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DOSE RATE EVALUATION AFTER ACCIDENT IN A PWR

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ABSTRACT

In this paper we present a calculation scheme for the radiation dose rate after accident in a PWR. These studies use a fine description of the geometry and of the fission product inventory. We give some results and precize some planned improvements.

INTRODUCTION

This study aims at defining the gamma dose rate at several points inside and outside a PWR reactor building in case of loss of coolant accident or degraded core accidents. In these accidents the two first barriers (fuel cladding and primary circuit) are broken and the core can melt down partly or completely. A significant part of fission products is spread in the building.

The fission products released in the containment are :

- in suspension in the containment atmosphere
- deposited on vertical walls and floors
- trapped in water held at different places (refueling pool, draining trap, bottom of reactor cavity).

The different calculation applications are the following :

- the first one deals with the definition of complementary instrumentation allowing to diagnose and to follow the accident, using dose rate measurement versus time after accident
- the second one is the evaluation of the integrated dose absorbed by the mechanical and electrical devices inside containment. Such an evaluation will also allow us to specify the operating limits on these devices
- the last one is the possibility to determine the access to various places in particular :
  - inside the containment during long-term post-accidental phasis
  - outside this one after the accident.

This work is a preliminary study where hypothesis on the fission product release phenomena are simplified and in which we have not taken into account the β radiation. But some rough evaluations show the great importance of the β dose rate. Next improvements are foreseen.

CALCULATION SCHEME

- The fission product inventory is made by the PEPIN[1] code
- The transport of gamma-rays emitted by the airborne source in the containment atmosphere or in the trapped water is made by the code MERCURE IV[2]
- The Monte Carlo TRIPOLI[3] code is used for calculation of the dose rate due to the gamma rays emitted by the fission products which are deposited on the walls.

At this step results are normalized to 100% of fission product release ; fission products are classed according to their physical and chemical properties.

The gamma dose rate $D_{n,J}(t)$ at the point P_n is given by the relation (1) :

$$D_{n,J}(t) = A^{-1} \sum_{g} \sum_{j \in J} D_{gn} S_{jg}(t) \qquad (1)$$

where :

- J represents a chemical family composed of several isotopes j
- g is the gamma energy group index
- $S_{jg}(t)$ represents the spectrum of gamma emitted by the fission product j in the group g at the cooling time t. This value is normalized to the complete core
- D_{gn} is the gamma dose rate at P_n due to an unitary source ($1\gamma/cm^3.s$ or $1\gamma/cm^2.s$).
- A is the containment volume or the area of the walls which retain the fission products.

We shall note that this scheme does not include particular calculations of the radioactive filiations in containment and assumes fission products released masses to be proportionnal at any time to core inventory. Nevertheless this scheme allows fast running calculations to be performed with a rather good accuracy.

- At last are used a summation code and the ANTARES[4] code which combines the different results to obtain the gamma dose rate with some hypothesis on emission and retention of the fission products.

Fission product inventory by using PEPIN code

The fission product inventory is made with the PEPIN code which solves analytically coupled differential equations binding concentrations of the 635 fission products during operating and cooling times. These equations describe the following phenomena :

- direct fission product formation using the independant yields for different fissile isotopes which take into account the fuel evolution versus burn-up
- production and disapearance by radioactive decay and neutron capture.

The emitted radiations are set by energy group and chemical species and they are studied versus time after accident. The gamma spectra are computed from the CEA library which contains 8298 gamma energy rays for 635 nuclides.

We present now a short qualification of the PEPIN code by using a more recent library[5] with 699 fission products. Figure 1 shows t x f(t), where f(t) is the total residual heat after U^{235} thermal elementary fission. The computed values are compared[6] with Dickens measurements.

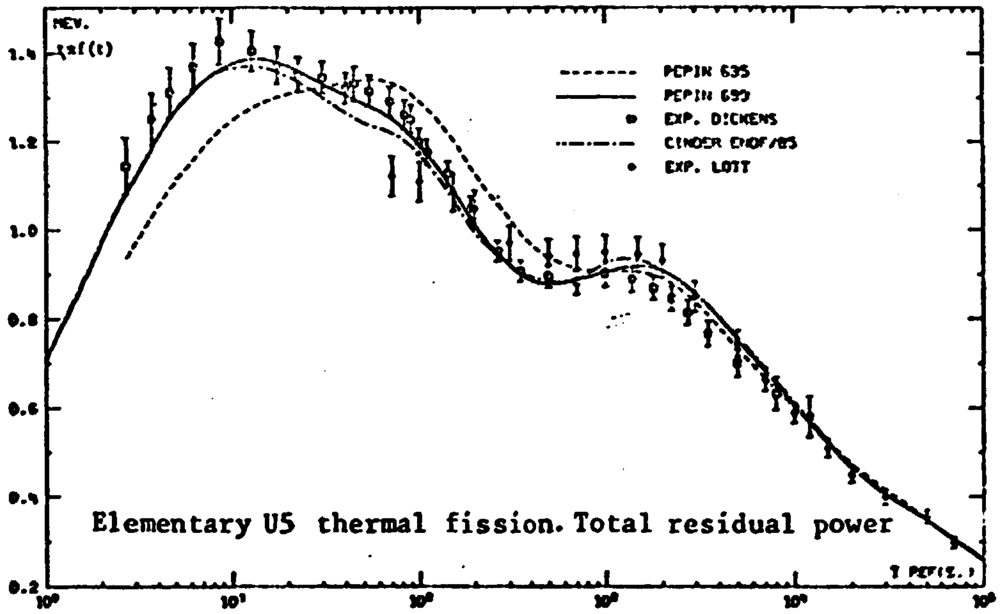

Figure 1

Figure 2 shows a gamma spectrum at t equal 1000 s after fission.

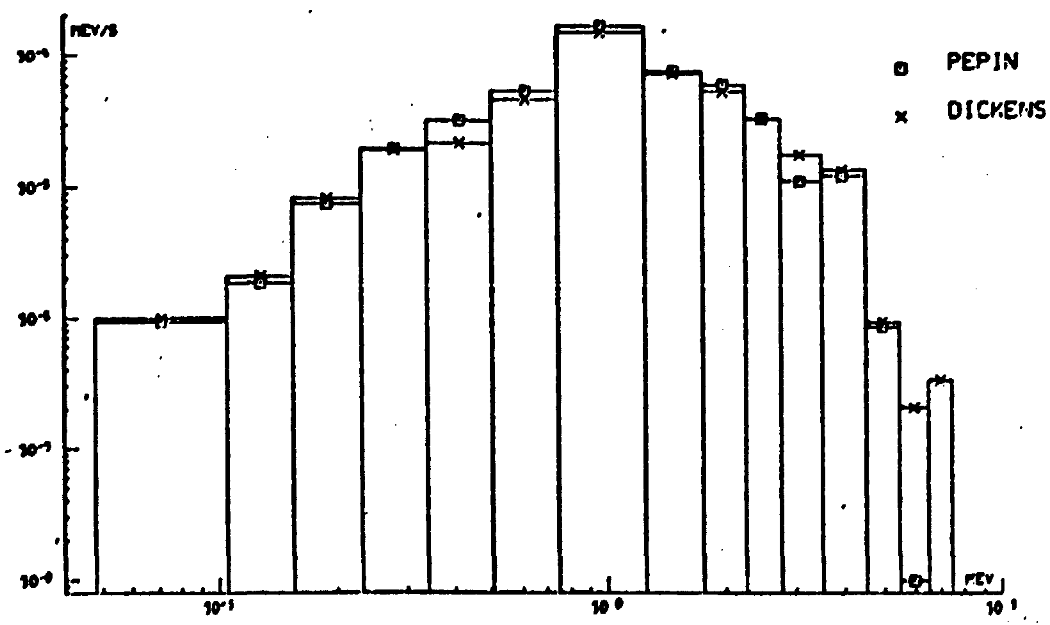

Fig.2 - Elementary U5 thermal fission-residual power per group

Transport of gamma from volume source

This calculation is performed by the MERCURE-4 code in a three dimensional geometry whose vertical cuts are shown on figures 3 and 4.

This geometry is composed by 210 homogeneous volumes limited by planes and quadratic surfaces and full of concrete, iron or air.

The code MERCURE-4 uses a line of sight point attenuation kernel method with build-up factor. The integration of this kernel is made by Monte Carlo method with optimized importance function. The gamma dose rate is evaluated at 7 points (see figure 4).

Transport of gamma from surface source

The gamma dose rates are computed by using the TRIPOLI code in the same geometry as the previous calculation. TRIPOLI is a general Monte Carlo code for neutron and gamma transport calculation. But we have used a special modification for this purpose and for calculation of the dose at points located inside the containment : the gamma dose rate $dD_{g,n}$ produced by the elementary surface dS is given by the relation (2) :

$$dD_{g,n} = \frac{R_g\, S_g\, dS}{4\pi r^2}\, e^{-\mu_g r} \qquad (2)$$

where g is the energy group index

S_g is the source surface density

R_g the conversion factor from flux to dose rate

μ_g the air attenuation coefficient.

This formula (2) may be transformed to give the relation (3) :

$$D_{gn} = \frac{R_g}{4\pi} \iint_{4\pi} e^{-\mu_g r(\vec{\Omega})} \frac{d\vec{\Omega}}{\vec{\Omega}\,\vec{n}\,(\vec{r}_s)} \qquad (3)$$

where $\vec{n}\,(\vec{r}_s)$ is the normal to the source surface at the point $\vec{r}_s$

$\vec{r}_s$ is the first point where the half line $\vec{r}_n - \rho\,\vec{\Omega}$ reachs the concrete or the steel ($\infty > \rho > 0$)

$\vec{r}_n$ is the coordinates of P_n.

In practice TRIPOLI emits an isotropic source at the point P_n.

We use the MERCURE-4 code with cylindrical surface sources to calculate the dose rate at points located outside the building (points 5 and 6 on figure 4).

FISSION PRODUCTS RELEASE AND TRANSPORT INSIDE CONTAINMENT

Each accidental sequence is characterized by different release rates of fission products from the core and by different degrees of retention in the primary circuit. The corresponding amount of fission products is assumed to be instantaneously and homogeneously released inside the containment building.

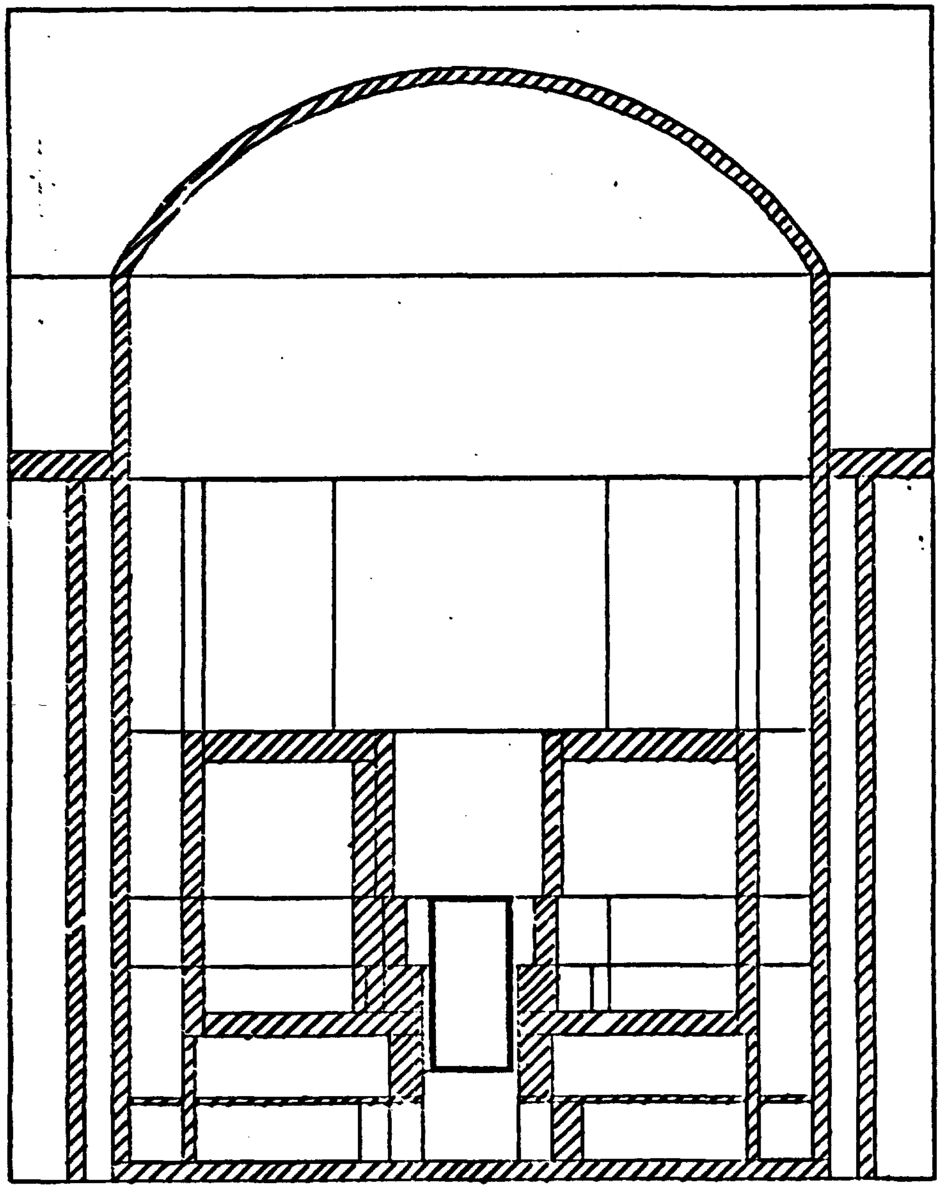

Figure 3 - X-AXIS CUT

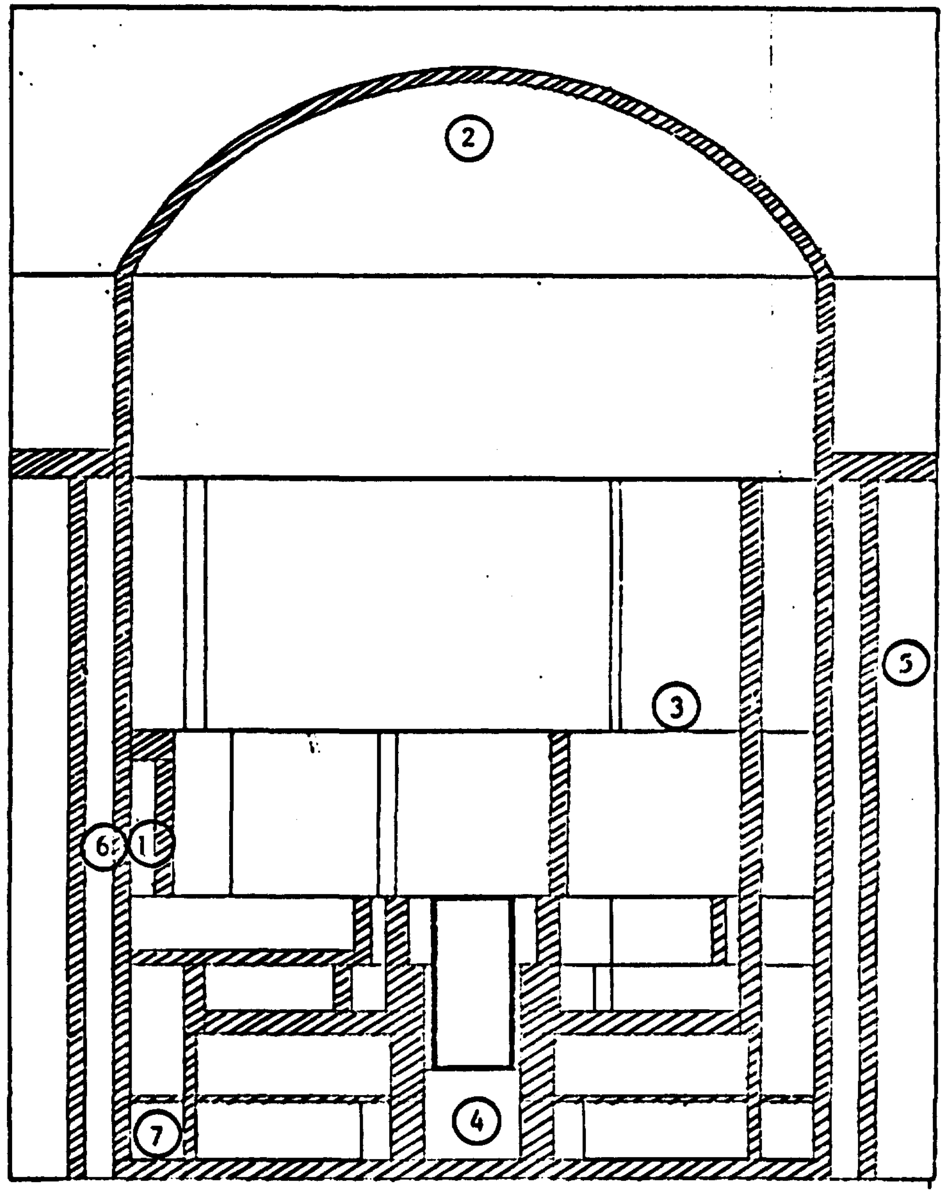

Figure 4 - Y-AXIS CUT

The behaviour of the fission products within the containment is modelized according to their physical and chemical characteristics. Three groups have been distinguished :noble gases and organic iodine, elemental iodine, aerosols. Emperical laws for elemental iodine natural plate-out and removal by water spray broadly based on CSE experiments, have been introduced. Simplified laws for aerosol behaviour have been inferred from calculations performed by using more complex codes[7], which account for all the physical phenomena involved. Large experimental and analytical studies are on going as regards fission product behaviour and are intended to provide better technical basis in the coming years.

Using postulated release rates and transport laws, the evolution of concentration of the fission products in the various sources (atmosphere, walls, sump,....) versus time can be evaluated in the ANTARES code and the gamma dose rate and integrated dose calculated, as explained above.

Some results obtained by using ANTARES code

ANTARES code have been used to evaluate the maximal dose rate which could be achieved in a PWR containment ($\sim 10^6$ rad/hour) and to calculate gamma dose absorbed by safety-related equipment during long-term post-accidental phasis. As an example, the evolution of dose rate in the containment building done (with and without spray) in case of an hypothetical severe degraded-core accident (90 % noble gases and iodine released) is presented on figure 5. Relative contributions of the different sources and of the different chemical species versus time are also provided : figure 6 shows such results for the integrated dose at the same location in the containment.

FUTURE DEVELOPMENTS AND APPLICATIONS

We intend to improve the calculations described above in the following ways :

- using the new PEPIN code library which contains 699 fission products and improved gamma-ray data, in particular as concerns short cooling times
- taking into account β dose rate, which highly contributes to the total dose rate in the containment. A recent PEPIN modification allows to compute fission products β spectra. The β transport calculation will be performed by using a special code which takes into account energy losses per track length unity $\left(\frac{dE}{dx}\right)$

ANTARES code will be used by French nuclear safety authorities in the implementation and application of regulatory guidelines[8] concerning the definition of the need for instrumentation and for qualification of safety-related equipments in PWR containment building. In spite of large uncertainties as regards fission products behaviour in containment, the code could also be an useful tool for monitoring the course of actual accidents by interpreting gamma dose rate measurements. The planned improvement concerning β dose rate should allow to evaluate the accessibility in the containment building during long-term post-accidental phasis. As a conclusion, we can outline the usefulness of these calculations in some important nuclear safety problems.

ACKNOWLEDGEMENTS

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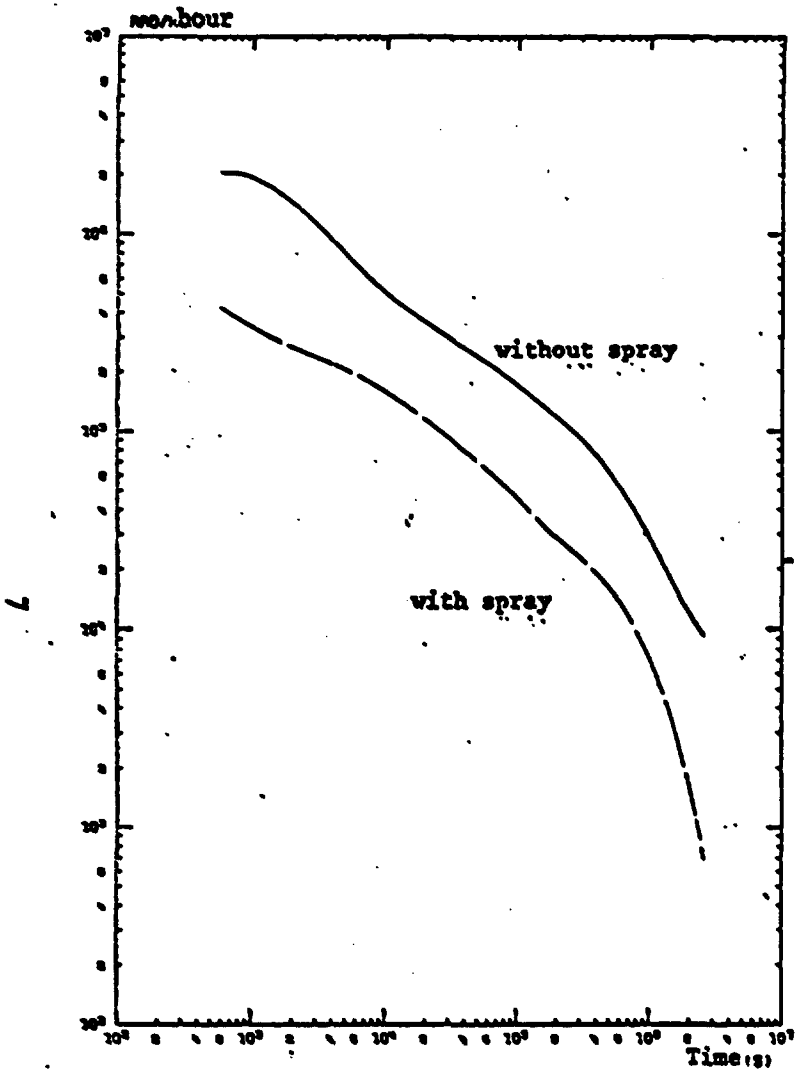

Fig.5 – Evolution of the gamma dose rate in a PWR containment following an hypothetical severe degraded-core accident point 2

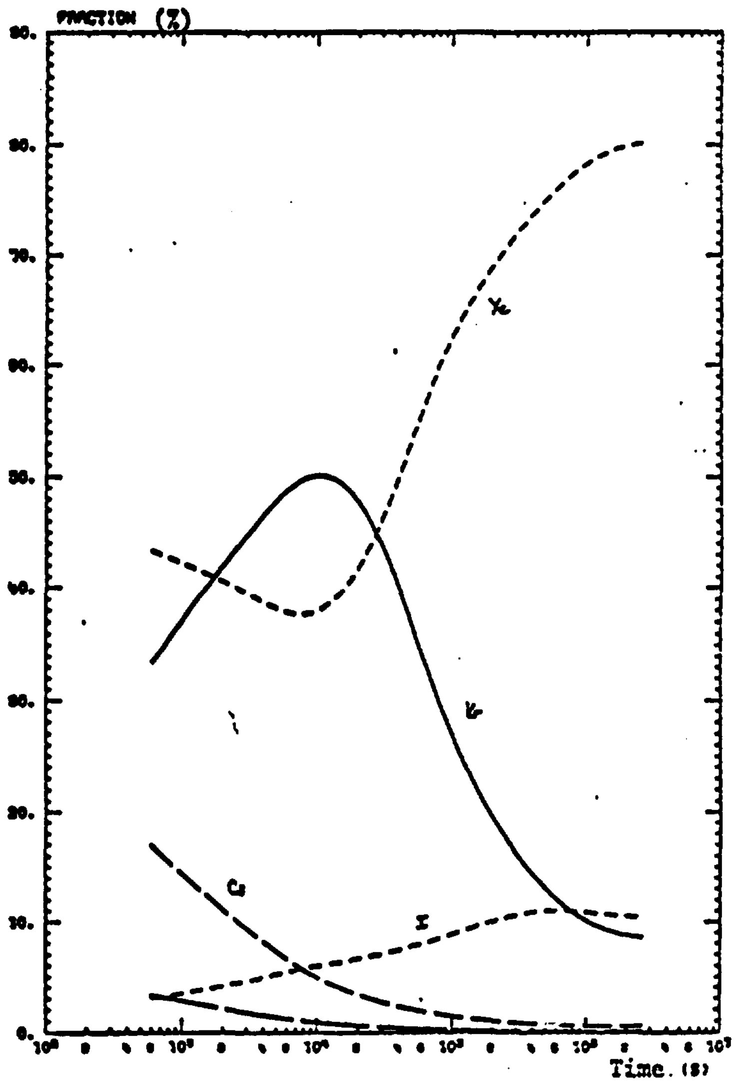

Fig.6 – Relative contribution of the different chemical species to the total integrated gamma dose (with spray)

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