The 15th International Congress of the International Radiation Protection Association

Holistic approach for radiological risk assessment in the transport of radioactive material in Cuba

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Abstract. The aim of this study was a holistic approach for radiological risk assessment in the operations related with transportation making for the two carriers of radioactive material by road from Cuba. In the first case, there is the Centre of Isotopes (CENTIS) which is designer, consignor and carrier of type A packages with radiopharmaceuticals and labelled compounds. In the other hand, the Centre of Protection and Hygiene of Radiations (CPHR) is the carrier through all the country of radioactive wastes and disused radioactive sealed sources, in industrial packages (BI-1) and type B packages, respectively.
Two used proactive methods of risk matrix and the failures and modes effects analysis with incident learning system, contributing to the improvement of the safety and quality of these practices. A conversion of first to second method, based in standard classification variables for the last and with relationship to workers and public, making a standard causes list and creating of an international incident database, as an integrated method, is the new aspects for risk assessment.
All this applied using the Cuban code SECURE-MR-FMEA version 3.0. The treated medium-level risk with very severe consequences for public included stolen or lost radioactive material and malicious act in spite of their no occurrence in our country. Some obtained results in graphic form as histogram for level-risk, by stage process in risk matrix and FMEA, Ishikawa diagram, initiating events matching with records from ILS and the main root causes from last two methods, allowed identifying operations with higher importance for risk and the safety measures and basic causes with most contribution. The shipments to airport and the cause of no fulfilment of procedures and best practices are the most important contributors. Packages of radioactive material with removable radioactive contamination on the outside surfaces or with defective shielding are occurrences with higher frequency and matching between model and records from database.
This experience may be useful for others in this field towards the radiological safety improvement and a safety culture development with a report culture and the lesson learned.

KEYWORDS: transport, radioactive material, risk analysis, risk matrix, failure mode and effect analysis, incident learning system.

1 INTRODUCTION

The state of the art shows that there is a limited publication on the use of half-quantitative methods for radiological risk in the transport of radioactive material. The risk matrix is suitable for the transport of radioactive sealed sources of category 1. [1] Nevertheless, there is no report of the combined use of prospective and reactive methods in this practice. Risk analysis takes part in the safety assessment and this is a regulatory requirement in Cuba.
The Centre of Isotopes (CENTIS) is designer, consignor and carrier of type A packages with open sources and the Centre of Protection and Hygiene of Radiations (CPHR) includes also this kind of packages and radioactive wastes and disused radioactive sealed sources in industrial packages (BI-1) and type B packages, respectively. [2]
The goal of this study is to evaluate the radiological risk assessment in these main carriers by road from Cuba by using a combination of risk matrix, failures and modes effects analysis (FMEA) and incident learning system (ILS) for workers and public. This is a holistic approach, as an answer of the Bon Call for action, which allows identify the main contributors to risk and allows to the decision makers to optimize efforts and resources, to eliminate of weaknesses and to put on good practices.

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2 MATERIALS AND METHODS

2.1 Models of risk matrix for the main Cuban carriers by road

Created two models belonging respectively to CENTIS and CPHR are taking into account differences in their processes, radioactive inventories and their packages.
A list of ‘‘initiating events’’ (IE) and their frequency taken from reports [3-9] and experts' approach were included in the model for applying the risk matrix method.
Thus an ‘‘accidental sequence’’ is a chain of events starting with the initiating events and possibly ending up in an undesired consequence, including accidental exposure. It includes the initiating event, the success or failure of the safety measures, and the potential appearance of the consequences in the form of an accidental exposure.
Considering all basic aspects [10], the risk matrix approach is applied considering the risk is a product of tree independent variables: the frequency (or annual probability of occurrence) of the hazard (initiating event) that challenges the process, P is the probability of failure of the barriers provided, and C is the severity of the potential harm (consequences).
Safety measures or barriers are the measures in place to avoid, prevent, detect, and stop an accidental exposure or to mitigate its consequences. Safety measures may be of a technological (such as alarms) or organizational nature (such as procedures or double checks to avoid or detect an error.) All of them are part of the defence in depth principle. Barriers (B) that do not stop the incident from progressing but that can reduce the probability of the initiating event or the severity of the consequences are called ‘‘frequency reducers’’ (FR) and ‘‘consequence reducers’’ (CR). All of them named as "control elements" in this research.
Four risk levels used to carry out the first screening of events in the process are very high risk (VHR), high risk (HR), medium risk (MR) and low risk (LR). Accidental sequences with a risk assignment of ‘‘low’’ do not require further analysis, so that attention can be focused on the fewer remaining sequences of ‘‘high’’ and ‘‘very high’’ risk. Besides, there is defined robustness for each control risk element as soft (S), normal (N) and robust (R).
Revised methodologies for safety assessment of dispersible material are for deriving dangerous quantities of radioactive material by each radionuclide (D values) [11] and the methodology known as the Q system which is described in the advisory material that accompanies the IAEA regulation [12]. The first of them selected taking into account the lesser values of ^{131}I activity for deterministic effects in thyroid and defining the consequences level for CENTIS.
Risk analysis carried out with the Cuban code SECURE-MR-FMEA 3.0, developed for applying the risk matrix methodology and its conversion in FMEA from the Institute of Applied Technologies and Sciences in Havana. [13]
From risk matrix inherent and residual risk in conjunction of the main defences are the most important results where is incorporating the impact from their elimination.

2.2 Holistic approach for risk analysis in the main Cuban carriers by road

There is a necessity of applying the holistic approach with the combined use of risk matrix, FMEA and IL with focus in the knowledge of root causes before preparing the quality and safety plan for improvement. For this purpose is using a standard list of root causes but wide, a similar structure of the data base incident and adapted SAFRON´s severity scale. [14-16]
Most contributors' sub-processes and root causes from FMEA are in correspondence with the risk priority number (RPN) and severity (S), but on the basis of equivalence showed in Table 1 with the previously adaptation of FMEA scale [14] but for workers and public. Also therein are an analysis of contribution of each sub-process, for workers and public, a conversion of each defence in a root cause by expert´s criteria and a deployment of root causes for independent point of view.
The created international data base incidents (IDB) has a total of 169 records until November 2019 from 16 countries, mainly from United State of America, United Kingdom and France. There is 114 records belonging to incidents and near miss with radioactive unsealed sources, which are valid for CENTIS and most often operations belonging to CPHR. For near misses it was used an adapted Nyflot´s five level scale originated from radiotherapy [16].

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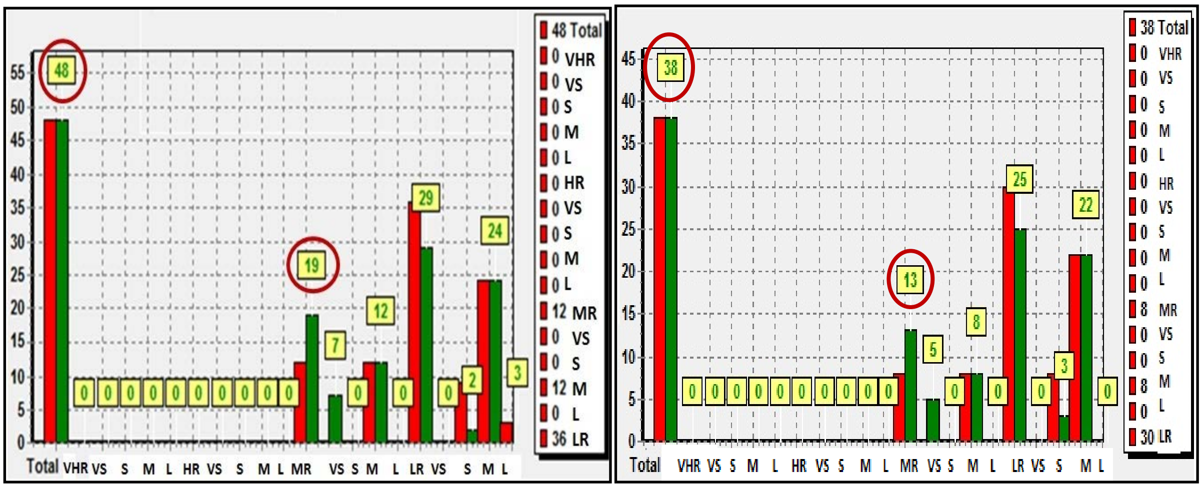
Table 1: Equivalence between risk matrix and FMEA used in its transformation

Frequency (RM)	Occurrence (FMEA)	Consequence (RM)	Severity (FMEA)	Amount of redundant barriers (RM)	Detectability (FMEA)
MB	1-3	B	1-2	0	9-10
B	4-6	M	3-4	1	7-8
M	7-8	A	5-7	2	5-6
A	9-10	MA	8-10	3	3-4
				4 or more	1-2

3 RESULTS AND DISCUSION

From developed models of risk matrix for CENTIS and CPHR are obtaining inherent risk and residual risk and these can be seen in Fig. 1. There were seven accidental sequences whom medium risk level with very severe consequences need to be eliminated in the first case (left side) and five in the second one (right side).

Figure 1: Comparative histograms belonging to inherent risk (green colour) and residual risk (red colour) for CENTIS (left side) and CPHR (right side) and the levels of very high risk (VHR), high risk (HR), medium risk (RM) and low risk (LR). For each one there are the consequences very severe (VS), severe (S), medium (M) and low (L) (they are in x-axis)



The most important barriers for CENTIS are shown in Fig. 2. It is important highlight the use of the impact from their elimination in the risk of accidental sequences as a meaningful complement of the participation analysis. In the same way most important frequency reducers (FR) and consequence reducers (CR) are shown in Fig. 3, only for their participation since lower robustness.

From risk matrix in the two studied contexts the consequences of incidents are severe for public with 12% and 16%, respectively. This is due to CENTIS has more accidental sequences than CPHR. Besides, workers have highest percent of medium consequences for CPHR since specific weight of their exposure from participation in the preparation of packages (Fig. 4).

For bow cases the transportation to airport is the stage process with the most important contribution to risk. CENTIS has more dispersible radioactive inventory and CPHR has category 3 radioactive sealed source for its supplier´s devolution. This can be observed in Figs. 5 and 7 from risk matrix (left side) and FMEA (right side).

In Fig. 6 there is a section of Ishikawa tree for CENTIS with selection criterions of RPN≥40 and severity index [14] (Sev) ≥ 4 and 20% of highest values of RPN. The most important sub-process is confirmed as the mentioned before.

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Figure 2: Fraction of the total accidental sequences in which there are barriers (B) contributing to risk level for CENTIS (y-axis in left side). Number and robustness of each barrier are in x-axis and legend (normal (N), robust (R) and soft (S)). Number of total accidental sequences in which lack barriers contributing to increase of risk level (right side)

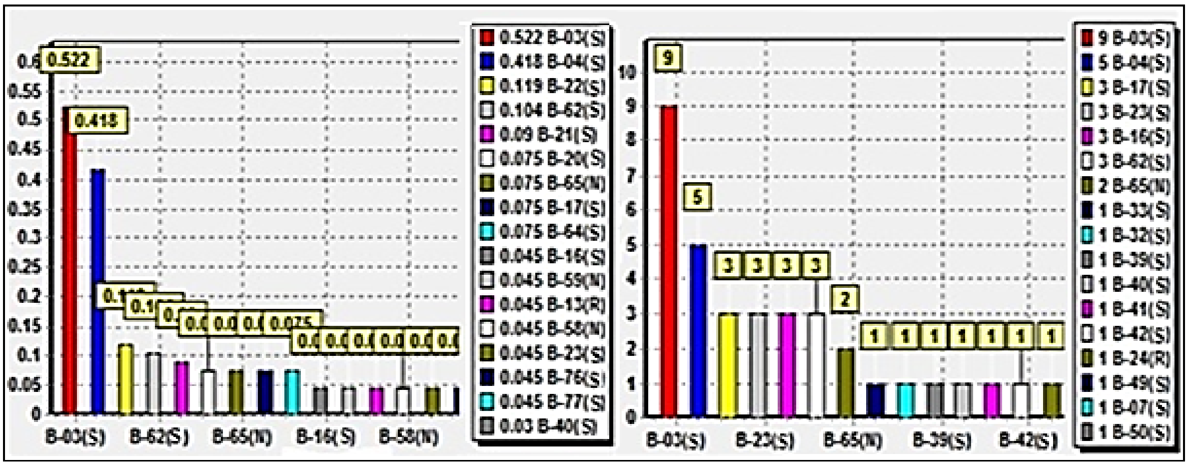

Figure 3: Fraction of the total accidental sequences in which there are frequency reducers (left side) or consequences reducers (right side) contributing to risk level for CENTIS (y-axis). Number and robustness of each FR (left side) or CR (right side) are in x-axis and legend (normal (N) and soft (S))

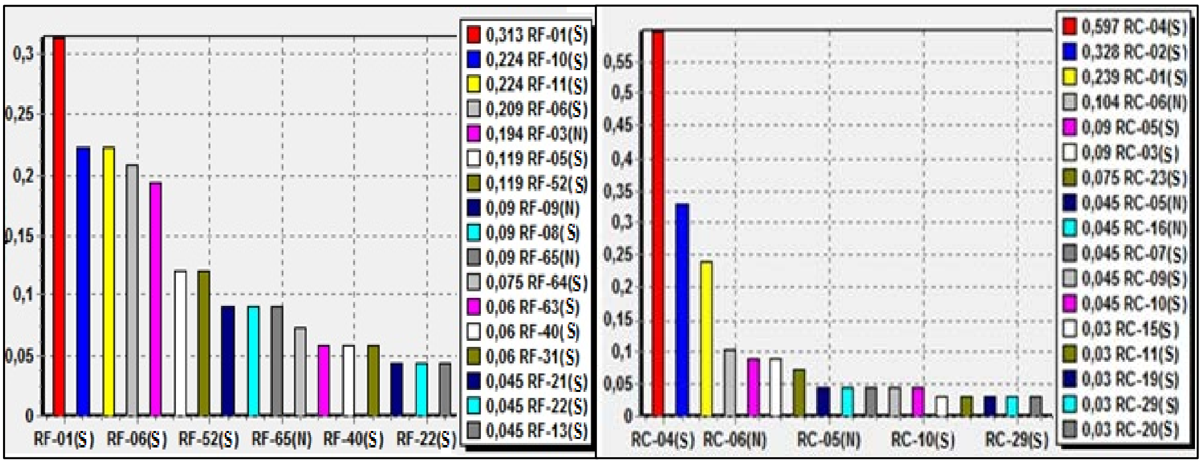

Figure 4: Fraction of the total consequences (y-axis) by each consequence level (medium (M), severe (S) and low (L)) belonging to workers (POE) and public (PUB) for CENTIS (left side) and CPHR (right side) in y-axis and legend.

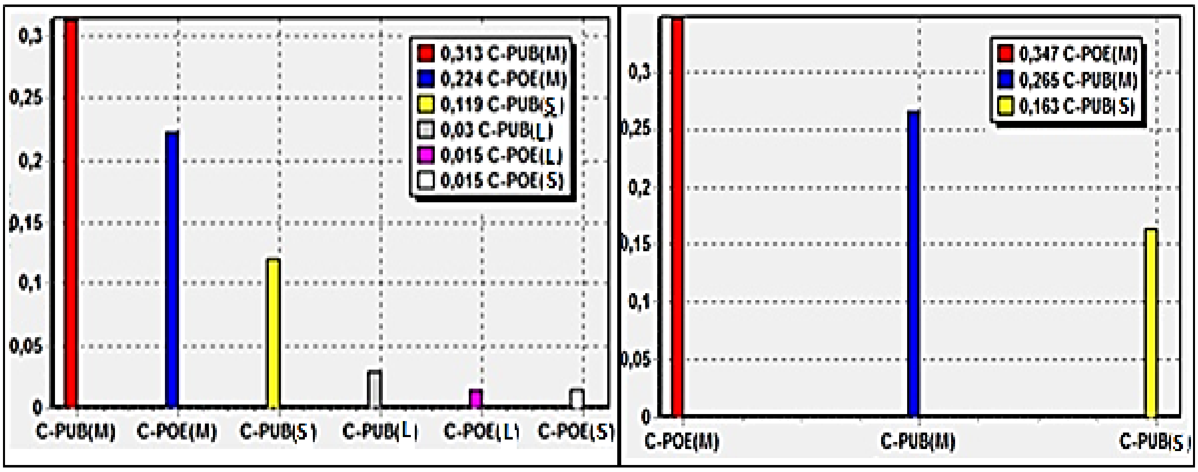

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Figure 5: Histograms by process stage for risk matrix (left side) and by sub-process for FMEA (right side) for CENTIS

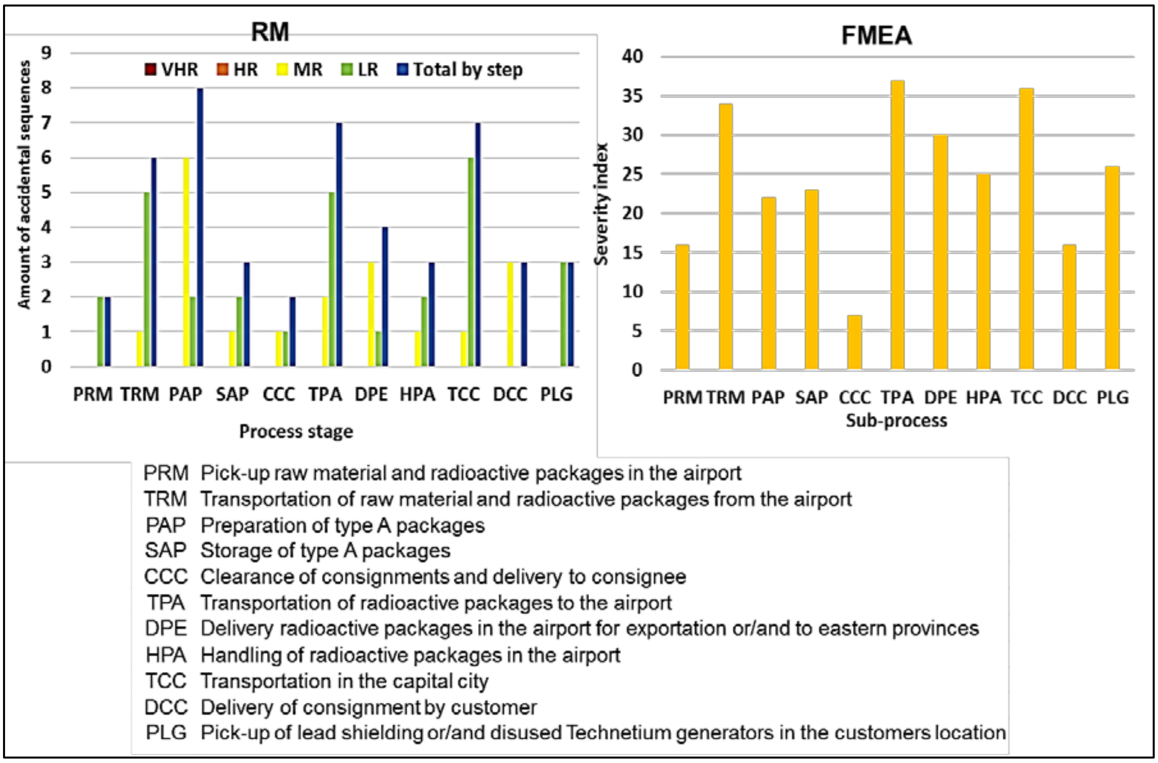
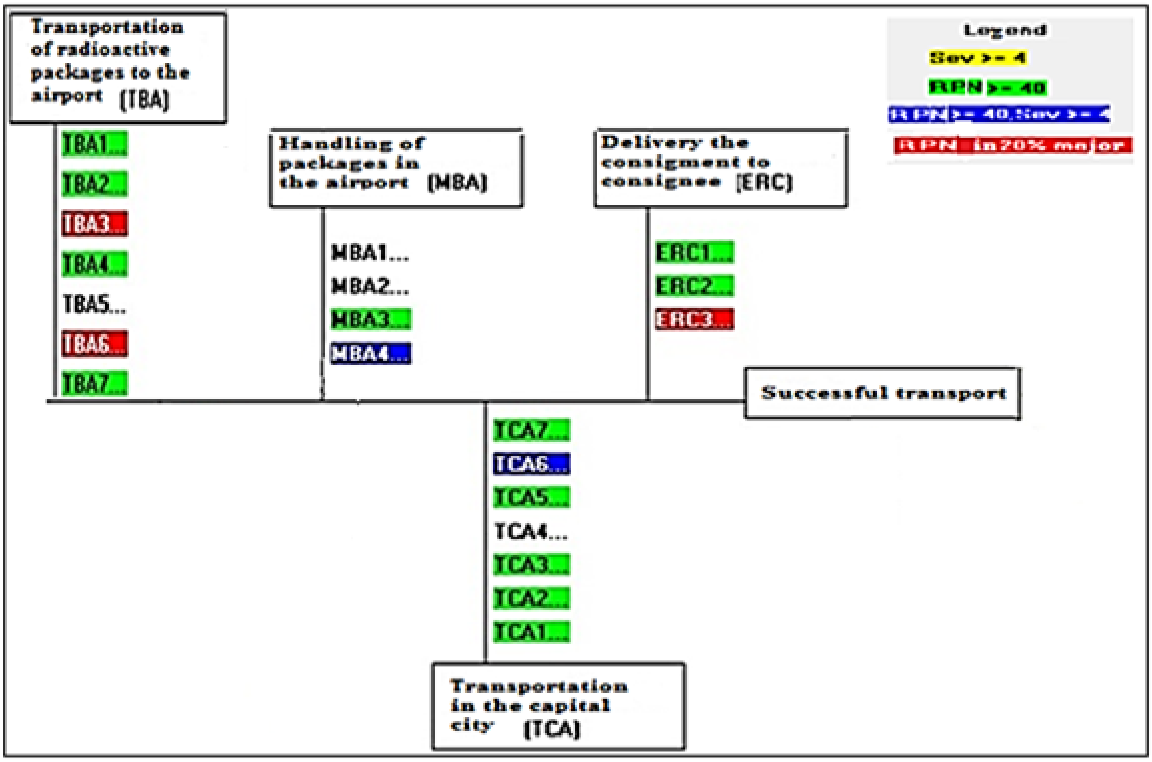


Figure 6: Section of the Ishikawa tree for CENTIS



There is a prevalence of human mistake with 81.25% for CENTIS since this has highest number of accidental sequences. The considered failures of equipment are a fire and explosion in the vehicle and the vehicle´s breaking in a place with public concentration.

The mistake in the preparation of packages and the lost of packages are the most registered incidents in IDB for radioactive unsealed sources. This behavior is showed in Fig. 8.

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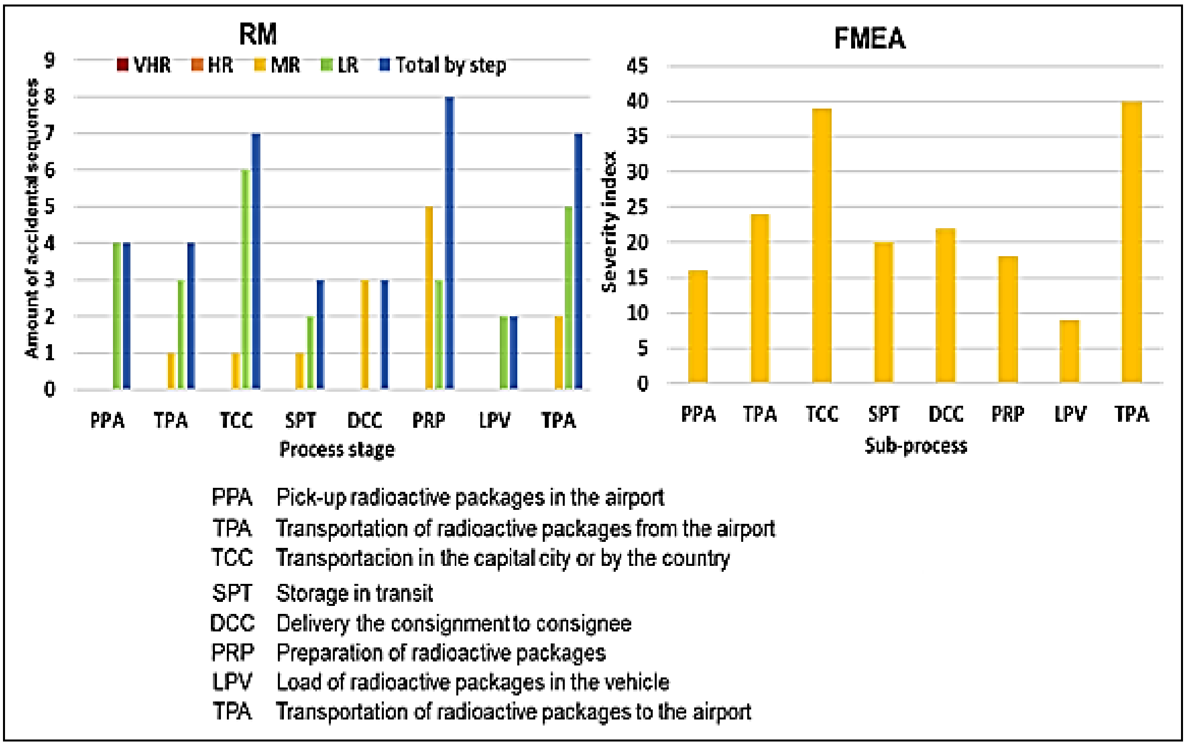
Obtained initiating events (IE) matching with records from synergy RM-ILS can be seen in Fig. 9. For both contexts are highlight the presence of external radioactive surface contamination of type A packages (CENTIS) and radioactive packages with deficient shielding (CPHR).

Figure 7: Histograms by process stage from risk matrix (left side) and by sub-process for FMEA (right side) for CPHR



The synergy FMEA-ILS focused in root causes delivers the most important to risk in Fig. 10. The non-fulfilment of practices, procedures or standards is highlight and this denotes a weakness of safety culture in these organizations. Besides, in the same way is the main basic causes from IDB records for CENTIS (Fig. 11). The adding new corrective or preventive actions for eliminating identified root causes together with defenses incorporated from obtaining residual risk is a complement for this analysis and represent a meaningful tool for decision makers.

Figure 8: Histogram by type of incident of BDI records for CENTIS

No.	Type of incident
1	Conveyance in accident
2	Air accident with fire
3	Release of contents due to conveyance in accident
4	Mistake in the package preparation
6	Handling package mistake in the airport
7	Release of contents in the airport
8	Mistake in the packages clearance
9	Mistake in fixing package on loading area of a vehicle
10	Handling package mistake
11	Mistake in consigment documentation
12	Mistake in air transport of consignment
13	Mistake with the consignee
14	Delay in a delivery
15	Loss of package
16	Theft of package
17	Non-autorised holding
18	Non-used personal dosimetry
20	Non-autorized transportation

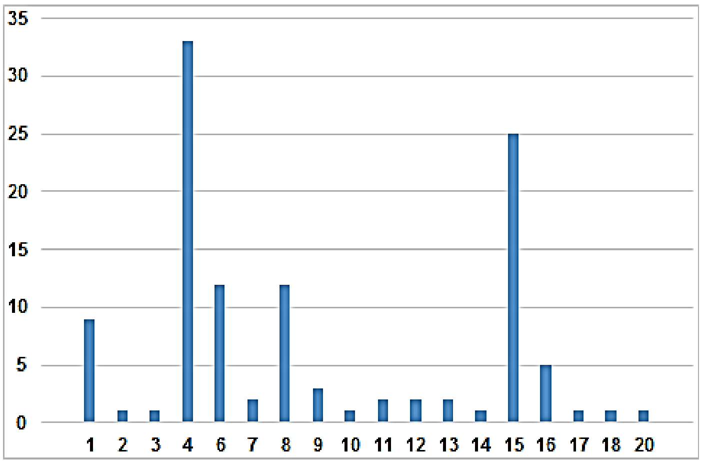


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Figure 9: Histograms of the initiating events (IE) with better matching from synergy RM-ILS for CENTIS (left side) and CPHR (right side)

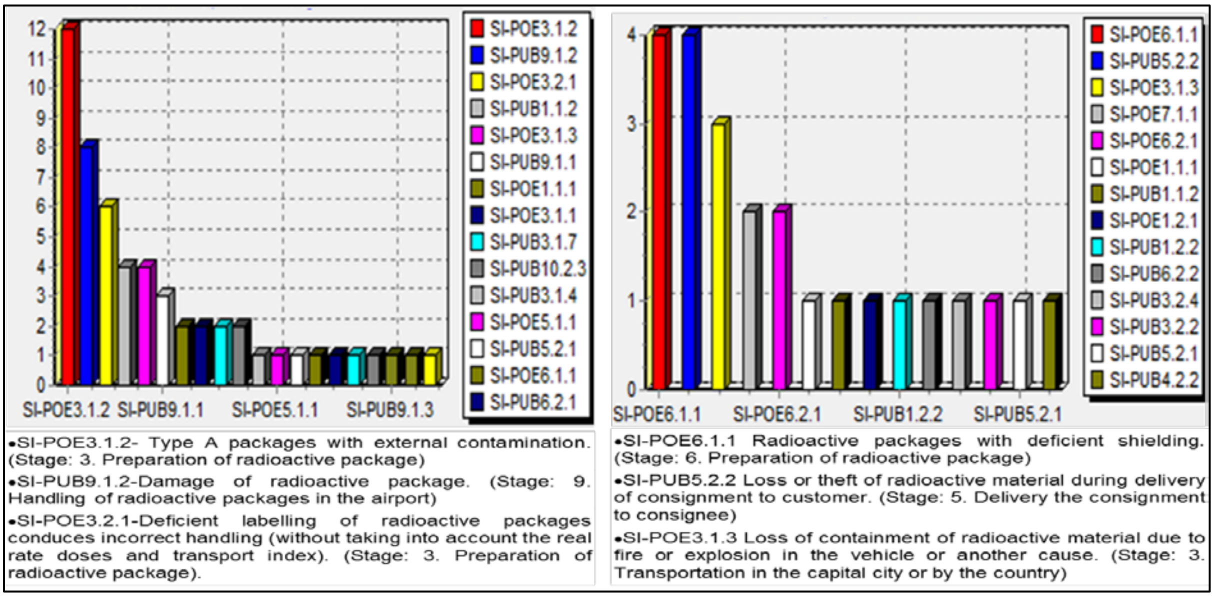
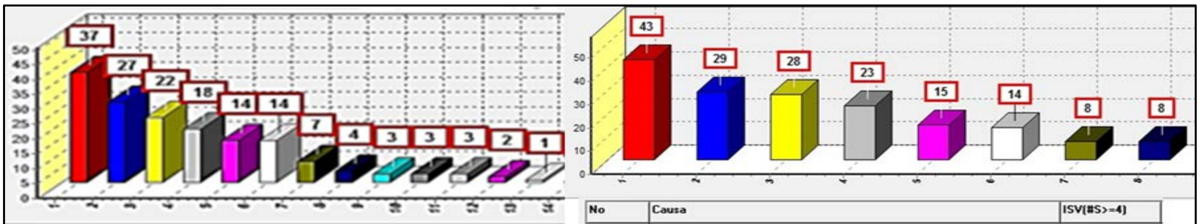


Figure 10: Histograms for the main basic causes from FMEA for CENTIS (left side) and CPHR (right side)



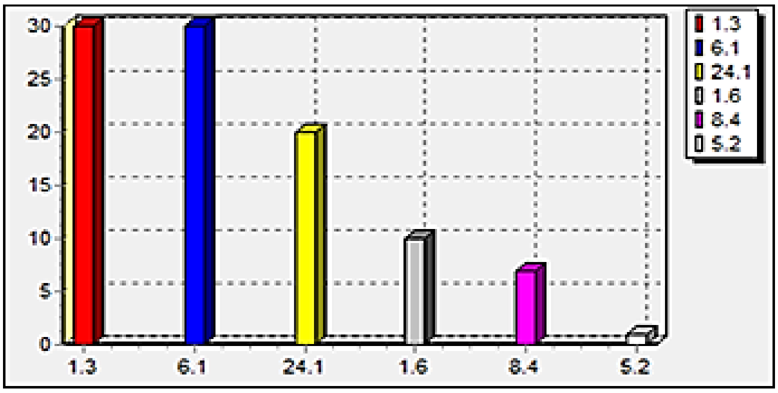
No	Causa	ISV(#S>=4)
1	1.3	58(7)
2	6.1	43(3)
3	1.2	35(2)
4	5.3	33(6)
5	2.1	22(5)
6	8.4	26(3)

No	Causa	ISV(#S>=4)
1	1.3	43(5)
2	5.3	29(5)
3	6.1	28(2)
4	2.1	23(4)
5	1.2	15(1)
6	8.4	14(1)
7	2.3	8(0)
8	3.2	8(0)

1.3 Practices/Procedures/Standards- non-compliance
6.1 Development of abilities and knowledge-inadequate training/orientation
1.2 Practices/Procedures/Standards- inadequate

1.3 Practices/Procedures/Standards- non-compliance
5.3 Communication-inadequate direction of communication/information
6.1 Practices/Procedures/Standards- inadequate

Figure 11: Histogram of root causes recorded in CENTIS IDB



1.3 Practices/Procedures/Standards- non-compliance
6.1 Development of abilities and knowledge-inadequate training/orientation
24.1 Safety and security culture-Lack of priority for safety and/or security

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4 CONCLUSIONS

This study focused on applying the holistic approach with the combined use of risk matrix, FMEA and ILS for risk analysis in the main two Cuban carriers by road. There is a necessity to apply defences to reduce the medium risk with very severe consequences in the lost or stolen of radioactive material. These events should be foreseen and each organization should be prepare for appropriately responding.
The identification of the most important root causes for risk improves effectiveness in the quality and safety management. Besides, this research allows strengthening of the safety culture in an organization and that decision makers could optimize efforts and resources to eliminate weaknesses and to apply good practices. The used tools and models provide an opportunity for self-evaluation, manage the safety measures that are most suitable to carriers of type A, BI-1 and B packages and facilitate the ongoing learning.

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