Making safeguards education and training more accessible: from the versatile MBA evaluation kits to the Virtual Platform for Safeguards Education and Training (VIPSET)

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Abstract

The demand for education and training (E&T) in nuclear safeguards is increasing in the past years in order to prepare the next generation of safeguards practitioners and to raise awareness of safeguards topics in the broad nuclear community. Several actions were carried out at international level to develop training courses and workshops both to cover a general introduction to nuclear safeguards, as well as to deepen knowledge on specific themes. One of the remarks often encountered in participants feedback is the importance of using real case scenarios and hands-on sessions during the E&T process.

Only a few nuclear facilities worldwide are offering a long-standing E&T offer in nuclear safeguards, and in addition access to nuclear material is not straightforward given the safety and security regulations in place. In the past year, the global pandemic caused by the Covid-19 virus added new difficulties to in-person E&T activities due to travel restrictions and health measures.

In the recent years PNNL developed a versatile transportable hands-on training kit for Material Balance Area (MBA) evaluation exercises using non-expensive and non-radioactive materials. The kit has been used several times to train national inspectors around the world and covers both bulk-handling and item-handling facilities. In order to offer an alternative to in-person training SCK CEN started to develop VIPSET: the Virtual Platform for Safeguards Education and Training. The first virtual case study on how to apply safeguards in bulk-handling facility has been developed in VIPSET and leveraged and expanded on the PNNL kit. The participant can complete the exercise via computer by downloading the stand-alone software or by accessing a browser-based version. This paper will present the available training case studies and discuss the possible extensions of VIPSET to cover other nuclear facilities and safeguards topics.

1 Introduction

The implementation of nuclear safeguards is one of the main instruments to avoid the spread of nuclear material and nuclear technology to the development of nuclear weapons. High-quality and sustained education and training (E&T) actions are needed to ensure a broad base of well-educated professionals with knowledge of nuclear safeguards. Such trained community can serve as a pool for safeguards inspectors and/or non-proliferation policy makers. The importance of education and training (E&T) and knowledge management both in the nuclear and in the scientific fields at large was stressed by several international institutions (IAEA, 2013), (JRC, 2014), (Hancock, 2015).

From the European side, a cornerstone in the safeguards E&T offer is represented by the ESARDA course on Nuclear Safeguards and Non-Proliferation, organized yearly since 2005 by JRC in Ispra (JRC, 2021). The ESARDA course features an intensive five-day schedule with lectures in the morning and technical visits to different JRC laboratories and practical sessions in the afternoon. Due to the Covid-19 pandemic situation the ESARDA course was cancelled in 2020, whereas it was offered fully online in 2021. In addition to the ESARDA course, a two-week safeguards course and four thematical workshops were organized in 2019-2020 in the frame of the "Advanced Networking for Nuclear Education, Training and Transfer of Expertise" (ANNETTE) Horizon2020 project funded by the European Commission (Rossa, 2018).

From the US side, examples of safeguards E&T are given by the US Government through the International Nuclear Safeguards Engagement Program (INSEP) out of the National Nuclear Security Administration's (NNSA) Office of International Nuclear Safeguards (INSEP, 2021). INSEP has engagements primarily focused on working with over 40 partner countries to help build their capacity to account for and declare nuclear materials and activities to the International Atomic Energy Agency (IAEA) in accordance with their international safeguards obligations. The primary focus is on engagement with State nuclear regulatory authorities. One method includes offering workshops and training events covering a broad range of topics related to international safeguards. One of these courses covers the conduct of national inspections (CNI) at both fundamental and advanced levels.

One of the remarks often encountered in participants feedback from safeguards courses is the importance of using real case scenarios and hands-on sessions during the E&T process. However, access to nuclear material is not straightforward given the safety and security regulations in place. In the past year the global pandemic caused by the Covid-19 virus added new difficulties to in-person E&T activities due to travel restrictions and health measures.

This paper describes two examples of versatile kits that can offer practical examples and hands-on sessions for future safeguards E&T activities. Both kits do not require nuclear material; the first kit can be used for in-person training whereas the second kit can be used for e-learning. Section 2 describes the versatile transportable kits developed by PNNL using non-expensive and non-radioactive materials, whereas Section 3 describes the Virtual Platform for Safeguards Education and Training (VIPSET) virtual reality (VR) tool developed by SCK CEN. Section 4 finally offers the conclusion and the outlook on future developments for safeguards E&T.

2 Physical kits

2.1 Motivation

After the co-author's participation in CNI training as an instructor, and based on past experience as an IAEA inspector, it became clear that hands-on exercises could greatly benefit the participants. We know that as opposed to passive listening, a hands-on approach is a more effective way to approach soft skills training, by giving participants the opportunity to not only learn but to apply and practice new skills in a safe environment. Instead of passively listening to a presentation that they may quickly forget, participants take an active role in their learning, which will increase retention and offer a practical approach to problem solving and critical thinking.

A hands-on method will teach participants specific skills including:

1. Establishing roles: leader and activity-based assignments for a team

2. Conducting entry and exit briefings with an operator
3. Accounting reconciliation
4. Assessing containment/surveillance status
5. Generating statistical sampling plans
6. Verification of nuclear material
7. Detecting and resolving discrepancies
8. Becoming an effective and efficient team.

2.2 Development of the physical kits

Determining how to teach about conducting nuclear material inspections using a hands-on approach led to the realization that an exercise using a Material Balance Area (MBA) kit does not require nuclear material or access to a real facility and could be easily duplicated with simple low-cost but highly effective material that could be purchased commercially, with the main challenge being to develop extensive documentation to cover all of the areas noted above. Above all, these kits need to be easily transportable. The final product was accomplished over a period of one year covering both Bulk-handling facility MBA Kits (related to facilities that process nuclear material in bulk form such as a fuel fabrication facility) and Item-handling facility MBA Kits (related to nuclear material in facilities that do not process nuclear materials such as a light water reactor). Each kit costs ~$1000 USD and fits in a rugged Pelican case for transport. Regarding location, the training area only needs to supply tabletop space and power supplies.

The intent of the bulk-handling facility MBA Kit, or “Bulk Kit”, exercise is to demonstrate the partitioning of a bulk-handling facility’s inventory into separate feed and product MBAs for accounting purposes, and to conduct a physical inventory verification on these MBAs. The Bulk Kit contains 25 feed and 25 product inventory cans, training scenarios, and mock operator and IAEA safeguards documentation. The cans are filled with marbles and beads, which represent nuclear materials. The cans are sealed with tamper-evident security tape with unique identifying numbers, representing IAEA tamper indicating devices (TIDs). Several of the inventory items have intentional defects. These defects are meant to be detected during the exercise but can be removed from the kit by the instructor if the goal of the exercise is changed. The exercises also include several discrepancies between what is documented in the simulated ledger and what is observed during the physical inventory verification; for example, one feed and one product can are not in the declared locations. Again, such discrepancies can be removed by simply changing the inventory database. Supporting documentation includes: two grids, labeled to simulate the feed MBA and product MBA locations (see Figure 1); a random statistical sampling spreadsheet; a seal’s database; appropriate facility source documents; an electronic balance; balance calibration weight; and mock inspector documents.

The item-handling facility MBA Kit, or “Reactor Kit”, supports demonstrations of various safeguards activities at item-handling facilities, including active fuel length measurements and physical inventory verification (PIV). The Reactor Kit consists of 20 mock fuel assemblies made of a polyvinyl chloride (PVC) pipe with a shorter wooden dowel centered inside. The wooden dowel is representative of the active fuel length or uranium within the “fuel rod.” Plastic dividers are used to hold the assemblies vertically in an array to simulate fresh fuel storage, core fuel, and spent fuel storage (see Figure 1). The user can determine the history of each mock assembly’s location with the operator’s fuel index history card. Some of the mock fuel assemblies have intentional defects. Participants can use a readily available commercial stud finder (capacitance/density changes) sensor (representing a handheld radiation detector) for active length measurements of selected mock fuel rod(s) and attempt to reconcile any differences using source documentation from the supplier. A general ledger database for the reactor assemblies is also included, along with inventory change reports, material balance reports, and physical inventory listings, using fixed format Code 10 accounting reports, to support user-defined PIV demonstrations.

As mentioned earlier, both kits have extensive documentation covering shipments, receipts, current inventory, ledger of all nuclear material including mass, storage location, and form. Also provided are the documents needed by the IAEA including seals database (adhesive seals, also known as a tamper indicating device, applied to bulk kit cans), State report on inventory, statistical sampling calculation spreadsheet with random number generator, verification measurement form including measurement control, discrepancy form, and final conclusions.

The MBA Bulk and Reactor kits have been used domestically and internationally to train partners in the basic principles of nuclear material accounting and control and common methods and techniques that national and international inspectors use to verify operator declarations.

Figure 1: Pictures of the Physical Kits developed for Bulk Facilities (left side) and for Item Facilities (right side).

2.3 Use of the physical kits

Participants begin the MBA Bulk kit exercise with an introduction to the facility scenario and typical activities conducted by the IAEA during a PIV at bulk facilities. The premise of the exercise is the reduction of a hypothetical country's stockpile of plutonium metal to mixed oxide fuel for its light water reactors. The conversion of metal to oxide takes place at the hypothetical conversion facility that receives the metal and ships the oxide. In the scenario, the conversion facility has just completed its physical inventory taking (PIT). All process lines have been cleaned out, and all plutonium remains in inventory cans in the Feed MBA and Product MBA. A receipt of two feed cans arrived after the State's reporting period to the IAEA. Training scenarios introduce participants to the typical activities conducted by the IAEA during a PIV at a bulk facility, including comparing records and reports, nuclear material accounting, inventory reconciliation, statistical sampling, measurement calibration, item selection, item measurement, TID inspection, and discrepancy identification and reconciliation. The exercise can be adjusted based on participant need; for example, the instructor can remove all ledger defects and provide a corrected ledger.

Where the MBA Bulk kit introduces users to activities at bulk-handling facilities, the MBA Reactor kit supports demonstrations of various IAEA safeguards activities at item-handling facilities. For this exercise scenario, besides the accountancy and statistical sampling calculations as in the Bulk kit, all participants are IAEA, national inspectors, or operators conducting an active length verification measurement activity at the hypothetical Unit 1 research reactor. Participants apply the stud sensor for active fuel length measurements of the randomly selected mock fuel rod(s); participants then take the determined length and reconcile this measurement with the active length declared by the operator using source documentation from the fuel fabricator. A general ledger database for the reactor assemblies will be provided, along with a set of inventory change reports, material balance reports, and physical inventory listings, using fixed format Code 10 (IAEA based) accounting reports, to support user-defined PIV demonstrations.

For each kit, a team leader is selected/assigned, as are the other team members, to reconcile the books against the physical inventory, check seals, calculate statistical sampling size, verify selected item, find and resolve discrepancies or freeze them if they cannot be resolved and overall learn to work as an efficient and effective team, providing an immersive and educational inspection experience.

3 VIPSET VR tool

3.1 Motivation

The VIPSET VR tool has been developed leveraging and expanding the idea from the physical kits developed within INSEP. Given the safety and security restrictions for access to nuclear material, and the additional limitations enforced due to the Covid-19 pandemic, SCK CEN developed VIPSET with the objective of providing an extremely versatile tool for education and training.

The VIPSET VR tool has the aim of reaching the same E&T goals of the physical kits but using VR instead of direct hands-on experience in a location. In this way the travel limitations imposed by the current Covid-19 pandemic can be avoided and training courses can still be offered online. Moreover, due to the flexibility of the online format, the VIPSET VR tool may be used as periodic refresher course also in case of regular travel options.

3.2 Development of VIPSET

The VIPSET bulk-handling facility has been built using the Unity game engine (Unity, 2021). The Unity engine is well-known for game development and has been used for developing games such as Pokémon Go and Call of Duty: Mobile. (Bradshaw, 2020)

The VIPSET VR tool can be accessed either as a stand-alone software to be downloaded or by accessing a browser-based version. A set of documents containing e.g. user guide, official declarations to IAEA, forms for inspection, is also given in virtual format to the participants ahead of the training. In fact, the participants need only a 64-bit computer (with internet connection in case of the browser-based application) to use the VIPSET VR tool.

The choice of keeping the graphic design to a minimum was taken to ensure the broadest accessibility to the software using even low-end computer systems, without the need of specific equipment (e.g. VR goggles). Thanks to this choice the participants focus only on the safeguards tasks and are not distracted by other effects. An improvement of the graphic design to resemble a real-life nuclear facility may be included in a future version of VIPSET.

3.3 Capabilities of VIPSET

3.3.1 Background information

The VIPSET bulk-handling facility represents a facility that converts nuclear material from metallic high-enriched uranium (HEU) to low-enriched uranium (LEU) in oxide form. All nuclear material in the VIPSET facility is stored in two MBAs. One MBA (WFEED) contains the feed cylinders with the HEU metal, and one

MBA (WPROD) contains the product cylinders with the LEU oxide obtained at the end of the process. Each MBA contains more than one significant quantity of nuclear material in the respective form. Figure 2 shows a view of the two MBAs in the VIPSET VR tool.

The VIPSET VR tool shows the two MBAs with the cylinders to be verified and the equipment available for verification. The cylinders included in the VR tool and in the exercise, documents are only a subset (25 cylinders in WFEED and 25 cylinders in WPROD) of the inventory present at the VIPSET bulk-handling facility (100 cylinders in WFEED and 750 cylinders in WPROD). Some of the cylinders in the VIPSET facility have been modified to reproduce gross, partial, and bias defects. In addition, some seals have been tampered with.

The participant can move around the VIPSET facility by using keyboard keys, controlling both position and camera point of view. The cylinders containing the nuclear material can be moved by drag-and-drop with the mouse or touchpad of a laptop computer. When hovering the mouse cursor over a cylinder, the corresponding cylinder label is displayed. The cylinder label shows the cylinder ID, gross weight, tare weight, net weight, and chemical form of the nuclear material contained in the cylinder.

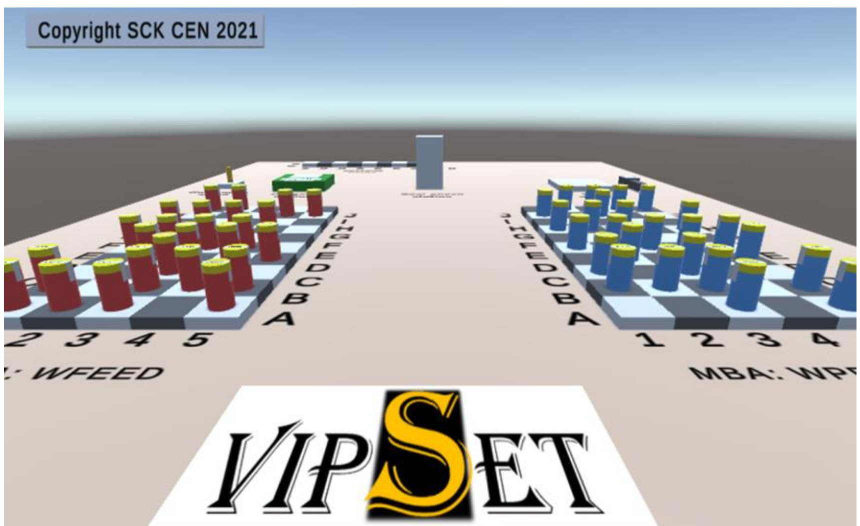

Figure 2: Screenshot of the VIPSET VR tool.

3.3.2 Documentation in support to the VIPSET VR tool

The VIPSET VR tool is provided with a set of documents that are needed for the training exercises. In order to conduct the training exercises the following documents are provided to the participants from the beginning:

- Exercise guide
- VIPSET book inventory form
- State report – VIPSET physical inventory listing
- State report – VIPSET inventory change report
- Random statistical sampling
- Inspector measurement form
- Inspection report

During the exercises the participants may use these additional documents:

- Shipping document form
- VIPSET record of weighing form
- VIPSET shipper receiver difference form

Some of the documents contain clerical errors and typos to include real case issues encountered during a safeguards verification in a facility.

3.3.3 Available equipment for verification

The VIPSET facility has one electronic balance that is used for weight measurements. In addition to the cylinders in the two MBAs, one certified weight is available for calibration of the instrument. To perform a weight measurement the user must place a cylinder on the measuring plate and the weight of the cylinder will automatically appear on the balance screen. Measurement of more than one cylinder at the same time is allowed and the balance shows the combined weight of the cylinders.

In addition, a gamma-ray detector similar to the HM-5 (IAEA, 2011) is available for the dose rate measurement of the cylinders. To perform a measurement the participant should first place the cylinder to be verified on the stand marked as “NDA station”. Then move the detector close to the cylinder by using the same instructions used to move a cylinder. The dose-rate measurement is immediate and keeping the detector at a fixed distance to the cylinder ensures a stable reading. Measurement of more than one cylinder at the same time is possible but strongly discouraged. The dose rate value displayed on the HM-5 detector screen is calculated according to the point source approximation. The expression used for the dose rate calculation is intended to give an approximate value and it must not be taken as representative of realistic scenarios. Effects such as source self-shielding and detector efficiency are not taken into account.

3.3.4 Available exercises

The proposed exercises simulate an IAEA Physical Inventory Verification (PIV) of the VIPSET bulk-handling facility. The content of the cylinders stored in the two MBAs must be statistically verified to meet the safeguards commitments. The following exercises are available and described in the exercise guide:

- *Verification of reporting*. The objective is to compare the IAEA’s Physical Inventory Listing with the Operator’s Inventory Form and with the inventory in the VIPSET software.
- *Statistical sampling*. The objective is to calculate the number of items to be verified for each MBA and to provide the list of cylinders that will be verified with measurements.
- *Measurements*. The objective is to carry out three exercises for each cylinder selected during the statistical sampling exercise. The declared gross weight is verified using the electronic balance, the integrity of the seal is visually checked, and the radiation emission is measured with the gamma-ray detector.
- *Reconciliation with the operator*. The objective is to summarize all issues encountered during the previous exercises and propose corrective actions to solve the issues with the operator.

Figure 3 shows screenshots from the measurement exercises with one cylinder placed on the weighing scale and another one being measured with the gamma-ray detector.

Figure 3: Screenshots of measurement exercises available in the VIPSET VR tool. The picture on the left depicts a weigh measurement whereas the picture on the right a radiation measurement.

4 Conclusion

Versatile and easy-to-use kits have been developed for education and training in nuclear safeguards, given the safety and security limitation on access to nuclear facilities and nuclear material and the travel restrictions due to the Covid-19 pandemic.

The physical kits developed within INSEP uses inexpensive and non-radioactive materials and can be used for in-person training courses for both item- and bulk-handling facilities. The virtual kit developed by SCK CEN uses VR to replicate the safeguards inspection in a bulk-handling facility. Both physical and virtual kits are associated with supporting documents and can be used as backbone of safeguards training courses. The physical kits have been already used in several training courses of national inspectors whereas the training course for VIPSET is still under development.

Future additional developments in the training kits include the extensions of VIPSET to cover other nuclear facilities and safeguards topics, such as the inspection of an item-handling facility. The detail level of the virtual facility can be improved to offer a real-life experience during the training course.

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