Safety Management of Hazardous Materials - Orphan Radioactive Sources: Contribution of STRASS Project

Stelios Xanthos[1,*], *Alexandros* Clouvas[2], *Fokion* Leontaris[2], and *Nikolaos* Liampas[1]

[1]Department of Industrial Engineering and Management, International Hellenic University, Greece
[2]Nuclear Technology Laboratory, Department of Electrical & Computer Engineering, Aristotle University of Thessaloniki, Greece

Abstract. STRASS project is an INTERREG project, collaboration between Greece and North Macedonia that includes the following aims a) Discovery and identification of radioactive materials (especially orphan radioactive sources and materials that are transferred mainly accidentally) during check in cross border area, b) Location of dangerous points of the roadway Thessaloniki-Skopje. c) Investigation of radiological risk after a traffic accident d) Establishment of common emergency response protocols for both countries. The project deals with circular economy and sustainability and its main challenge that is presented here is to minimize any risk of accident (traffic accident during transportation, dispersion, loss etc) and pollution when handling and transferring willfully or accidentally hazardous radioactive materials.

1 Introduction

Global challenges like health, safety and environmental issues require transnational and interdisciplinary approaches. An effort towards this direction is being done by STRASS project. STRASS project is an INTERREG project, collaboration between Greece and North Macedonia that focus on two axes. One that has to do with radiation protection and a second one that deals with safe transportation. The combination of above-mentioned fields is the main objective of the project which is about safe transportation of hazardous materials and especially radioactive ones.

For the first field Radiation Portal Monitors (RPM) are commonly used to detect and intercept unauthorized movement of nuclear and other radioactive materials both at borders and within States [1]. However, under certain circumstances, detection portals can fail to detect radiation (eg due to shielding). After this step of detection in the border area of a hazardous load that may fail or not the next challenge is to minimize traffic accidents with trucks carrying these hazardous materials.

For the second field it is well known that traffic accidents are the leading cause of death for people aged under 50 [2] and the second-leading cause of death worldwide [3] for children aged 5–14 years and young people aged 15–29 years. Greece and especially Central Macedonia are negative pioneers in traffic accidents counting thousands every year. Among

---

* Corresponding author: xanthos@autom.teithe.gr

38 European countries, Greece is ranked in the seventh highest position in road crash fatalities, (24 men and 5 women per 100,000 citizens) [4]. To eliminate them and reduce their consequences requires a systematic analysis.

The purpose of the present study is to examine a) safety and detection of radioactive materials provided by the installation of Portal Monitors in the Evzoni border station and b) the traffic accidents on roadway from Thessaloniki to Evzoni border station and therefore the safety of transported products.

2   Methodology

As mentioned before, this research is oriented towards two branches: a) radiation detection and determination of Minimum Detectable Activities of RPM in Evzoni and b) traffic accidents on roadway from Thessaloniki to Evzoni. They are discussed in detail bellow.

2.1 Radiation Detection

In the Greek-North Macedonia border, Radiation Portal Monitors have been installed since 2004 for detecting and intercepting unauthorized movement of nuclear and other radioactive materials. The detection system is a TSA PM 700 AGN polystyrene portal monitor with two scintillating detectors per pillar.

The calculation of the threshold over which the alarm will be triggered is directly dependent on the background of natural radioactivity and is given by the following formula

$$TL = background + c \times \sqrt{background} \qquad (1)$$

TL : The alarm threshold in counts per second
background : background of natural radioactivity in counts per second
c: Constant that determines the confidence level

Obviously, the $\sqrt{background}$ indicates a Gaussian (normal) background distribution. In fact, the distribution of the background in counts per second is not a normal distribution, but it is very similar to it [5]. Therefore, constant *c* determines the confidence level of this distribution (eg for *c* = 3, we have a confidence level of 99.73%).

In order to estimate Minimum Detectable Activities for different radionuclides, Monte Carlo simulations and measurements were used in combination.

Simulation of the scintillating detectors of the Radiation Portal Monitors in the Greek-North Macedonia border was carried out with a set of Monte Carlo simulations. The tool used in order to simulate spatial response to gamma radiation of these detectors was the MCNP a general-purpose Monte Carlo N-Particle code of the Los Alamos National Laboratory.

In order to test the scintillating detectors of the RPMs, Monte Carlo simulations were performed in combination with in situ gamma radiation measurements. Measurements were performed using Eu-152 and Cs-137 radioactive point sources located 70 cm above ground and in half distance between pillars of the portal (3m) for Eu-152 and 30 cm from the detector for Cs-137. This is due to the fact that Cs-137 had very low activity (0.35 μCi).

2.2 Traffic accidents

The following procedure was followed for this research on the part that deals with traffic accidents:

- Examination of traffic accidents data on roadway Thessaloniki to Evzoni was carried out.

- It was decided to exclude from the investigation the section of the highway E1 from Thessaloniki to the intersection of Chalastra, because most of the vehicles in this section of the highway travel for south, western and northern Greece.
- The data, which were used for this research, was the recorded traffic accidents by the traffic departments of Thessaloniki and Kilkis, which are responsible for the section of the PATHE E75 highway from the intersection of Chalastra to the Evzoni border station.
- Because of its completely different morphology the part of motorway that is under consideration is divided in two sections. The first one is a single carriageway 47 km long, begins from intersection of Chalastra (485 km) and stops nearby the exit of Nea Kavala (532 km) and the second part is a continuation of the first part extends up to the Evzoni border station, (549 km) is 17 km long, is dual carriageway having two lanes per direction.
- The road was examined for locating dangerous points of truck accidents. Because the number of truck accidents were limited, only 11 occurred in the last decade, we could not draw safe conclusions. For this reason, we used all the recorded traffic accidents (77).
- The percentage and impact of truck accidents were compared with all the other accidents.
- A correlation study was performed between weather conditions and traffic accidents involving a truck.
- Furthermore, it was examined if the months of the year, the days of the week, the daylight and the hours of the day were correlated to increased number of traffic accidents.

3 Results and discussion

3.1 Simulation Results of RPMS

The following numerical "experiments" were performed: By Monte Carlo simulations were calculated the number of photons per second (cps) detected by the scintillator per μCi. Cs-137 and Co-60 point sources were placed in different distances from the scintillator (0 up to 3 meters). The radioactive sources were located 70 cm above soil. Three meters is the half distance between the two pillars of the RPM. The installation is shown in figure 1.

Figure 1. Distance in meters from the scintillator.

As mentioned before calculation of the threshold over which the alarm will be triggered is directly dependent on the background of natural radioactivity and is given by formula (1)

For the calculation of the minimum alarm activity we assume that the cps measured by the detector due to the source is 4 sigma of the cps of the Background. In the Evzoni area the

counts per second due to background is 303 cps for the total window (22-1595 keV) of the scintillator. Following the above remarks:

- the threshold over which the alarm will be triggered in the RPM is:
  $$TL = 303 + 4 \times \sqrt{303} = 373 \ cps$$
- the minimum activity of the source for triggering the alarm corresponds to $4 \times \sqrt{303} = 70$ photons per second detected in the scintillator due only to the source (background subtracted).

In Table 1 are presented the calculated (by MC simulations) cps per μCi for Cs-137 and Co-60 point sources placed 70 cm above soil and 300 cm away from the scintillator. As mentioned above three meters is the half distance between the two pillars of the RPM. Dividing the value of 70 cps by the tabulated values (second column of Table 1) we deduce the minimum activities for triggering the alarm which are presented in column 3.

Table 1. Calculated cps per μCi for Cs-137, Co-60 point sources placed 70 cm above soil and 300 cm away from the scintillator and the corresponding minimum activities for triggering the alarm of the RPM.

POINT SOURCE	cps/μCi	Minimum activities for triggering the alarm of RPM
Cs-137	11.9	5.9 μCi
Co-60	38.0	1.8 μCi

3.2 Measurement Results of RPMs

As mentioned before, in order to validate results from Monte Carlo simulations of the scintillation detectors of the RPMs, in situ gamma radiation measurements were performed in combination with simulations. Experimental measurement results are presented below.
Estimation of the minimum activity of Eu-152 source for Alarm triggering of the RPM.

- The Eu-152 source (unshielded) is located 70 cm above soil and in the half distance between the two pillars of the RPM (3 meters).
- The activity of the source is 42.5 μCi.
- The measurement in the RPMs due to the source is 604 cps more than 5 times higher the background (BKG =116 cps). The energy window of the RPMs is the default one (22-144 keV). For the calculation of the minimum alarm activity we assume that the cps measured by the detector due to the source is 4 sigma of the cps of the Background.
- A minimum alarm activity of about 3 μCi (111 kBq) is estimated for Eu-152.

Estimation of the minimum activity of Cs-137 source for Alarm triggering of the RPM.

- The source Cs-137 (unshielded) is located 70 cm above soil and in the half distance between the two pillars of the portal (3 meters). Unfortunately, we do not have high activity Cs-137 source in order to perform such measurement at 3 meters.
- We have performed, measurements with a Cs-137 point source of activity 0.35 μCi up to 0.3 meters from the detector.
- The measurement in the RPMs due to the source at 30 cm is 161 cps. In order to deduce the cps at a distance d = 3 meters we use the $d^{-1.7}$ distance dependence factor found experimentally for the Eu-152 source. With such dependence the estimated cps for a Cs-137of 0.35μCi source at 3 meters is estimated at 3.2 cps.
- For the calculation of the minimum alarm activity we assume that the cps measured by the detector due to the source is 4 sigma of the cps of the background which was 144 cps.
- A minimum alarm activity of about 5.2 μCi (192 kBq) is estimated for Cs-137.

Similar results concerning minimum alarm activities for Cs-137 sources were taken from 19 radiation portal monitors in Spain [6].

3.3 Investigation for dangerous points and traffic accidents in the roadway Chalastra - Evzoni

The research showed that in the last decade (2007-2018), seventy-seven (77) traffic accidents were recorded, the impact was 28 deaths, 12 serious injuries and 94 slightly injured.

The highest proportion of accidents had involved cars, which is quite normal due to the majority of traveling the road axis. Trucks and motorcycles were following.

In the following figure 2, comparison of the number of traffic accidents and their severity in the motorway Single carriageway 47 km long (485 – 532 km) and Dual carriageway 17 km long (532 – 549 km) is depicted.
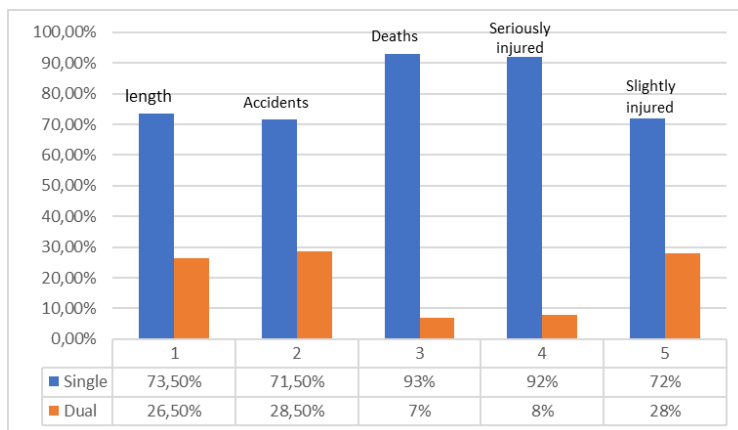

	1	2	3	4	5
Single	73,50%	71,50%	93%	92%	72%
Dual	26,50%	28,50%	7%	8%	28%

Figure 2. Comparison of traffic accident rates and their severity

After examining the data, it was found that the percentage of the number of recorded traffic accidents in the above two parts is approximately proportional to their lengths. Although the same percentage of accidents is reported, their severity was four times less in the second part than in a first one.

Traffic accidents involving trucks were recorded on the first part of the roadway (single carriageway). They were uniformly distributed throughout this part of the motorway and it includes long straight sections.

In order to characterise a km of the roadway as a dangerous point three repeatable traffic accidents should have been occurred in the last decade. Afterwards the topography and the type of accident that occurred in each point were investigated.

The examination had shown that there are no road points that can be described as dangerous. Most recurring accidents had taken place in perfectly straight sections, without dangerous causes compared with other sections of the whole roadway.

3.4 Causes of truck accidents and impacts.

The main reason of serious traffic accidents is due to the movement in the opposite traffic lane, that causes often a head-on collision. This is also confirmed in our study, where all the deadly truck accidents caused by movement in the opposite traffic lane. In the following table 2, causes of truck accidents and impacts are presented.

Furthermore, it was investigated if weather conditions and night hours were associated with the occurrence of truck traffic accidents. The conclusion is that there is no correlation between bad weather or limited light and truck accidents. Finally, a relationship between morning hours (07:00 - 12:00) and truck accidents due to the increased traffic in those hours was observed.

Table 2. Causes of truck accidents and impacts

Causes of accidents	Movement in the opposite traffic lane	Lack of attention	Uknown	Priority	Are being investigated
Number of accidents	5	2	2	1	1
Accident impacts	4 deaths & 1 slightly injured	3 slightly injured	3 slightly injured	1 severe injured	2 slightly injured

4 Conclusions

Based on the above we come to the following conclusions after this study:

For Radiation Detection part of this study:

Minimum activities of Cs-137, Co-60 sources for alarm triggering of the RPMs were calculated by Monte Carlo simulations and found in good agreement with those (Cs-137) deduced experimentally. They are also in good agreement with the literature. Minimum activities for triggering the alarm of the RPM were estimated for Cs-137 and Co-60 radioactive sources for 70cm above ground and 300cm away from pillar (half distance between both pillars) were estimate and found 5.9 μCi and 1.8 μCi respectively.

For Traffic Accidents part of this study:

- The percentage of traffic accidents involving a truck is 12%, with the same percentage of impacts compared with all the other traffic accidents.
- It was observed that the severity of all the vehicle accidents in the dual carriageway part from 532 km up to 549 km with two lanes per direction is four times less.
- There is a relationship between all serious and fatal truck accidents with the movement in the opposite traffic lane and head-on collisions.
- It was observed that all truck traffic accidents were recorded in the single carriageway part from 485 km up to 532 km which is 47 km long.
- There are no road points that can be described as dangerous. Most recurring accidents had taken place in perfectly straight sections, without differences if compared with other points of the roadway.
- There is no correlation between bad weather or limited light and truck accidents. There is a relationship between the morning hours (07:00 - 12:00), with increased number of truck accidents and their severity with increased traffic load. There is a relationship between the weekend and increased number of truck accidents which cannot be reasoned.

References

1. S. Apikyan, D. Diamond, R. Way, *Prevention, Detection and Response to Nuclear and Radiological Threats* (Springer, 2008)
2. P. Saukko, B. Knight. *Forensic Pathology*. 281–300 (Arnold, 2004)
3. M. Peden, R. Scurfield, D. Sleet, *World report on road traffic injury prevention*, (World Health Organization., 2004)
4. WHO Regional Office for Europe, *Atlas of health in Europe*, 56 (WHO, 2008).
5. J. Ely, R. Kouzes, J. Schweppe, E. Siciliano, D. Strachan, D.Weier, , Nucl. Instr. and Meth. Phys. A 373-387 (2006)
6. C. Correa, T. Ortiz, O. González, J.I. Serrano, J.A. González., IRPA12, (2008)