Nuclear detection systems in traffic

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Illicit trafficking in nuclear materials (nuclear criminality) has become a problem, due to the circulation of a high number of radioactive sources caused by the changes of the organisational infrastructures to supervise these material within the successor states of the former Soviet Union. Aim of this paper is to point out the technical requirements and the practicability of an useful monitoring system at preselected traffic check points (railway and highway border crossings, industrial sites entry gates, international airports).

For the purpose of investigation and testing the following categories of nuclear detection instruments have been defined:

1. Fix-installed monitoring instruments
2. Pocket type instruments
3. Hand held instruments (searching instruments, dose rate survey meters, isotope identification instruments)

The fix-installed monitoring systems should detect gamma as well as neutrons. Pocket type and hand held instruments have not to be sensitive for neutrons.

Currently, two methods are available for testing and certifying of fix-installed monitoring instruments:

1. Test cycle method according to IAEA
2. Analytical method based on radiation efficiency.

Both of these methods are to be described in our present work in greater detail.

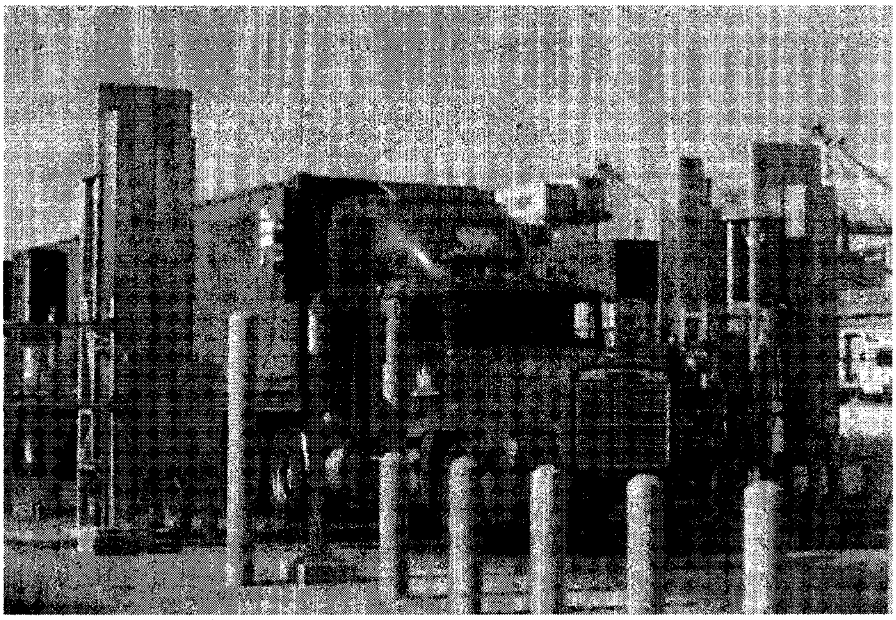

Fig.1: A heavy truck passing fix-installed radiation monitoring gate at the ironwork entrance terminal.

The test cycle method

A thorough technical testing of nuclear monitoring systems has been performed under the supervision of IAEA in the framework of ITRAP study at Austrian Research Center Seibersdorf from November 1997 to February 1998.

The ITRAP lab test was designed to work as strict benchmark to qualify border monitoring systems with very low false alarm rates, in addition the minimum sensitivity to give an alarm has been defined for fix-installed systems, pocket type and hand held instruments.

Lab test of fix-installed systems

In summary 14 fix-installed systems have been installed in a circular geometry to measure all instruments at the same time. In the centre the test source was located in an exact distance of 3 m to the reference point of the detector (Fig.1). For two pillar monitoring systems each single pillar has to fulfil the IAEA minimum requirements.

The systems are located in a fenced, outside area, unprotected against temperature changes, humidity, etc. The control units are in a protected location, close to the detectors. For the alarm sensitivity tests, a gamma source (^{137}Cs, ^{241}Am, ^{60}Co) as well as a neutron source (^{252}Cf) have been used to exposure the systems for time period of 1s, in the case of a gamma and 10s, in the case of a neutron source, according the IAEA minimum requirements for these instruments. The increase of the dose equivalent rate is 0,1 μSv/h above a background of 0,2 μSv/h for all used gamma sources. After the exposure the source stayed for a minute behind the shielding and starts afterwards the next test cycle. The facility is able to operate continuously for several weeks. The natural background is increased by an additional radiation source (^{137}Cs) in the centre according to the IAEA test requirements.

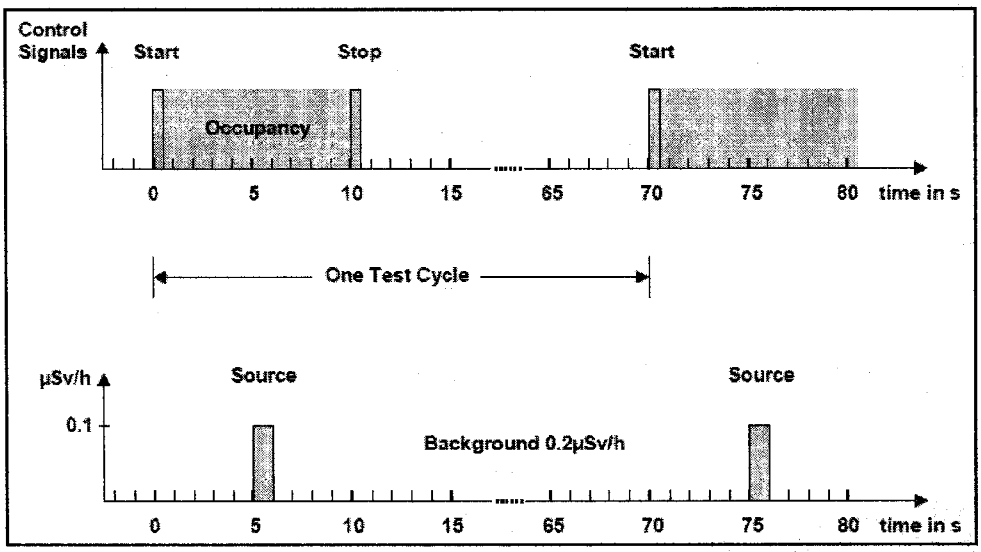

Fig. 2: Test cycle for the gamma alarm test for fix-installed monitors. The ITRAP control system provides all monitoring systems and instruments with start and stop signal to simulate the "occupancy" situation of a vehicle or pedestrian. The status of all systems was checked every 0,5s by the ITRAP control system. During the waiting period the systems had time to recalibrate.

For the neutron tests a special prepared Californium source (^{252}Cf) was used to simulate the weapons plutonium. The source is shielded against gamma radiation, use a moderator and provides the required neutron rate of 20000 n/s at 2m distance. To test the false alarm rate (rate of false positive) the same test facility, under the same background conditions, was used but without a radioactive test source.

ITRAP lab test conclusions

The ITRAP lab tests for the fix-installed systems started at May 1998 and first results were given in September 1998. Conclusion: Only 2 of 14 fix-installed monitoring systems could fulfil the minimum requirement for neutron detection. 7 of 14 fix-installed monitoring systems (50%) passed the ITRAP lab test.

IAEA Minimum requirements for fix-installed monitoring systems at border crossings

<u>Alarm level for gamma radiation:</u> increase of the dose rate at the reference point of the detector from a background level of 0,2 μSv/h by a dose rate of 0,1 μSv/h for a duration of 1 second. This

requirement has to be fulfilled in a continuous, incident gamma energy range from 60keV to 1,5 MeV (tested with ^{137}Cs, ^{241}Am and ^{60}Co).

Reference point: Most sensitive location at the detector system.

Alarm level for neutron radiation: A neutron flux density of 20000 n/s emitted from weapons Plutonium for a duration of 10 seconds at 2m distance from the reference point of the detector, gamma radiation shielded to less than 1%, should trigger alarm. (Tested with a modified, gamma shielded Cf-252 source).

Search region: Geometrical region in which the minimum requirements for alarm level are fulfilled:
Pedestrian monitor: vertical: 0 to 1,8 m, horizontal: up to 1,5 m.
Vehicle monitor: vertical: 0 to 3 m; horizontal: up to 4 m.
Train monitor: details to be defined.

Analytical method for testing of fix-installed radiation monitors based on radiation efficiency.

The analytical method developed and used for certification of installed radiation monitors in the Slovak Institute of Metrology consists in measurement of radiation activity of selected radionuclide in defined conditions.

Objects of the examination are stationary instruments intended for investigation of hidden radioactivity in personal and cargo traffic. The essential measuring element is usually a large detector sensitive to gamma rays. Generally it consist of a large area plastic scintillation detector and a photomultiplier or a high volume proportional detector with permanent gas filling. Several detectors placed in the volume of interest assure higher detection efficiency. At the absence of a vehicle, the detector registers background gamma radiation. The output signal of the detector is the electric pulse count rate, which is proportional to the radiation intensity.

The electronic equipment consist of a high voltage source for the detector, an amplifier, a pulse shaper and discriminator, a counter and an electronic timer. The system usually contains a computer performing necessary arithmetic operations and storing data as well. The count rate discriminator can trigger an alarm signal, when preset threshold is reached. The count rate threshold can be preset as stable one or it can vary according to changes in measurement conditions. In addition, the instrument comprise a vehicle movement detector, a signalling device intended for the movement control and an auxiliary equipment measuring the ambient temperature, vehicle mass and others.

Mathematical model can be expressed by equation:

$$A = \frac{m-b}{\sum \varepsilon(E).p(E)}.K = \frac{m-b}{\varepsilon_R}.K$$

where A represents radionuclide activity contained in source,
m is registered count rate in the presence of source, which includes selected radionuclide,
b is registered count rate of background, it means in absence of source, it can vary during the measurement according to ambient changes and according to the presence of passive objects (vehicles) in volume of interest,
$\varepsilon(E)$ is registration efficiency of gamma rays of certain energy E, this is essentially detector sensitivity as a function of energy,
$p(E)$ is probability of the emission of photons with energy E, accompanying radiation conversion of given radionuclide, since as a rule radionuclides produce photons with multiple energies, in the denominator is the sum of products of partial efficiencies and probabilities of emission,
ε_R is total measurement efficiency of given radionuclide in given geometrical configuration,
K is total correction factor , which is a product of a number of partial correction factors, among them the most important are geometrical factor and absorption factor.

Since we cannot identify the measured radionuclide apriori, installed monitors are not able measure the radionuclide activity A, instead we use the physical quantity "net count rate" as:

$$n = m - b \qquad [s^{-1}]$$

Dependency of activity A as a function of the distance between the source and the detector can be mathematically modeled by introducing a new quantity named radiation efficiency R:

$$R = \frac{A}{r^2} \qquad [Bq/m^2]$$

where r means the distance between the source and the detector. This is only an idealized geometry configuration, that can be satisfied when measuring relatively small sources with surface detector at higher distances (so called "geometry of small space angle"), the later condition is usually satisfied by fix-installed monitoring systems.
Radiation efficiency R is interconnected with another dosimetric quantity named "Dose rate", which is defined as:

$$\dot{D}_R = \Gamma_R . \frac{A}{r^2} = \Gamma_R . R \qquad [W.kg^{-1}]$$

where Γ_R is a factor depending on the radionuclide properties, as well as the properties of the absorbing media (air, water, etc.).
Corrected measurement model can be then written as:

$$\eta_R = \frac{m-b}{R} . K \qquad [s^{-1} \cdot Bq^{-1} \cdot m^2]$$

where η_R represents efficiency of the measurement of the radiation efficiency R for a given radionuclide source. Ideally this quantity should be independent on the source – detector distance, that makes it very suitable as a metrology quantity.

References:

[1] ITRAP Final Report, Austrian Research Centers Seibersdorf, 2000
[2] Operating instructions 12/250/02, Slovak Institute of Metrology, 2002

Abbreviations:

ITRAP – Illicit Trafficking Radiation Detection Assessment Program
IAEA – International Atomic Energy Agency
SIM - Slovak Institute of Metrology