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ABSTRACT

A critical aspect of international safeguards activities performed by the International Atomic Energy Agency (IAEA) is the verification that facility design and construction (including upgrades and modifications) do not create opportunities for nuclear proliferation. These Design Information Verification activities require that IAEA inspectors compare current and past information about the facility to verify the operator's declaration of proper use. The actual practice of DIV presents challenges to the inspectors due to the large amount of data generated, concerns about sensitive or proprietary data, the overall complexity of the facility, and the effort required to extract just the safeguards relevant information. Planned and anticipated facilities will (especially in the case of reprocessing plants) be ever larger and increasingly complex, thus exacerbating the challenges. This paper reports the results of a workshop held at the Idaho National Laboratory in March 2009, which considered technologies and methods to address these challenges. The use of 3D Laser Range Finding, Outdoor Visualization System, Gamma-LIDAR, and virtual facility modeling, as well as methods to handle the facility data issues (quantity, sensitivity, and accessibility and portability for the inspector) were presented. The workshop attendees drew conclusions about the use of these techniques with respect to successfully employing them in an operating environment, using a Fuel Conditioning Facility walk-through as a baseline for discussion.

INTRODUCTION

The International Atomic Energy Agency (IAEA) implements nuclear safeguards and verifies that countries are compliant with their international nuclear safeguards agreements, pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). One of the key provisions in the INFCIRC/153 IAEA Model Safeguards Agreement is the requirement for the country to provide nuclear facility design and operating information to the IAEA, relevant to safeguarding the facility.[1] This provides the opportunity for the IAEA to verify the safeguards relevant features of the facility and to periodically ensure that those features have not changed. The design information is initially conveyed from the facility operator through the national authorities (State System of Accounting for, and Control of Nuclear Material – SSAC) to the IAEA using the completed Design Information Questionnaire (DIQ) and updated as required by written addendum. Design information examination (DIE) of declared information is carried out by IAEA safeguards inspectors to design a safeguards approach for each specific facility. IAEA safeguards inspectors

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also perform a design information verification (DIV) using this information, together with other available information, to confirm that a facility is built and operated as declared.[2]

This report presents the findings from a technical workshop [3] sponsored by the U.S. Department of Energy (DOE), National Nuclear Security Administration (NNSA) Office of International Regimes and Agreements (NA-243), under the Advanced Safeguards Approaches (ASA-100) project, and in support of Institutionalizing Safeguards by Design (ISBD).[4] This project and workshop are also in support of the NNSA Next Generation Safeguards Initiative, specifically to provide enabling technologies for improving nuclear facility design information verification for safeguards.[5] The NNSA sponsored this technical workshop, involving international nuclear safeguards experts within the DOE Complex, as well as foreign safeguards partners in overseas organizations, such as the European Joint Research Centre at Ispra, Italy (JRC/Ispra), to address the status of the DIE/DIV activity and consider how it could be improved.

The purpose of the workshop was to review how nuclear facility design information is currently verified and consider advanced tools and methods that could improve the efficiency and effectiveness of this activity. The focus was first on reviewing the fundamental safeguards need, and secondly to consider appropriate available technology to more efficiently address that need. It has been recognized by NNSA and the U.S. DOE National Laboratories that there is a need to more effectively and efficiently verify that nuclear facilities are as declared, in support of international nuclear safeguards.

CURRENT DIE/DIV SAFEGUARDS NEEDS

The primary objective of the DIE/DIV activity is to verify, from a nuclear safeguards perspective, that the facility is constructed as declared, and has not been changed or modified without notice. Specifically, the DIV activity is to verify that the location, purpose, function, size and capacity for handling, processing, and storing uranium, plutonium and thorium are as declared.

Consequently, there is a need to verify the:

1. Name and location of the facility (To confirm declared facility name and location);
2. External size, dimensions, and manner of facility construction (To confirm the overall size and gauge the capacity of the facility);
3. Size of main process areas and absence of undeclared process space, including basements, sub-basements and pipe trenches (To confirm the overall size of the process, estimate the process capacity, and inspect for concealed process or interconnected areas);
4. Size, number, list, and configuration of essential process equipment, vessels and piping (To confirm the size and process capacity and to better determine nuclear material flow key measurement and other strategic points);
5. Nuclear material flow path, entries and exits, manner of conveyance or transfer, and measurement points (To verify the nuclear material pathway, possible diversion paths, and determine flow key measurement and other strategic points);
6. Nuclear material inventory, hold-up, storage areas, and containment and surveillance features (To verify the features for measuring, storing, containing, and surveilling the nuclear material inventory, and for determining the inventory key measurement points);
7. Installed or planned safeguards instruments, for both the operator and inspector (To verify that the points or containers measured, and associated safeguards data, will meet the needs

for nuclear material accounting for verifying nuclear material inputs, outputs, transfers, waste transfers, hold-up, and inventory. This includes an assessment of the representativeness of sampling, instrument accuracy, measurement frequency, and data collection and transmission security).

According to the IAEA Annual Report for 2007, the IAEA implements safeguards and conducts inspections at 949 nuclear facilities, in both non-nuclear weapon and nuclear weapons states.[6] Of these, we estimate that approximately 30 are currently under construction or are undergoing start-up. The facilities that are subject to regular or routine inspection will normally be subject to one physical inventory verification (PIV) per year, which is typically when the design information is periodically re-verified. It is also important to note that the total number of facilities is constantly growing, and the types of facilities are becoming more complex and strategically important, i.e. potentially handling or processing fissile material such as in uranium enrichment, fuel fabrication, spent fuel reprocessing, and Pu-MOX fuel fabrication plants. Consequently, it takes inspectors with greater knowledge and experience, with applicable training to perform proper DIE/DIV visits at these facilities.

An updated DIQ or addendum to an existing DIQ may require a DIE/DIV visit outside of a scheduled PIV. Life cycle phase changes associated with a facility's pre-construction, construction, commissioning, operating, maintenance or modification, shutdown, close-down and decommissioning require that inspectors evaluate the change and determine viability of an additional visit for verification. Time expended by an IAEA Safeguards Inspector to review and verify a change in life cycle depends largely upon the complexity of the facility and transparency of the SSAC to provide essential information in the working language of the IAEA (English).

Worldwide facility design verification is a challenging aspect of IAEA safeguards that demands programmatic and technical support from the United States. The number and types of DIE/DIV tools available to international nuclear safeguards inspectors are currently limited and need to be further expanded to include user friendly and easily transported systems.

CURRENT DIE/DIV PRACTICES

To verify the above aspects of a facility, the safeguards inspector compares the information in the DIQ with what they find during their inspection. They will look up articles and information on the facility and confirm the location and exterior appearance. At the facility, they will use construction tape-measures, laser distance instruments, and Global Positioning Satellite coordinates to verify that the buildings match the construction drawings and facility plans provided through the SSAC. Inside the facility the inspector will use the same tools, i.e., tape-measures, laser distance tools, and plant drawings, as well as photographs and notes or sketches from previous inspections. Additionally, the IAEA has a limited number of 3-Dimensional Laser Range Finder (3DLR) units (described below) that can produce a digital image of the interior of the facility for comparative purposes. If required, a team of inspectors will perform the inspection, to allow the entire facility to be verified. The inspector also must verify the material flow paths, entry/exit points, and the equipment placed at key measurement points. They must take note of hallways, connected piping and ductwork, and any changes or alterations to the facility relevant to drawing a conclusion about the safeguards of the facility.

The current DIV activities are very labor intensive and dependent upon the individual experience and capabilities of the inspector. Tools that would assist the inspector in managing the complex facility information, improve their ability to extract the safeguards relevant data, and speed up or automate the data collection and analysis would greatly improve the DIV capability of the IAEA inspectors.

MODERN TOOLS FOR DIE/DIV

Modern tools that would enhance the capability of IAEA inspectors to perform DIV inspections were presented at the workshop. They are described herein.

3-Dimensional Laser Rangefinder [7]

The 3DLR is a laser-based survey tool that has been adapted for use in facility DIV inspections by the safeguards development team at the JRC/Ispra. A rastered laser beam is rotated to produce a spherical emission pattern. The Doppler shift of the reflected beams allows calculation of distance (out to approximately 80 meters), and a 3-D image of the area can thus be produced. The images are processed with software than can detect differences between images that correspond to millimeters of displacement within the facility. Coupled with software that highlights these differences, the 3DLR is very useful for drawing an inspector's attention to changes that warrant closer inspection, as illustrated in Fig. 1. The IAEA currently uses 3DLR in a limited fashion -- most notably, there is a 3DLR unit permanently assigned for use at the Rokkashomura Reprocessing Plant (RRP) in Japan.

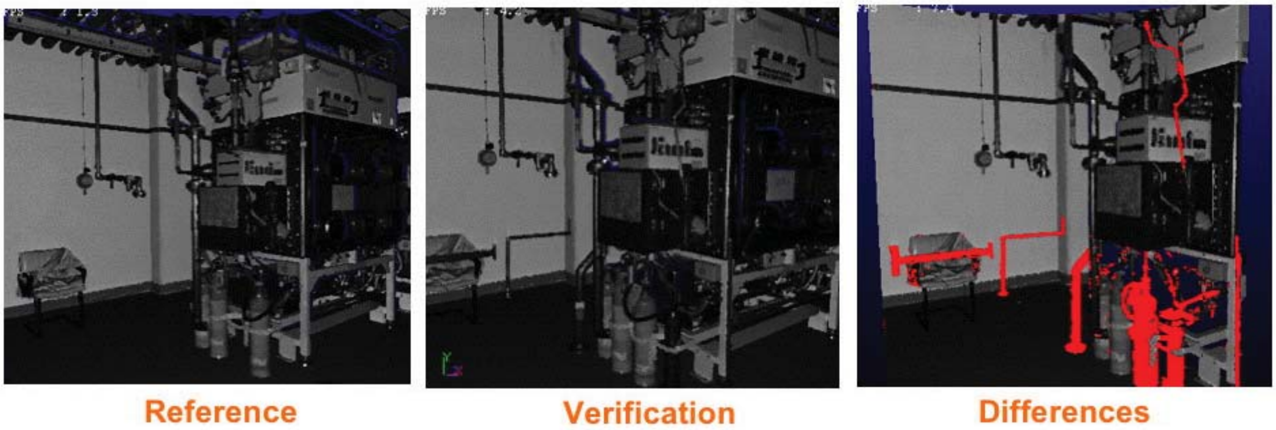

Figure 1. 3DLR Automated Change Scene Detection Feature. The 3DLR has been designed to compare two images and highlight the differences. [Ref. 7]

Compton Gamma Radiation Imaging [8, 9]

The image derived from the 3DLR, while of high utility, can only show what is already visible to the inspector. Inspectors also have the need to ensure that there is not hidden piping or diverted material in undeclared flow pathways. Adding a radiation detection component would enhance the ability to meet this need. A Compton Compact Imager (CCI) has been developed that provides an image with a high spatial resolution showing the location of radiation sources. Coupling the CCI with a 3DLR, shown in Fig. 2, allows the location and intensity of radiation sources to be mapped over the image of the facility. The combined system, referred to as Gamma-LIDAR (Light Detection and Ranging) has been demonstrated in laboratory conditions by locating a source concealed in piping.

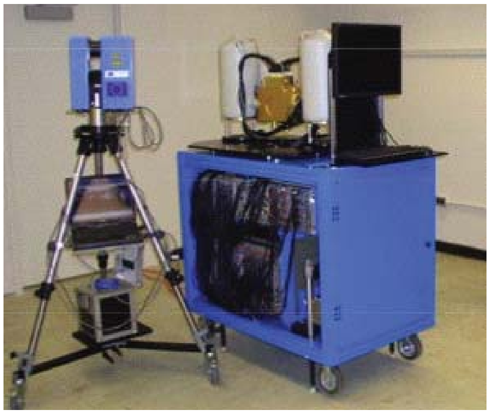

Figure 2. 3DLR modified with Compact Compton Imager. The facility image produced by the 3DLR will be merged with radiation intensity information to verify material presence and flow pathways. [Ref. 8]

Enhanced Ground Penetrating Radar

The workshop team discussed Ground Penetrating Radar (GPR) to detect undeclared or concealed process equipment, material flow paths, or additional underground structures. The IAEA has limited experience with GPR; primarily in countries that have agreed to implementation of the Additional Protocol. Enhanced models that can produce a 3-D image (as opposed to the planar image of earlier models) have become available, and would be of use in the DIV activities to verify the location and size of facilities.

Virtual Reality for Facility Models [10]

One of the most significant challenges an inspector faces when performing DIV is the sheer volume and complexity of the information. They have to take the provided facility diagrams, equipment layout, drawings, and photos and notes from previous inspections and understand the material flow pathways and other safeguards relevant information. Projected virtual reality (VR) offers the ability to integrate this collection of information into a tool that improves the inspector's ability to prepare for and perform the DIV inspection. An example, showing a model of the Fuel Conditioning Facility at the Idaho National Laboratory (INL) (See Fig. 3), was presented at the workshop. The utility of the model for training purposed was demonstrated by a walk through of the VR facility. During the walk through of the actual facility the next day, it was apparent that the workshop participants recognized features they had seen in the VR model. Creating a VR model of a facility allows the creation of a tool that can contain detailed design information that can be registered to the facility location it applies to, allowing training or practice before the inspection and access to the information as needed during the DIV.

Figure 3: Image of the Fuel Conditioning Facility (FCF) Virtual Model. [Ref. 9]

Change Detection System [11]

A common element of DIV is to compare images of the facility with those from previous inspections. In practice, this often involves photographic prints that the inspector must visually (and manually) compare with current photographs. A Change Detection System (CDS) has been developed that can rapidly and effectively compare any two digital images. The complexity of the picture (of, for example, the extensive piping and an enrichment facility) is reduced by software alignment to just the differences between the two images. Scanning old photographs into a digital format and using digital cameras to collect future images would allow CDS to be put to use quickly and easily to enhance the DIV capability of inspectors.

Robotics [12]

Advances in robotics and human machine interaction have advanced the ability for robots and people to work as members of a team. The robot can enter areas the person cannot (i.e. high radiation fields or contaminated areas), while better control interfaces make it very realistic for non-experts to improve their performance by using a robot. Robots have been successfully employed in other fields to map areas and carry sensors. Robots deployed for DIV activities could produce facility maps to compare against declarations, both inside and outside the facility.

Outdoor Verification System [13]

An inspector must also verify the outside of a facility to see if undeclared capacity has been constructed and to determine whether nearby buildings are functionally linked. The JRC/Ispra has developed the Overhead Verification System, which operates similarly to the 3DLR, but effective to a greater range and designed to be mounted atop a vehicle. A 3-D image is produced that can give the inspector the ability to pan and zoom as needed to perform their DIV inspection.

SUMMARY OF WORKSHOP FINDINGS

From the panel discussion, the workshop team noted the following major findings:

1. IAEA inspectors continue to perform DIV using primarily hand-tools, blueprints, and visual observation. Modern techniques exist to dramatically improve the DIV activity.

2. The 3-Dimensional Laser Range Finder (3DLR), developed by JRC/Ispra and used by the IAEA, is one such modern tool for performing DIV, as demonstrated at the Rokkashomura Reprocessing Plant from 2002 to 2006.
3. Broader use of the 3DLR at the IAEA appears to be limited, for lack of additional instruments and inspector training in use of the instrument. (The IAEA possesses only three 3DLR units of the older original Mark-I design, one of which is permanently resident at the RRP Site in Northern Japan. The workshop team estimates that of the approximately 250 designated inspectors at the IAEA, only about 40 have been trained in the use of this instrument, and of those perhaps only 30 remain at the IAEA.)
4. DOE/NNSA should encourage broader use of the 3DLR by the IAEA, especially in Japan, where a resident instrument is pre-positioned.
5. Other technologies show promise for improving the effectiveness and efficiency of performing DIV.
6. The Outdoor Verification System (OVS), developed by JRC/Ispra, is a mobile variant of the 3DLR. It permits the computerized mapping and verification of entire nuclear sites from the platform of a Jeep or other vehicle. The OVS provides detailed three dimensional mapping at a very local level that shows trenches, burial grounds, and connective features between nuclear facilities on a site. It would address the need for verifying design information at the broader site-level.
7. The OVS shows promise for verifying complete nuclear sites, such as the uranium enrichment plant site in Natanz, Iran, and the Yongbyon research reactor and radiochemical laboratory site in North Korea.
8. Researchers at LLNL, LBNL, and ORNL have demonstrated that a gamma camera can be combined with the 3DLR to address the need to detect undeclared piping and vessels containing gamma emitting nuclear material. This instrument could potentially be further developed to detect the presence of highly-enriched uranium (HEU) in nuclear facilities.
9. PNNL has demonstrated enhanced ground penetrating radar (GPR) to visualize buried objects in three dimensions, which could address the safeguards need to detect buried or concealed process vessels and/or piping during DIV.
10. LANL, INL, and ORNL have demonstrated virtual reality software tools to address the need for portable facility reference models for use during DIV. Such tools could also be used for facility specific pre-inspection briefing and inspection training.
11. INL has demonstrated CDS for planar images that can be used with scanned images of older existing Polaroid photos and other design information to detect changes on a laptop, after taking a digital photograph of the current installation. This technology would allow a more systematic review by the inspector during DIV, especially where only older reference photos are available.
12. Future developments in support of DIV should consider a heads-up viewer and display that would access a portable computer with reference DIV information on demand. The heads-up viewer and display would be able to recognize existing features and automatically compare against the reference images in the computer. Changes would be noted in the viewer, with the highlighting of safeguards relevant changes.
13. Model responses to the IAEA design information questionnaire (DIQ) have not been revised since 1978. DOE previously provided these model DIQ responses through the U.S. Support Program to the IAEA to aid others in the proper completion of the DIQ. NNSA should consider updating these model DIQ responses, by facility type.

CONCLUSIONS AND RECOMMENDATIONS

At the Workshop on DIE/DIV for Nuclear Safeguards, the Team came to the following conclusions:

1. The DIE/DIV process as currently conducted by the IAEA offers many opportunities for improvement in both efficiency and effectiveness. As emphasized by former IAEA inspectors in the workshop, this activity is lacking in automation and relies heavily on individual inspector knowledge and experience.
2. The greatest needs of IAEA inspectors in conducting DIE/DIV are:
    a. Increasing an understanding of the facility design and operation, especially the technology in the facility that is safeguards-relevant,
    b. Providing the ability for inspectors to have reference materials on hand during inspection, instead of the current practice wherein the reference materials are often locked away from the inspection location,
    c. Demonstrating an ability to extract safeguards-relevant data from changes in the facility, such that manpower is not wasted on non-relevant facility alterations
3. Prospective technology or tools in support of DIE/DIV should be judged on the following proposed criteria:
    a. Can the technology be used in existing facilities with existing facility attachments?
    b. What is the "Technology Readiness Level" of the technology for deployment?
    c. Does the technology or tool address IAEA DIE/DIV needs?
    d. For which facility type or application is the technology or tool needed?
    e. When is the technology or tool needed? - i.e., is the need urgent?
    f. What will the technology or tool cost, including equipment purchase, training, and maintenance or replacement?
4. Many of the technologies and tools presented at the workshop on DIE/DIV for safeguards would address identified IAEA needs in support of the DIE/DIV. The Team recommends that DOE/NNSA engage in active dialog with the IAEA to confirm their needs in support of DIE/DIV, and continue to support the development and demonstration of the tools and technology recommended.
5. Workshop participants saw possibilities for combinations of the presented technology, as they are often mutually supportive. The 3DLR can generate the data required for quickly creating VR training simulations, including hot spots (gamma-camera) in a facility or locating material in an area designated to be cold by the operator. Individual items (such as the pipe leading into a hot cell with pure product) can be highlighted as "safeguards relevant" in the VR SIM on a laptop carried by the inspector, with each item having an intractable folder that shows the picture history of the component for CDS.

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