USE OF COSYMA IN THE DESIGN OF EPIDEMIOLOGICAL STUDIES IN CASE OF RADIOLOGICAL ACCIDENTS

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I. INTRODUCTION

In case of a radiological accident, the epidemiological assessment of health effects in exposed populations is necessary to verify risk predictions, to detect any unexpected effect and to improve the knowledge on the effects of low protracted doses of ionizing radiation (in some accidental situations, most of the people would be exposed to such low doses). This assessment is also useful to determine health needs of exposed populations, to adapt health care resources and to provide the "media" and the public with independent and validated information.

The Chernobyl accident demonstrated the necessity of a preparation for the implementation of epidemiological studies in such circumstances, in order to get the most accurate information on the health consequences. Although effects may appear years after the accident (e.g. cancers), the lack of early data collection on exposure and the number of people lost of follow-up make the evaluation of cancer excess risks very difficult. By simulating various radiological accidents with the code COSYMA [1] and predicting cancer risks for all of them, it is intended to calculate the key parameters that are necessary for the prompt implementation of effective epidemiological studies.

II. GENERAL OBJECTIVE

This study focuses on the assessment of post-accidental cancer risks. For this purpose, when designing epidemiological studies, the scientist has to answer the following questions :

* what types of cancer are mostly expected after the accident ?
* what population groups should be followed and how many subjects could or should be included in a study ?

The following parameters should be assessed for the entire population as well as for various groups (e.g. children who are more radiosensitive) :

* average doses to various organs (e.g. thyroid gland, bone marrow...) and to the whole body,
* number of exposed people in various dose intervals,
* number of expected spontaneous and predicted excess cancers for various organs and tissues in the exposed group,
* statistical power of any planned study on cancer, that is its probability to detect an excess risk.

Then, the epidemiologist has to define a dose level to classify the subjects in two groups: those with significant doses who will be considered as "exposed" and those with lower doses, "not exposed". The choice of this level could be optimized according to statistical power criteria. This means that one has to compromise with the expected risk in the followed group and the size of this group in order to be able to detect the excess risk statistically.

The work presented here aims at calculating the above parameters and the statistical power for various radiological accident scenarios. From the results, a typology of epidemiological studies will be constructed which could be used to guide the early collection of relevant data if a real accident occurred.

III. METHOD

The study was carried out as follows:

1. definition of a set of radiological accident scenarios;
2. for each scenario, simulation of N accidental situations and estimation of dose distributions, sites of expected cancers, and associated risks;
3. classification of the N accidental situations according to health effects and epidemiological criteria (number of exposed people, distribution of whole body and organ doses, types of expected cancers, excess risk values) ;
4. extraction of n typical situations among the N simulated ones;
5. statistical power calculations for the n situations to assess the probability to detect cancer excesses by epidemiological studies.

IV. DEFINITION OF A SET OF SCENARIOS

The list of possible scenarios of radiological accidents should be as exhaustive as possible. The characterization of an accidental situation is based on the type of accident (power reactor, reprocessing plant, transportation), the amount of radioactivity and the kind of radionuclides released into the environment (source term), the location of the accident (local meteorology and demography), and the set of countermeasures undertaken (evacuation, sheltering, stable iodine distribution, relocation). For plant calculations, three typical french sites were selected: one PWR located in the Loire valley, another one located in the Rhone valley, and the reprocessing plant of La Hague. The main characteristics of these sites are presented in Table 1. For transportation accident calculations, there is no particular location, and by looking at the routes of transportation a few rural and urban sites for potential accidents can be defined.

V. USE OF COSYMA IN SIMULATIONS

COSYMA was chosen among the various accident consequences assessment codes because of its power and flexibility. It performs all the calculation steps from activity release and dispersion to cancer risks, for any site of interest, using specific data input and allowing the retrieval of non-standard outputs. As a probabilistic code, COSYMA realizes a large number of simulations for one accident in the same run just by changing the weather sequence.

PWR source terms were constructed using the inventory of the COSYMA users intercomparison exercise [2] and release fractions for french nuclear reactors S1, S2, S3 (Table 2) [3]. For the reprocessing plant, two source terms were chosen arbitrarily, based on the actual radioactive materials present in the plant and on the radioactive decay of reprocessed PWR fuel (1g Plutonium and 0.01g Curium releases, Tables 4 and 5). For the transportation scenarios, several source terms still need to be defined, according to the materials transported, the modes of transportation, and the types of packaging. The post-accidental scenario has identical main options for all installations and source terms. The ingestion pathway was not treated in this study because of its unsatisfactory modeling in COSYMA. The intervention levels for the various countermeasures were drawn from ICRP 40 recommendations (Table 3) [4]. Both low and high levels were used for evacuation, sheltering and stable iodine prophylaxis. For long term actions, only the low intervention level was applied.

For the epidemiological calculations, the execution procedure of COSYMA was modified to save two non-standard output files. These files contain the individual organ doses and the individual risks for the late health effects calculated for all weather sequences. A program was written to extract the data from these files for one chosen weather sequence; it calculates the distribution of whole-body and organ doses in the population and performs statistical power calculations for prospective studies. Figure 1 shows the statistical power of a cohort study (prospective follow-up of an exposed group) as a function of the dose level defined above, for one accident in the nuclear power plant of the Rhone valley with wind oriented north. In this example, a maximal statistical power is observed for a dose level between 10 and 40 mSv. Under 10 mSv risks are low and could not be detected despite a large number of exposed subjects. When the dose level exceeds 40 mSv, the statistical power decreases despite higher risks, as the number of exposed subjects has become too low. A statistical power of 0.8 is generally accepted to conduct an epidemiological study.

VI. CONCLUSION

COSYMA is a powerful code for the assessment of a wide range of accident consequences. It has been satisfactory because of the possibility to get access to the code itself and to change options like release duration or outputs. COSYMA is a probabilistic code, but, in this application, it has been used in a deterministic way by extracting the results for one weather sequence only.

From an epidemiological standpoint, a few issues limit the use of COSYMA. Following a radiological accident, some tumors are expected, like thyroid cancers or leukemias. For these tumors, survival rates are rather good and therefore, to assess the health impact in epidemiological studies, morbidity data should be preferred to mortality data as those used in COSYMA. Indeed, the count of incident cases instead of deceased cases would increase the statistical power which is a critical parameter for the study of low protracted dose effects. In addition, it would be of great interest to look at different age classes and different periods of follow-up. It is not feasible by COSYMA which evaluates only cancer risks for the lifetime and the general population, since population and risk data are not detailed enough in the code.

VII. FIGURE AND TABLES

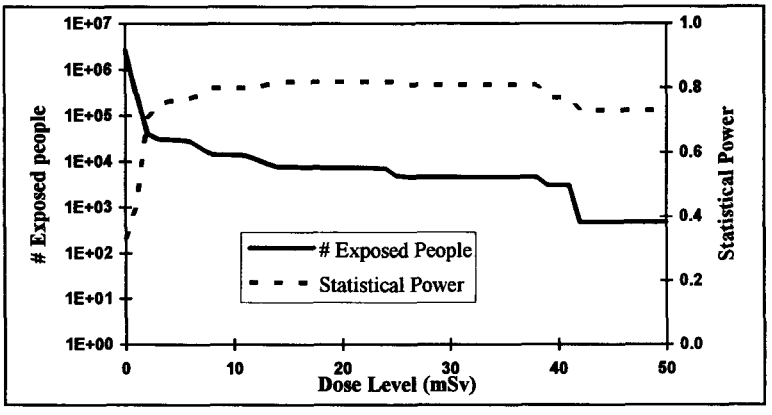

Figure 1 : Total number of exposed people and statistical power to detect an excess incidence of cancers as functions of the dose level that defines the exposed group. (Results for the thyroid gland)

Table 1 : French Sites Selection for Plants

Site	Main Wind Direction	Inhabitants within a radius of : 10 km	20 km	40 km	100 km
La Hague	West / South-West	7 841	84 098	194 158	638 487
Rhone valley	North ("Mistral")	34 977	92 372	340 463	1 941 728
Loire valley	-	20 769	56 342	430 897	1 967 423

Table 2 : Release fractions for PWRs

	Xe,Kr	I	Cs,Rb	Te,Sb	Ba,Sr	Co,Ru	La,Act
S1	8.10^{-1}	$6.6\ 10^{-1}$	$4\ 10^{-1}$	$8\ 10^{-2}$	$5\ 10^{-2}$	$2\ 10^{-2}$	$3\ 10^{-3}$
S2	$7{,}5.10^{-1}$	$3.2\ 10^{-2}$	$5.5\ 10^{-2}$	$5.5\ 10^{-2}$	$6\ 10^{-3}$	$5\ 10^{-3}$	$8\ 10^{-4}$
S3	$7{,}5.10^{-1}$	$8.5\ 10^{-3}$	$3.5\ 10^{-3}$	$3.5\ 10^{-3}$	$4\ 10^{-4}$	$3\ 10^{-4}$	$5\ 10^{-5}$

Table 3 : Intervention Levels.

COUNTER-MEASURES	INTERVENTION LEVEL (mSv)	
	low	high
evacuation	50	500
sheltering	5	50
stable iodine	50	500
relocation	50*	50*
resettlement	5*	5*

*** projected dose, integration time 1 year**

Table 4 : Source term for the Pu release.

Isotope	mass %	Activity (Bq)
^{238}Pu	1.5	$1.37\ 10^{10}$
^{239}Pu	58.0	$1.98\ 10^{9}$
^{240}Pu	23.0	$2.80\ 10^{9}$
^{241}Pu	7.5	$4.12\ 10^{11}$
^{242}Pu	5.5	$1.15\ 10^{7}$
^{241}Am	4.5	$1.83\ 10^{11}$

Table 5 : Source term for the Cm release.

Isotope	mass %	Activity (Bq)
^{242}Cm	0.5	$8.84\ 10^{9}$
^{243}Cm	2.4	$6.61\ 10^{8}$
^{244}Cm	97.1	$4.19\ 10^{10}$

VIII. REFERENCES

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[3] D. Quéniart, A. Sugier, J. Lochard, "Consideration of Postaccident Consequences in the determination of Safety Objectives for Future Nuclear Power Plants in France", NUCLEAR SAFETY vol. 35 No 2 (1994).

[4] ICRP Publication 40, "Principles for Intervention for Protection of the Public in a Radiological Emergency", Pergamon Press, (1984).