprocessing plant that's dealing with solutions and complex change of radioactive material into a fabrication plant - it becomes much simpler because there is only flow and not change of state going on. And so process monitoring of neutron signals in a MOX plant will become an important added safeguards information that was not there in past safeguard activities.

Yusuke: Can I raise one point. We are already talking about the future nuclear fuel cycle which may include real reprocessed fuel, we've got to include curium in the process, not only in the reprocessing but also at the fuel fabrication plant.

Tom: So behind biological shields then because of radiation considerations.

Yusuke: Then this neutron system, the entire package of neutron system cannot measure direct plutonium, they can detect only curium.

Tom: Curium emission rate is much greater than plutonium emission rate.

Yusuke: This would be disaster for the safeguards system.

Shirley: Actually right now that curium emission is a lifesaver in our waste measurements - once we establish a curium/plutonium ratio, where as what you say - it may be a hindrance in the future.

Tom: That's a remaining area I wanted to touch upon, maybe you'd open this up a bit. The question of what happens when you have intense fission product emissions and minor actinides present, either in the form of spent fuel, which is still sitting in a storage pool or something, the leached hulls for these systems are both measurement systems that can give you a discrete measurement on inventory or inventory change verification or they are a continuous system where they are monitoring the flow.

Starting at the head end you have spent fuel coming in, you can't have an inspector there all the time so there are the gamma neutron systems along with surveillance to monitor that flow along with the spent fuel and hopefully we've talked with Howard and other people we might even be able to do some sort of fingerprint that tells us this is the fuel transferring into the head-end part of a reprocessing plant. There again you have monitoring systems that are a combination of radiation measurement systems and surveillance that follows the fuel continuously until it's chopped. Then goes into the process and you have solution monitoring following the solutions through, converting to powders, in the conversion area we go to the neutron systems we were just speaking of with the helium three tubes and then into the product storage area. But, what do you do about those hulls that are at the front end that have huge fission products, very very small amount of plutonium in them. Howard is the guru of curium.

Howard: About 15 years ago we introduced to the IAEA the concept that in certain parts of the process the plutonium/curium ratio doesn't change and the curium is such a prolific neutron source that if you can quantify the curium and you know the ratio then you can give the plutonium by the ratio.

Shirley: Now this ratio is actually established by taking samples and particularly in the hulls area by taking samples of the input solutions so that does have to be done in the laboratory.

Howard: So once you have homogenized and sampled you get from the DA an average ratio of curium and plutonium. Actually it's curium and all the isotopes, not only plutonium, that are done in the DA. The curium becomes the tag that then goes into waste streams such as the leached hulls and some other waste. So you can quantify the waste by the curium.

Shirley: Random samples are taken to confirm that this ratio is staying somewhat constant.

Howard: And using that ratio - you were involved in the discussion - is a feasible technique. And it has been implemented in a reprocessing plant but also in some alternatives like the DUPIC fuel cycle and other things. If the chemistry has not separated the curium then it is a tag for the plutonium. As we go into the future if there is curium contamination in the plutonium stream, then we have to deal with that, and if its varying for whatever reason – then there's potential new ways to deal with it, but that's part of the future.

6. SAMPLING UNCERTAINTIES

Tom: Now I think we will transition away from the measurement techniques, to look at the types of situations that occur and Erwin maybe you can talk about the issues of capturing materials for verification purposes. The bulk measurement issue is a critical one - in a reprocessing environment we saw a recent case where large scale spills occurred at a plant that wasn't subject to IAEA safeguards, which led to a remarkable amount of Pu being accumulated in a process cell. So confirming that the material remains under control. The sampling business – how samples are to be collected, selected, how do you assure that they are representative, how do you plan for when samples are collected, error estimation.

Erwin: the first part – the incident you mentioned, I think there were 30 cubic meters of input solution that leaked out into a hot cell. This is an event that would be, should be caught be a monitoring or measurement system like Shirley mentioned. Now, if I could talk about the process you selected – DA – its very important not only for the safeguards, but for the operators of a facility, because DA is used to establish the amounts of material in the facility, and these results should enable the operator to know at any point in time how much material he has and where it is. Now for safeguards, you mentioned before, it has to verify this. And the inspectors can't take100% of the samples, they calculate the random sampling plan, and if I should talk only about DA samples – what is important. First, you need to make sure the sample is representative of the item. So you minimize sampling uncertainties. Even if you have a representative sample, you need to be sure it can be shipped – Pu samples, larger quantities you can't ship any more. If its representative, then you need to make sure it's sufficient for the DA method you're going to use – you can obtain a result with the expected accuracy and precision. Before all this you have to negotiate with the operators – how samples will be taken and packaged, and you have to have suitable sample containers. Sounds simple, but its complicated. Perhaps later on facility specific issues, you'll see that in my opinion, most of the issues relate to sampling. I mentioned shipment – transport restrictions which may require special treatment of the samples – or an on site laboratory – uranium samples are usually not a problem to ship, if you stay below 15g of 235U, but Pu samples its complicated – only very few countries allow type B, 15 g of Pu, but in most its type A, which is reactor grade Pu is 30-40 mg of Pu, maximum in one container. That requires at the facility side, that when the inspector takes the sample, it has to be dissolved, aliquoted, spiked maybe, so in order to reduce the quantity so it can be shipped. Next point is data storage, analysis, evaluation quality – sample arrives at the AL, analyzed, AL will report results to safeguards. We also need to have operators declared data and results of the measurement. Inspector measures the mass of an item to be sampled, and collect from the operator the declaration for the item – mass, volume, element concentration, isotopic composition. So when results are reported to safeguards, the inspection data, everything goes to a central database for evaluation. What are done – for every inspection – samples are taken so there's a comparison for every sample taken inspector-operator evaluation - mainly done for values of interest – mass of element, isotopic content, mass of u235 in an item, etc. These are stored in a database and at the end of a material balance period, they're retrieved and used to establish the "D" – the difference – the amount of material or inventory for a facility as declared by the operator, and verified by the agency using a random number of samples. The same data is used to perform historical evaluations – so you'd use operator-inspector paired data over longer periods of time for the estimation of random and systematic uncertainties. This is what the Agency calls inspection performance verification measurement performance evaluations – these estimates used for several purposes – first of all to calculate sampling plans. How many samples have to be taken with the different verification methods you have available. That's where these performance estimates flow in. Used during verification to recheck limits. Is the difference between instrument check and operator significant or not? They are also used to draw conclusions on the material balance. The facility operator will declare the Material Unaccounted For (or MUF) – the question is – is this amount significant – yes or no. The agency takes the performance estimates they have from the historical data they have, and calculates the sigma-MUF. When the sigma-MUF is larger than the int'l standard, then the conclusion is that when the sigma-MUF is larger it doesn't meet the standard for quality. If its larger than 3 sigma, then conclusion is that MUF is significant and follow up actions would take place in the facility. One last thing – this verification measurement experience which the IAEA has is based on almost 30 years of data for DA for all facilities world wide, and for more than 20 years on NDA measurements. It's a huge database, the knowledge from this database is used to set up target values for measurement uncertainties, which describe measurement quality which should be achievable under daily routine operating conditions.

How often are they updated?

Erwin: The first time IAEA published ITVs (International Target Values) was 1993, there was an update in 2000, and the next update will be in 2010.

Tom: But what you're talking about is - a meeting of scientists and analysts came together, and discussed what they could achieve, and what they were capable of and willing to support, as being target values that would guide their own behavior. And now you're saying, over the years, on the basis of actual measurement performance data as reported by states and by the agency, through the SAL and network laboratories, the results are based on actual performance. Is there a driver to do better?

Erwin: certainly over time we see improvement in measurement quality. We talked earlier about IDMS using LSD spike – that's improved.

Tom: an individual facility may see performance which isn't remarkable, but over time they improve.

Erwin: first discussion about target values was in the ESARDA working group on destructive analysis, as early as 1979. And what we've seen is, if you talk to an analyst, he'll give you a lovely number; he's proud and knows what he does. But he doesn't know about the sampling error. The IAEA takes the sample, has to be packaged, shipped. How do you control the sample integrity? We believe the operator inspector database, what we actually observe all over the world, is the best information we can count on.

Ted: You're talking about – the target value is very good information, to use when designing the MC&A system at the facility. But the ITV is not concerned with sampling error.

Erwin: I have to disagree, because from the beginning in the concept of ITVs, we were also looking at sampling errors. The ITVs we have - I should perhaps say, what do they mean? This is the level of measurement quality that should be achievable in the daily routine operation conditions. There are ITVs which look at random and systematic uncertainties, for mass-volume, sampling, and for the different types of materials, element concentration, isotopic enrichment, and for sampling, there's a recommendation for sample size.

Tom: does this include NDA also?

Erwin: yes. There's a table for uranium concentration, uranium-plutonium, total mass of U, Pu, and total mass of ^{235}U . DA and NDA. This is since 1997.

Shirley: about sampling error, though. There is an indication of sampling error in the ITV. But your other statement was that it was included in the actual data we collect in the database? Is there some way to pull that sampling error out? Because it can be very facility specific.

Erwin: good question. It can be very specific to a facility. It certainly is material type specific. From the original data which we see, when we do verification measurement performance evaluation, its not immediately visible. You know that the operator takes a sample at a point in time to do his declaration, the inspector takes one at a different time. You know how good your analytical measurement is, so you can guess on the sampling error. To know what the errors will be, just ask the operators. They should know.

Shirley: During Design Information, when the operator is commissioning, they're going to do repetitive sampling and try to determine that error. And it's the IAEA's responsibility to participate in that. For NDA you don't have to worry about that sampling error.

Erwin: I said earlier, that when the IAEA calculates sigma MUF, its compared to the international standard of accountancy. The quality or uncertainty is expected, with which the operator should be able to close his material balance. If you have a situation where the facility accumulates heterogeneous scrap, the uncertainty which surrounds the measurement of that scrap, it'll affect the sigma MUF. And so you will reach a point, if you're inventory grows, if your inventory in scrap grows, the conclusion will be reached that your measurement quality control system doesn't meet international accountancy standards.

Tom: dominated by the scrap inventory component.

Erwin: Right.

Tom: Is it worse for uranium than plutonium?

Erwin: its not a simple answer. You have to look at the type of facility and the way they operator. Most of the facilities are flow dominated – they receive a lot of material and produce a lot. If you look at the inventory – at the beginning of the material balance period and the end – it will be small compared to the throughput. So the impact will be less. The problem gets bigger if suddenly they don't produce anymore, and you look at the inventory, then the MUF will be small, and the inventory will be large.

Ted: In my experience, the process hold up measurement contributes to the cumulative MUF because many facilities, fuel fabrication facilities, they will account for in process material – it's a big contributor.

Erwin: Yes, if you don't account for the material held up in process, it shows up as material unaccounted for. And you will reach a point where the IAEA will say, that's unacceptable.

Shirley: I was at a workshop a few years ago on hold up and discovered that there are numerous definitions of hold up. So in the reprocessing arena, we actually defined them. So when a plant is operating, the in process inventory, or hold up, is what is expected during operating conditions. And we referred to this earlier in the glove boxes when they're operating is hold up. Then there is unmeasureable hold up, which is in areas that you can't get to – you have to measure it indirectly, via inputs and outputs, then there's residual hold up, which is that which gets held up in filters, on walls, that remains after you've cleaned out the process. And that can be a real challenge to measure, a real problem.

Erwin: I've seen situations where if you're plotting cumulative MUF, the shape of the curve was exactly identical to the cumulative throughput. So you have either a measurement problem, or you're constantly losing material in the process.

7. DESIGN INFORMATION VERIFICATION (DIV)

Tom: perhaps we can talk about the design information process, and Shirley, if you could take the lead in discussing this, starting with the implementation of safeguards at a facility, so how do you set yourself up, how do you characterize what the operator's capabilities are, and how does this impact the activities over the life of the facility, for setting up requirements for inspections, and for periodic reverification of this design information.

Shirley: And I'll add a little bit of the history to document it here, that design information has always been required under the agreements, the individual agreements with states, and so it was certainly a right and a requirement that the inspectors carry out the verification of, not just the physical design of the facility, but the accountancy system, the measurement system, reporting systems, it actually covers a number of areas. But the guidelines for that were never really established and the inspectors were kind of on their own for all these years, for how to carry out design verification, how to record it, report it, and so the practice was that when a facility had completed construction, the agency was informed, the inspectors came and verified the basic design, it was documented some way, maybe with pictures, written reports, and those reports then often times got lost, because there wasn't a method of retaining the reports. So as a strengthening measure in the early 93+2 Programme part 1 measures, one of those was to enhance the DIV activities and the task force that I headed under that looked at and wrote guidelines for the inspectors, established a way of reporting it, using a computerized method, and started pushing for employment of tools. We didn't have tools, a lot of it was dependent on observation of the inspectors, and not all inspectors are experts in all different areas, an inspector that is well versed in enrichment, and you put them in a reactor, they may not really know what elements they should be looking at, the characteristics. Do we just do one verification? We verify the design when that facility was built and then we never verify it again? Often times operators do modifications, they don't realize the safeguards significance, and so its not reported or recorded. It's an innocent thing on the operator's part. So that was another reaffirmation or confirmation that was done by the Board and the GC that the agency had the right during the entire lifetime of the facility to carry out DIE and DIV, even looking at the drawings. So with that, inspectors had to start looking at all their facilities, even those operating for ten or fifteen years, what was going to be the importance during those different phases of operation, shutdown, closedown, and eventual decommissioning of that facility.

Tom: Shirley, talk if you would about the DIV activities at reprocessing plants, and also vitrification plants since there are some similarities in the way in which materials are processed.

Shirley: well I think that probably under the JNFL (Japan Nuclear Fuel, Limited) project, the design verification approach, there was the most extensive program that was ever put together by the IAEA and it really took years to carry that out starting with the clearing of the land and the site, and then from construction on out, to have periodic visits there to have verification, because in the reprocessing plant, many of the characteristics that you're interested in, as an inspector, that you need to verify, to ensure that this plant is being designed for its declared purpose, are really not going to be available later on. They need to be there and it must be documented in some way, that the continuity of knowledge of the verification also needs to be maintained. I should interject that also as a result of the JNFL project and the need for documentation and retaining that documentation was the development of a 3D laser range finder system, which I give you credit for, Tom, originally, for recognizing the need, engaging the Joint Research Center in Ispra, that was developed there and employed extensively at the Rokkasho Reprocessing Plant, to document pipe runs, interiors of cells, trenches between facilities, that would be covered up later. And these cells would not be accessible later, they were either sealed in a manner, or the physical sealing that the operator carried out brick and mortar was documented so that if there was a change it could be recognized later on. As it progressed, through construction, we built up with that facility from the bare bones of it, and it was rather interesting to be able to watch that come to be, pretty soon halls became halls, and cells were cells, and laboratories, but as they introduced equipment, and vessels, the added complication that these systems had to be tested. These are the operators systems, they're going to do their systems and declare those values for accountancy systems. And also there's the introduction of the IAEA systems. Those had to be installed in a number of places.

Tom: I'd like to come back a little to the situation – all facilities are different. Reprocessing facilities are chemical processing factories in effect, which are complex systems required for moving solutions of reagents and fluids etc, and so there are over a thousand kilometers of piping…

Shirley – there are over 1700 km of piping at Rokkasho. And 38 buildings at the Rokkasho Site. And hundreds of vessels.

Tom – So the basic challenge from an inspectors' point of view – what's going on? What's each of these things mean? How is material going to be moved? And does it allow for something unusual to occur?

Shirely _ yes, and such a large facility – its not always to your eye – its not visible. Some of it has to wait until the plant starts doing its testing – you start to see that material flows where its supposed to be flowing, but the vessels – 92 of the tanks were calibrated and instrumented for IAEA use. This calibration is a very work intensive operation – three calibrations on each vessel, each one taking a continuous 2-3 days. So that, day and night – once you started tank calibration it cannot be stopped.

Tom: So from the standpoint of the inspector – did you have inspectors present during that entire period?

Shirley: We did. But 1700 km of pipe, you're not going to trace every one of them. So it kind of goes back to the random sampling plans that we were talking about – when you're taking samples – that had to be employed at the Rokkasho plant – we had to divide into three categories: those that had the highest strategic importance to safeguards, then medium, and then those that were very low importance, support, utilities, reagents – and this had to do with cells, tanks, pipes, buildings even. Then within those very high was 100%. Medium was about 50% verification. Low was quite random. Then there was over time you'd go back and reverify certain items if you felt you had not maintained sufficient control or there's a possibility it could've been changed. So very intensive, teams of inspectors there, maybe 5 inspectors at a time. Some ways it was actually very interesting and fun as you crawl along pipe runs, if you had claustrophobia it was kind of a problem there, but otherwise a very interesting and almost very intimate activity with the facility. I'm sure the operator had some heart attacks at some points.

Tom: I can imagine industrial safety concerns come to mind. The problem is that you don't want someone to get hurt – particularly the IAEA because then you're in the headlines.

Shirley: Yes, and the operator is very conscious of that at all times. Harness headgear training, it certainly was employed at all times. The cooperation with the operator in this instance was very good. I think of some of the previous facilities we went to, complex ones, it really depended on the cooperation with the operator. Vitrification plants - it's not so different, in that it's a process with fluids flowing, a very high fission product content, high radiation areas – there it's more of a challenge for the operator because of the mechanical demands of that vitrification process. Here again, we can't take samples of the vitrified product so all you can really do is take random samples of the feed material. So it's all in a hot cell. Most of the vit plants do have lead glass windows so you can see into the cells and have an idea if things are being changed. All use remote handling equipment.

Tom: Through this, from the standpoint of construction, the cold periods – when your access isn't limited by radioactive activity, the point where there's cold operations – during which time you're calibrating various operator systems and installing agency equipment.

Shirley – It's a very critical stage. It's the end of the construction period, and then going into the cold testing. There are so many last minute changes that occur. This looked like a good plan in the beginning but maybe it's not a good plan now. You have to adapt to it. For Rokkasho, they haven't finished their active commissioning – they're still doing some testing in that particular area. The cold testing during that period was really a time where you could identify some problems and change them. Active commissioning is really difficult. Hopefully you've done most of your design verification by that period.

Tom – that's when safeguards inspections start going on…

Shirley – well, they've introduced material, so it's under inspection by that point in time as well.

Tom – and different types of facilities require different types of inspections –reprocessing plants have required continuous inspection presence largely because in the past, and I don't know the situation in more modern facilities, that it wasn't possible to verify the inputs except if there was an inspector present. So whenever there was a shearing and dissolution, that an inspector had to be available to witness the activity. Take samples.

Shirley: With the unattended systems that are being introduced, it doesn't necessary require the inspector to be there, and the on site laboratory – where the samples are selected, and automatically taken and sent to the laboratory, its becoming a real necessity to have the inspectors there is that equipment hasn't reached the point of being that reliable. It's just not robust enough, and so the inspectors spend a lot of time trouble shooting, having equipment problems, does the operator have equipment problems and determining what's going on. I've had some situations, and I know within the agency, they're having discussion s about random inspections, and it comes down to – we've got to have an inspector there. It doesn't work. To work, you've got to have an inspector there. It's a real challenge for the future. Maybe a challenge to the industry out there that's developing the equipment.

Tom: For a reprocessing plant, you have concerns about diversion from declared flows and inventories. You also have a concern about undeclared reprocessing. And in an enrichment plant you have the possibility of overproduction of LEU or that somehow you're configuring your plant to produce HEU. In which case the role of DIV has become so critical that it is an essential part, in combination with inspections, that you see it as part of the ongoing activity for verification.

Shirley – Certainly, it always is ongoing discussion about what do you do – inspector need for access, and operator need for confidentiality. I think in the reprocessing plant you have a little more advantage – to make changes to your highly radioactive areas in closed cells is a bit more challenging to the operator – they still could do it but its more challenging. In an enrichment plant, if they want to reconfigure, it's not as difficult. You don't have inspectors in there.

Tom: some are easier than others, yes? For some, from the control room, you push the button.

Shirley: so yeah, it's an ongoing discussion and will be for a long time.

Tom: I want to know, from the point of the maintenance, the accountancy system requires care and feeding. Yusuke, if you could talk for a moment what's necessary to keep a laboratory going? People, equipment, a new plant there are always initial failures and disappointments, and requirements for correcting things as you go along, but over time, a laboratory, how do you make certain that you're going to be there with the performance that's needed.

Yusuke: This is kind of a problem of uncertainty, of the weight itself. You have to consider the quality of measurement from the point of especially in the accountancy measurement. Nuclear accountancy is an area in which we have to consider quality so much. Especially the measurement system needs the characterization first, very accurate first of all and for characterization you need reference material for the characterization – so you can trust the reference material, but it also has uncertainty. So everybody has to understand where uncertainty exists. Experts should know, you can buy this measurement equipment and trust it. But this doesn't work in the analytical world of nuclear accountancy. So what we are using is reliable reference material…

8. SAFEGUARDS HUMAN RESOURCE SHORTAGE

Tom: let's turn for a moment – an analyst that's going to work at your laboratory. Where does this person come from? What does it take for them to be producing results that you satisfied with. And after that please talk about the safeguards laboratory and the analytical network.

Yusuke: Not only the facility and laboratory program, but also the SAL – we need alot of people that have to be educated before coming here, but also nuclear itself has a problem about human resources, so destructive analysis is getting much smaller number of people in this area so we have to find the people that have the capability and the knowledge in this – we have to train them in the laboratory. Normally reprocessing plants should have 100 people in the laboratory – destructive analysis needs are reducing because changing this measurement to NDA – of course it's a nice on one aspect, but on the other hand, there are fewer capable people in the DA.

Erwin – you were speaking about two things - on the one side you said, facility laboratory – your idea would be that you recruit somebody, they start in the process control laboratory and later on move to the accountancy lab with the higher requirements for measurement quality but then you were talking about reduction of samples and this reduction – is this about the IAEA? Yes. I would support this, because I have observed over the last years that the number of samples which are taken for DA by the IAEA is number going down too much…

Yusuke – let me return to QA again – not only characterization, but we have to do the duplicated measurement – this is part of the quality. This is the QC – known sample and the operator is giving a sample of unknown and the operator has to measure it and we compare the operator results to the known sample characteristics to see what their performance is. This is part of quality assurance. In addition, there are some samples provided by the reference material laboratory – if you can get the sample then you can get…

TOM: a number of laboratories analyze the sample in a round robin…

Yusuke – yes – you can find your performance, sometimes you are low, sometimes high. Some other times you can use a different technology, this is another QA technique. This is a complicated world, but our type of guys has to understand it.

9. FUTURE CHALLENGES AND FUNDING REQUIREMENTS FOR SAFEGUARDS

Tom – I'm going now to take us to the realm of where are the remaining challenges in safeguards? We talked about some of the issues associated with spikes, with He-3, but in terms of the industry, let's talk a little bit about where things stand today and what mechanisms are available and being pursued to improve, and then I'd like to open up a little speculation on a **fissile material cutoff treaty** which could have a dramatic impact on the application of this nuclear materials accountancy to different type of undertaking. So, Erwin, you're the master of knowing all things about what happens in facilities. What problems would you estimate would happen in uranium and plutonium work – there's very little movement in the plutonium fuels area – one country is pursuing with great vigor (that's subject to IAEA safeguards, and others that are not).

Erwin: I'm looking at the accountancy measurement systems and I would say that the final analytical measurements are not the problems – I think the measurement technology has developed to a point where these measurements are to a very high level of precision and accuracy if you apply the right procedures and quality control to it. In enrichment facilities, as far as establishing amounts of material is concerned, certainly the measurement of the depleted uranium is a problem – the tails – yes – because the tails are collected in these huge cylinders and there's no way to homogenize the contents of these cylinders and there are variations in the tails, this tails are filling and they deposit and you have layers, and the tank where the cylinder is full – you pull a sample from the gas phase, and you'll get a result representative of the last period before when this was filled. Uranium fuel fabrication facilities, we touched on it earlier, they're the biggest problem because if the scrap and other heterogeneous material inventory is large, then again they're obtaining representative samples for the scrap, and especially for U235 enrichment it's a problem I think. Reprocessing, analytical measurements were touched upon, IDMS it's 1%, but again sampling uncertainties automatic sampling systems, with huge tanks, with material transported using airlift methods – the sample itself is affected by the airlift. The sample will have higher concentration than the tank due to the airlift method. Is it .1%, .2% its very difficult to determine, and I don't know if this is reproducible.

Shirley – there is some work done in that area. Identification of these.

Erwin – when the product of a reprocessing plant will be 1:1 MOX as we see in facilities I think there again the question is how homogeneous is this 1:1 product – and this is where Howard has an advantage – he looks at a 1:1 MOX canister and doesn't have sampling error – he looks at the entire item. So finally – MOX fuel fabrication there the problem again may be sampling errors on the product pellets – these are produced by oxide blending, and there is never perfect homogeneity for a pellet lot, in element concentration – there will always be uranium and plutonium concentration variance from pellet to pellet, and how much is it? You know we can measure at the end with .1% using IDMS on Pu concentration but the sampling error might be 1% if you take one sample or pellet.

Tom: to Howard – where do you see the greatest challenges now in NDA applications?

Howard: there are new material forms and combinations that are a challenge

Tom – so the fuel cycle evolving.

Howard – the fuel cycle evolving, isotopes are changing. You get potential interferences, the accuracy will always be a challenge – whatever you can do, both NDA and DA accuracy there's a challenge to do better. The control of nuclear material might want to be at a level that's beyond what might be currently possible, so accuracy will always be a challenge. In the NDA world, as you get more unattended continuous operation in the data flow coming in to IAEA is increasing by orders of magnitude, so how do you make sense of the data and pull out the safeguards conclusions will be a challenge, and that is a challenge I have on my mind is training and bringing in new staff, to replace some of the older staff, who might be in this crowd, so the mentoring and training is a challenge.

Tom: so we have no end in sight, and even without change the challenges will remain, and changes will come about. In an earlier speech, the present Deputy Director General of the IAEA Department of Safeguards Olli Heinonen, mentioned that the traditional safeguards – the nuclear material accountancy – had advanced to the point that states that have contemplated proliferation haven't seriously considered diverting from declared facilities. That the chances of getting caught are simply too great. So they establish clandestine activities, which is again a success story for this particular area. As we prepare to conclude our discussions for today, I would like to turn us now for the prospects for FMCT. The CD [Conference on Disarmament] is moving again – they have established a work plan, negotiations are likely to commence in early 2010. Its impossible to say how long it would take to conclude a treaty or what its provisions would be, but the principle targets for this are nine countries that currently possess nuclear weapons, that have been tested, many of those have facilities where verification provisions of such a treaty would be applied, and I can only imagine that nuclear material accountancy is going to be one of the fundamental measures in that system as well, in which case the numbers game that we talked about will suddenly take an enormous boost because while there are a very few countries that are doing reprocessing that are under IAEA safeguards now, the numbers will increase, or its safe to assume that verification is going to be essential and that NMA is going to once again be the fundamental measure of safeguards mechanism used in that verification system.

Shirley – maybe I can talk a little bit since I have been doing some work in it. There's going to be a lot the agency is going to have to do just in the "what is the criteria going to be for these facilities? Does the current criteria apply in NWS?"

Tom – I think that'll be part of the negotiation?

Shirley – is an SQ of material - is kgs of Pu - an SQ ? Is that relevant to a NWS? Is the timeliness of one month - does that make sense for a NWS? And so that, when looking at a verification requirement, is going to have a big impact. Then you've got a lot of old facilities, hopefully most of those are going to be shut down, but some may go on to be used for commercial purposes. Retrofitting safeguards systems into old facilities will be a real challenge. Taking samples… What you just mentioned – what will the resource requirements be even as my proposals in my papers have been to go to a more random, short notice inspection regime – with unattended systems (robust unattended systems) – its' still nine countries that have a lot of facilities – that's a lot of human resources, and where's the funding coming from for that?

Tom – the big question you just asked is where is the money going to come from? Given there's no guarantee there's going to be a treaty at all, or that it will be firmly set what the actual requirements are until the window is completing this particular drafting, and the treaty is opened for signatures then.

Howard: is that when? I heard there's going to be a transparency issue – in that if you were in a FMC regime, you could not really have part of the activity that is hidden and part that is open. The entire nuclear activity has to be available to the treaty or there's no point to the treaty, so transparency is a big hurdle.

Tom – you're correct, that in a way that's similar to the nonproliferation situation, you're concerned with verified declared quantities and providing assurance that nothing else is going on. In a state where a lot has gone on in the past, where nuclear weapons already exist, and inventories of material which are never going to be subject to verification until the arms reductions take place, then that further complicates that situation. Yusuke, you had a point…

Yusuke: Of course, these are already nuclear weapons countries, we may not have to take care so much in Japan, but this is a challenge for the NPT – an equality issue. Equality - we are asking for equality all the time – because of this complaint. A good chance for transparency – not only for the … checking, but also the counting facilities.

Tom: Now it turns out that Japan has borne the brunt of the safeguards effort, because its chosen to have this very extensive nuclear industry, but under a cutoff treaty, Japan becomes the teacher to effect, having an impact on what gets done at the other facilities. I'm going to now start to have some final remarks. I would go over to Takeshi first.

12. CLOSING STATEMENTS

Takeshi: Currently, some states' NMCA system is only for undertaking for IAEA safeguards, however, I work with the IAEA because of nuclear security measures – and these need to be combined with accounting systems. As well as safety. So personally I'm very supportive of this program (for integration of safety, safeguards and security), to implement it to all member states.

Howard: When I started in the NDA activities 42 years ago, I thought to myself, that after about 5 years of development and R&D that most of the problems would be solved, and I could move on and become a university professor somewhere, and 42 years later I see more ahead than in the past and the challenges that I mentioned a little bit ago of – you can't have accuracy that outdoes the requirements and that the amount of material types and the way its deployed keeps increasing, I see a large need to increase in general the ability to do accurate measurements - its just crucial for the nonproliferation regime.

Tom – big need for enhanced cooperation to make sure these challenges can be addressed.

Yusuke – I need to say, the importance of destructive analysis needs to be recognized in the international community, especially the human resource problem and some reference material shortages and problems, we have to find solutions for this. Of course I understand that current technology is already mature, but for the future fuel cycle, we have to think of importance of DA again.

Tom – all of us would second and support that.

Erwin – my comment is very much along the same line. What I have observed along the years, is that the importance of DA, and I'll use the same words, is not being recognized anymore, and we have to stress it as often as we can, that the DA is the basis for NMA (Accountancy) and will remain the basis for NMA. It's for the facility operators because they need to know where the material is, and it's important for the state, it's the state's responsibility to report the inventories to the IAEA, and its important to the IAEA to have a credible verification system in place. If I look back at having been a DA person for more than 30 years, I think we have with DA, achieved a lot, we have in many instances provided a good service to operators in cleaning up their house. Improving the analytical techniques, etc., etc., I think if we look back, we have been successful, but it takes an effort to maintain quality.

Tom: So the challenge is how to assure that the system recognizes that and doesn't start to relax and walk away from that, which would bring it to a condition where it would fail. Inevitably, and particularly to not serve as a basis for subsequent expansion.

Erwin: I also mentioned training – you need to attract young people to be interested in this area – facilities are profit driven, and DA costs money – they have to realize its part of their obligation. What I'm concerned about these days, everyone talks about environmental sampling, detection of undeclared activities, and some – that's one part of strengthened safeguards, system, but the NMA system is still there.

Tom – that's such a fundamental point to make. Clearly as a result in having succeeded in the NMA area, in effect, potential proliferators are driven to doing things outside of it. This is the baseline, it's still the place in which I don't know what percentage of the agency's inspection effort goes into traditional safeguards measures, but I'm certain it's well above 50%, but it receives less attention in the public stage, because of the concerns or great difficulties in detecting undeclared facilities, which will be the subject of another interview.

Shirley: the DDG recently said that maybe future inspection should be done from the office in Vienna-that the inspectors wouldn't be on site, but I for one really hope that doesn't happen. But I think *Horrors* - I don't think anybody at the meeting thought it was a good idea, but I certainly think that because of the resource requirements, that something does need to happen to reduce some of the inspector presence in facilities. And some of this is going to have to be unattended measurement systems that transmit data remotely. And I say over and over again that they've got to be robust, reliable systems. But also as we move in to these large commercial facilities, we have a problem with accountancy systems – we can't meet the requirements of accountancy because of measurement uncertainties, so we have to use process monitoring as a supplement or complement of that system. The problem is that's a qualitative technique and how do we evaluate the qualitative system like that? It's something that one of the committees I'm working on now is looking at – how do we give some credit to process monitoring that yes, we know that this facility is ok. All of this comes down to producing a lot of data. A lot of data and we don't have data systems right now that are handling this – intelligent data systems that can actually do some of the inspector work – at least the pre work.

Tom – and with that I would start to bring us to a close, and to say that the application of NMA is fundamental to safeguards for nonproliferation purposes now, it will remain so in the future, it will become a fundamental part of any FMCT regime, there's a necessity to continue to bring in people, to invest money – there are questions or whether the traditional goals can be met, perhaps the multinational facility ownership and operation arrangement that have been suggested at least change the nature of the situation in which case we're no longer looking at a country that is exclusively in control of a facility. With that I'll bring this session to a close and look forward to the next one.