DERIVED RELEASE LIMITS FOR AIRBORNE EFFLUENTS AT TRIGA - INR REACTOR

Authors: A. Toma, C. Dulama, O. Hirica, S. Mihai, I. Oprea
Institute for Nuclear Research, Pitesti, Romania

Abstract

Beginning from fulfilling the purposes of dose limitation system recommended by ICRP, and now accepted in radiation protection, this paper presents an environmental transfer model to calculate derived release limits for airborne and gaseous radioactive effluents at TRIGA-INR, 14 MW Steady State Reactor, in function on INR-Pitesti site.

The methodology consists in determination of the principal exposure pathways for different groups of population and dose calculations for each radionuclide. The characterization of radionuclides transfer to environment was made using the compartimental model. The parameter transfer concept was used to describe the distribution of radionuclides between the different compartments.

Atmospheric dispersion was very carefully treated, because it is the primary mechanism of the radionuclides transfer in the environment and determine all exposure pathways. Calculation of the atmospheric dispersion was made using ORION-II computer code based on the Gaussian plume model and which takes account of site's specific climate and relief conditions.

Default values recommended by literature were used to calculate some of the parameters when specific site values were not available.

After identification of all transfer parameters which characterize the most important exposure pathways, the release rate corresponding to the individual dose rate limit was calculated. This maximum release rate is the derived release limit for each radionuclide and source. In the paper, the derived release limits are calculated for noble gases, radioiodines and other airborne particulate radionuclides, which can be released on the TRIGA-INR reactor stack, and are important to radiation protection.

INTRODUCTION

Everyone in the world is exposed to radiation from natural and artificial sources. Any realistic system of radiological protection must have a clearly defined scope. The primary aim of radiological protection is to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving risk to radiation exposure. Furthermore it is presumed that even small doses may produce some deleterious health effects.

ICRP recommended a system of radiological protection based on the following general principles:

- No practice involving exposure should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes (**The justification of a practice**);

- For any particular source the individual doses, the number of exposed people and the likelihood of incurring exposures (were these are not certain) should all be kept as low as reasonably achievable, economic and social factors being taken into account (**The optimisation of protection**);

- The exposure of individuals resulting from the combination of all relevant practices should be subject to dose limits (**Individual dose limitation**).

The control of public exposure in all normal situation is exercised by the application of controls at the source rather then the environment. The controls are achieved almost entirely by the procedures of constrained optimisation and the use of prescribed limits. It is convenient to class together individuals who form a homogenous group with respect to their exposures to a single source. When such a group is typical of those most highly exposed by the source, it is none as a **critical group**. The dose constraint should be applied to the mean dose in the critical group from the source for which the protection is being optimised.

The scope of dose limits for public exposure is limited to the dose incurred as the result of practices. Doses incurred in situations where the only available protective action is the intervention are excluded from that scope.

BASIC PRINCIPLES FOR INDIVIDUAL LIMITS IN PUBLIC EXPOSURE

The deleterious effects of radiation are classified as stochastic and deterministic.

There is a finite probability for the occurrence of **stochastic effects** even at small doses. As the dose is increases, the frequency of such stochastic events increases, but in the absence of other modifying factors, the severity of the resulted changes is not expected to increase in contrast to **deterministic effects,** when the number of killed cells reach a detection level which constitutes a threshold, the magnitude of which will depend on the chosen injury level.

Due to the proportionality between dose and probability for stochastic effects the doses are additives. The probability of individual harmful effects or risk is proportional to **effective dose** :

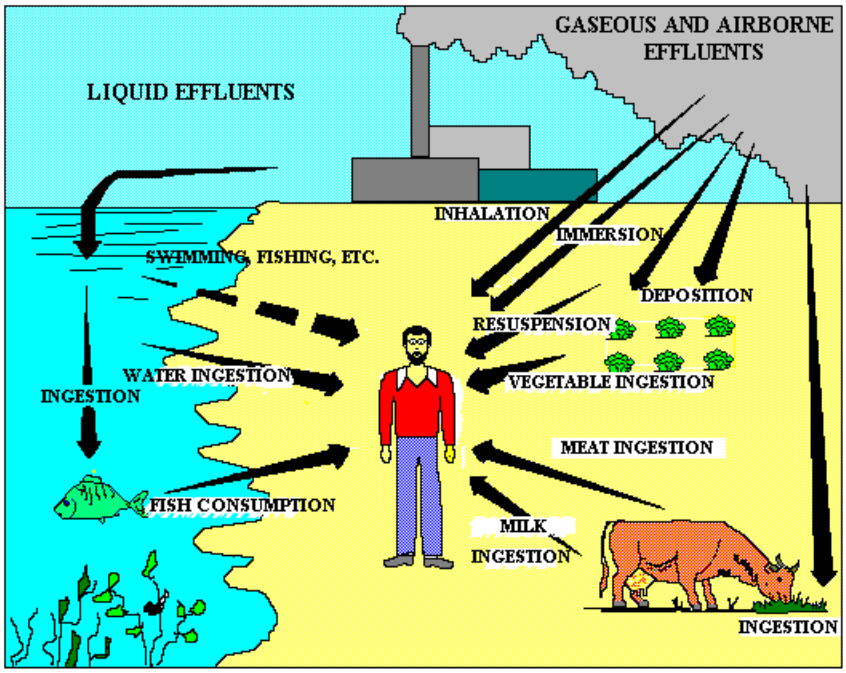
$$H_E = \sum_T w_T H_T \qquad (1)$$

where H_T is the equivalent dose in tissue or organ T and w_T is the weighting factor for tissue T.

ICRP recommended the committed effective dose E (τ) as the effective dose integrated over the time interval τ. If is not specify it is implied that the value of 50 years for adults and 17 years for children are used.

METHODOLOGY

As shown pictorially in Fig. 1, radionuclides in airborne and liquid effluents can result in radiation exposure to man in the environment via a number of routes or “pathways”. Some pathways, such as ingestion of food, result in internal exposures; others, such as immersion in a radioactive cloud, result in internal exposures. However, the total exposure to an individual via all significant pathways from an effluent source must be taken into account to ensure that the regulatory dose limits are not exceeded.



The methodology consists of, firstly, determining for each radionuclide released from each source the most important pathways with regard to radiation exposure of individuals in various localised groups. Usually these groups are real but for a better evaluation and for a long practice, it must consider these groups even hypothetical.

The following step is calculation of the maximum release rate (q_M) corresponding to the individual dose-rate limits for each pathways, then, for each exposed group, are summed the q_M - values in such a way as to determine the maximum permissible release rate (Q_M) for the radionuclide from the particular source.

Finally, are identified the smallest of the Q_M values. The minimum value of Q_M will be the DRL for that radionuclide and source. The exposed group for which the minimum applies is the “critical group”.

The DRL (as defined above) then represents an upper limit to the rate of release of a radionuclide from a single source. Releases from other sources and other radionuclides from the same source must be taken into account in an overall assessment of radiation exposure, but this is not the purpose of this paper, this is a problem for the regulatory body.

In this paper, for the assessment of DRL many parameters are used. However, in many cases, local values are not known accurately and in these cases, the value chosen be on the conservative side.

DESCRIPTION OF ENVIRONMENTAL TRANSFER PATHWAYS

Not all of the pathways shown in Fig.1 are important in the TRIGA-INR environment and some may be excluded either because they are not applicable or their contribution to the exposure is insignificant compared with other pathways. Consideration of these various factors has resulted in the selection of the following six pathways for the TRIGA-INR calculations:

-Pathway A (immersion) - external exposure while being immersed in a cloud of radioactive noble gases from airborne effluents;

-Pathway B (standing on contaminated ground) - external exposure while standing on ground contaminated with radionuclides deposited from originally airborne material;

-Pathway C (inhalation) - internal exposure due to direct inhalation of radionuclides in the plume from airborne effluents;

-Pathway D (vegetable ingestion) - internal exposure due to ingestion of home-grown vegetables contaminated with radionuclides deposited from airborne effluents;

-Pathway E (milk ingestion) - internal exposure due to ingestion of radionuclides via the grass-cow -milk pathway in which the cow is assumed to graze at the INR upriver boundary on grass contaminated with radionuclides from airborne effluents;

Pathway F (meat ingestion) - internal exposure due to ingestion of contaminated meat from animals which are assumed to graze contaminated grass.

DRL ASSESSMENT FOR A SINGLE PATHWAY

Each pathway can be considered as be made up of a series of systems or reservoirs with "transfer parameters" connecting each system in the sequence. Following in the whole paper, transfer parameters are named $P_{i,j}$, where i and j are the system or reservoir between the transfer is made indexes (usually notation). Usually, for the primary source i = 0 and it is characterised by an emission rate Q.

As an example, for pathway C (inhalation), the overall transfer parameter $P_{0...13}$ between the source and the "effective dose equivalent rate" would be given by the products of the individual transfer parameters applicable to each step along a particular sequence:

$$P_{0...13} = P_{0,1}\, P_{1,9}\, P_{9,11}\, P_{11,12}\, P_{12,13} \qquad (3)$$

and the dose rate, DR, is related to the release rate, Q, by the expression:

$$DR = P_{0...13} \bullet Q \qquad (4)$$

The maximum permissible release rate, q_M, for the pathway would then be given by dividing the dose-rate limit by the overall transfer parameter:

$$q_M = \text{Dose-rate limit}/\, P_{0...13} \qquad (5)$$

RESULTS

Using a mathematical model, derived release limits were calculated for significant radionuclides in gaseous emissions of the TRIGA reactor. For every radionuclide, organ doses were calculated for every contamination pathway as well as external doses for both skin and whole body. The calculations were performed for 16 directions and 10 distances up 10 km from the source, for a unit release. We didn't calculate doses for distances higher than 10 km, because of rapid decrease after 2000 m. Following calculations we observed a critical direction (SE), with maximum doses for almost radionuclides excepting noble gases. The identified sites with maximum exposure were not situated in populated areas, but hypothetical critical groups were proposed to establish dose value for DRL determination.

The most important transfer parameter for airborne effluents is the atmospheric dispersion. The concentration of the radionuclides in a point was calculated using the Gaussian plume model:

$$\chi(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\cdot\left\{\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right\} \quad (6)$$

where u = the wind speed at the stack high (m/s);

H = the stack high;

σ_y, σ_z = the lateral and vertical dispersion parameters (m).

Because in public dose calculation is used the radionuclides concentration at ground level, z = 0 and:

$$\chi(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\cdot\exp\left(-\frac{H^2}{2\sigma_z^2}\right) \quad (7)$$

In dose calculation was used the computer code ORION II.

Committed effective doses were calculated and external exposure added for each radionuclide and a fixed emission rate. The relationship between the emission rate and dose was established for each radionuclide, then we calculated dose-emission rate ratio which we used to calculate DRL using the relationship (5).

The results are presented in Table 1 which presents the derived release limits for airborne and gaseous effluents. DRL values presented in Table 1 are overestimate because many physical values were conservatives recommended by the literature. But we can say that we obtained values very close to those of Chalk River Nuclear Laboratories which have a 61 m stack, about the same height as TRIGA-stack.

Table 1
Derived release limits for airborne and gaseous effluents for TRIGA reactor stack

Radionuclide	Q_{max}(Bq/year)	Q_{max}(Bq/sec)	Critical organ	Critical Group
Ar-41	**1.609E+16**	**5.099E+08**	**-**	**-**
Xe-135	**3.989E+16**	**1.264E+09**	**-**	**-**
Xe-133	**1.229E+17**	**3.895E+09**	**-**	**-**
Xe-138	**2.342E+16**	**7.420E+08**	**-**	**-**
Xe-133m	**9.572E+16**	**3.033E+09**	**-**	**-**
Kr-85	**8.379E+16**	**2.655E+09**	**-**	**-**
Xe-131m	**1.373E+17**	**4.351E+09**	**-**	**-**
Kr-90	**1.190E+17**	**3.770E+09**	**-**	**-**
Kr-89	**1.983E+16**	**6.285E+08**	**-**	**-**
Kr-88	**1.044E+15**	**3.308E+07**	**-**	**-**
Xe-135m	**8.138E+16**	**2.578E+09**	**-**	**-**
Xe-137	**3.516E+16**	**1.114E+09**	**-**	**-**
Kr-87	**1.294E+16**	**4.099E+08**	**-**	**-**
Kr-85m	**5.630E+16**	**1.784E+09**	**-**	**-**
Kr-83m	**6.748E+17**	**2.138E+10**	**-**	**-**
I-135	**1.309E+15**	**4.148E+07**	**THYROID**	**TEENAGERS**
Mn-54	**3.945E+11**	**1.250E+04**	**G.I.T.**	**ADULTS**
Sr-89	**4.070E+12**	**1.289E+05**	**BONES**	**TEENAGERS**
I-134	**5.373E+15**	**1.702E+08**	**THYROID**	**TEENAGERS**
I-133	**1.012E+15**	**3.205E+07**	**THYROID**	**TEENAGERS**
I-132	**4.135E+15**	**1.310E+08**	**THYROID**	**TEENAGERS**
I-131	**9.176E+12**	**2.907E+05**	**THYROID**	**TEENAGERS**
I-130	**4.749E+14**	**1.504E+07**	**THYROID**	**TEENAGERS**
Te-132	**3.670E+13**	**1.163E+06**	**G.I.T.**	**TEENAGERS**
Nb-195	**1.327E+13**	**4.207E+05**	**G.I.T.**	**ADULTS**
Cs-137	**1.936E+11**	**6.135E+03**	**LIVER**	**INFANTS**
Cs-134	**3.662E+11**	**1.160E+04**	**LIVER**	**INFANTS**
Fe-59	**9.811E+12**	**3.109E+05**	**LIVER**	**ADULTS**
Ce-144	**3.792E+12**	**1.201E+05**	**G.I.T**	**TEENAGERS**
Co-58	**9.398E+12**	**2.978E+05**	**G.I.T**	**ADULTS**
Co-60	**1.926E+11**	**6.103E+03**	**G.I.T**	**ADULTS**
Cr-51	**6.278E+14**	**1.909E+07**	**G.I.T**	**ADULTS**
Zr-95	**1.071E+13**	**3.394E+05**	**G.I.T**	**ADULTS**
Y-90	**4.706E+13**	**1.491E+06**	**G.I.T.**	**TEENAGERS**
Sr-90	**5.686E+10**	**1.802E+03**	**BONES**	**CHILDREN**