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MODERN SAFEGUARDS TOOLS FOR EFFICIENT AND EFFECTIVE DESIGN INFORMATION VERIFICATION

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Abstract

Design Information Verification (DIV) is becoming increasingly important in International Safeguards as a way of verifying that facility set-up is consistent with the declared design and activities. This is particularly true for the complex environments of new nuclear installations. Member States Support Programmes (MSSPs) enabled the IAEA to develop and obtain a set of advanced tools designed to improve the efficiency and the effectiveness of DIV activities. This paper provides a comprehensive overview of these advanced tools based on laser, radar, X-ray fluorescence and infrared imaging technologies and their potential for being applied to containment- and other verification activities.

Introduction

By performing design information verification (DIV) the IAEA probes the completeness and correctness of the design information provided by operators of nuclear installations as part of their obligations under the Safeguards treaties. The verification has the aim to discover possible undeclared activities and material. To this end, critical locations and process steps of the plant have to be identified and checked.

Mostly, DIV have been performed by using blueprints and visual observation, complemented by simple hand-held instruments. A more sophisticated approach is getting important after the coming in force of additional protocols and integrated safeguards.

In this paper we will present some specific tools for DIV that were selected and authorized for Safeguards use in the last few years. Typically, these make use of techniques developed in other fields, like the broad range of geophysical methods, or of recent advances of instrumentation and sensors, like laser technologies. Tried and true technologies become portable tools due to miniaturisation of electronic components and affordable through economies of scale, like infra red imaging. Specifically, we will briefly discuss portable X-ray fluorescence devices, ground penetrating radar (GPR), and infrared imaging (IR). The biggest part of the discussion will be devoted to the 3D laser range finder (3DLR). Possibilities for further development will also be discussed.

X-ray fluorescence (XRF)

XRF provides the capability for the characterisation of various metals and alloys and possible dual-use materials by means of X-ray fluorescence. The sample is irradiated by an X-ray photon field generated by an X-ray tube. The characteristic X-ray fluorescence spectrum emitted by the sample is then measured. XRF allows the relative determination of the constituents of metals, alloys or other materials in different forms (pipes, rotors, bulk). Due to the measurement principle, only the surface of a given material can be analysed.

XRF is a non-destructive technique that has been used in industrial applications for decades, e.g. in reception control. Due to the development of small X-ray tubes, portable instruments have been developed which can positively identify most types of alloys in a matter of seconds. For this application, portable XRF devices require little or no data analysis by the user.

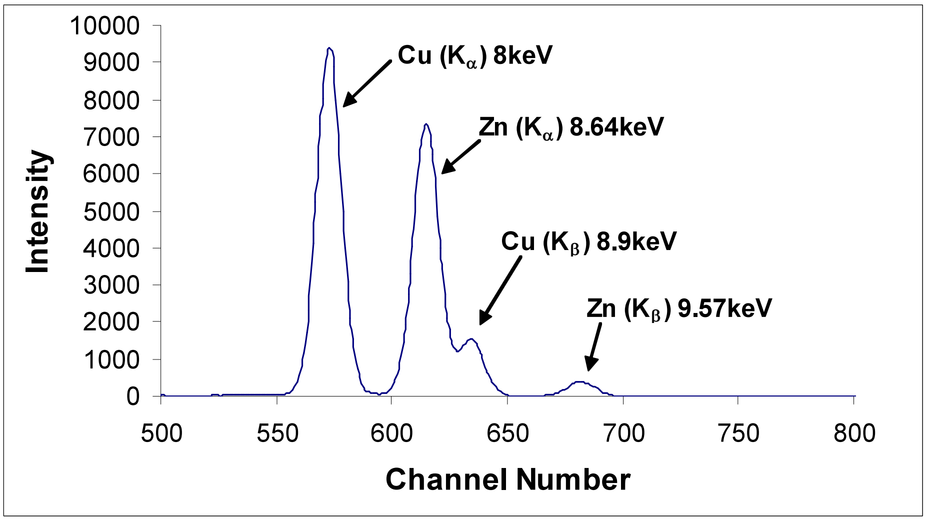


Figure 1: XRF Spectrum collected using SiLi detector for NIST reference material number 1107 (C1107) treated as "unknown sample". The spectrum shows the intensity of the dominant constituent of the sample.

Measurement results are given in the table below.

Element	declared concentration (%)	measured concentration (%)
Cu	59.0	63.70
Zn	40.0	37.45
Fe	0.0004	0.2582
Ni	0.025	0.2381

Table: Declared and measured concentration of the reference sample (NIST 1107, C1107) using elemental sensitivity method

Ground penetrating radar (GPR)

GPR uses pulses of electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and reads the reflected signal to detect subsurface structures and objects without drilling, probing or otherwise breaking the ground surface. Applications include locating buried voids/cavities, underground storage tanks, sewers, buried foundations, ancient landfills. It can also be used to characterize bedrock, the internal structure of floors/walls, water damage in concrete, and the internal steelwork in concrete.

GPR uses transmitting and receiving antennae. The transmitting antenna radiates short pulses of the high-frequency radio waves into the ground. When the wave hits a buried object or a boundary with different electrical properties, the receiving antenna records variations in the reflected return signal. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy. The range of the scan is affected mostly by the conductivity and composition of the ground; the resolution of the scan is affected by the scanning frequency. Higher frequencies do not penetrate as far as lower frequencies, but give better resolution. Best penetration is achieved in dry sandy soils or massive dry materials such as granite, limestone, and concrete where the depth of penetration is up to 15 meters. In moist and/or clay soils and soils with high electrical conductivity, penetration is sometimes less than 1 meter.

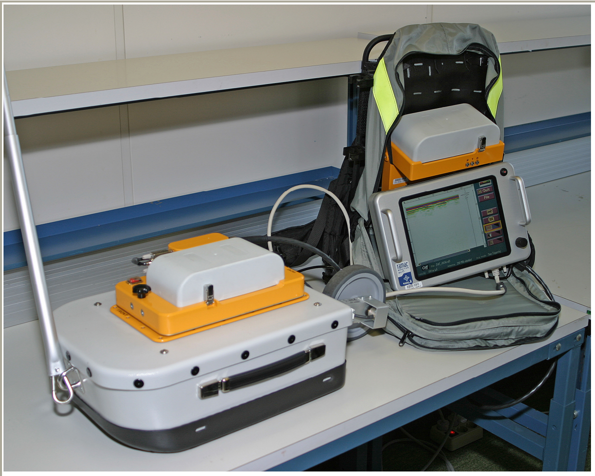


Figure 2: Off-the-shelf GPR equipment as used by IAEA for inside and outside scans, assaying structures in the ground (250 and 500 MHz antenna depending on application)

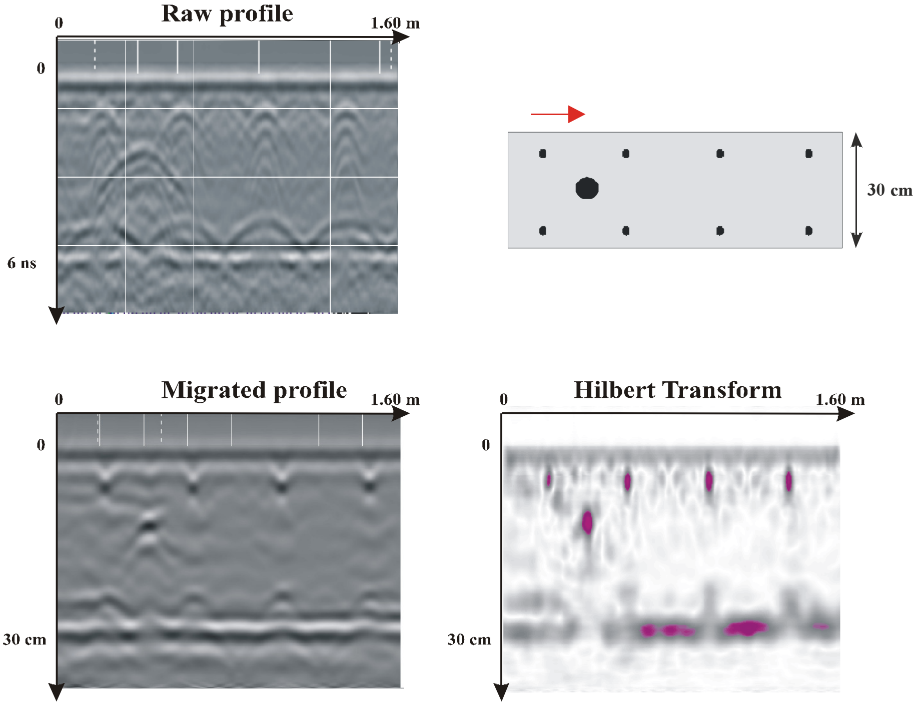


Figure 3: 1.5 GHz GPR profiles on a post-tensioned beam. In the lower part, the data are processed (migration with v=0.12 m/ns and Hilbert transform)).

Figure 3 shows raw data, schematic structure and post-processed GPR data of a post-tensioned beam, Figure 4 displays schematic positions and unprocessed GRP scan of a metal box through a floor.

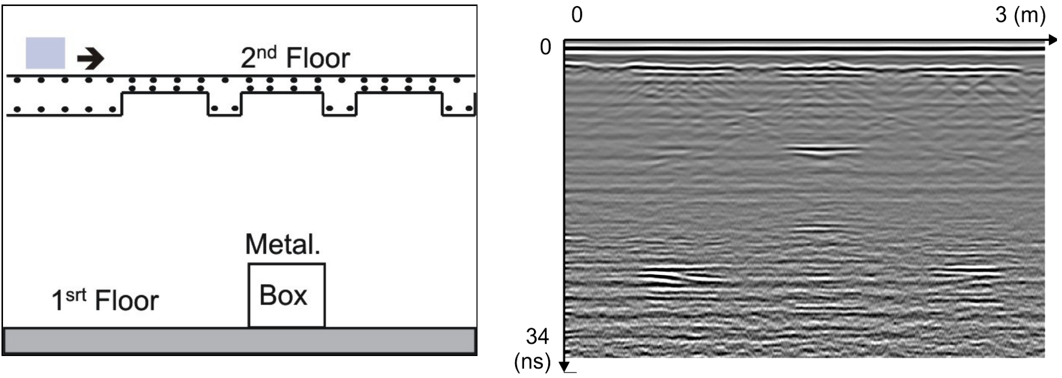


Figure 4: Metal box below floor; schematic (left), GPR signal (right)

Infra red imaging

Industrial processes that might be indicative of nuclear activities can give rise to temperature differences in pipework that may be visualised by infrared imaging, even through walls. Temperature differences can also indicate building structures of different heat parameters.

Figure 5: Off-the-shelf infra red camera as used by IAEA for IR imaging (temperature resolution 0.1 K at 30 C, measurement accuracy ±2% over –measurement range -40 C to 1200 C)

Typical examples are shown in Figure 6 and visualising pipework and building structures, respectively, contrasting visual and IR images.

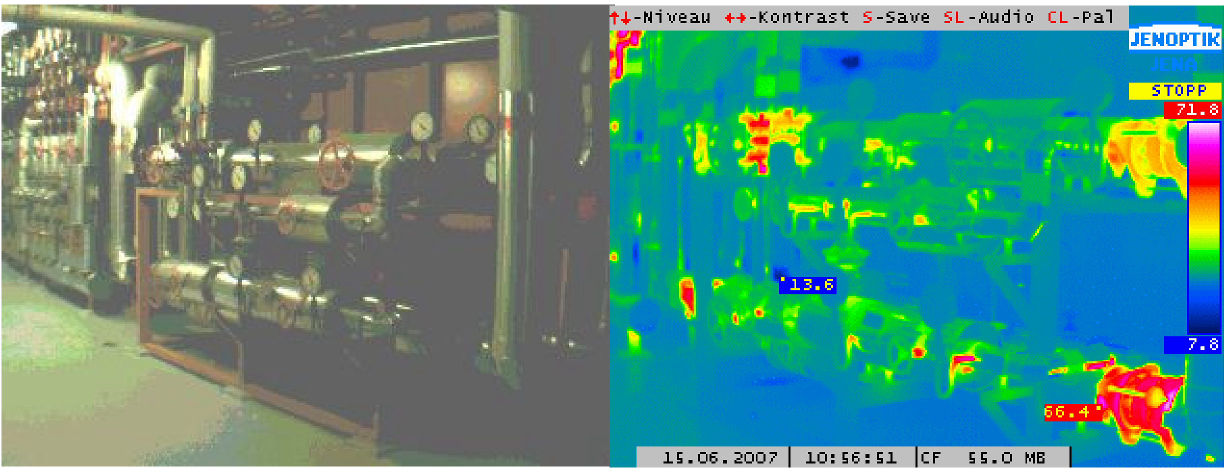
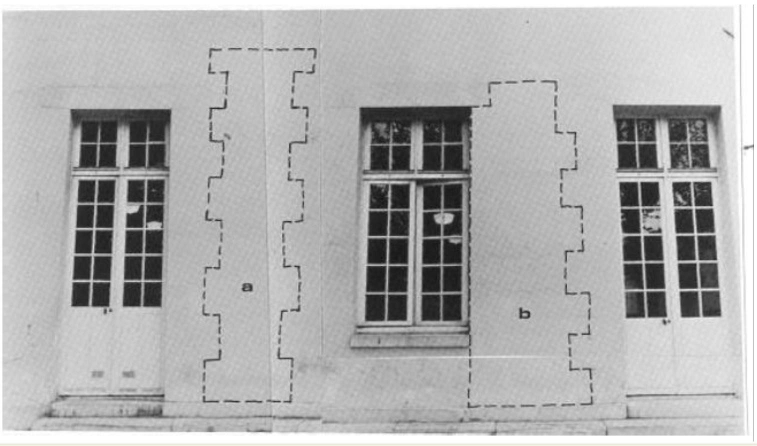


Figure 6: Utility room for heating and cooling, left visual image, right IR image



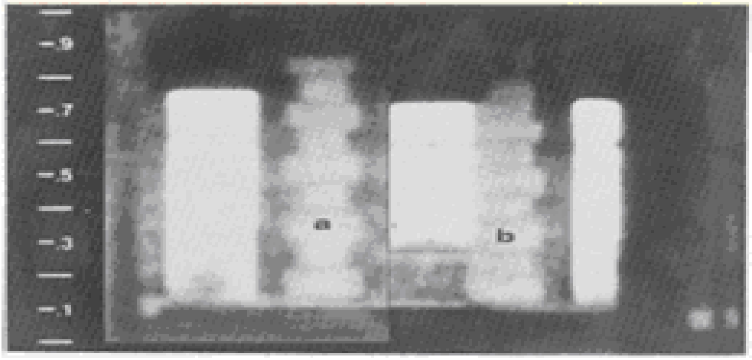


Figure 7: Identification of slabs or walls – visual image above and IR image below at end of sunny afternoon

3D Laser-Rangefinder (3DLR)

3DLR is a tool developed by the Joint Research Centre (JRC) Ispra to assist inspectors in performing their Design Information Verification (DIV) duties, at a given environment, is based on the comparison of two 3D models acquired at different instants in time. To initiate the DIV process there is the need to define at a given time the reference model for the given plant. This reference model should be as complete and accurate as possible as it will be subsequently used as term of comparison.

Building a 3D Reference Model.

The Reference Model consists basically in the 3D geometric surface description of a given environment. The reference model provides a good description of the area, or, more exactly, volume, under observation. The quality of the DIV activities is highly dependent on how accurately and realistically the “as-built” 3D model documents the plant. As such, the reference model should be acquired with the best possible conditions including a) higher spatial resolution, b) lower measurement noise and c) multiple views to cover possible occlusions. The number of required scans depends on the complexity of the scene. In addition, any source of data containing a 3D representation of the reference area can be used. Available CAD models can be used as a reference of the ideal construction.

Initial Verification of the 3D models

This verification is performed by comparing the 3D Model versus the CAD model or the engineering drawing provided by the plant operator. In the case of unavailability of CAD models, survey data such as distance measurements, accurate calculation of container diameters, heights, pipe diameters and other complex distances impossible by traditional measurement tools can be made in the virtual 3D environment.

Re-verification.

Following a specific Safeguards approach and criteria, an area for verification is selected, and a new 3D model is created with fresh data. The new model is then compared with the Reference model and changes automatically identified. The result of the change-detection is a displacement-map for each element in the verification scan. The automatic detected changes can be further analyzed by an inspector using visualization enhancing tools. Detected changes should then be investigated and documented by the Safeguards inspector. The re-verification phase can occur at any time after the reference model is constructed.

3DLR System

The main components of the 3DLR system are:

a) 3D Data acquisition equipment
b) Software tools to create 3D models of the environment “as built”
c) Software tools capable of automatically detecting changes between the current 3D reconstructed model and a previous model used as reference
d) Software tools to track and document changes in successive inspections.

A laser range scanner is used to acquire the 3D data which, when processed and integrated, will constitute the model describing a given environment. Figure 8 shows the complete 3DLR system.

The laser scanner can be placed “stand-alone” or on a tripod with a dolly. One should note that a single scan does not normally capture all the geometry of a scene. This is due to the presence of occlusions (i.e., objects hidden behind another object). As such, multiple scans from different positions are needed to create a complete model.

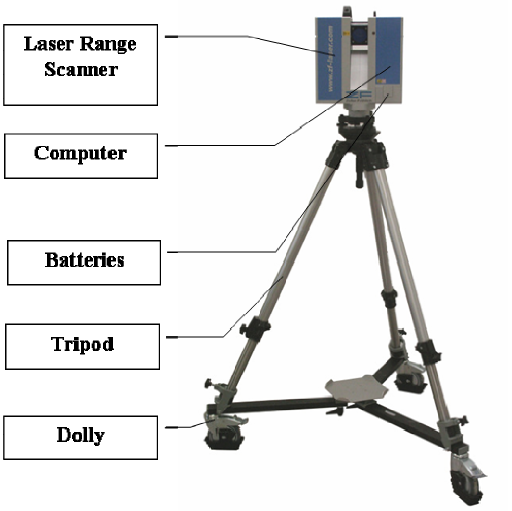


Figure 8: 3DLR laser scanner system with tripod

At this point, one should note that the whole system is designed such that when acquiring data for the verification, there is absolutely no need to locate the laser scanner at the same position from where the reference model was built. Further, the laser scanning equipment can be different, i.e., with different measurement accuracy as well as different spatial and depth resolutions. 3DLR allows safeguards inspectors to identify and focus on objects which have been moved more than a specified amount – interactively set by the inspector. Figure 2 shows an inspection result with this colour coding technique.

The result can be treated in such a way that areas or volumes which have distance changes above a threshold are saved to an inspection log file containing a global unique location reference (xyz location and extension).

Figure 2: Reference model (L), verification scan (M), automatically detected differences in red (R)

There are two main advantages of the 3DLR system:

a) It is possible to create a highly accurate representation – millimetre accuracy – of the scene under verification in a few minutes. This representation can be as complete as desired and the inspector has full control on data quality;

b) Given the accuracy and completeness, it is possible to detect any structural change, even minor, introduced in the plant. This further provides confidence in the capabilities of the 3DLR system.

UTILISATION AND FUTURE APPLICATIONS OF 3DLR

After a first prototype in 2002, JRC continued the development of the 3DLR targeted to IAEA needs. The system was tested and used at a Japanese facility [4]. Being a new technology the applications for 3DLR extend beyond DIV. Consequently the technology is currently being tested for scene change detection at large storage areas and as a reactor containment verification tool. It is expected that improvements can come from future commercial 3D laser scanning devices – faster, with better spatial resolution and more accurate. Further, practical input and feedback received from end-users (i.e., inspectors) will be taken into account for future versions of the software.

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