# Scientific Study on

## *EXTERNAL IONISING RADIATION EXPOSURE DURING CARGO / VEHICLE RADIOGRAPHIC INSPECTIONS*

***Executive Summary and Recommendations***


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HR EXCELLENCE IN RESEARCH

## Introduction

Effective customs, border, port and other inspection authorities increasingly use gamma and x-ray non-destructive (non-intrusive) inspection technology (NDT) in order to produce high-quality interior images of commercial vehicles with or without cargo inside. Ionising radiation easily penetrates cargo and closed containers. The purpose of this scanning is to fight theft, reveal contraband and other types of illegal trade including illicit trafficking of people - illegal immigrants - stowaways, weapons and dangerous goods, nuclear devices and bio-threats.

Following the September 11, 2001 attacks in the USA and subsequent terrorist acts, the number of commercial vehicles being scanned has dramatically increased. Therefore, inspection authorities consider scanning tools as an efficient complement to their cumbersome work of manual inspections. This means that standard customs scanning has been widely broadened to encompass modern day security issues.

In fact, heavy commercial vehicles may be scanned several times a day on the same route and during the same trip. This has led to considerable concern from the road transport industry as often no preventive measures are available to protect drivers, nor are drivers informed through easily accessible information on control procedures and the possible risks and impacts that ionising radiation inspections have on their health.

## Study objective and approach

The objective of this scientific study is to investigate the hazards and risks associated with transport activities which are unavoidably connected with the possible exposure of drivers and other employees to ionising radiation while undergoing the cargo/vehicle scanning process.

Over a period of a few months the scientist investigated x-ray scanning practices, procedures and levels of radiation exposure at selected border crossings and undertook scientific measurements of radiation exposure and residual radiation in selected vehicles, using professional radiation detection equipment and personal dosimeters, including active electronic dosimeters (AED). In addition to the quantitative radiation exposure level measurements, the scientist observed and recorded all practices and procedures related to x-ray scanning at the selected border crossings and compared them to recognised international standards such as the IEC[1] 62523 “Radiation protection instrumentation – cargo/vehicle radiographic inspection system” for production, and the NCRP[2] Commentary No. 20 “Radiation Protection and Measurement issues related to Cargo Scanning with Accelerator-Produced High-Energy X Rays”, for use and protection.

Furthermore, the study initiates discussions on whether truck drivers are exposed to an occupational risk, as trucks are scanned while the driver is performing his professional duties, or should the driver be treated as a member of the general public as they are not exposed to primary radiation and do not work in defined radiation protection control areas.

In this respect the study refers to the International Labour Organization (ILO) definition of a work place for which a high possibility exists of being inadvertently exposed to ionising radiation used to scan the cargo/vehicle. The workers (drivers) are defined according to the EU basic safety standards Directive[3] (Council Directive 96/29/ Euratom), laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation (Official Journal, L-159 29.06.1996,) and the Draft of Euratom Basic Safety Standards Directive; Version 24 February 2010 (Final) laying down

[1] International Electrotechnical Commission
[2] National Council on Radiation Protection
[3] ***Exposed workers***: persons, either self-employed or working for an employer, subject to an exposure incurred at work from practices covered by this Directive and liable to result in doses exceeding one or other of the dose levels equal to the dose limits for members of the public

Basic Safety Standards for Protection against the Dangers Arising from Exposure to Ionising Radiation.

The possible existence of a radiation exposure area inside the truck cabin is assessed. It is important to note that the study does not address the transport of nuclear and radioactive material because the occupational risk and transport technology are covered by numerous specialised national and international regulations.

Lastly, the study did not look specifically into the special NORM (Naturally Occurring Radioactive Material) transport control procedures, but recognises that radioactive residues can occur during the collection of scientific measurements because the NORM had been previously transported in the container in question.

## Methodology

### *Instrumentation:*

The instrumentation chosen for the investigation was in accordance with NCRP and ICRU[4] guidance for pulsed fields. In addition, an active personal electronic dosimeter (AEPD), ALARA OD, specially developed for the purpose of study measurements, was prepared for the scientific investigation as a unique measuring device which delivered a new set of reliable dosimetric data, with a special emphasis on the exact time when the scanning occurred. Thermo luminescent dosimeters (TLD) used were calibrated with $Co^{60}$ energy quality to be used in high-energy photon fields. An ionisation chamber (for pulsed high-energy photons), GM tubes and fast response scintillation counters were also used. The calibration of the three different measurement probes is shown in Figure 1.

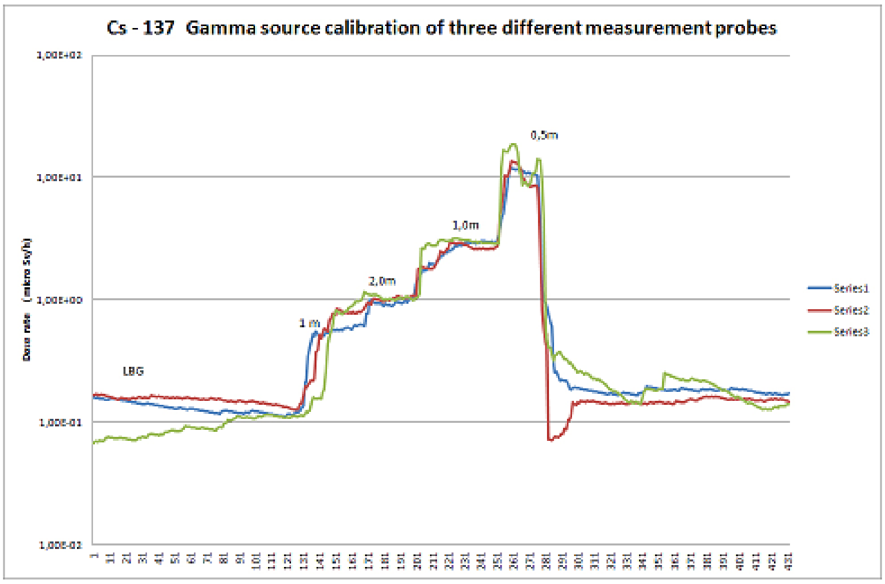



Figure 1 - Equipment calibration in the direct beam of known calibration sealed source at various distances from the source
(Three measuring probes validation – series 1, 2 and 3).

In order to prepare the proper calibration (Picture 1) of the radiation measurement instrumentation and the personal dosimeters, and to ensure the reliability of measured data in high-energy photon pulsed radiation fields, radiation protection authorities were consulted

[4] International Commission on Radiation Units and Measurements

in advance and scanner certification documentation was requested, along with radiation protection protocols.

Picture 1 – Water phantom, representing the driver and dosimeter on the driver seat in the scanned truck cabin.

**Technical Investigation:**

Two types of modern scanning technologies are assessed in this study. One, where the driver has to drive the truck/vehicle past the scanner – with possible occupational exposure to scattered radiation. Two, where the driver must wait outside the exclusion zone of the scanning unit. The dose expected in the latter is not higher than is acceptable for members of the public[5]. During the inspection of border crossings both scanning devices were observed and documented. The specific devices were:

- Dual-energy x-ray device up to 450 keV operating in continuous exposure mode - fluoroscopic mode (also known as Silhouette Mobile Scanner). The same types of images are produced with gamma ray scanning technology operating in the same manner.
- Linear accelerator producing high-energy x-rays from 2.5 MeV to 9 MeV working in pulsed mode up to 400 Hz (such as mobile LINAC 4.5 MeV scanner produced in the USA, EU, China, Japan).


Picture 2 – Silhouette scanner type – (300 keV) transmission dual energy x-ray unit, continuous exposure. The driver sits inside the scanned vehicle while driving it through the scanner.

[5] *Members of the public* individuals in the population, excluding exposed workers, apprentices and students during their working hours and individuals during the exposures referred to in Article 6(4)(a), (b) and (c) of Council Directive 96/29/ Euratom of 13 May 1996

The operational difference between the two devices is that the 450 keV dual energy x-ray device is positioned in such a manner that the driver has to drive the truck at the requested low-speed near the scanning device (Picture 2) and through the constant radiation field which automatically starts after the truck cabin passes the laser indicators. This ensures that the cabin, with the driver inside, is not scanned, but only the cargo trailer/container.

It should be noted, however, that there is a possibility that the driver is exposed to scattered radiation from the cargo trailer behind the cabin. An incident can also occur if the exposure start mechanism and cameras malfunction and automatic exposure control (AEC) begins prematurely, exposing the truck cabin, together with the driver, to radiation. All other persons involved in the inspection process must be outside the exclusion area around the vehicle being scanned (Picture 3).

Picture 3 – Silhouette scanner type – 300 keV transmission
x-ray unit, continuous exposure. Exclusion zone around the full operational unit is shown.

Mobile LINAC scanners operate in a different manner. The cargo truck remains parked inside a given parking area and the mobile scanning LINAC truck moves the scanning device (Linatron Mi type or other) at a constant speed along the entire cargo truck length (Picture 4). The entire truck is irradiated. The driver is not inside the cabin.

Picture 4 – LINAC, high-energy x-ray scanning unit type – 4.5 MeV pulsed exposure.
Driver is not inside the stationary cargo truck.

To accelerate the scanning process (inspection process) LINAC mobile technology enables inspectors to scan a queue of correctly aligned, parked vehicles as shown in Picture 5. Drivers are not inside the cabins.

Picture 5 – LINAC, high-energy x-ray scanning unit (type – 4.5 MeV pulsed exposure) scans the properly lined queue of vehicles.

### *On site investigation:*

The measurements were carried out using two different approaches. In cases where the scanning of vehicles was considered a question of national security, the investigation was carried out with the general approval of national customs and radiation protection authorities. The site visits were, however, carried out on rather short notice so that procedural shortcomings and deficits in the equipment were certain not to be changed in such a short period of time.

In this case, trucks involved in the measurement procedures were picked by customs inspectors. The customs selection criteria were not transparent but did follow a certain pattern which was not within the scope of this study. To ensure a variety of scanned vehicles and to cover the worst possible case of exposure during measurements, the scientist also suggested the vehicle selection. The selected trucks were either completely empty, full of cargo with high material density to ensure the full scanning exposure load, or the container was made of steel, etc.

Under these “controlled” conditions, the background radiation measurements (Figure 2) and a complete set of dosimetric measurements, including the phantom driver measurements (Picture 1), were carried out. In the second approach, truck drivers carried the dosimeters themselves while other dosimeters were placed in the truck cabins during their trips. After their trip the dosimeters were measured.

For both cases, comparison measurements were carried out using specially prepared active electronic dosimeters, the measurements of which showed the exact time when vehicle scanning (if any) occurred. This was compared with the measurements initially taken.

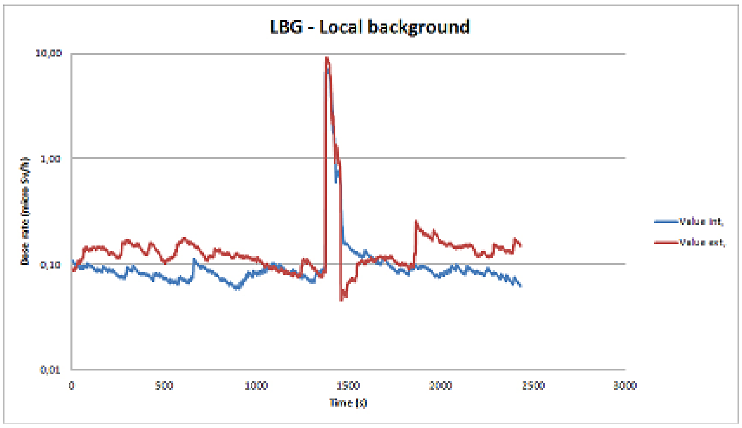



Figure 2 - Local radiation background measurement (two probes) at the site.
The peak represents the calibration check with known $^{137}Cs$ sealed calibration source.

Also, in both cases an observation point was chosen and customs inspection procedures were monitored independently in order to gain additional data about the overall behaviour of customs officials and truck drivers.

In addition to the measurements and observations, interviews with customs officers, x-ray scanning unit operators, inspection staff and drivers were conducted at every border crossing visited. The operators were interviewed about the scanning procedures, their radiation protection knowledge and their obligation concerning drivers. They were asked to explain the minimum information they have to present to a truck driver when his/her truck is selected for scanning.

Drivers were asked if they knew anything about scanning procedures, how many times the cargo was scanned during their present trip, their concerns, along with many other informal questions which were focused on gathering information and drivers' opinions on scanning devices and the daily routine during customs inspections.

## Results

The results of the field study show that there are no occupational health and safety hazards for drivers if the scanning of their trucks/vehicles was performed using LINAC high-energy x-ray scanning technology.

Figure 3 shows the results of a dosimeter's measurements after several scans of a vehicle during a given trip. Every scan and the corresponding time had been recorded. In this test the electronic dosimeter representing the driver was inside the truck cabin during the trip but the driver was not.

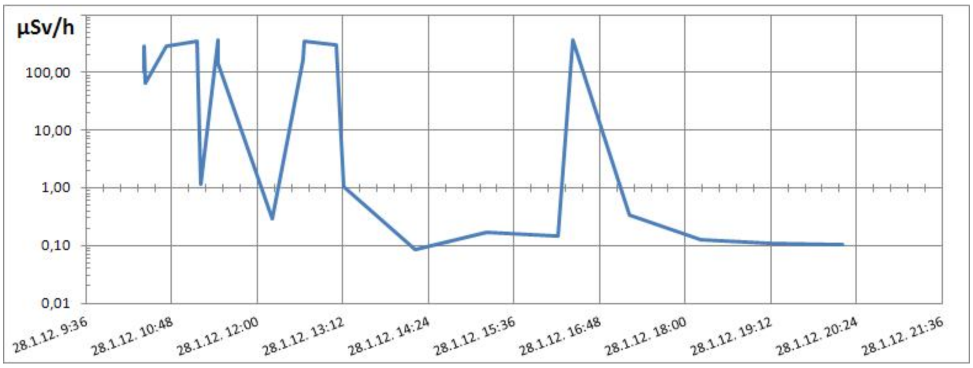



Figure 3 - The dose rate in time; view showing the frequency and exact time of repeated scanning of the same dosimeter

Figure 4 shows the total accumulated dose of about 20 μSv measured by an electronic dosimeter during recorded scans, meaning that the described high energy scan procedure can be repeated numerous times without any additional exposure risk to drivers' health (Figures 3 and 4).

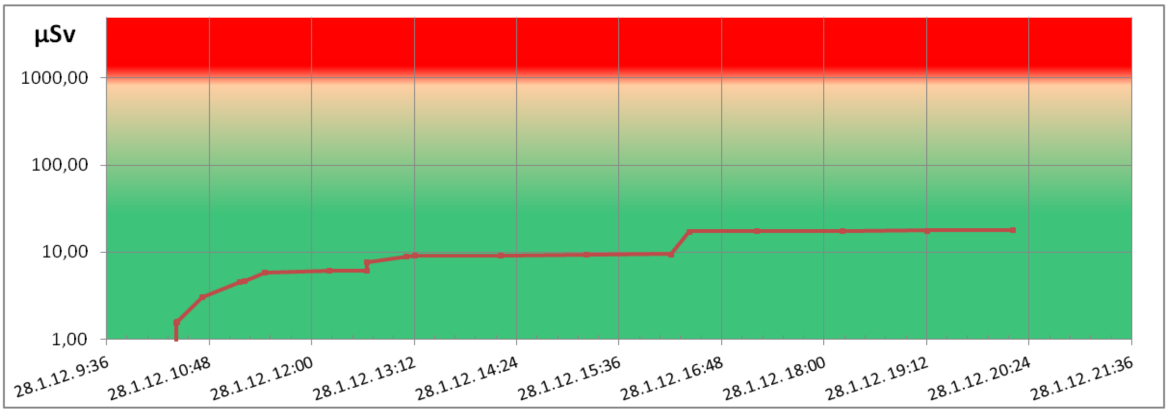



Figure 4 - ALARA OD accumulated dose corresponding to the scan frequency and time of scanning shown in Figure 3. Measuring device was placed in the truck cabin and/or driver seat during several LINAC scanning process over a one day period.

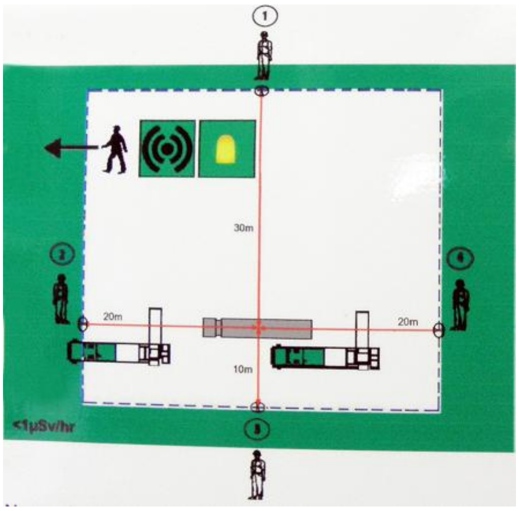
In addition to accumulated background radiation, acceptable exposure limits for members of the public are given to be 1 mSv/year, indicated with the red highlighted area on Figure 4 above. Occupational limits are set to 100 mSv during a period of five years (20 mSv per year). This said, even an occupational dose will be of no health concern to drivers and driver exposure will not reach the occupational exposure limit of 1 mSv/y.

Slightly older technology (mobile Silhouette scanners shown in Picture 3 or modern gamma ray scanners), where the driver has to drive the vehicle along the scanning device, can contribute to a possible increased exposure of the driver. This exposure has to be measured at the drivers' work place (seat in the cabin) and is due to scattered x-ray radiation from the cargo and vehicle itself. Incidents can happen and drivers can be partially exposed to a primary beam if the maintenance of the security systems of the scanner is poor or if the operators are not following radiation safety procedures and drivers are not following the given instructions. Even if such incidents do occur, and even if the driver is exposed to scattered radiation, the exposure level does not exceed the regulated[6] level of 1 mSv/y, even if inadvertent exposure of the truck cabin is repeated several times during the same trip (Figures 3 and 4). Only if the driver reaches the regulated level of 1 mSv/y will he then be regarded as an occupationally exposed worker. The driver must then be monitored and his maximum legal exposure levels will be increased to 50 mSv/y, a level which is still not regarded as dangerous.

Furthermore, the measurements and analysis show that after the truck and cargo were scanned with high-energy x-ray up to 9 MeV, residual radiation presumed to be generated by the scanning procedure does not occur in the cargo or truck cabin.

It was also observed that scanning procedures were not always followed according to internationally recognised radiation protection standards such as the IAEA, IEC and EC or NCRP standards on x-ray scanning. As a simple example of these standards not being applied, the scientist observed that drivers were not always asked to leave the given safety zone (Picture 6) or the zone was put arbitrarily around the scanner. This often happened when the scanning was performed at locations along highways, in parking lanes or for security reasons.

[6] Regulated level for the member of the general public, not occupational




Picture 6 - LINAC regulated exclusion zone with scanner and scanned truck scheme and demanded position of the operator and driver outside the exclusion zone which has to be clearly marked on scanning site.

As can be seen in Picture 7 below, there was no clear, visible indication of the safety zone around the scanning unit. In Picture 7, the driver had been instructed to leave the exclusion zone and was in fact within the safety zone. He was permanently accompanied by a customs officer, which is standard protocol in this situation. Drivers are, in general, not acquainted with radiation protection, scanning or inspection standards, but they obey the instructions given by inspectors. In addition, it was observed that drivers often do not speak the scanner operator's language; knowledge of English or another internationally accepted language is scarce. Furthermore, drivers wanted to be near their truck because they feared for their belongings and cargo.


Picture 7 - LINAC exclusion zone showing scanner and scanned truck and position of the operators and driver outside the exclusion zone, real observed situation.

## Recommendations

The protection of drivers against sickness and injury arising from their work activities is an important matter, and how to manage the hazards and risks associated with transport activities which are unavoidably connected to the possible exposure of employees to ionising radiation whilst undergoing the cargo/vehicle scanning process was a key question of this study.

Therefore, all stakeholders have a role in enhancing the radiation protection culture within the road transport sector. As it is clear that drivers included in this study are not regarded as occupationally exposed to ionising radiation, the scientist recommends the following:

***Recommendations for concerned ministries and competent border authorities:***

- Install appropriate information panels, which include pictograms, highlighting that x-ray scanning is performed and giving clear indications on what the driver should do to avoid unnecessary exposure;
- At concerned border crossings, make available multi-lingual information leaflets, including pictograms, which describe the x-ray process, risks and safety information;
- Develop and introduce a mutually recognised x-ray scanning certificate to prevent repeated scanning and thus facilitating and accelerating the control process;
- Ensure, with the support of the International Atomic Energy Agency (IAEA), the European Commission (EC), the International Labour Organization (ILO) and the World Customs Organization (WCO), the correct implementation of internationally accepted x-ray scanning procedures;
- Ensure that customs officers and x-ray equipment operators are properly trained on the functioning and risks of x-ray scanning machines enabling them to operate the equipment safely and give adequate safety instructions to drivers; and
- In cooperation with x-ray machine manufactures, ensure that x-ray equipment is properly maintained.

***Recommendations for x-ray machine manufacturers***

- Train customs officers and x-ray machine operators on the proper functioning, risks and safety instructions of x-ray scanning;
- In cooperation with radiation protection specialists and in consultation with stakeholders involved in vehicle scanning, develop up-to-date leaflets in several languages, which include pictograms, for x-ray operators, customs officers and drivers.

**Recommendations for road transport operators:**

- By making best use of competent training institutes such as the IRU Academy, improve the basic education of drivers on the scanning process, related risks and safety instructions of x-ray scanning through appropriate driver safety cards.

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