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IMPACT FROM ROAD TRANSPORT OF RADIOACTIVE WASTES IN SPAIN

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EXTENDED ABSTRACT

Transports of radioactive wastes in Spain are becoming issues of renewed interest, due to the increased mobility of these materials which can be expected after the building and operation of the planned central repository for this country in a near future. Such types of residues will be mainly of the medium and high activity classes and have raised concerns on the safety of the operations, the radiological protection of the individuals, the compliance with the legal regulations and their environmental consequences of all kind.

In this study, relevant information for the assessment of radiological risk of road transport were taken into account, as the sources and destination of the radioactive transports, the amount of traveling to be done, the preferred routes and populations affected, the characterization of the residues and containers, their corresponding testing, etc. These data were supplied by different organizations fully related with these activities, like the nuclear power stations, the companies in charge of radioactive transports, the enterprises for inspection and control of the activities, etc., as well as the government institutions which are responsible for the selection and location of the storage facility and other decisions on the nuclear policies of the country.

Thus, we have developed a program for computing the data in such a form that by entering the radiation levels at one meter of the transport loads and by choosing a particular displacement, the computer application is capable to calculate the corresponding radiological effects, like the global estimated impact, its relevance to the population in general or on those people living and driving near the main road routes, the doses received by the most exposed individuals (e.g. the workers for loading or driving the vehicle), or the probability of detrimental on the human health.

The results of this work could be of help for a better understanding and management of these activities and their related impacts; at the same time that the generated reports of the computer application are considered of particular interest as innovative and complementary information to the current legal documentation, which is basically required for transporting radioactive wastes in the country, according with the international safety rules (like IAEA and ADR).

Though main studies are still in progress, as the definite location for the Spanish storage facility has not been decided yet, preliminary results with the existing transports of residues of medium activity indicate that the radiological impact is very low in conventional operations. Nevertheless, the management of these transports is complex and laborious, making it convenient to progress further in the analysis and quantification of this kind of events, which constitutes one of the main objectives of the present study for the radioactive road mobility in Spain.

Keywords: high-level radioactive wastes, nuclear transports, central temporary storage facility, radiological impacts, radiological protection, health detriment, environmental management.

1. INTRODUCTION

Safety of individuals and workers [1], environmental compliance and commitment with the legal framework are of fundamental importance in transports of high level radioactive wastes (HLWs), mainly coming from the spent fuels of nuclear power stations. Typical composition of this waste is: 94.7% uranium (0.7% of this being U-235), 4.1% fission products, 1.1% plutonium and 0,1% minor actinides; it is a solid product which decays its activity with time and which is generated in relatively small quantities (about 5 g per person-year in the European Union).

But a long `radioactive route´ of more than 2000 km for transporting spent nuclear fuels can be expected in Spain, presumably by road, from current and decommissioned power facilities to the planned central repository (ATC).

2. TRANSPORT REGULATIONS FOR HLWs

Transports of HLWs are regulated by a series of internationally accepted documents based on the IAEA safety standard ("Regulations for the Safe Transport of Radioactive Materials" TS-R-1) and the European agreement for carriage of dangerous goods by road (ADR) [2]. Safety regulations for transport in these documents lie above all on containers (suitable shielding for gamma and neutron radiation, maintenance of subcritical conditions and cooling the decay heat emitted by spent fuels), stipulating the types B (U) and B (M), and establishing design criteria approved by the regulatory body in accordance with the activity and physical form of radioactive materials which they contain.

Construction of industrial-scale containers for spent fuels is necessary to check the behaviour of materials exposed to extreme conditions of neutron irradiation, which usually experience a loss of ductility due to alteration of their microstructure. Weakening and embrittlement due to neutron irradiation are phenomena governed by interactions of multiple variables, like the material type, its composition, initial microstructure, irradiation temperatures, flow and neutronic spectrum) [3]. However, no modifications can be expected in the initial properties of the materials designed for use in containers for transportation purposes.

Another fundamental requirement is training of drivers for vehicle transports, as well as monitoring and control by safety counsellors [4].

3. EVALUATION METHODOLOGY

The methodology used in this study is based on `descriptive-explanatory methods', which allow the observation and collection of data by means of 'case study' approaches [5, 6]. The aim is to describe systematically the logistics for HLW transports and its associated radiological impact. We have chosen the transport of spent nuclear fuels for its complexity in the sphere of radioactive transports, as well as for the controls imposed by the regulatory body, the relevant framework that regulates it and for its importance within the current national energy scenery.

There are six nuclear power plants in operation in Spain: Cofrentes, Garoña, Vandellos II, Trillo, Almaraz and Ascó [7], with a total of 8 reactors, and one plant that has been declared definitively shut down (Jose Cabrera); according with the government commitment and action plan, wastes from all these facilities will be shipped to a central temporary repository to be located and built next years. Several companies have collaborated in the elaboration of this work, like the nuclear power industries, the national company for radioactive wastes, the radioactive hauliers, etc.).

Although the main objective of this study is to evaluate the radiological exposure of population from the emission of ionizing radiations associated with the transport of radioactive materials, it also aims to determine the probability of health risks. The radiations produce ionization upon passing through the tissues of living organisms, and this disturbs the chemical behaviour of the constituents of the affected cells, some of which can regenerate while others may be damaged.

Exposed individuals are not bound to suffer cancer or genetic injuries, but they run a higher risk than non-irradiated persons and this risk increases with dose [8].

To make widely applicable estimates, the International Commission on Radiological Protection recommends a series of values of risk, obtained from populations of different continents and countries [9]; the average of these values, regarding the probability of death by cancer, is “5% per *Sievert* in a population of all ages, as long as the doses and dose rates in question are low”.

In order to assess quantitatively the biological damage, an equivalent dose scale is used which measures the biological effects produced by the ionizing radiations in the living organisms [10]. In the case of this study, these are gamma and neutron emissions.

4. IMPACT OF HLWs ROAD TRANSPORTS IN SPAIN

Negative impacts associated with this kind of transports affect the environment, especially living organisms exposed to radiations and in particular human health. Thus we began by establishing the number of transports that are to be performed annually [11]. In total `8 routes´ for transporting high level wastes are considered, along which `48 movements´ should be made during the annual period under review; we identified the provinces affected by the transport routes, the distances travelled and time taken, along with population in each route and national (with regard to the last point, only the exposed population of all routes were taken into account, leaving aside Galicia, Cantabria, the Basque Country, Navarra, Murcia and Andalucía).

The estimated total impact caused by ionizing radiations in the environment, as sum of number of transports per hours travelled and per the radiation levels at a distance of 1 m away from the vehicle, is 34.55 $mSv \cdot a^{-1}$ (table 1); which is within the permitted annual legal limit for professional exposures to ionizing radiations in Spain (50.00 $mSv \cdot a^{-1}$), and it is also of the same order as for transports of radioactive materials not associated with the spent fuels (46.64 $mSv\ a^{-1}$) [12].

However, with ionizing emissions there are processes of mitigation according to the distances, i.e., as we move away from the emitting source, the radiation level decreases.

The dose that an individual can receive (driver or passenger of other vehicle that coincides with the transport of radioactive materials) is 0.97 $\mu Sv \cdot a^{-1}$. This is comparable to estimations of other studies [13], indicating that the radiation doses for persons located 10 m away from the circulation route of spent nuclear fuels travelling at 20 km/h would be only 0.025 µSv.

The impact on the “exposed group” [14], located in regions through which this type of transport passes (national impact), applied to all residents of the different provinces is $1.92 \cdot 10^{-3}$ $\mu Sv \cdot a^{-1}$. This is also comparable to the studies of environmental impact statement for transports of spent nuclear fuel to the deep geological repository in Yucca Mountain, U.S. [15] , which considers that the average dose to members of the public would be 0.005 $\mu Sv \cdot a^{-1}$.

As vehicles are usually in motion, the doses (D) at a point P produced by the moving source can be obtained in function of the transport index (IT) and distance from the radioactive material to P (fig. 1). In order to maintain dimensional consistency, we introduce a constant (K_D) whose value is 1 m^2, and the dose produced by the moving sources along the entire trajectory is obtained by integrating the expression:

$$D(P) = K\,\frac{A}{d_1^{\,2}} \qquad D(B) = K\,\frac{A}{d_2^{\,2}} \qquad A = \textit{activity of the source} \tag{1}$$

$$D(P) = D(B)\,\frac{d_2^{\,2}}{d_1^{\,2}} \qquad D(P) = \frac{IT}{d_1^{\,2}} \qquad d_1^{\,2} = v^2 \cdot t^2 + b^2 \tag{2}$$

$$\int dD(P) = \int_0^{\infty} K_D \cdot IT \Big/ (v^2 \cdot t^2 + b^2) \cdot dt = K_D \cdot IT \Big/ b \cdot v\,(arctg\ v \cdot t/b) \tag{3}$$

And finally, we obtain: $$D(P) = \pi \cdot K_D \cdot IT / b \cdot v \qquad (4)$$

IT = transport index, the radiation level at $d_2 = 1$ m from the source (µSv/h)
b = distance to the vehicle (m)
v = speed of the vehicle (m/h)

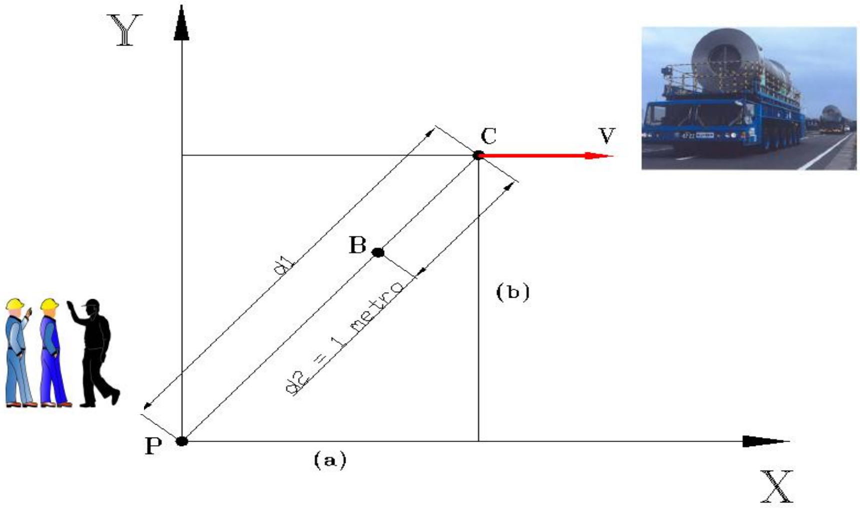

Figure 1: Dose produced at one point by a moving vehicle carrying radioactive materials

The last expression is used to calculate the exact radiation doses that a group of people would receive when they are located at a given distance from the transport vehicle moving at speed *v*.

If we focus on the impact generated upon national population, taking into consideration:

1. the overall dose of 34.55 $\mu Sv \cdot a^{-1}$, calculated according to the radiation level at 1 m of transports, for a speed of 40 km/h (in accordance with the road safety guidelines for this type of transport),
2. and impact distance of approximately 1 km (a radius within the bulk of the population of big cities like Madrid or Barcelona may be found, i.e. the most significant groups),

we can obtain:

$$D(P) = \pi \times 34.55 / 40000 = 2.71 \cdot 10^{-3}\ \mu Sv \cdot a^{-1} \qquad (5)$$

which is similar to the dose that we had already obtained of $1.92 \cdot 10^{-3}$ $\mu Sv \cdot a^{-1}$ (table 1).

These calculations are just general estimates in terms of the distances, vehicle speed, location of the population, etc. Nevertheless, the objective is to compare differences between the initial treatment of data and its calculation using more scientific processes; though, as it was observed, the two sets of data are similar.

As assumed, the dose rates decrease with the inverse squares of distances from the packages. However, this is not entirely valid, as containers for spent fuels are typically about 5 m long and 2 m in diameter; thus, they do not represent point sources at 1 m, and the dose rates will initially decrease more slowly with the distances. Only at a distance of several metres, the `square law´

inverse becomes a suitable approximation; however, when the distances are greater than a few tens of metres, photon scattering and absorption phenomena in air will become appreciable and the dose rates will fall off more rapidly than the square law.

Probability for the most exposed individuals developing a severe illness (cancer), resulting from the exposure to radiations, is $2.58 \cdot 10^{-7}$, and $9.86 \cdot 10^{-11}$ if considered at national level (table 1). This figure is obtained as the quotient between the dose received by the general public and the probability of death from cancer of 5% per Sv in a population of all ages, provided that the dose and dose rates are low.

In a recent epidemiological study of the possible health effects of ionizing radiations arising from the operation of the Spanish nuclear fuel cycle and radioactive facilities, on population living in the areas surrounding such installations [16], the "effective dose", was proposed as an indicator of exposure, since several external exposure paths for radiations were identified along with others such as liquid and gaseous effluents that can be incorporated into the human body.

In this paper, "distance" is proposed as main indicator, on the basis of the attenuation achieved in the process of emission, being in opinion of the authors the most appropriate approach in this case, since we dealt only with external exposures to the ionizing radiations.

Table 1: Radiological impact from road transport of high level radioactive wastes in Spain

EXPECTED ANNUAL RADIOLOGICAL IMPACTS ASSOCIATED WITH THE TRANSPORT OF HIGH LEVEL RADIOACTIVE WASTES (HLWs) BY ROAD IN SPAIN							
ROUTES	**Total dose impact ($\mu Sv \cdot a^{-1}$)**	**Dose to most exposed individual ($\mu Sv \cdot a^{-1}$)**	**Dose to public (impact on route) ($\mu Sv \cdot a^{-1}$)**	**Dose to public (national impact) ($\mu Sv \cdot a^{-1}$)**	**Detriment to health (most exposed individual)**	**Detriment to health (public on route)**	**Detriment to health (national impact)**
FROM NUCLEAR POWER PLANTS TO CENTRALISED REPOSITORY	28050	0.97	3.80 E-03	1.59 E-03	2.41 E-07	1.90 E-10	8.19 E-11
FROM FRANCE THROUGH LA JUNQUERA (VITRIFIED FUEL) TO CENTRALISED REPOSITORY	6500	0.55	9.37 E-04	3.33 E-04	2.75 E-07	4.68 E-11	1.67 E-11
OVERALL	**34550**	**0.76**	**N/A**	**1.92 E-03**	**2.58 E-07**	**N/A**	**9.86 E-11**

Overall dose impact: Value obtained from the contribution of all shipments performed on all the routes.

Dose of most exposed individual: 5 seconds x 7 overtaking manoeuvres on route. The transport travels at 40 km/h and private vehicles, truck or car, at 90 km/h on the longest route. We assume that drivers of private vehicles travel on the route at the same time as radioactive material is transported.

Dose to public: Consideration is given to the population of all ages living in the provinces through which the shipment passes.

Dose to public, national impact: Population of all ages in the national environment, subjected to impact.

Health detriment (death by cancer): the average value as regards probability of death by cancer is 5% per Sievert in a population of all ages.

Although units for description of overall impact are proposed in equivalent doses (µSv), it would be better to express them in units of exposure or absorbed dose (µGy), since doses may or may not be acquired by human beings (depending on whether they are or not in areas of exposure). Anyway, in the case of gamma emission the exposure is similar to the absorbed dose and same as the equivalent dose. Consequently, as values for the radiation level one metre away from the transport vehicle are measured in units of equivalent dose, the impacts obtained in this study are expressed in such units in all cases.

5. CALCULATION PROGRAM FOR RADIOLOGICAL IMPACT

As final contribution, we present a computer application for treatment of the data studied, along with a summary sheet: "Radiological impact associated with the transport by road of high level radioactive waste in Spain".

This is perhaps the most interesting part of this work and constitutes a step forward in the study of impacts, serving also to complement the required documentation for this kind of operations.

With this programme, one has only to enter the radiation levels measured at one metre from the transport vehicles and choose the routes (figure 2), data which are all supplied by the shippers. Thus, the associated radiological impacts are obtained (figure 3).

By the way and while the final location of the ATC in Spain is still to be determined, we propose a hypothetical location (e.g. the municipality of Ascó in Tarragona).

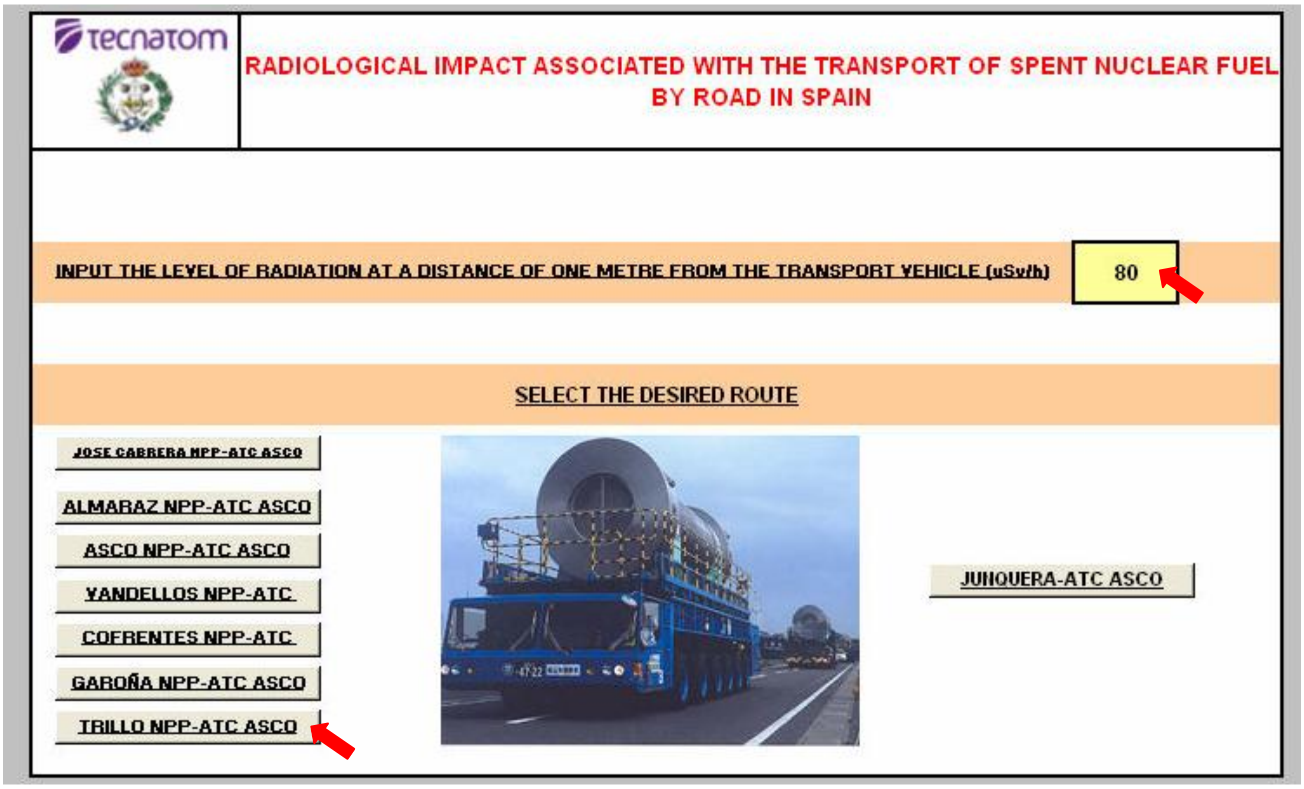

Figure 2: Page for data entry

RADIOLOGICAL IMPACT ASSOCIATED WITH THE TRANSPORT OF SPENT NUCLEAR FUEL BY ROAD IN SPAIN

ROUTE:	**TRILLO-ATC ASCO**
TIME IN ROUTE:	8,5 Hours
EXPOSED POPULATIONS:	Guadalajara-Soria-Zaragoza-Huesca-Tarragona
OVERALL RADIOLOGICAL IMPACT (uSv):	680
MOST EXPOSED INDIVIDUAL DOSE (uSv):	2,76
DETRIMENT TO HIS HEALTH:	1,38E-07
CONTRIBUTION TO POPULATION ON ROUTE (uSv):	1,56E-03
CONTRIBUTION TO NATIONAL DOSE (uSv):	1,74E-04
HEALTH DETRIMENT:	8,71E-12

CONSIDERATIONS:

Data reflect a research work considering those journeys carried out in a calendar year in Spain; worst case scenery has been assumed in the comprehensive study.

Figure 3: Page of results

6. CONCLUSIONS

As a first conclusion of this work, it has been demonstrated that ionizing radiations generated by transports of high level radioactive wastes in Spain are not significant in terms of producing adverse effects for human health. Furthermore, in normal conditions, the annual overall radiological impact is very low and has a negligible adverse impact.

Secondly, the radiological impacts associated with transportation of HLWs can be calculated by a new software application for processing the data on selected input materials and routes. This can be useful to advance in the analysis of impacts from such operations and to supplement the legal documentation required for this type of transports, if deemed necessary.

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