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Assessment of management alternatives for LWR wastes

(Volume 5)

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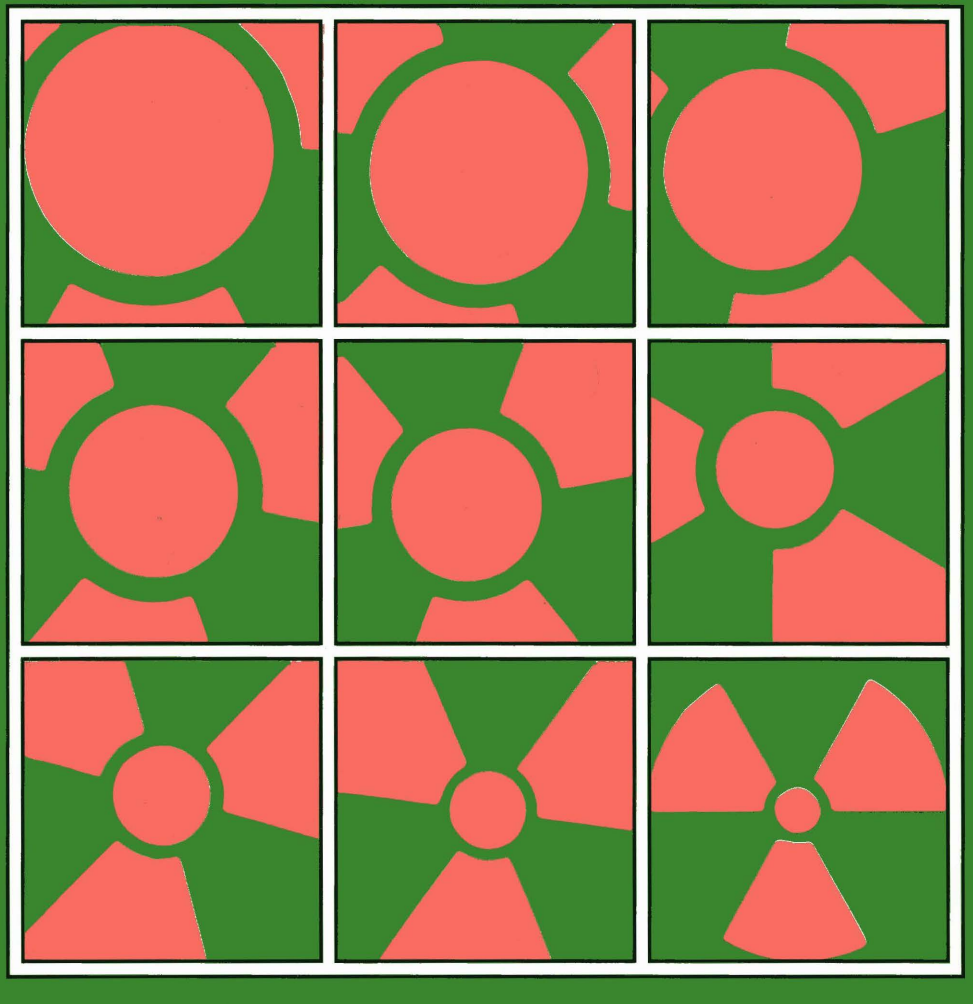

Report

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Assessment of management alternatives for LWR wastes

(Volume 5)

Assessment of the radiological impact to the public resulting from discharges of radioactive effluents

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Final report

Work performed as part of the shared cost programme (1985-89) on management and disposal of radioactive waste of the European Communities

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FOREWORD

This report deals with the assessment of the radiological impact to the public resulting from discharges of radioactive effluents in connection with the implementation of the Belgian Scenario for the management of PWR waste. This study is part of an overall assessment study aiming at evaluating a selection of management routes for LWR waste based on economical and radiological criteria.

Actually the assessment study was implemented through complementary contributions provided by nine organisations and companies, i.e.
CEN - Fontenay-aux-Roses, INITEC - Madrid, KAH - Heidelberg, BELGATOM - Brussels, TASK R&S - Ispra, SGN - St. Quentin-en-Yvelines, EDF/SEPTEN - Villeurbanne, FRAMATOME - Paris-la-Défense, GNS - Essen, co-ordinated by the Commission of the European Communities (Brussels).

The main achievements of the assessment study have been summarised by BELGATOM-Brussels.
These different contributions are published as EUR Reports in 1992 (listed as below):

VOLUME N°	MAIN AUTHORS	ORGANISATION	TITLE	EUR REPORT N°
1	R. Glibert	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Main achievements of the joint study	14043 EN/Vol 1
2	E. de Saulieu C. Chary	SGN EDF	Assessment of Management Alternatives for LWR Wastes : Description of a French scenario for PWR waste	14043 EN/Vol 2
3	S. Santraille K. Janberg H. Geiser	FRAMATOME - GNS	Assessment of Management Alternatives for LWR Wastes : Description of German scenarios for PWR and BWR wastes	14043 EN/Vol 3
4	J. Crustin R. Glibert	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Description of a Belgian scenario for PWR waste	14043 EN/Vol 4
5	B. Centner	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Assessment of the radiological impact to the public resulting from discharges of radioactive effluents	14043 EN/Vol 5
6	G.M. Thiels S. Kowa	TASK R & S KAH	Assessment of Management Alternatives for LWR Wastes : Cost determination of the LWR waste management routes (Treatment/Conditioning/Packaging/ Transport Operations)	14043 EN/Vol 6
7	J. Malherbe	CEA	Assessment of Management Alternatives for LWR Wastes : Cost and radiological impact associated to near surface disposal of reactor waste (French concept)	14043 EN/Vol 7
8	N. Sanchez-Delgado	INITEC	Assessment of Management Alternatives for LWR Wastes : Cost and radiological impact associated to near surface disposal of reactor waste (Spanish concept)	14043 EN/Vol 8

SUMMARY

This work has enabled to assess the doses to the critical individuals, as well as the collective doses resulting from the liquid and the gaseous wastes released into the environment and generated by the operation of a reference 900 MWe PWR (PWR3 type). The calculations were performed for an in-land and a coastal plant. Two different source terms, i.e. two different levels of reactor coolant contamination were used : a "real" case characterized by a primary coolant contamination corresponding to the upper bound of the actual contaminations observed in modern PWRs and a "design" case characterized by a primary coolant contamination higher by one order of magnitude than that of the real case.

Both critial individuals and collective doses are higher for the in-land than for the coastal plant.
For the in-land plant and for the real case, the results are summarized hereafter :

Type of Release	Doses to critical individual (μSv/y)		Collective doses (Man.Sv/y)	
	Whole body	Thyroïd	Whole body	Thyroïd
Liquid	1,0 (0)	3,6 (0)	3,1 (-1)*	4,5 (-1)
Noble gases	1,6 (-1)	1,6 (-1)	4,1 (-3)	4,1 (-3)
Iodine + C14 + H3 + aerosols	1,2 (0)	1,4 (1)	7,7 (-3)	7,4 (-1)

* $3{,}1\ (-1) = 3{,}1 \times 10^{-1}$

For each type of release and for each type of exposure (critical individual, collective doses), the thyroïd is the most exposed organ.
The whole body dose is governed by H3 and caesium isotopes.
The drinking water is the main exposure pathway of the collective whole body dose, while watering and irrigation products are the main exposure pathways of the collective thyroïd dose.

TABLE OF CONTENTS

1. INTRODUCTION

1.1. Objectives and Scope

During the last few years, reactor waste management practices in the European Community have taken advantage of many improvements as far as processes, organisation and safety are concerned. In order to take stock of these new practices, to compare them on a sound basis and at the end of the process to highlight those aspects which might require some further improvements, the Commission of the European Communities launched a joint theoretical study on the assessment of a selection of management routes for LWR wastes relying to a large extent on the experience gained in France, Belgium and the Federal Republic of Germany. Although emphasis was placed on the evaluation of management routes for PWR wastes, the case of BWR wastes was also looked into.

This study was performed within the framework of the third research programme of the Commission of the European Communities on "Radioactive waste management and disposal" (1985-1989).

Actually the whole study consisted of evaluating five management routes (three on PWR waste and two on BWR waste) on the basis of economic and radiological criteria.

Each route was defined as an assembly of all intermediate management stages which are usually occurring from the waste production at the source up to the storage or disposal of waste packages. With the view to make the different routes comparable, whenever possible, it was attempted to fit in national management routes within a joint framework featured by a fixed nuclear capacity, similar primary waste inventories and common discharge limits.

On the basis of an extensive description of the main equipments involved in each route, a cost evaluation was performed using the same methodology. The radiological impact associated to the implementation of each route was mainly quantified for the part of the public living around the nuclear facilities of concern. In addition, possible long term doses to the public resulting from disposal of radioactive waste packages in near surface sites were determined.

1.2. Contents of the report

The joint study was performed through contributions provided by several organisations according to a breakdown of tasks reported in the foreword. In this respect, the contents of this report first deals with the description of a methodology for determining the radiological impact to the public resulting from the discharge of radioactive effluents into the environment and then with the application of this methodology to the specific case of the Belgian scenario for the management PWR waste as described in the volume 4 of the series.

The methodology for assessing the radiological impact has been developed for the case of discharging radioactive effluents (airborne and liquid effluents) from the Tihange nuclear site located in the South East part of Belgium. Based on the characteristics of this site, and the distribution and the life habits of the population around, a number of exposure pathways have been identified enabling the determination of the dose factors (for maximum individual and collective doses) for the main important radionuclides released through the stack or in the Meuse river.

In order to cover a wider range of scenarios, a coastal site has also been considered for the assessment of the radiological impact resulting from the discharge of PWR effluents.

Relying on the decontamination performances of the different treatment processes implemented in the Belgian scenario for PWR wastes, this report quantifies the radionuclide inventory of the airborne and liquid effluents generated as input data for the subsequent radiological impact assessment. Moreover, two extreme reference cases were considered concerning the level of contamination of the source term (primary coolant contamination).

Accurate calculations of the maximum individual and collective doses have been performed for each set of hypothesis considered in the study - likewise, doses were determined for total body as well as for the most exposed organs.

The report is concluded by an analysis and a discussion of the results achieved.

It is worth mentioning that the methodology described in this report was applied to the determination of the radiological impact resulting from the implementation of the other PWR management routes investigated in the joint study. In this way, the three reference PWR routes based on Belgian, French and German practices could have been compared to the same basis (see volume 1 of the series).

2. SOURCE TERM

2.1. Liquid waste

The liquid waste generated from a 900 MWe PWR operation are listed in table 1.

The isotopic compositions for the primary and auxiliary liquid effluents are listed in table 2.

Comments

a) The isotopic composition of the primary coolant has been derived from ref. 1, adjusting the isotopic fractions of all β-γ emitters but H3, so as to obtain a total fraction equal to 100%.

H3 annual release via the liquid waste has been set to 600 Ci/y, i;e; a realistic value for Zircalloy fuel elements. For an annual release of $10.000\ m^3/y$ (a realistic value in case of load follow), the corresponding H3 activity in the primary waste is $6 \times 10^{-2}\ ci/m^3$.

b) Sr90 activity in the primary coolant:

Old available U.S. data (ref. 2) indicate that the ratio $\frac{Sr90}{Cs137}$ is about 5×10^{-4} in the primary coolant.

More recent data, gained from European PWRs (Germany, Switzerland), indicate that this ratio amounts to about 0.01 in the reactor coolant and in the liquid waste discharged from the plants.

A ratio $\frac{Sr90}{Cs137} = 0.01$ has thus been selected in the present study. The data of table 2 have been reviewed accordingly.

2.2. GASEOUS WASTE

The gaseous waste generated from a 900 MWe PWR operation are listed in table T3 (data derived from ref. 2).

Comments

a) For sake of consistency, the volume of gaseous waste transfered tot he gaseous waste processing unit (TEG) is set to be equal to the primary effluents volume.

The isotopic compositions of hte waste transferred to the "TEG" and of the waste discharged via the ventilation are assumed to be indentical.

b) The gaseous gross activity has been set up respectively to 30 and 300 Ci/Nm^3 for the real and the design values.

These activities are consistent with "out of gas" activities respectively aqual to 1 and 10 Ci/t in the primary coolant.

c) The gross volumic activity in the ventilation stream has been set to 10^{-5} ci/Nm^3 for the design value, so as to obtain an annual value limit (20.000 Ci/y).

d) C14 releases

The annual atmospheric discharge of C14 from PWRs is set to 2.0 Ci/GW (th) y, i;e; 5.4 Ci/y for a 900 MWe (or 2700 MWth) PWR - Ref. 4. The same annual discharge rate is used for both real and design cases.

Most (i.e. about 85%) of the C14 released to the atmosphere originates from the discharges of the gaseous waste storage tanks (TEG).

e) H3 releases

The annual atmospheric discharge of H3 from the reference PWR is set to 150 Ci/y for both real and design cases. The H3 atmospheric releases originate mainly from (ref. 5):

- the reactor containment purge operations (22%)

- the spent fuel pit building ventilation (66 %)
- the nuclear auxiliary buildings ventilation (12 %)

3. RADIOACTIVE LIQUID WASTE PROCESSING SYSTEM

3.1. PRIMARY WASTE

The primary waste processing system simplified flow diagram is shown on figure 1.
Figure 1 also gives the main characteristics of the equipment (storage capacities and decontamination factors).

Overall decontamination factors (DF)

Isotopes	DF
Iodine	10^3
Others	10^5

Note : Actually, the distillate coming from each evaporator can be polished by a demineralizer (mixed bed type). For the real case, no account has been taken of this equipment.
In the design case, the primary waste evaporator polishing demineralizer is supposed to be valved in operation.
The DF of the demineralizer is set to 10 for each isotope.

The transit time in the storage tank and in the transfer tanks has been calculated on the basis of a plant load factor of 0,85.
The primary waste daily make-up is thus :

$$\frac{10.000}{365 \times 0,85} = 32 \text{ m}^3/\text{d} \text{ in the real case.}$$

The time required to fill the make-up storage tank (R1) is thus :

$$\frac{220}{32} = 7 \text{ days}$$

In the design case, the corresponding time is 3 days.

3.2. SECONDARY WASTE

The secondary waste processing system simplified flow diagram, as well as the equipment main characteristics (storage capacities, DF) are shown on figure 2.

The secondary waste are only processed by evaporation.(*)

The overall DF are :

Isotopes	DF
Iodine	10^3
Others	10^4

The secondary waste daily make-up is :

$$\frac{2500}{365 \times 0,85} = 8 \text{ m}^3/\text{d in the real case}$$

The time required to fill the make-up storage tank (R1) is thus :

$$\frac{32}{8} = 4 \text{ days}$$

The corresponding time in the design case is 2,5 days.

(*) Note : actually, the evaporator's distillate can be processed by a mixed-bed demineralizer. However, in this assessment, this demineralizer is assumed to be by-passed.

3.3. LAUNDRY WASTE

The laundry wastes are discharged without processing.

3.4. CHEMICAL AND DECONTAMINATION WASTE

The chemical and decontamination waste processing syste simplified flow diagram, as well as the equipments mair :ha- racteristics are shown on figure 3.
In the real case, these waste are only processed by fl :la- tion.

In the design case, these waste are processed by flocu .ion. The purified solution originating from the floculator then processed by the evaporator of the secondary wast >ro- cessing system.

The chemical and decontamination waste overall DF are :

- For the real case : DF = 10 for all isotopes.

- For the design case : DF = 10^3 for all isotopes.

In the case of the purified solution originating from the floculator, the DF of the secondary waste evaporator is set to 100 for all isotopes.

The chemical and decontamination daily make-up is :

$$\frac{1510}{365 \times 0,85} = 5 \text{ m}^3/\text{d in the real case.}$$

The time required to fill the make-up storage tank (R1) is thus :

$$\frac{36}{5} = 7,2 \text{ days}$$

In the design case, the corresponding value is 5.5 days.

3.5. BUILDING WASTE

The building waste processing system simplified flow diagram, as well as the equipments main characteristics are shown on figure F4.

The waste are processed by floculation and by evaporation.

For all isotopes, the overall DF is set to 10^3.

The building waste daily make-up is :

$$\frac{3000}{365 \times 0,85} = 10 \text{ m}^3/\text{d in the real case.}$$

The time required to fill the make-up storage tank is thus :

$$\frac{36}{10} = 3,6 \text{ days}$$

In the design case, the corresponding value is 1.8 days.

3.6. DECONTAMINATION FACTORS OF THE LIQUID WASTE PROCESSING EQUIPMENT

The selected values of the DF of the equipment being involed in the liquid processing systems are in accordance with ref.2.

The floculators (equipment not listed in ref. 2) are characterized by a DF value of 10. This value corresponds to the lower range of the "in-site" measured DFs for those types of waste.

3.7. TRANSFER TANKS (DISCHARGE TANKS)

The reference plant (i.e. - Tihange Unit n°2) is provided with 2 large storage capacities transfer (or discharge) tanks which collect all the different types of liquid waste after processing.

Those large capacities (800 et 500 m^3) have been selected, to enable the storage of the liquid waste during the periods when the flow rate of the river (Meuse) is low and when the discharge of the processed liquid waste has to be significantly reduced, in order to respect the instantaneous activity limits in the river (i.e. : added volumic activity $\leq$ 20 pCi/l for β-γ emitters other than H3 and 2000 pCi/l for H3).

On the basis of the liquid waste production rate listed in table 1, the average filling time of those tanks is 10 days. However, no account has been taken of the transit time for short half lived isotopes in the transfer tanks, these being rather site specific (to accomodate for the storage of liquid waste during the periods of low flow rates of the Meuse) than related to the technology of the liquid waste processing systems.

4. LIQUID WASTE RELEASE - CALCULATIONS

The purpose of this paragraph is to illustrate the calculation methodology by numerical examples for the real case.

4.1. LONG HALF-LIFES ISOTOPES

For long half lifes isotopes, the radiological decay is practically not effected by the staying time in the storage tanks upstream of the process chains.

4.1.1. Release from primary waste

$$R_{i,p} = Vp * a_{t,p} * \frac{x_{i,p}}{100} * \frac{1}{DF_{i,p}} \qquad (1)$$

$R_{i,p}$ = annual release of isotope i (Ci/y) from primary waste

Vp = annual production of primary waste = 10,000 m³

$a_{t,p}$ = global β-γ activity (H3 excluded) Ci/m³ (Table 1)

$x_{i,p}$ = volumic fraction of isotope i in the primary waste (%) (Table 2)

$DF_{i,p}$ = Decontamination factor of isotope i for the whole treatment chain

if i = Cs 137, $DF_i = 10^5$ (§ 3.1)

$$(1) \rightarrow R_{Cs\ 137,p} = 10^4 * 1 * \frac{1,8}{100} * \frac{1}{10^5} = 1,8.10^{-3}\ Ci/y$$

4.1.2. Release from secondary waste

$$R_{i,s} = V_s * a_{t,s} * \frac{xi,s}{100} * \frac{1}{DFi,s} \qquad (2)$$

For Cs 137, (2) gives :

$$R_{Cs\ 137,s} = 2,5.10^3 * 10^{-2} * \frac{19}{100} * \frac{1}{10^4} = 4,8.10^{-4}\ Ci/y$$

4.1.3. Release from laundry waste

These waste are not processed.

$$R_{i,L} = V_L * a_{t,L} * \frac{xi,L}{100} \quad (3)$$

$$R_{Cs\ 137,L} = 4.10^3 * 10^{-5} * \frac{19}{100} = 7,6.10^{-3}\ Ci/y$$

4.1.4. Release from chemical and decontamination waste

$$R_{i,c} = V_c * a_{t,c} * \frac{xi,c}{100} * \frac{1}{DFi,c} \quad (4)$$

$$V_c = 10 + 1500 = 1510\ m^3/y$$

$$a_{t,c} = \frac{10 * 10^{-2} + 1500 * 10^{-3}}{1510} = 1,1.10^{-3}\ Ci/m^3$$

The gross activity $a_{t,c}$ is thus the result of the mixing of chemical and decontamination waste.

$$R_{Cs\ 137,c} = 1,51.10^3 * 1,1.10^{-3} * \frac{19}{100} * \frac{1}{10} = 3,2.10^{-2}\ Ci/y$$

4.1.5. Release from building waste

$$R_{i,B} = V_B * a_{t,B} * \frac{xi,B}{100} * \frac{1}{DFi,B} \quad (5)$$

$$R_{Cs\ 137,B} = 3.10^3 * 1.10^{-3} * \frac{19}{100} * \frac{1}{10^3} = 5,7.10^{-4}\ Ci/y$$

4.2. SHORT HALF-LIFES ISOTOPES

For those isotopes, the release from the treatment chains is affected by the radiological decay in the collection tanks.

4.2.1. Release from the primary waste

The activity inventory of isotope i in the primary waste collection tank is :

$$\frac{dAi,p}{dt} = q_p * a_{t,p} * \frac{x_{i,p}}{100} - \lambda_i A_{i,p} \quad (6)$$

q_p = average daily primary waste make-up rate (m^3/d)

$A_{i,p}$ = activity inventory of isotope i in the collection tank (Ci)

t = time (d)

$a_{t,p}$; $x_{i,p}$: see a) hereabove

λi = radioactive decay of isotope i (d^{-1})

$$(6) \rightarrow A_{i,p} = q_p * a_{t,p} * \frac{x_{i,p}}{100} * \left[\frac{1 - e^{-\lambda i,p * t}}{\lambda i}\right] \quad (7)$$

For I131, tp : 7 days (tp = time required to fill the primary waste tank in the real case), q = 32 m^3/d,

$$(7) \text{ gives } A_{I\ 131,p} = 32 * 1 * \frac{10,4}{100} * \left[\frac{1 - e^{-8,61.10^{-2} * 7}}{8,61.10^{-2}}\right]$$

= 17,5 ci

The number Np of batches of primary waste processed during 1year is $Np = \frac{10.000}{220} = 45,5$ (8)

The annual release of isotope i is thus :

$$R_{i,p} = Np * \frac{A_{i,p}}{DF_{i,p}} \quad (9)$$

$$\text{Fr I131, (9) gives } R_{I131,p} = \frac{45,5 * 17,5}{10^3} = 0,8 \text{ Ci/y}$$

4.2.2. Release from the secondary waste

$$(7) \rightarrow A_{i,s} = q_s * a_{t,s} * \frac{x_{i,s}}{100} * \left[\frac{1 - e^{-\lambda i,s * t}}{\lambda i}\right] \quad (12)$$

$$\text{For I131, } A_{I131,s} = 8 * 10^{-2} * \frac{0,46}{100} * \left[\frac{1 - e^{-8,61.10^{-2} * 4}}{8,61.10^{-2}}\right]$$

$$= 1,25.10^{-3} \text{ Ci}$$

$$(8) \rightarrow N_s = \frac{2500}{32} = 78,1$$

$$(9) \rightarrow R_{I131,s} = \frac{78,1 * 1,25.10^{-3}}{10^3} = 9,7.10^{-5} \text{ Ci/y}$$

4.2.3. Release from the laundry waste

These waste are not processed :

(3) gives $R_{I131,L} = 4.10^3 * 10^{-5} * \frac{0,46}{100} = 1,8.10^{-4}$ Ci/y

4.2.4. Release from the chemical and decontamination waste

$$(7) \rightarrow A_{i,c} = q_c * a_{t,c} * \frac{x_{i,c}}{100} * \left[\frac{1 - e^{-\lambda i,c * t}}{\lambda i} \right] \quad (11)$$

$$\text{For I131, } A_{I131,c} = 5*1,1.10^{-3} * \frac{0,46}{100} * \left[\frac{1 - e^{-8,61.10^{-2} * 7,2}}{8,61.10^{-2}} \right]$$

$$= 1,4.10^{-4} \text{ Ci}$$

$$(8) \rightarrow N_c = \frac{1510}{36} = 42$$

$$(9) \; R_{I131,c} = 42 * \frac{1,4.10^{-4}}{10} = 5,8.10^{-4} \text{ Ci/y}$$

4.2.5. Release from the building waste

$$(7) \rightarrow A_{i,B} = q_B * a_{t,B} * \frac{x_{i,B}}{100} * \left[\frac{1 - e^{-\lambda i,B * t}}{\lambda i} \right] \quad (12)$$

$$\text{For I131, } A = 10 * 10^{-3} * \frac{0,46}{100} * \left[\frac{1 - e^{-8,61.10^{-2} * 3,6}}{8.61.10^{-2}} \right]$$

$$= 1,4.10^{-4} \text{ Ci}$$

$$(8) \rightarrow N_B = \frac{3000}{36} = 83,3$$

$$(9) \rightarrow R_{I131,B} = 83,3 * \frac{1,4.10^{-4}}{10^3} = 1,2.10^{-5} \text{ Ci/y}$$

4.3. LIQUID WASTE RELEASE - RESULTS

4.3.1. Annual liquid waste release in the real case

Table 4 lists the annual releases of the significant radionuclides, calculated on the design bases mentioned in § 3. The total release amounts to 1.74 Ci/y.

Comments

a) About 85 % of the annual release consist of iodine (I131, I133, I135) coming out from the primary waste processing system due to limited DFs of the primary waste evaporators when these are used for boron recovery (see § 3.1. and figure 1).

b) The annual release of isotopes having half lives > 8 days, i.e. the annual release of radiologically significative isotopes amounts to 1.0 Ci.

c) Should the transit time of the isotopes in the transfer (discharge) tanks be taken into account, the total annual release would reduce to about 0,9 Ci (influence of staying time on I131 radiological decay rate).

4.3.2. Annual liquid waste release in the design case

Table 5 lists the annual releases of the significant radionuclides, calculated on the design bases mentioned in § 3. The total release amounts to 6,8 Ci/y.

Comments

a) About 88 % of the annual release consist of I131, I133 and I135 coming out from the primary waste processing system (see § 4.1 comment a).

b) The annual release of radiological isotopes having half life > 8 days amounts to 2,9 Ci.

c) Should the transit time in the transfer tanks be taken into account, the total annual release would reduce to about 3,3 Ci.

4.4. LIQUID WASTE RELEASE - CONCLUSION

The proposed discharge limits of liquid waste are (ref 1) :

- 2 Ci/y for the real case (objective value)

- 9 Ci/y for the design case

From § 4.3.1. and 4.3.2., it appears that the design of the reference plant enables to meet these criteria for both proposed source terms.

5. ASSESSMENT OF RADIOLOGICAL IMPACT OF THE LIQUID RELEASES TO THE PUBLIC

The assessment of the radiological impact to the public resulting from the discharge of liquid waste has been performed according to the methodology developed in ref. 3 and summarized in Appendix A.1 of this report.

The dose assessments for both real and design cases are summarized in Tables 6 and 7 for the reference in-land site and Tables 8 and 9 for the coastal site.

Comments

5.1. IN-LAND SITE

5.1.1. Real case

For the adult critical individual, the total body dose rate is 0,10 mrem/y (1μSv/y).
The most exposed organ is the thyroid for which the dose rate is 0,36 mrem/y (3,6μSv/y).

5.1.2. Design case

For the adult critical individual, the total body dose rate is 0,2 mrem/y (2μSv/y).
The most exposed organ is the thyroid, for which the dose rate is about 1 mrem/y (10μSv/y).

5.2. COASTAL SITE

5.2.1. Real case

For the adult critical individual, the total body dose rate is 0,023 mrem/y (0,23μSv/y).
The most exposed organ is the thyroïd, for which the dose rate is 0,26 mrem/y (2,6 μSv/y).

5.2.2. Design case

For the adult critical individual, the total body dose rate is 0,035 mrem/y (0,35 μSv/y).
The most exposed organ is the thyroïd, for which the dose rate is 0,7 m rem/y (7 μSv/y).

6. RADIOACTIVE GASEOUS WASTE PROCESSING SYSTEM

The gaseous waste generated by the operation of a PWR consist of :

a) hydrogenated waste originating from the chemical and volume control tank purge (CVCS tank)

b) hydrogenated waste originating from the degassing of the primary liquid waste

c) aerated waste originating from the ventilation of the auxiliary nuclear buildings and from the reactor containment purge during the shutdown periods for maintenance and refueling

The annual production of each type of gaseous waste is listed in table 3. In normal operation, the CVCS tank is not purged. This tank actually acts like a decay tank. During cold shutdown periods (i.e. for reactor refueling), the hydrogen content of the CVCS tank is replaced by nitrogen. However, the gaseous waste production resulting from this operation is negligible compared to that resulting from the primary liquid waste degassing operations.

The volume of hydrogenated waste generated annually by the degassing of the primary waste (in Nm^3/y) is equal to the volume of primary waste generated during the same period (see § 2.2 and 3.1).

7. GASEOUS WASTE RELEASE

7.1. ACTIVITY RELEASED FROM THE HYDROGENATED WASTE PROCESSING SYSTEM - TEG

The hydrogenated waste processing system of the reference plant is shown on figure 5 (TEG). It consists of 7 tanks, each tank having a volume of 35 m³ and an operating pressure of 7 bara.

The storage capacity of each tank is thus equal to 245 Nm³ (*)

By the completion of the filling of a storage tank, the activity inventory is given by :

$$Ai\ (tf) = \frac{\tau i}{\lambda i} (1 - e^{-\lambda i * tf}) \qquad (1)$$

Ai (tf) = Activity inventory in the tank (for isotope i) by completion of the filling - Ci -

τi = daily makeup rate of isotope i to the storage tank - Ci/d -

$$\tau i = Qd * Xi * at \qquad (2)$$

Qd = daily makeup rate of gaseous waste to the tank ; for the real case :

$$Qd = \frac{10.000}{365 * 0,85} = 32\ Nm^3/d$$ - see also § 3.1 -

for the design case, Qd = 77 Nm³/d

Xi = isotopic fraction of isotope i in the gaseous waste - see Table 3 -

at = gross gaseous activity of the waste (Table 3)
For the real case, at = 30 Ci/Nm³
For the design case, at = 300 Ci/Nm³

λi = isotope i decay rate (d^{-1})

(*) On figure 5, only tanks 1 to 7 are used to store gaseous waste up to 7 bara. Tank no.8 is operated only at low pressure. The purpose of this tank is to collect any potential discharge from the pressure relief valves installed on the gaseous waste processing system downstream of the compressors.

t_f = tank filling operation duration =

$$\frac{\text{storage capacity } (Nm^3)}{Q_d}$$

For the real case, $t_f = \frac{245}{32} = 7,7$ days

For the design case, $t_f = \frac{245}{77} = 3,2$ days

The residual activity in the decay tank by the time of the venting is given by :

$$A_{i,r} = A_i(t_f) * e^{-\lambda i * ts} \qquad (3)$$

$A_{i,r}$ = residual activity in the tank by the time of the venting (Ci)

ts = gaseous waste storage period in the decay tank
ts = (number of storage tanks - 1)*t_f
For the real case, ts = 6 * 7,7 = 46,2 days
For the design case, ts = 6 * 3,2 = 19,2 days

The annual release from the "TEG" to the atmosphere is given by :

$$R_{i,p} = Np * \frac{A_{i,r}}{DFi} \qquad (4)$$

$R_{i,p}$ = annual release of isotope i to the atmoshpere from the TEG (Ci/y)

DFi = decontamination factor of the non-bypassable filter on the TEG venting line

For iodine isotopes, DFi = 10 (ηi = 90%)
For aerosols, DFi = 100 (ηi = 99%)
For noble gases, DFi = 1 (ηi = 0%)

Np = number of tanks (number of batches) annually vented to the atmosphere

For the real case, $Np = \frac{10.000}{245} = 41$

For the design case, $Np = \frac{24.000}{245} = 98$

Remark

In the hereabove real and design cases, the selected yearly (or daily) production of hydrogenated gaseous waste sent to the "TEG" is equal to the corresponding production rate of primary liquid waste (see table 1) for sake of consistency.

However, for sake of completeness, an additional calculation is also performed with the yearly (or daily) production recommended by the ECC, i.e.

- 6.000 Nm^3/y and 30 Ci/m^3 for the real case
- 10.000 Nm^3/y and 300 Ci/m^3 for the design case

For the yearly production rate of 6.000 Nm^3/y :

$$Qd = \frac{6.000}{365 * 0,85} = 19,2 \ Nm^3/d$$

$$tf = \frac{245}{19,2} = 12,8 \ d$$

$$ts = 6 * 12,8 = 76,8 \ d$$

Rearranging relationships (1), (2), (3) and (4) gives :

$$Ri,p = \frac{Np}{DFi} * \frac{Qd*Xi*at}{\lambda i} * (1-e^{-\lambda i*tf}) * e^{-\lambda i*ts} \ (Ci/y) \qquad (5)$$

7.2. ACTIVITY RELEASED FROM THE VENTILATION SYSTEM

The yearly release to the atmosphere from the ventilation is given by :

$$R'i,V = Qv * 8760 * \frac{xi * a't}{DFi} \qquad (6)$$

R'i,V = annual release of isotope i from the ventilation (Ci/y)

Qv = ventilation extraction rate = 150.000 Nm^3/h

8760 = Hours/y

xi = isotopic fraction of isotope i in the ventilation rate (Table 3)

a't = gross activity in the ventilation extraction rate :

a't = 5.10^{-7} Ci/Nm^3 for the real case

a't = 1.10^{-5} Ci/Nm^3 for the design case (Table 3)

DFi = decontamination factor of the filters on the ventilation extraction lines
DFi = 1 for the noble gases
DFi = 10 for the iodine isotopes
DFi = 10^2 for the aerosols

For the design case, the filters are supposed to be valved in service. For the real case, these filters are assumed to be by-passed as it is generally the case under normal operating conditions.

Note :
The ventilation filters, when in service, are operated in series with the "TEG" non by-passable filters. In that case, the overall DFi values from the TEG releases become equal to :

. 1 for the noble gases
. 10 x 10 = 100 for iodine isotopes
. $10^2 \times 10^2 = 10.000$ for aerosols

7.3. GASEOUS WASTE RELEASE - RESULTS AND COMMENTS

Tables 10.1 to 10.4 list the annual releases from the TEG, from the ventilation and the total annual releases from the unit of both design and real cases

Comments

7.3.1. Storage period in the decay tanks (TEG)

Tables 10.1 to 10.4 show the significant influence of the hydrogenated waste production on the storage period in the decay tanks and on the corresponding releases from the TEG for Xe 133 and I 131.

For the real case, the increase of the effluent production rate from 6.000 to 10.000 Nm^3/y (this latter figure being chosen for sake of consistency with the primary liquid waste production rate) reduces the filling time from 12,8 days to 7,7 days and the storage period from 76,8 days to 46,2 days.

Such a reduction of the storage period greatly affects the release of I 131 (half-life = 5,28 days) and I 131 (half-life = 8,05 days).

For the design case, the increase of the effluent production rate from 10.000 to 24.000 Nm^3/y reduces the filling time from 7,7 days to 3,2 days and the storage period from 46,2 days to 19,2 days.

7.3.2. Discharge limits

Noble gases
The objective value is 2000 Ci/y for the real case. This objective is met for both cases studied (i.e. hydrogenated waste production of 6000 and 10.000 Nm^3/y).

The annual limit corresponding to the design value (20.000 Ci/y) is met for a gaseous waste production of 10.000 Nm^3/y but is exceeded for a gaseous waste production of 24.000 Nm^3/y (see § 8.4.1)

Aerosols

The objective value of 0,02 Ci/y is met for both cases studied (i.e. gaseous waste production of 6.000 and 10.000 Nm^3/y).
The annual limit corresponding to the design value (0,5 Ci/y) is also met for both cases studied. From table 10.3 and 10.4, it can be noted that this annual discharge limit could also be met without HEPA filters in the ventilation releases.

Iodine

On the basis of the isotopic composition recommended by the CEC (see table 3), it can be seen that the objective value (0,02 Ci/y) cannot be met if the iodine filters are not valved in service in the ventilation releases (Tables 10.1 and 10.2).

This is due to a somewhat too high value of the isotopic fraction of iodine in the gaseous waste (xi = 0,01% for I131 - see table 3) -

Such a high value can be demonstrated by the following reasoning :

- On the basis of an annual production of 10.000 m^3/y of primary liquid waste and of an I 131 activity, equal to 0,1 Ci/m^3 (see tables 1 and 2), the annual I 131 input into the primary liquid waste collection tanks R1 (see figure 1) amounts to 1000 Ci/y

- On the basis of a corresponding annual production of 10.000 Nm^3/y of hydrogenated gaseous waste and of an I 131 activity equal to $\frac{0,01}{100} * 30 = 0,003$ Ci/Nm^3, the annual I 131 activity extracted from the primary waste collection tanks and transferred into the "TEG" tanks amounts to 30 Ci/y.
  The fraction of I 131 extracted from the primary liquid waste amounts thus to $\frac{30}{1000} * 100 = 3\%$.
  The actual value is not greater than 1 %.

On the basis of the hereabove values, the iodine partition coefficient in the primary liquid waste collection tanks, i.e. the ratio :

$$\frac{\text{Iodine activity in the liquid phase (Ci/m}^3\text{)}}{\text{Iodine activity in the gaseous phase (Ci/m}^3\text{)}}$$

is equal to $\frac{0,1}{0,003} = 33$

All theoretical and analytical works (*) on Iodine partition coefficients under conditions prevailing in PWRs operation lead to partition coefficient values greater (or much greater) than 100.

Therefore, the iodine isotopic fraction in the gaseous waste should be reduced by a factor at minimum equal to 3, so as to give :

- $X_{I\ 131} = 0,003$ % (max)
- $X_{I\ 133} = 0,01$ % (max)

In that case, the annual I 131 release in the real case would amount to 0,02 Ci/y for a gaseous waste production of 6000 Nm³/y and to 0,04 Ci/y for a gaseous waste production of 10.000 Nm³/y (see Table T10.2 and T10.1).

Similarly, the annual I 131 release in the design case would amount to 0,06 Ci/y for a gaseous waste production of 10.000 Nm³/y and to 0,44 Ci/y for a gaseous waste production of 24.000 Nm³/y (see Table T10.4 and T10.3).

7.4. Gaseous waste release - conclusions

In order not to exceed the discharge limits, the following suggestions are proposed :

- Reduce the isotopic fraction of I 131 and I 133 respectively to 0,003 % and 0,01 %
- Set the I 131 objective values to 0,05 Ci/y for the real case and to 0,5 Ci/y for the design case

In that case, the objective limit value can be met with hydrogenated waste production ranging from 6.000 to 10.000 Nm³/y and a gross activity up to 30 Ci/Nm³. No filtration is required on the ventilation.

The design limit value can be met with hydrogenated waste production ranging from 10.000 to 24.000 Nm³/y and a gross activity up to 300 Ci/Nm³. A filtration is required on the ventilation.

(*) Parsly, Eggleton, etc..

8. ASSESSMENT OF RADIOLOGICAL IMPACT OF THE GASEOUS RELEASES TO THE PUBLIC

The radiological assessment of the atmospheric releases, for the critical individual, involves :

- the noble gases β and γ external irradiation from the plume
- the internal doses resulting from the inhalation of C14, H3, iodine and aerosols
- the internal doses resulting from the ingestion of food products contaminated by the deposits and incorporation of C14, H3, iodine and aerosols.

As far as the public radiations exposure due to the atmosphere releases is concerned, there is no fundamental difference between in-land and coastal sites because :

- the exposures pathways are essentially the same (grass-cow-milk pathway,land uses...)
- one might expect better atmospheric dilution factors for coastal sites. However, this effect is compensated by the fact that atmopheric releases occur via low or moderate heights vents for coastal plants, while such releases occur via high stacks for in-land plants.

8.1. NOBLE GASES EXTERNAL IRRADIATION

8.1.1. Total body dose due to γ irradiation

The whole body γ exposure is calculated according to :

$$D_{i,\gamma} = R_{i,TEG} * D'_{i,\gamma} * \left(\frac{X}{q}\right)_{TEG} + R_{i,vent} * D'_{i,\gamma} * \left(\frac{X}{q}\right)_{VENT} \quad (1)$$

$D_{i,\gamma}$ = whole body γ exposure due to isotope i (rem/y)

$R_{i,TEG}$ = activity release from TEG for isotope i (Ci/y - see table 10)

$\left(\frac{X}{q}\right)_{TEG}$ = atmospheric dilution factor associated with the release duration from "TEG" (s/m^3)

$D'_{i,\gamma}$ = dose-contamination conversion factor for γ irradiation from isotope i $\left(\frac{rem.m^3}{Ci.s}\right)$

The values of $D'_{i,\gamma}$ are given in App.2 - Table 1. These values have been calculated according to the methodology of USNRC Regulatory Guide 1.109.

$R_{i,vent}$ = activity release from the ventilation for isotope i (Ci/y - see table 10 -)

$\left(\frac{\chi}{q}\right)_{VENT}$ = atmospheric dilution factor associated with the release duration from the ventilation (s/m^3)

The evolution of χ/q in function of the release duration is shown on figure A2-F1 for the reference plant. The values shown on figure A2-F1 are the maximum values for a 95% confidence level.
The ventilation releases extend continuously over the whole year. Therefore fig A2-F1 gives :

$$\left(\frac{\chi}{q}\right)_{VENT} = 3.10^{-7} \ s/m^3$$

The venting operation of a decay tank extends over a period which is, at least, equal to 4 hours (an orifice limits the discharge rate to 75 Nm^3/h when the tank pressure is maximum - see fig.5 -)

The number of decay tanks venting operation depends on the hydrogenated waste production.

For the real case and for a production of 10.000 Nm^3/y, 41 decay tanks' contents are vented annually to the atmosphere (see section 8.1).

The cumulated duration is thus at least equal to 41 * 4 = 164 hours and the corresponding value of

$$\left(\frac{\chi}{q}\right)_{TEG} = 2,1 \ . \ 10^{-6} \ s/m^3$$

For the design case and for a production of 24.000 Nm^3/y, 98 tanks contents are vented annually to the atmosphere (see § 8.1). The cumulated duration is thus at least equal to 392 hours and the corresponding value of

$$\left(\frac{\chi}{q}\right)_{TEG} = 1,3 \ . \ 10^{-6} \ s/m^3$$

Relationship (1) can thus be rewritten as :

$$Di,\gamma = \left[Ri,TEG * 2,1.10^{-6} + Ri,Vent * 3.10^{-7} \right] * D'i,\gamma * 10^{3} \quad (mrem/y) \qquad (2)$$

for the real case ; and

$$Di,\gamma = \left[Ri,TEG * 1,3.10^{-6} + Ri,Vent * 3.10^{-7} \right] * D'i,\gamma * 10^{3} \quad (mrem/y) \qquad (3)$$

for the design case.

8.1.2. Skin doses due to β irradiation

For the skin exposure, relationships (2) and (3) also apply after replacing $D'i,\gamma$ by $D'i,\beta$.

$D'i,\beta$ = dose-contamination conversion factor for β irradiation from isotope i (rem.m³/Ci.s) - see Appendix 2, table 1

8.1.3. Results - Total body and skin doses

Table 11 lists the total body and skin doses for the critical individual corresponding to the real and design cases.

For the real case, the exposures are very low

(<0,1 mrem/y or < 1 μ Sv/y)

For the design case, the exposure remain low

(<1 mrem/y or < 10 μSv/y) for an hydrogenated waste production not exceeding 10.000 Nm³/y.

For an hydrogenated waste production of 24.000 Nm³/y, the total body and skin doses amount respectively to 5,5 mrem/y and 11,7 mrem/y, essentially due to the short storage periods of Xe133 in the decay tanks.

Still in that case, the critical individual exposures remain close to the corresponding design limits recommended by the USNRC - 010CFR50 Appendix I - i.e. : 5 mrem/y and 15 mrem/y for total body and skin doses.

8.2. IODINE AND AEROSOLS RELEASES

8.2.1. Doses assessment methodology

The radiological assessment resulting from C14, H3, Iodine and aerosols atmospheric releases for the critical individual is calculated by :

$$Dij = 10^3 \left\{ \left[Ri, TEG \left(\frac{X}{q}\right)_{TEG} + Ri, VENT \left(\frac{X}{q}\right)_{VENT} \right] Dij, inh + \left[Ri, TEG \left(\frac{W}{q}\right)_{TEG} + Ri, VENT \left(\frac{W}{q}\right)_{VENT} \right] Dij, ingest. \right\} \quad (4)$$

Dij = dosis to organ j (j = liver, lungs, thyroïde, total body...) due to the anneed release of isotope i for the critical individual adult (mrem/y)

10^3 = conversion factor (mrem/rem)

Ri,TEG = annual release of isotope i via the gaseous waste storage tanks - TEG system (Ci/y).

Ri,VENT = annual release of isotope i via the ventilation (Ci/y)

$\left[\frac{X}{q}\right]$ TEG , $\left[\frac{X}{q}\right]$ VENT = atmospheric dilution coefficients

applicable to the releases from the gaseous waste storage tanks (TEG) and to the releases from the ventilation.

From § 8.1.1., we have :

$$\left[\frac{X}{q}\right] \text{TEG} = 3.10^{-7} \text{ s/m}^3$$

$$\left[\frac{X}{q}\right] \text{TEG} = 2{,}1.10^{-6} \text{ s/m}^3$$

$\left[\frac{W}{q}\right]$ TEG and $\left[\frac{W}{q}\right]$ VENT = iodine and aerosols deposition rates corresponding to the relases from the "TEG" and from the ventilation ($1/m^2$).

The deposition rates are derived from the atmospheric dilution coefficients, by :

$$\left[\frac{W}{q}\right] = \left[\frac{X}{q}\right] . Vd$$

Vd = deposition velocity (m/s)

For molecular iodine, $Vd = 10^{-2}$ m/s

For aerosols, $Vd = 10^{-3}$ m/s

Therefore, $\left[\frac{W}{q}\right]$ VENT = 3.10^{-9} / m² for molecular iodine

$\left[\frac{W}{q}\right]$ VENT = 3.10^{-10} /m² for aerosols, and

$\left[\frac{W}{q}\right]$ TEG = $2,1.10^{-8}$ /m² for molecular iodine

$\left[\frac{W}{q}\right]$ TEG = $2,1.10^{-9}$ /m² for aerosols

Dij, inh = dose - contamination conversion factor for organ j due to the inhalation of isotope i (rem. m³/Ci.s)

The values of Dij, inh.for the adult critical individual are given in Appendix 2 - Table 2.

Dij, ing = dose - contamination conversion factor or organ j due to the ingestion of isotope i deposited on this ground (rem.m²/Ci).

The values of Dij, ing. for the adult critical individual are given in Appendix 2 - Table 3.

The value of Dij, inh.and Dij, ingest, for the critical individual, are calculated according to the methodology developed in USNRC Regulatory Guide 1-109 (see § 7 - Ref. 3).

The ingestion and inhalation rates taken into account for the calculation of Dij, inh.and Dij, ingest, are listed in Appendix I - § A1-1.

For the aerosols, the ECC same term (see table 3) only enables to calculate an annual gross release (see table 10). Therefore, in order to assess the doses to the public, it has been assumed that the aerosols releases consist of Cs 137 (*) and Co 60 (**), each for 50% of the annual release. Tables A2-T2 and A2-T3 show that such an isotopic composition is conservative.

Relationship (4) can thus be written as :

- for I 131 and I 33

$$Dij = \left[Ri,TEG * 2,1\ 10^{-3} + Ri,VENT * 3,0.10^{-4} \right] * Dij,inh + \left[Ri,TEG * 2,1.10^{-5} + Ri,VENT * 3,0.10^{-6} \right] * Dij,ing \quad (mrem/y) \qquad (5)$$

- for aerosols (Co 60, Cs 137)

$$Dij = \left[Ri,TEG * 2,1.10^{-3} + Ri,VENT * 3,0.10^{-4} \right] * Dij,inh + \left[Ri,TEG * 2,1.10^{-6} + Ri,VENT * 3,0.10^{-7} \right] * Dij,ing \quad (mrem/y) \qquad (6)$$

(*) i.e. the most representative isotope among the fission products
(**) i.e. the most significant isotope among the activation products

9. COLLECTIVE DOSES (see appendix 3)

9.1. COLLECTIVE DOSES DUE TO NOBLE GASES RELEASES

9.1.1. In-Land Site

The total body collective doses resulting from the noble gases releases is given by :

$$D^{G}_{C,\,TB} = \sum_{i} \left[(Ri,\,TEG) * K + Ri,VENT \right] * D'^{G}_{TB,i} * F^{P}_{Ext} \qquad (1)$$

$D^{G}_{C,TB}$ = Total body collective doses due to the release of noble gases (Man.Rem/y or Man.Sv/y)

Ri,TEG; Ri,VENT = annual release of isotope "i" from TEG system and from the ventilation (see § 8.1.1.) in Ci/y

$D'^{G}_{TB,i}$ = dose-contamination conversion factor for total body external irradiation from isotope i in rem.m³/Ci.s (see Appendix 2 - Table 1)

$$K = \frac{\left(\frac{\chi}{q}\right)_{TEG}}{\left(\frac{\chi}{q}\right)_{VENT}},$$

$\left(\frac{\chi}{q}\right)_{TEG}$ and $\left(\frac{\chi}{q}\right)_{VENT}$ are defined in § 8.1.1

It is conservatively assumed that the value of K, in the case of the collective doses, is equal to the corresponding value of K in the case of the critical individual doses.
From §8.1.1., we have :

K = 7 for the real case (10.000 Nm³/y and 30 ci/Nm³ - see table T10.1)

K ≃ 7 for the design case (10.000 Nm^3/y and 300 ci/Nm^3 - see table T10.4)

K = 4 for the design case (24.000 Nm^3/y and 300 ci/Nm^3 - see table T10.3)

F^P_{EXT} = Population distribution factor for external irradiation and inhalation in $Man.sec/m^3$

F^P_{EXT} takes into account the population distribution in all the sectors around the site up to 80 km, each sector being characterized by a specific value of $\left(\frac{\chi}{q}\right)$.

The calculation methodology developed to obtain F^P_{EXT} is given in Appendix 3.

For the reference in-land site,

$F^P_{EXT} = 7,4.10^{-3}$ $Man.sec/m^3$

For the reference coastal site, F^P_{EXT} is selected to be equal to 50 % of the in-land site, i.e.

$F^P_{EXT} = 3,7.10^{-3}$ $Man.sec/m^3$

Table 15 lists the total body collective doses and the contribution of each isotope. For the in-land site, the whole body collective doses amounts to :

- 0,41 Man.Rem/y ($4,1.10^{-3}$ Man.Sv/y) for the real case (10.000 Nm^3/y and 30 Ci/Nm^3)
- 6,3 Man.Rem/y ($6,3.10^{-2}$ Man.Sv/y) for the design case (10.000 Nm^3/y and 300 Ci/Nm^3)
- 129 Man.Rem/y (1,29 Man.Sv/y) for the design case (24.000 Nm^3/y and 300 Ci/Nm^3)

9.1.2. Coastal site

For the coastal site, the collective doses are estimated equal to 50 % of the respective above values, because the population is only distributed on two of the four quadrants around the site.

9.2. COLLECTIVE DOSES DUE TO PARTICULATES RELEASES

9.2.1. In-land site

The total body collective doses resulting from the particulates releases (including C14 and H3) is given by :

$$- D^{P}_{C,TB} = D^{P,inh}_{C,TB} + D^{P,ing}_{C,TB} + D^{P,dep}_{C,TB} \qquad (1)$$

$D^{P}_{C,TB}$ = Total body collective doses due to the releases of particulates, including C14 and H3 (Man.Rem/y or Man Sv/y)

$D^{P,inh}_{C,TB}$, $D^{P,ing}_{C,TB}$ = Total body collective doses due respectively to inhalation and ingestion of particulates (Man.Rem/y or Man.Sv/y)

$D^{P,dep}_{C,TB}$ = Total body collective doses due to the irradiation of aerosols deposited on the ground (Man.rem/y or Man.Sv/y)

$$- D^{P,inh}_{C,TB} = \sum_{i} \left[(Ri, TEG).K + Ri, VENT \right] . D^{P,inh}_{TB,i} \times F^{P}_{EXT} \qquad (2)$$

Ri,TEG ; Ri,VENT ; K and F^{P}_{EXT} are defined in § 9.1.1.

$D'^{P,inh}_{TB,i}$ = Average dose-contamination conversion factor for total body inhalation from isotope "i" expressed in (rem.m³/Ci.s)

F^{P}_{EXT} = Population distribution for inhalation in Man.sec/m³ (§9.1.1.)

$$- D^{P,ing}_{C,TB} = D^{P,ing}_{C,TB,m} + D^{P,ing}_{C,TB,L} + D^{P,ing}_{C,TB,M} \qquad (3)$$

$D^{P,ing}_{C,TB,m}$, $D^{P,ing}_{C,TB,L}$, $D^{P,ing}_{C,TB,M}$ = Total body collective doses due respectively to ingestion of milk (m), vegetables, fruits and grains (L) and Meat (M) (Man.Rem/y or Man.Sv/y)

$D^{P,ing}_{C,TB,M} = D^{P,ing}_{C,TB,B} + D^{P,ing}_{C,TB,P}$ where suscripts B and P refer respectively to the ingestion of Beef and Pork

$$- D^{P,ing}_{C,TB,m} = 10^{-3} * \sum_{i} * \sum_{j} c^{i}_{m,j} * pm,j * \overline{D^{P\,i}_{TB,m}} \qquad (4)$$

$$- D^{P,ing}_{C,TB,L} = 10^{-3} * \sum_{i} * \sum_{j} c^{i}_{L,j} * pL,j * \overline{D^{P\,i}_{TB,L}} \qquad (5)$$

10^{-3} = conversion factor (Rem/mRem)

$C^{i}_{m,j}$ = milk contamination by isotope i in circular sector j, centered on the site and defined by radii Rj - 1 and Rj (pCi/l) - see § A3.7.

$C^{i}_{L,j}$ = vegetables, meat, fruits and grains contamination in circular sector j, centered on the site and defined by radii Rj-1 and Rj (pCi/l) - See § A3.8. -

i = isotopes considered in the aerosols releases.

i = C14, H3, I131, I133, Co60 and Cs137
The annual releases of isotopes for the real and design cases are listed in table 12 to 14.

$p_{m,j}$ = population concerned by the ingestion of milk in circular sector j (see Appendix 3) :

$$p_{m,j} = \frac{P_{m,j}}{136} \text{ (individuals)}$$

$P_{m,j}$ = annual milk production in sector j (l/y) - see App. 3

136 = individual annual milk consumption (l/man.y)

$p_{L,j}$ = Population concerned by the ingestion of vegetables, fruits and grains in sector j (see App.3):

$$p_{L,j} = \frac{P_{L,j}}{195} \text{ (individuals)}$$

$P_{L,j}$ = annual, fruits, grains and vegetables production in sector j (Kg/y) -see App.3-

195 = individual annual fruits, grains and vegetables consumption (Kg/man.y)

$D_{TB,m}^{\bar{P}i}$; $D_{TB,L}^{\bar{P}i}$ = population average dose-contamination conversion factor for milk (m) and for grains, fruits and vegetables (L) pathways (mrem.l/pCi.y or mrem.Kg/pCi.y) - see appendix 3 -

Similarly,

$$-D_{C,TB,M}^{P,ing} = 10^{-3} \sum_i \sum_j \left(C_{B,j}^{i} * P_{B,j} + C_{P,j}^{i} * P_{P,j} \right) * D_{TB,M}^{Pi} \quad (6)$$

$C_{B,j}^{i}$; $C_{P,j}^{i}$ = beef and pork contamination by isotope i in circular sector j, centered on the site and defined by radii Rj-1 and Rj (pCi/kg) - - see App. 3 -

$P_{B,j}$; $P_{P,j}$ = population concerned by the ingestion of beef and pork in sector j (individuals) :

$$p_{B,j} = \frac{P_{B,j}}{81}$$

$$p_{P,j} = \frac{P_{P,j}}{81}$$

$P_{B,j}$; $P_{P,j}$ = Beef and pork production in sector j (Kg/y) - see Appendix 3 -

81 = individual average beef or pork consumption in sector j (Kg/y)

$\overline{Pi}$
$D_{TB,M}$ = population average dose-contamination conversion factor for meat (beef and pork) pathways (mRem.kg/pCi.y) - see Appendix 3 -

The collective dose due to aerosols deposited on the ground is given by :

$$D_{C,TB}^{P,dep} = \sum_i \sum_j SF * R_{i,tot} * Vdi \left(\frac{1 - e^{-\lambda i.tp}}{\lambda}\right) * DF_i^G * \left(\frac{\chi}{q}\right)_j . p_{inh,j}$$

$D_{C,TB}^{P,dep}$ = collective dose due to aerosols deposited on the ground (Man.rem/y or Man.Sv/y)

SF = shielding factor = 0,7 for all isotopes

$R_{i,tot}$ = total release of isotope i (Ci/y)

$R_{i,tot} = K*R_{i,TEG} + R_{i,VENT}$ (see § 9.1.1)

Vdi = deposition rate of isotope i (m/s)

Vdi = 10^{-2} m/s for I131, I133

Vdi = 10^{-3} m/s for Co^{60}, Cs^{137}

λi = radiological decay rate of isotope i (y^{-1})

t_p = ground activity build-up period = 15y

DF_i^G = Dose rate - ground contamination conversion factor

(DF_i^G values are taken from R.G1.109 in Rem/y/Ci/m²)

$$\sum_j \left(\frac{X}{q}\right)_j \cdot p_{inh,j} = F_{EXT}^P \quad \text{(Man.s/m}^3\text{)- see § 9.1.1}$$

$$\text{By setting } SF * DF_i^G * \left(\frac{1 - e^{-\lambda i.tp}}{\lambda i}\right) = DF'_i{}^G,$$

(6) can be written as :

$$D_{C,TB}^{P,dep} = \sum_i Ri,tot * vdi * DF'_i{}^G * F_{EXT}^P \qquad (7)$$

The $DF'_i{}^G$ values are listed hereafter :

Isotope	$DF'_i{}^G$ (rem.m²/Ci)
I131	$2,72.10^{2}$
I133	$3,91.10^{1}$
Co60	$6,88.10^{5}$
Cs137	$3,27.10^{5}$

Taking into account that $F_{EXT}^P = 7,4.10^{-3}$ (Man.s/m³)

(7) can be written as :

$$D_{C,TB}^{P,dep} = 7,4.10^{-3} \sum_i Ri,tot * Vdi * DF'_i{}^G \qquad (8)$$

Note : For thyroïd collective dose, relationships (1) to (8) also apply with the appropriate dose-contaminaiton conversion factors.

RESULTS

The whole body collective doses due to the atmospheric releases of H3, C14, I131, I133 and aerosols are listed in table 16 for the real and design cases. The contribution of the different exposures pathways are also indicated. The thyroïd being the most exposed organ (see tables 12 to 14), the thyroïd collective dose has also been evaluated (see table 16).

The thyroïd collective dose ranges from 74 Man.Rem (0,74 Man.Sv) in the real case to 950 Man.Rem (9,5 Man.Sv) in the extreme design case, this latter value reflecting the significant increase of I131 release, when the hydrogenated gaseous waste production increases from 10.000 to 24.000 Nm^3/y, the storage time in the gaseous waste tanks decreasing accordingly.
The whole body collective dose ranges from 0,77 Man.Rem/y ($7,7.10^{-3}$ Man.Sv/y) in the real case to 2,51 Man.Rem/y ($2,51.10^{-2}$ Man.Sv/y) in the extreme design case. C14 an H3 are the main contributors to the collective dose except in design case (c), where I131 is the main contributor.
Globally, the ingestion is the largely dominant exposure pathway. However for Co60, the exposure to contaminated ground is the dominant pathway. For Cs137, the ingestion and the exposure from contaminated ground are comparable.
The global whole body collective doses, including ingestion, inhalation exposure from contaminated ground and exposure from the plume (noble gases) are summarized in § 10.
For both design cases considered (case (b) and case (c)), the external exposure due to the noble gases in the plume are the dominant pathway.

9.2.2. Coastal site

The collective doses due to atmospheric releases can be evaluated to 50 % af the corresponding values for an in-land site.

9.3 COLLECTIVE DOSES DUE TO LIQUID RELEASES

9.3.1. In-land site

9.3.1.1. Definition of the populations exposed to the routine liquid releases from the in-land reference unit (i.e. Tihange 2 in the present analysis)

These populations can be classified into 4 groups :

1. The population of the city of Antwerpen and it's neighbourhood estimated to 2.10^6 inhabitants. The drinking water of this population is produced from pumping stations along the Albert Canal which consists of 78 % of Meuse water.

2. The population of the city of Rotterdam and it's neighbourhood estimated to $1,1.10^6$ inhabitants. The drinking water of this population is produced from "Biesbosch Reservoirs" which consist of 53 % of Meuse water.

3. The population concerned by Meuse fishes ingestion. The fishes production is estimated to :

   - 35 t/y for the section of the Meuse located between Tihange (reference plant) and the Dutch border
   - 100 t/y for the section of the Meuse located in the Netherlands.

4. The population concerned by the ingestion of products irrigated with Meuse water and by the ingestion of animals products watered with Meuse water.
   The area irrigated with Meuse water is estimated to 50.000 ha and the concerned population amounts to $1,5.10^6$ inhabitants (réf. 7).

9.3.1.2. Population ages classes and food products consumption

The data of ref. 3 are taken into account in this evaluation.

9.3.1.3. Meuse river hydraulic characteristics

Annual average flow rate at the reference plant : 100 m^3/s

Transit times (réf. 7) :

- From the reference plant to the Antwerpen water pumping stations = 82 days

- From the references plant to the Biesbosch (Rotterdam) water pumping stations = 15 days.
  The storage and distribution system of drinking water to the Rotterdam inhabitants is shown on figure A4-F1. The water, pumped from the Meuse, flows sequentially through De Gijster ($V1 = 4{,}07.10^7$ m³), Honderd En Dertig ($V2 = 3{,}42.10^7$ m³) and Petrus Plaat ($V3 = 1{,}53.10^7$ m³) reservoirs and is distributed from that latter reservoir to the population.
  The relationship between the activity (ai) in the drinking water and the activity in the Meuse river (ai,Meuse) is given by :

$$ai = \prod_{j=1}^{j=3} \left[\frac{q/vj}{q/vj + \lambda i} \right] * ai,Meuse \quad (pCi/l) \qquad (1)$$

  q = drinking water makeup-rate = 7.10^5 (m³/d)

  λi = decay rate of isotope i (d^{-1})

- From the reference plant to the irrigation water pumping stations (Hasselt in Belgium and Roermond in the Netherlands) : 6,6 days (réf. 7)

Natural purification by sediments in the Meuse river

The sediments concentration in the Meuse is equal to 50 g/m³ (average value).

The distribution coefficients (Kd) values are (réf. 6) :

Isotope	Kd (m³/t)
Cs134, Cs137	2000
Co58,Co60,Mn54,Fe59	1000

A natural purification by sediments of 10 % for Cs isotopes and of 5 % for Co, Mn an Fe isotopes can thus be taken into account. For the other isotopes, the natural purification is totally negligible.

Purification in the drinking water preparation plants

Due to the lack of data, no purification effect has been taken into account in the drinking water preparation plants.

9.3.1.4. Animal consumption rates

During the grazing period

- Irrigated grass consumption rate = 60 kg/d (réf. 3)

- Watering consumption rate = 10 l/d

Note

The total water consumption by the grazing animals is estimated to 58 l/d. The water needs are covered by :

- watering (10 l/d)
- the water content of the grass (48 l/d), 80 % of the ingested grass consisting of water.

During the grazing period, the contamination of the water consumed by the animals is equal to that of the water used for irrigation. The same remark also applies to the water consumed outside of the grazing periods except for short half-life isotopes (I131) which have totally decayed. Grazing period : 9 months/y.

9.3.1.5. Irrigation periods

For pasture grass, vegetables, fruits and grains production, an irrigation period of 6 months has been taken into account. For vegetables, fruits and grains pathways, the time elapsed between the end of the irrigation and the harvest has been taken equal to 1 month.

9.3.1.6. Collective dose due to drinking water ingestion

For the populations of Antwerpen and Rotterdam areas, we have :

$$D^{P}_{DW,j} = 10^{-3} * \sum_i \overline{Pi}\, D_{DW,j} * \left[2.10^{6} * C^{i}_{W,A} + 1,1.10^{6} * C^{i}_{W,R}\right] Ri \quad (1)$$

$D^{P}_{DW,j}$ = collective dose to organ j due to ingestion of isotope i via the drinking water - Man.Rem/y -
j = whole body, thyroïd (i.e. the most exposed organ due to the liquid releases)

$C^i_{W,A}$; $C^i_{W,R}$ = contamination of the drinking water in the areas of Antwerpen and Rotterdam for a release of 1 Ci/y (pCi/l/Ci/y).

The values of $C^i_{W,A}$ and $C^i_{W,R}$ are given in Appendix A4.1.1 and A4.1.2.

2.10^6 ; $1,1.10^6$ = concerned populations in the areas of Antwerpen and Rotterdam (inhabitants)

$\overline{D^{Pi}_{DW,j}}$ = population average dose - contamination factor for the organ j due to isotope i via the ingestion of drinking water (mrem.l/pCi.y) - see § A4.1.3

Ri = annual release of isotope i via the liquid waste (Ci/y).

RESULTS

The whole body and thyroïd collective doses are given in table 17. The whole-body dose amounts to 17,5 Man.Rem/y (0,175 Man.Sv/y) in the real case and to 19,9 Man.rem/y (0,199 Man.Sv/y) in the design case. The whole body collective dose is essentially governed by H3 (90 % in the real case and 79 % in the design case).
The same remark applies for the thyroïd collective dose.

9.3.1.7. Collective doses due to fishes ingestion

The collective dose due to fishes ingestion is calculated by :

$$D^P_{F,j} = \Sigma_i D^{P,i}_{F,j} * Ri \qquad (1)$$

$D^P_{F,j}$ = collective dose to organ j due to fish ingestion (Man.Rem/y or Man.Sv/y)
j = whole body, thyroïd

$D_{F,j}^{P,i}$ = collective dose to organ j due to fish ingestion resulting from the release of 1 Ci/y of isotope i (Man.Rem/y/Ci/y) (see §A.4.2. and table A4-T3)

Ri = annual release of isotope i via the liquid waste (Ci/y)

RESULTS

The collective doses resulting from fishes ingestion are given in table 18. The whole body collective dose amounts to 1,63 Man.Rem/Y ($1,63.10^{-2}$ Man.Sv/Y) in the real case and to 3,88 Man.Rem/Y ($3,88.10^{-2}$ Man.Sv/Y) in the design case. The whole body collective dose is governed only by Cs134 and Cs137. The thyroïd collective dose amounts to 1,76 Man.Rem/Y ($1,76.10^{-2}$ Man.Sv/Y) in the real case and to 4,0 Man.Rem/Y ($4,0.10^{-2}$ Man.Sv/Y) in the design case.
The thyroïd collective dose is governed only by I131.

9.3.1.8. Collective dose due to milk ingestion (watering + irrigation)

The collective dose due to milk ingestion is calculated by :

$$D_{m,j}^{P} = 10^{-3} \sum_{i} C_{m}^{i} * D_{m,j}^{\overline{Pi}} * 1,5.10^{6} * Ri \qquad (1)$$

10^{-3} = Rem/mRem

C_{m}^{i} = contamination of milk by isotope i due to cow watering and pasture grass irrigation (pCi/l/Ci/y)

The calculation of C_{m}^{i} is given in Appendix A4.3 for the release of 1 Ci/y of each isotope.

$D_{m}^{\overline{Pi}}$ = population average dose-contamination conversion factor to organ j due to isotope i via the milk pathway (mrem.l/pCi.y) - see table A4-T2

$1,5.10^{6}$ = exposed population for ingestion of milk contaminated by watering and irrigation (inhabitants).

Ri = annual release of isotope i (Ci/y)

$D^P_{m,j}$ = collective dose to organ j due to the ingestion of milk contamined by watering and irrigation process (Man.Rem/y or Man.Sv/y)

The collective whole body and thyroïd doses due to the release of 1 Ci of each isotope are given in table A4-T4.

The collective whole body and thyroïde doses due to milk ingestion are given in table 19 for the real and design cases.

The whole body collective dose ranges from 3,3 Man.Rem/y ($3,3.10^{-2}$ Man.Sv/y) in the real case to 4,1 Man.Rem/y ($4,1.10^{-2}$ Man.Sv/y) in the design case and is essentially governed by H3 (85 % in the real case and 69 % in the design case).
The cesium isotopes contribution amounts to 15 % in the real case and to 28 % in the design case.

9.3.1.9. Collective dose due to meat ingestion (watering and irrigation)

The collective dose due to meat ingestion is calculated by :

$$D^P_{M,j} = 10^{-3} \sum_i C^i_M * D^{\overline{Pi}}_{M,j} * 1{,}5.10^{6} * Ri$$

C^i_M = Contamination of meat by isotope i due to animal watering and pasture grass irrigation (pCi/l/Ci/y).
The calculation of C^i_M is given in A4.3.1.

$D^{\overline{Pi}}_{M,j}$ = Population average dose -contamination conversion factor to organ j due to isotope i via the meat pathway (see table A4-T2) - mrem.Kg/pCi.y -

$D^P_{M,j}$ = Collective dose to organ j due to the ingestion of contaminated meat (Man.Rem/y or Man.Sv/y).

1(-3); 1,5(6) and Ri : see § 9.3.1.8.
The collective whole body and thyroïd doses due to the release of 1Ci of each isotope are given in table A4-T5.

The collective whole body and thyroïd doses are given in table 19 for the real and design cases.

The whole body collective dose ranges from 1,79 Man.Rem/y (1,8.10-2 Man.Sv/y) in the real case to 1,94 Man.Rem/y ($1,9.10^{-2}$ Man.Sv/y) in the design case and is governed by H3. The thyroïd collective dose ranges from 2,44 Man.Rem/y ($2,4.10^{-2}$ Man.Sv/y) in the real case to 3,88 Man.Rem/y in the design case. The thyroïd collective dose is governed by H3 in the real case and by I131 in the design case.

9.3.1.10. Collective dose due to vegetables, fruits and grains ingestion

The collective dose due to vegetables, fruits and grains ingestion are calculated from :

$$D^{P}_{L,j} = 1(-3) \sum_{i} C^{i}_{L} * D^{\overline{Pi}}_{L,j} * 1,5(6) * Ri \qquad (1)$$

$D^{P}_{L,j}$ = collective dose to organ j due to the ingestion of vegetables, fruits and grains contaminated by irrigation (Man.Rem/y or Man.Sv/y).

C^{i}_{L} = Contamination of irrigation products due to the release of 1 Ci/y of isotope i (pCi/Kg/Ci/y). The C^{i}_{L} values are calculated according to the methodology of ref (3) - see A4.3.2 -

$D^{\overline{Pi}}_{L,j}$ = population average dose - contamination conversion factor to organ j due to isotope i via the irrigation products pathway (see table A4-T2) (mrem.kg/pCi.Y)

1(-3); Ri; 1,5(6) : see § 9.3.1.8.

The collective whole body and thyroïd doses due to the release of 1 Ci of each isotope are given in table A4-T6.

The collective whole body and thyroïd doses are given in table 20 for the real and design cases.

The whole body collective doses amount to 6,3 Man.Rem/y ($6,3.10^{-2}$ Man.Sv/y) in the real case and to 7,6 Man.Rem/Y ($7,6.10^{-2}$ Man.Sv/y) in the design case and are largely governed by H3 (85 % in the real case, 71 % in the design case). The other significant isotopes are Cs134, Cs137 and Sr90.

9.3.1.11. Conclusion

The whole body and thyroïd collective doses resulting from the different exposure pathways and the corresponding main isotopes constribution are summarized in table T21 for the real case. The whole body collective dose amounts to 31 Man.Rem/y (0,31 Man.Sv/y). The contributions of the different exposure pathways are :

- drinking water = 57,4 %
- fish = 5,3 %
- watering and irrigation products = 37,3 %

The whole body ingestion collective dose is dominated by H3 for all exposure pathways expect for fish ingestion where Cs134 and Cs137 are the dominant isotopes.
The thyroïd ingestion collective dose amounts to 45 Man.Rem/y (0,45 Man.Sv/y). The contributions of the different exposure pathways are :

- drinking water = 36,3 %
- fish = 3,9 %
- watering and irrigation products = 59,8 %

The thyroïd collective dose is governed by :

- I131 for fish and milk exposure pathways
- H3 for the other exposure pathways.

9.3.2. Coastal site

9.3.2.1. Dispersion of the radionuclids in the sea water

The radionuclides are assumed to be dispersed in the Western North Sea.
In order to calculate the radionuclids dispersion, the following model is used (see fig; A5-F1) :

- The Western North Sea is represented by a compartment (volume = 1.400 Km^3) exchanging streams with 2 adjacents compartments (the East Channel compartment, V = 1300 Km^3 and the Central North Sea compartment V = $1,4.10^4$ Km^3)

- The sea water exchange rates between the compartments are shown on fig. A5-F1)

The main characteristics of the compartments are (réf. 8) :

COMPARTMENT	SEDIMENTATION RATE ($t/m^2.y$)	AVERAGE DEPTH (m)	SUSPENDED SOLIDS CONCENTRATION (t/m^3)
East Channel	1.10^{-4}	40	1.10^{-6}
Western North Sea	1.10^{-4}	20	6.10^{-6}
Central North Sea	1.10^{-4}	50	6.10^{-6}

9.3.2.2. Population radiological exposure

The collective dose is calculated taking into account the ingestion of fishes, crustaceas and molluscs. The following consumptions are taken into account (T/y) - (réf. 8) :

COMPARTMENT	FISHES	CRUSTACEAS	MOLLUSCS
East Channel	56.10^{3}	$3,2.10^{3}$	35.10^{3}
Western North Sea	133.10^{3}	$9,0.10^{3}$	137.10^{3}
Central North Sea	$1,06.10^{6}$	30.10^{3}	24.10^{3}

The concentration factors of the radionuclides in each species are taken from ref. 8.

The collective doses are calculated by :

$$D^{P}_{F+C+M,j} = \sum_i I_i * \overline{D}^{i}_{j} * Ri \quad (1)$$

$D^{P}_{F+C+M,j}$ = collective dose to organ j due to ingestion of sea water fishes, crustaceas and molluscs (Man.Rem/y or Man.Sv/y)

I_i = Annual isotope i total activity intake, via all the above mentioned exposure pathways for an annual release of 1 Ci/y (Man.Ci/Ci/y) - see table A5-T2

$\overline{D}^{i}_{j}$ = population average dose-contamination conversion factor for organ j due to ingestion of isotope (Rem/Ci)

The $\overline{D}^{i}_{j}$ values are calculated from ref. 3

Ri = annual release of isotope i via the liquid releases (Ci/y).

The I_i values are given in § A5.2.

The whole body and thyroïd collective doses are given in table 22.

The collective whole body dose rate amounts to $3,10.10^{-2}$ (Man.Rem/y) ($3,2.10^{-4}$ Man.Sv/y) in the real case and to $6,9.10^{-2}$ Man.Rem/y ($6,9.10^{-4}$ Man.Sv/y) in the design case. The whole body collective dose is governed by cesium isotopes.

Similarly, the thyroïd collective dose rate amounts to 0,34 Man.Rem/y ($3,4.10^{-3}$ Man.Sv/y) in the real case and to 0,97 ($9,7.10^{-3}$ Man.Sv/y) in the design case.

10. RADIOLOGICAL ASSESSMENT - SUMMARY - CONCLUSIONS

10.1. RADIOACTIVE ROUTINE RELEASES

This analysis has enabled to quantify the liquid and gaseous routine releases of a reference 900.MWe PWR and the related radiological consequences for 2 sets of operating data :

- a real case with 1 Ci/t fo β-γ emitters (excluding H3 and noble gases) and 30 Ci/t of noble gases in the reactor coolant;
- a design case with 10 Ci/t of β-γ emitters (excluding H3 and noble gases) and 300 Ci/t of noble gases in the reactor coolant.

10.1.1. Liquid releases

10.1.1.1. Primary waste

Table 4 shows that the annual releases of significant isotopes (i.e. isotopes having an half life > 8 days), H3 excluded, amounts to 1,05 Ci in the real case, among which :

- primary waste = 0,81 Ci (0,8 Ci I131)
- secondary waste = $2{,}4.10^{-3}$ Ci
- laundry waste = $8{,}7.10^{-2}$ Ci
- chemical + decon. waste = 0,15 Ci
- building waste = $2{,}7.10^{-3}$ Ci

The releases via the primary waste system are thus largely dominant (80 %) and are practically made of I131 (98 %). This is due to the moderate decontamination factors of I131 for the anionic resin (DF = 10) and for the evaportators (DF = 100). Operating in a low pH (boric acid) environment.

Different ways can be investigated in order to reduce the releases via the primary waste processing system :

- the mixed bed demineraliser on the evaporators distillate could be valved in service (see fig. 1).
  In the real case, this demineralizer has been assumed not to be in service (see § 3.1). This could bring an additional DF=10 for iodine and 2 for other isotopes,
- the recycling of the primary waste distillate in order to take advantage of iodine removal via the CVCS mixed bed (Chemical and Volume Control System), avoiding thereby the need of an additionnal equipment.

The recycling of the primary waste would also imply the recycling of H3 and thus some accumulation of H3 in the primary circuit. This should not lead to operational problems as long as the H3 activity in the reactor coolant does not exceed a value of about <0,5 - 1> Ci/t ($1,9.10^4$ - $3,7.10^4$ MBq/t).

Remark

The recycling of the primary waste enables to reduce the production costs of demineralised and degassed makeup water to the primary system to compensate for the primary water losses due to boron dilution and to leaks from the primary system.

However, from a radiological stand point, the benefit of primary waste recycling decreases as the activity of the primary system decreases.

Example : - for the real case considered (β - γ activity = 1 Ci/t H3 excluded), the recycling of the primary wastes would enable to reduce, at most(*), the liquid releases from 1,05 Ci to about 0,3 Ci/y (i.e. a reduction of about 0,8 Ci/y).
This would only affect significantly the thyroïd dose of the critical individual (reduction from 0,36 mrem/y to about 0,05 mrem/y).
The whole body and other organs doses will not be significantly affected.

- for very low activities in the primary system (β - γ activity = 0,1 Ci/t), the recycling of the primary wastes would enable a reduction of the annual release of about 0,08 Ci/y in the best case(*). In that case, the population doses (critical individual and collective exposure) are governed by H3 and the primary waste recycling will have practically no effect on doses reduction.

(*)Assuming that primary waste recycling does not lead to excessive H3 concentration in the primary system.

10.1.1.2. Chemical and decontamination wastes

Table 4 also indicates that the releases from the chemical and decontamination waste are the most important for non iodine isotopes.
In the real case, these wastes are only processed by floculation (DF = 10, see fig. 3 and § 3.4).

In order to significantly reduce the releases via that way, the supernatant phase originated from the floculator could be processed by the secondary waste evaporators (additional DF = 100). Such an alternative would reduce the whole body dose of the critical individual from 0,1 to 0,05 mrem/y in the real case (i.e. $\beta - \gamma$ activity of 1 Ci/t in the primary system.

For activities in the primary system significantly lower than 1 Ci/t, any additional processing of the supernatant phase originating from the floculator will have little if any impact on the population doses as these become governed by H3.

10.1.2. Gaseous releases

10.1.2.1. Noble gases

The gaseous waste storage capacity of the reference plant enables to limit the gaseous releases from the TEG (essentially Xe133) from 60 to 430 Ci/y for hydrogenated waste production ranging from 6000 Nm^3/y to 10000 Nm^3/y in the real case.
Even on the basis of the conservative approach taken into account as far as the meteorological diffusion coefficients are concerned (see § 8.1.1.), the whole body dose of the critical individual as well as the collective whole body dose are quite low (about 0,01 mrem/y and 0,4 Man rem/y respectively).

The use of an additional storage tank will reduce these values by about 35 % for a production of 10.000 Nm^3/y and will have no effect on the dominant isotopes (C14 and H3). In the case of an hydrogenated gaseous waste production of 6.000 Nm^3/y (or lower), the use of an additional decay tank will have no effect on the population exposure due to noble gases releases, Kr85 being the only isotope released from the TEG (see table T10.2).

10.1.2.2. C14, H3 and aerosols releases

Table 12 shows that the releases of aerosols are quite low ($3,7 \cdot 10^{-4}$ Ci/y). In the real case, the releases of aerosols from the TEG are processed by an HEPA filter and the releases from the ventilation are not filtered. Table 12 also shows that an increase by a factor 10 of the aerosols activity in the source term will have no significant effect on the whole body dose and the organs dose of the critical individual, except for thyroïd and skin doses.

The thyroïd dose is controlled by I131 (see hereafter).
An increase by a factor 10 of the aerosols releases will lead to an increase of the skin dose from $8 \cdot 10^{-4}$ mrem/y to $4,1 \cdot 10^{-3}$ mrem/y, this latter value remaining extremely low.

The whole body, bone, liver, kidneys and lungs doses are controlled by C14 which is not affected by decay tanks and by the filtering systems.

10.1.2.3. Iodine releases

In the real case, the TEG releases are filtered by a charcoal filter (DF = 10) and the ventilation release are not filtered. For an hydrogenated gaseous waste production of 10.000 Nm^3/y, the resulting thyroïd dose for the critical individual amounts to 1,3 mrem/y and is higher by about one order of magnitude than the whole body dose.

However such a value is still much lower than the current applicable limits (EX USNRC limit = 15 mrem/y). An increase (for instance, by the installation of a deep bed charcoal filter with a residence time at least equal to 0,5 sec.) by a factor 10 of the DF of the TEG releases processing filter (i.e. DF = 10^2 instead of DF = 10) will reduce the I131 thyroïd dose from 1,3 down to 0,16 mrem/y.

In that case, the I131 contribution to the thyroïd dose becomes comparables to that of C14.

10.2. RADIOLOGICAL ASSESSMENTS

The radiological assessments (doses to critical individuals and collective doses) are summarized hereafter for the real and design cases.

1. LIQUID EFFLUENTS	REAL CASE		DESIGN CASE	
	INLAND	COASTAL	INLAND	COASTAL
DISCHARGES (Ci/y)	1,74 ; $H3 = 6.10^2$	1,74 ; $H3 = 6.10^2$	6,8 ; $H3 = 6.10^2$	6,8 ; $H3 = 6.10^2$
DOSES TO CRITICAL INDIV. µSv/y — 1. TOTAL BODY	1,0	0,23	2,0	0,35
DOSES TO CRITICAL INDIV. µSv/y — 2. MOST EXP. ORGAN.	3,6 (Thyroïd)	2,6 (Thyroïd)	10 (Thyroïd)	7 (Thyroïd)
COLLECTIVE DOSES - Man.Sv/y				
1. Total Body	$3,1 \cdot 10^{-1}$	$3,2 \cdot 10^{-4}$	$3,7 \cdot 10^{-1}$	$6,9 \cdot 10^{-4}$
2. THYROID	$4,5 \cdot 10^{-1}$	$3,4 \cdot 10^{-3}$	$8,1 \cdot 10^{-1}$	$9,7 \cdot 10^{-3}$

2. GASEOUS EFFLUENTS (*) (INLAND)	REAL CASE		DESIGN CASE	
	10.000 Nm^3/y 30 Ci/m^3	6.000 Nm^3/y 30 Ci/m^3	24.000 Nm^3/y 300 Ci/m^3	10.000 Nm^3/y 300 Ci/m^3
RELEASE (Ci/y) — NOBLE GASES	$1,1.10^3$	713	$3,91.10^5$	$1,75.10^4$
RELEASE (Ci/y) — IODINE (**)	0,31	0,27	1,72	0,563
RELEASE (Ci/y) — AEROSOLS	$3,7.10^{-4}$	$2,5.10^{-4}$	$8,5.10^{-5}$	$4,3.10^{-5}$
DOSES TO CRITICAL INDIV. 1. Total Body - Noble gases (µSv/y)	0,16		52	2,5
2. Total Body - Iodine + particulates (µSv/y)	1,2		1,4	1,2
3. Most exposed Organ (Thyroïd) (µSv/y)	14		$1,9.10^2$	16
COLLECTIVE DOSES (Man.Sv/y) Noble gases + Aerosols + iodine				
1. whole body	$1,2 \cdot 10^{-2}$		1,3 ·	$7,1 \cdot 10^{-2}$
2. Thyroïd	$7,5 \cdot 10^{-1}$		9,5	$8,4 \cdot 10^{-1}$

(*) In the case of the atmospheric releases, the doses to the critical individual are the same for in-land and coastal sites. The collective doses of a coastal site are evaluated to 50 % of corresponding values for an in-land site.

(**) Including I131 + I133 releases.

Table 23 lists, for the real case, the contribution of the different exposures to the collective whole body and thyroïd doses for the in-land and coastal sites. For the in-land reference site, the total whole body doses amounts to 32 Man Rem/y (0,32 Man Sv/y) and is largely dominated by the liquid releases.

The total thyroïd collective dose amounts to 120 Man Rem/y.

Liquid and gaseous releases contribute respectively for about 38 % and 62 % of the thyroïd collective dose.

As one could expect, the collective doses of the coastal site are much lower than the corresponding values of the in-land site. The total whole body collective dose amounts to 0,63 Man Rem/y ($6,3 \cdot 10^{-3}$) and is largely dominated by the gaseous releases.

The total thyroïd collective dose amounts to 37 Man.Rem/Y and is largely dominated by the gaseous releases.

Tables 15 to 22 list the contribution of the different isotopes to the collective doses.

It is worth to note that, in the case of the liquid releases from the in-land site, all exposure pathways but fish are essentially governed by H3 as far as the whole body dose is concerned. The whole body collective dose due to fish ingestion is controlled by cesium isotopes. H3 is also a dominant isotope for the thyroïd dose via drinking water, meat and irrigation products ingestion.

Tables 17 to 21 shows that H3 contributes up to 90 % of the whole body collective dose and up to 57 % of the thyroïd collective dose.

For primary system contaminations lower than that considered in the real case ($\beta - \gamma$ emitters < 1 Ci/t), the whole body collective dose will not change significantly (reduction lower than 10 %), and the relative contribution of H3 will become still higher.

On the contrary, for the coastal site, H3 plays only a minor role in the collective doses, these latter being controlled by cesium isotopes (I131 for thyroïd dose).

The whole body dose due to the gaseous releases depends up to 53 % on H3 and C14 (tables T16 and T23) and up to 35 % on noble gases, while the thyroïd collective dose depends essentially on I131.

It is also worth to point out that land surrounding the reference sites (in-land and coastal) has the following characteristics :

(a) High population density (about 375 inhabitants/Km², see table A3-T2).

(b) The soil consists of a mixture of arable and grass land. 60 % of the land use is dedicated to agriculture. The breakdown of the land uses are the following (see tables A3-T3 and A3-T4) :

- 27 % of the land uses are dedicated to pasture grass for milk and animal products;
- 27 % of the land uses are dedicated to the production of cereals and grains;
- 6 % of the land uses are dedicated to the production of fruits and vegetables.

A comparison of the data listed in tables A3-T2, A3-T3 and A3-T4 shows that the production of milk products, fruits, cereals and vegetables within a radius of 80 km around the site largely exceeds the needs of the population living in that area. For the milk products, the autarchy (*) level is $\frac{16 \cdot 10^6}{7,5 \cdot 10^6} \simeq 2,1$; for the vegetables, fruits, cereals and grains, the autarchy (*) level is $\frac{15,6 \cdot 10^6}{7,5 \cdot 10^6} \simeq 2,1$

Hereabove points (a) et (b) mainly concern the collective doses due to the gaseous releases of both in-land and coastal sites.

(c) Extensive uses of river water downstream of the in-land reference plant for :

- drinking water production ($3,1 \cdot 10^6$ inhabitants)
- animals watering and irrigation purposes ($1,5 \cdot 10^6$ inhabitants).

(*) Autarchy level of a region is the ratio between the population potentially concerned by the ingestion of the region food products and the population actually living in that region

This point concerns the collective doses due to the liquid releases of the in-land reference site.

It is also important to note that the average value of the Meuse River flow rate, along which the in-land reference site is located, is 100 m^3/s (value taken into account in this study). Such a flow rate is much lower than average flow rates of other european rivers such as the Rhône (2.200 m^3/s), the Rhein (1.200 - 2.200 m^3/s), the Loire etc.

This means, namely, that the dilution of the radioactive releases of a plant located along the Meuse will be much smaller (by one order of magnitude at least) than the dilution of the radioactive liquid releases of the same plant located along one the above mentioned rivers. Consequently, for a same annual release rate, the activity of the Meuse water used for drinking water production, irrigation and the contamination of the fishes in the river Meuse will be much higher than the corresponding values of other european rivers.

From above points (a), (b) and (c), it results that the collective doses obtained in the frame of this study can be considered as an upper bound of the collective doses of a 900 MWe PWR in the European Community.

11. REFERENCES

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Primary waste inventories for liquids (PWR's)

Waste Origin	Design Value	Real Value
Primary circuit effluents	300 Ci/m³ (with gas) 10 Ci/m³ (without gas) 24 000 m³/y	1 Ci/m³ (out of gas) 10 000 m³/y
Secondary drain wastes	1 Ci/m³ (peak value) * 10^{-1} Ci/m³ (on average) 4 000 m³/y	10^{-2} Ci/m³ 2 500 m³/y
Laundry waste	10^{-4} Ci/m³ 4 000 m³/y	10^{-4} Ci/m³ (peak value) 10^{-5} Ci/m³ (on average) 4 000 m³/y
Decontamination operations	10^{-1} Ci/m³ 500 m³/y	10^{-2} Ci/m³ 10 m³/y
Chemicals	10^{-2} Ci/m³ 1 500 m³/y	10^{-3} Ci/m³ 1 500 m³/y
Building waste	10^{-3} Ci/m³ 6 000 m³/y	10^{-3} Ci/m³ 3 000 m³/y

* The peak value corresponds to max 10 % of the operational time

Radionuclide composition for the primary liquids effluents

Radionuclide		Mn-54	Co-58	Co-60	Sr-90	Nb-95	Mo-99	Ag-110m
%		0.44	3.0	0.6	0.018	0.001	0.44	0.44
Radionuclide	Sb-124	I-131	I-132	I-133	I-134	I-135	Cs134	Cs137
%	0.44	10.4	18.2	31.2	10.2	20.8	1.79	1.79

(a) Note : for H3 and Sr90, see § 2.1.

Radionuclide composition for all the other auxiliary liquid effluents

Radionuclide	H-3	Mn-54	Co-58	Co-60	Sr-90	Nb-95	Mo-99	Ag-110m
%	1	4.75	31.66	6.33	0.19	0.013	4.75	4.75
Radionuclide	Sb-124	I-131	I-132	I-133	I-134	I-135	Cs134	Cs137
%	4.75	0.46	0.79	1.38	0.46	0.92	19.00	19.00

(a) Note : for Sr90, see § 2.1.

GASEOUS WASTE INVENTORIES (PWRs)

Waste Origin	Design Value	Real Value
Chem. & Volume Control system + Primary Circuit degasing	24 000 Nm^3/y 300 Ci/Nm^3	10 000 Nm^3/y 30 Ci/Nm^3
Ventilation	150 000 Nm^3/h 10^{-5} Ci/Nm^3	150 000 Nm^3/h 5×10^{-7} Ci/Nm^3

Radionuclide composition for gas (PWR's)

Radionuclide	C-14	Kr-85	Kr-85m	Kr-87	Kr-88	Xe-133	Xe-133m
%	(a)	0.03	1.83	1.25	3.32	80.41	1.75
Radionuclide	Xe-135	I-131	I-132	I-133	I-134	I-135	Aerosols
%	11.31	0.01	0.02	0.03	0.01	0.02	0.00001

(a) C14 : annual release of C14 = 5,4 Ci/y (§ 2.2.)

Annual Radioactive Liquid Waste Release - Real Case

Isotope	Release from (Ci/y)					
	Primary	Secondary	Laundry	Chemical + Decontam.	Building	Total
Mn54	4,4 (-4)	1,2 (-4)	1,9 (-3)	7,9 (-3)	1,4 (-4)	1,1 (-2)
Co58	3,0 (-3)	7,9 (-4)	1,3 (-2)	5,2 (-2)	9,5 (-4)	7,0 (-2)
Co60	6,0 (-4)	1,6 (-4)	2,5 (-3)	1,1 (-2)	1,9 (-4)	1,5 (-2)
Sr90	1,8 (-5)	4,8 (-6)	7,6 (-5)	3,2 (-4)	5,7 (-6)	4,2 (-4)
Nb95	1,0 (-6)	/(a)	5,2 (-6)	2,2 (-5)	/(a)	2,9 (-5)
Mo99	2,1 (-4)	7,5 (-5)	1,9 (-3)	3,6 (-3)	9,4 (-5)	5,9 (-3)
Ag110m	4,4 (-4)	1,2 (-4)	1,9 (-3)	7,9 (-3)	1,4 (-4)	1,1 (-2)
Sb124	4,4 (-4)	1,2 (-4)	1,9 (-3)	7,9 (-3)	1,4 (-4)	1,1 (-2)
I131	8,0 (-1)	9,7 (-5)	1,8 (-4)	5,7 (-4)	1,2 (-5)	8,0 (-1)
I132	3,7 (-2)	6,8 (-6)	3,2 (-4)	2,5 (-5)	/(a)	3,7 (-2)
I133	5,7 (-1)	1,0 (-4)	5,5 (-4)	4,0 (-4)	1,4 (-5)	5,7 (-1)
I134	7,8 (-3)	1,5 (-6)	1,8 (-4)	5,6 (-6)	/(a)	8,0 (-3)
I135	1,2 (-1)	1,8 (-5)	2,9 (-4)	6,7 (-5)	2,4 (-6)	1,2 (-1)
Cs134	1,8 (-3)	4,8 (-4)	7,6 (-3)	3,2 (-2)	5,7 (-4)	4,2 (-2)
Cs137	1,8 (-3) (c)	4,8 (-4)	7,6 (-3)	3,2 (-2)	5,7 (-4)	4,2 (-2)
Total						1,74 (0)
H3	6,0 (+2)	/(b)	/(b)	/(b)	/(b)	6,0 (+2)

Notes (a) annual release < 10^{-6} Ci/y

(b) annual release < 1 Ci/y

(c) 1,8 (-3) = $1,8.10^{-3}$

Annual Radioactive Liquid Waste Release - Design Case

Isotope	Release from (Ci/y)					
	Primary	Secondary	Laundry	Chemical + Decontam.	Building	Total
Mn54	1,1 (-3)	1,9 (-3)	1,9 (-2)	3,1 (-3)	2,9 (-4)	2,5 (-2)
Co58	7,2 (-3)	1,3 (-2)	1,3 (-1)	2,1 (-2)	1,9 (-3)	1,7 (-1)
Co60	1,4 (-3)	2,5 (-3)	2,5 (-2)	4,2 (-3)	3,8 (-4)	3,3 (-2)
Sr90	4,3 (-5)	7,6 (-5)	7,6 (-4)	1,3 (-4)	1,1 (-5)	1,0 (-3)
Nb95	2,4 (-6)	5,2 (-6)	5,2 (-5)	8,6 (-6)	/(a)	6,8 (-5)
Mo99	7,8 (-4)	1,4 (-3)	1,9 (-2)	1,7 (-3)	2,3 (-4)	2,3 (-2)
Ag110m	1,1 (-3)	1,9 (-3)	1,9 (-2)	3,1 (-3)	2,9 (-4)	2,5 (-2)
Sb124	1,1 (-3)	1,9 (-3)	1,9 (-2)	3,1 (-3)	2,9 (-4)	2,5 (-2)
I131	2,3 (0)	1,7 (-3)	1,8 (-3)	2,5 (-4)	2,6 (-5)	2,3 (0)
I132	2,1 (-1)	1,8 (-4)	3,2 (-3)	1,3 (-5)	3,6 (-6)	2,1 (-1)
I133	3,0 (0)	2,4 (-3)	5,5 (-3)	2,1 (-4)	4,4 (-5)	3,0 (0)
I134	4,5 (-2)	3,9 (-5)	1,8 (-3)	3,0 (-6)	/(a)	4,7 (-2)
I135	7,1 (-1)	4,6 (-4)	2,9 (-3)	3,5 (-5)	9,2 (-6)	7,1 (-1)
Cs134	4,3 (-3)	7,6 (-3)	7,6 (-2)	1,3 (-2)	1,1 (-4)	1,0 (-1)
Cs137	4,3 (-3) (c)	7,6 (-3)	7,6 (-2)	1,3 (-2)	1,1 (-3)	1,0 (-1)
Total						6,8 (0)
H3	600	4	/(b)	/(b)	/(b)	604

Notes : (a) annual release $< 1.10^{-6}$ Ci/y

(b) annual release < 1 Ci/y

(c) 4,3 (-3) = $4,3.10^{-3}$

Radiological Assessment of Routine Liquid Waste Discharge in fresh water - Real Case

Isotopes	Discharge (Ci/yr)	Doses to adult critical individual (mrem/yr)							
		Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Mn54	1,1 (-2)	1,3 (-4)	2,5 (-4)	1,3 (-4)	1,7 (-4)	1,3 (-4)	5,0 (-4)	2,0 (-4)	2,0 (-4)
Co58	7,0 (-2)	2,5 (-4)	3,6 (-4)	2,5 (-4)	2,5 (-4)	2,5 (-4)	2,7 (-3)	5,1 (-4)	2,9 (-4)
Co60	1,5 (-2)	2,7 (-3)	2,9 (-3)	2,7 (-3)	2,7 (-3)	2,7 (-3)	4,2 (-3)	2,9 (-3)	3,1 (-3)
Sr90	4,2 (-4)	7,6 (-3)	2,0 (-8)	2,0 (-8)	2,0 (-8)	2,0 (-8)	2,2 (-4)	1,9 (-3)	1,1 (-7)
Nb95	2,9 (-5)	7,5 (-8)	6,0 (-8)	4,0 (-8)	6,0 (-8)	4,0 (-8)	1,2 (-4)	5,2 (-8)	4,9 (-8)
Mo99	5,9 (-3)	7,0 (-7)	4,5 (-6)	7,0 (-7)	9,4 (-6)	7,0 (-7)	9,4 (-6)	1,4 (-6)	1,2 (-6)
Ag110m	1,1 (-2)	3,3 (-4)	3,3 (-4)	3,3 (-4)	3,3 (-4)	3,3 (-4)	1,2 (-3)	3,3 (-4)	3,8 (-4)
Sb124	1,1 (-2)	1,8 (-4)	2,2 (-4)	2,8 (-7)	-	9,0 (-4)	3,3 (-3)	4,6 (-4)	-
I131	8,0 (-1)	8,0 (-4)	1,1 (-3)	2,8 (-1)	1,7 (-3)	2,2 (-4)	4,4 (-4)	7,0 (-4)	2,8 (-4)
I133	5,7 (-1)	2,3 (-4)	3,2 (-4)	3,1 (-2)	4,8 (-4)	1,1 (-4)	3,0 (-4)	1,8 (-4)	1,8 (-4)
Cs134	4,2 (-2)	2,2 (-2)	4,6 (-2)	2,4 (-3)	1,5 (-2)	7,5 (-3)	3,3 (-3)	3,7 (-2)	2,8 (-3)
Cs137	4,2 (-2)	2,8 (-2)	3,7 (-2)	3,6 (-3)	3,1 (-2)	7,6 (-3)	4,2 (-3)	2,6 (-2)	4,2 (-3)
H3	6,0 (+2)	-	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	1,4 (-3)
TOTAL (mrem/y)		6,2 (-2)	1,3 (-1)	3,6 (-1)	8,8 (-2)	5,6 (-2)	5,7 (-2)	1,0 (-1)	1,3 (-2)
TOTAL (μSv/y)		6,2 (-1)	1,3 (0)	3,6 (0)	8,8 (-1)	5,6 (-1)	5,7 (-1)	1,0 (0)	1,3 (-1)

Radiological Assessment of Routine Liquid Waste Discharge in fresh water - Design Case

Isotopes	Discharge (Ci/yr)	Doses to adult critical individual (mrem/yr)							
		Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Mn54	2,5 (-2)	3,0 (-4)	5,7 (-4)	3,0 (-4)	3,8 (-4)	3,0 (-4)	1,2 (-3)	3,5 (-4)	3,5 (-4)
Co58	1,7 (-1)	5,9 (-4)	8,8 (-4)	5,9 (-4)	5,9 (-4)	5,9 (-4)	6,5 (-3)	1,2 (-3)	7,1 (-4)
Co60	3,3 (-2)	5,9 (-3)	6,3 (-3)	5,9 (-3)	5,9 (-3)	5,9 (-3)	9,2 (-3)	6,3 (-3)	6,9 (-3)
Sr90	1,0 (-3)	6,2 (-4)	1,1 (-9)	1,1 (-9)	1,1 (-9)	1,1 (-9)	9,9 (-5)	1,8 (-5)	1,0 (-7)
Nb95	6,8 (-5)	1,8 (-7)	1,4 (-7)	9,5 (-8)	1,4 (-7)	9,5 (-8)	2,8 (-4)	1,2 (-7)	1,2 (-7)
Mo99	2,3 (-2)	2,8 (-6)	1,8 (-5)	2,7 (-6)	3,7 (-5)	2,8 (-6)	3,7 (-5)	5,5 (-6)	4,8 (-6)
Ag110m	2,5 (-2)	7,5 (-4)	7,5 (-4)	7,5 (-4)	7,5 (-4)	7,5 (-4)	2,7 (-3)	7,5 (-4)	8,7 (-4)
Sb124	2,5 (-2)	2,5 (-4)	5,0 (-4)	6,5 (-7)	-	2,0 (-4)	7,5 (-3)	1,0 (-4)	-
I131	2,3 (0)	2,3 (-3)	3,2 (-3)	8,0 (-1)	4,8 (-3)	6,2 (-4)	1,3 (-3)	2,0 (-3)	8,0 (-4)
I133	3,0 (0)	1,2 (-3)	1,7 (-3)	1,6 (-1)	2,6 (-3)	6,0 (-4)	1,6 (-3)	9,3 (-4)	9,3 (-4)
Cs134	1,0 (-1)	5,1 (-2)	1,1 (-1)	5,8 (-3)	3,5 (-2)	1,7 (-2)	8,0 (-3)	8,7 (-2)	6,7 (-3)
Cs137	1,0 (-1)	6,8 (-2)	8,9 (-2)	8,7 (-3)	3,6 (-2)	1,8 (-2)	1,0 (-2)	6,2 (-2)	1,0 (-2)
H3	6,0 (+2)	-	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	3,6 (-2)	1,4 (-3)
TOTAL (mrem/y)		1,3 (-1)	2,5 (-1)	1,0 (0)	1,2 (-1)	8,0 (-2)	8,4 (-2)	2,0 (-1)	4,1 (-2)
TOTAL (μSv/y)		1,3 (0)	2,5 (0)	1,0 (+1)	1,2 (0)	8,0 (-1)	8,4 (-1)	2,0 (0)	4,1 (-1)

Radiological Assessment of Routine Liquid Waste Discharge in coastal sea - Real Case

Isotopes	Discharge (Ci/yr)	Doses to adult critical individual (mrem/yr)							
		Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Mn54	1,1 (-2)	6,2 (-5)	2,7 (-4)	6,2 (-5)	1,2 (-4)	6,2 (-5)	7,3 (-4)	1,0 (-4)	7,1 (-5)
Co58	7,0 (-2)	1,1 (-4)	2,2 (-4)	1,1 (-4)	1,1 (-4)	1,1 (-4)	2,4 (-3)	3,7 (-4)	1,3 (-4)
Co60	1,5 (-2)	1,3 (-3)	1,4 (-3)	1,3 (-3)	1,3 (-3)	1,3 (-3)	2,7 (-3)	1,5 (-3)	1,5 (-3)
Sr90	4,2 (-4)	1,4 (-5)	9,2 (-9)	9,2 (-9)	9,2 (-9)	9,2 (-9)	4,1 (-6)	3,5 (-5)	1,9 (-8)
Nb95	2,9 (-5)	5,2 (-8)	3,5 (-8)	1,6 (-8)	3,5 (-8)	1,6 (-8)	1,2 (-4)	2,7 (-8)	1,9 (-8)
Mo99	5,9 (-3)	1,0 (-7)	1,7 (-6)	1,0 (-7)	3,8 (-6)	1,0 (-7)	3,9 (-6)	4,1 (-7)	1,1 (-7)
Ag110	1,1 (-2)	1,9 (-4)	1,9 (-4)	1,5 (-4)	2,1 (-4)	1,5 (-4)	9,8 (-3)	1,7 (-4)	1,9 (-4)
Sb124	1,1 (-2)	1,6 (-4)	3,1 (-6)	3,8 (-7)	-	1,5 (-4)	3,4 (-4)	6,6 (-5)	-
I131	8,0 (-1)	5,0 (-4)	7,0 (-4)	2,1 (-1)	1,1 (-3)	5,7 (-5)	2,2 (-4)	4,2 (-4)	6,9 (-5)
I133	5,7 (-1)	5,7 (-5)	9,7 (-5)	1,4 (-2)	1,7 (-4)	5,7 (-6)	9,1 (-5)	3,4 (-5)	6,8 (-5)
Cs134	4,2 (-2)	2,0 (-3)	3,1 (-3)	1,2 (-3)	1,8 (-3)	1,4 (-3)	1,2 (-3)	2,7 (-3)	1,4 (-3)
Cs137	4,2 (-2)	2,8 (-3)	3,2 (-3)	1,8 (-3)	2,3 (-3)	1,9 (-3)	1,8 (-3)	2,7 (-3)	1,9 (-3)
H3	6,0 (+2)	-	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	5,8 (-3)
TOTAL (mrem/y)		7,2 (-3)	2,5 (-2)	2,6 (-1)	2,2 (-2)	2,1 (-2)	3,5 (-2)	2,3 (-2)	1,1 (-2)
TOTAL (μSv/y)		7,2 (-2)	2,5 (-1)	2,6 (0)	2,2 (-1)	2,1 (-1)	3,5 (-1)	2,3 (-1)	1,1 (-1)

Radiological Assessment of Routine Liquid Waste Discharge in coastal sea - Design Case

Isotopes	Discharge (Ci/yr)	Doses to adult critical individual (mrem/yr)							
		Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Mn54	2,5 (-2)	1,4 (-4)	6,2 (-4)	1,4 (-4)	2,7 (-4)	1,4 (-4)	1,6 (-3)	2,3 (-4)	1,6 (-4)
Co58	1,7 (-1)	2,7 (-4)	5,4 (-4)	2,7 (-4)	2,7 (-4)	2,7 (-4)	5,9 (-3)	9,0 (-4)	3,0 (-4)
Co60	3,3 (-2)	2,9 (-3)	3,1 (-3)	2,9 (-3)	2,9 (-3)	2,9 (-3)	5,9 (-3)	3,3 (-3)	3,3 (-3)
Sr90	1,0 (-3)	3,4 (-5)	2,2 (-8)	2,2 (-8)	2,2 (-8)	2,2 (-8)	9,9 (-6)	8,4 (-5)	2,6 (-8)
Nb95	6,8 (-5)	1,2 (-7)	8,1 (-8)	3,9 (-8)	8,1 (-8)	3,9 (-8)	2,8 (-4)	6,3 (-8)	4,6 (-8)
Mo99	2,3 (-2)	3,9 (-7)	6,7 (-6)	3,9 (-7)	1,6 (-5)	3,9 (-7)	1,5 (-5)	1,6 (-6)	4,4 (-7)
Ag110m	2,5 (-2)	4,2 (-4)	4,2 (-4)	3,5 (-4)	4,7 (-4)	3,5 (-4)	2,2 (-2)	4,0 (-4)	4,2 (-7)
Sb124	2,5 (-2)	3,8 (-4)	7,0 (-6)	8,7 (-7)	-	3,5 (-4)	7,8 (-4)	1,5 (-4)	-
I131	2,3 (0)	1,4 (-3)	2,0 (-3)	6,0 (-1)	3,2 (-3)	1,6 (-4)	6,4 (-4)	1,2 (-3)	1,9 (-4)
I133	3,0 (0)	3,0 (-4)	5,1 (-4)	7,2 (-2)	9,0 (-4)	3,0 (-5)	4,8 (-4)	1,8 (-4)	3,6 (-4)
Cs134	1,0 (-1)	4,7 (-3)	7,3 (-3)	2,8 (-3)	4,3 (-3)	3,3 (-3)	2,9 (-3)	6,5 (-3)	3,3 (-3)
Cs137	1,0 (-1)	6,7 (-3)	7,6 (-3)	4,3 (-3)	5,4 (-3)	4,6 (-3)	4,3 (-3)	6,5 (-3)	4,6 (-3)
H3	6,0 (+2)	-	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	1,5 (-2)	5,8 (-3)
TOTAL (mrem/y)		1,7 (-2)	3,7 (-2)	7,0 (-1)	3,3 (-2)	2,7 (-2)	5,7 (-2)	3,5 (-2)	1,9 (-2)
TOTAL (μSv/y)		1,7 (-1)	3,7 (-1)	7,0 (0)	3,3 (-1)	2,7 (-1)	5,7 (-1)	3,5 (-1)	1,9 (-1)

RADIOACTIVE GASEOUS WASTE RELEASED TO THE ATMOSPHERE

Case A : Real case - 10.000 Nm^3/y (a) and 30 Ci/Nm^3 (b)

ISOTOPE	Annual release from (Ci/y)		TOTAL (Ci/y)
	" TEG "	Ventilation	
Kr 85	9,0 (1)	-	9,0 (1)
Kr 85m	- (c)	1,2 (1)	1,2 (1)
Kr 87	-	8,2 (0)	8,2 (0)
Kr 88	-	2,2 (1)	2,2 (1)
Xe 133	3,44(2)	5,28(2)	8,72(2)
Xe 133m	-	1,2 (1)	1,2 (1)
Xe 135	-	7,4 (1)	7,4 (1)
TOTAL GASES	4,34(2)	6,56(2)	1,09(3)
I131	4,2 (-2)	6,6 (-2) (d)	1,1 (-1)
I133	- (c)	2,0 (-1)	2,0 (-1)
Aerosols	3,0 (-4)	6,6 (-5) (e)	3,7 (-4)

(a) annual production of hydrogenated waste = 10.000 Nm^3/y

(b) activity of hydrogenated waste = 30 Ci/Nm^3

(c) release < 1 Ci/y for noble gases and < 1(-3) Ci/y for iodine isotopes

(d) the releases from the ventilation are calculated assuming the iodine and particulates filters out of service

(e) notation : 6,6 (-5) means $6,6.10^{-5}$

RADIOACTIVE GASEOUS WASTE RELEASED TO THE ATMOSPHERE

Case B : Real case - 6.000 Nm^3/y (a) and 30 Ci/Nm^3 (b)

ISOTOPE	Annual release from (Ci/y)		TOTAL (Ci/y)
	" TEG "	Ventilation	
Kr85	5,4 (1)	-	5,4 (1)
Kr85m	- (c)	1,2 (1)	1,2 (1)
Kr87	-	8,2 (0)	8,2 (0)
Kr88	-	2,2 (1)	2,2 (1)
Xe133	2,8 (0)	5,28(2)	5,31(2)
Xe133m	-	1,2 (1)	1,2 (1)
Xe135	-	7,4 (1)	7,4 (1)
TOTAL GASES	5,7 (1)	6,56(2)	7,13(2)
I131	1,5 (-3)	6,6 (-2) (d)	6,8 (-2)
I133	- (c)	2,0 (-1)	2,0 (-1)
Aerosols	1,8 (-4)	6,6 (-5)	2,5 (-4)

(a) annual production of hydrogenated waste = 6.000 Nm^3/y

(b) activity of hydrogenated waste = 30 Ci/Nm^3

(c) release < 1 Ci/y for noble gases and < 1(-3) Ci/y for iodine isotopes

(d) the releases from the ventilation are calculated assuming the iodine and particulate filters out of service

RADIOACTIVE GASEOUS WASTE RELEASED TO THE ATMOSPHERE

Case C : Design case - 24.000 Nm^3/y (a) and 300 Ci/Nm^3 (b)

ISOTOPE	Annual release from (Ci/y)		TOTAL (Ci/y)
	" TEG "	Ventilation	
Kr85	2,16(3)	3,9 (0)	2,16(3)
Kr85m	- (c)	2,4 (2)	2,4 (2)
Kr87	-	1,6 (2)	1,6 (2)
Kr88	-	4,4 (2)	4,4 (2)
Xe133	3,76(5)	1,06(4)	3,87(5)
Xe133m	1,85(2)	2,3 (2)	4,2 (2)
Xe135	-	1,5 (3)	1,5 (3)
TOTAL GASES	3,78(5)	1,32(4)	3,91(5)
I131	1,2 (0)	1,31(-1) (d)	1,33(0)
I133	- (c)	3,9 (-1)	3,9 (-1)
Aerosols	7,2 (-5)	1,3 (-5)	8,5 (-5)

(a) annual production of hydrogenated waste = 24.000 Nm^3/y

(b) activity of hydrogenated waste = 300 Ci/Nm^3

(c) release < 1 Ci/y for noble gases and < 1(-3) Ci/y for iodine isotopes

(d) for the design case, the releases from the ventilation are assumed to be filtered. The filters of the ventilation, being in "series" with the filters of the TEG, give an additional DF of 10 for iodine and 100 for aerosols released from the TEG.

RADIOACTIVE GASEOUS WASTE RELEASED TO THE ATMOSPHERE

Case D : Design case - 10.000 Nm^3/y (a) and 300 Ci/Nm^3 (b)

ISOTOPE	Annual release from (Ci/y)		TOTAL (Ci/y)
	" TEG "	Ventilation	
Kr85	9,0 (2)	3,9 (0)	9,0 (2)
Kr85m	- (c)	2,4 (2)	2,4 (2)
Kr87	-	1,6 (2)	1,6 (2)
Kr88	-	4,4 (2)	4,4 (2)
Xe133	3,44(3)	1,06(4)	1,4 (4)
Xe133m	-	2,3 (2)	2,3 (2)
Xe135	-	1,5 (3)	1,5 (3)
TOTAL GASES	4,34(3)	1,32(4)	1,75(4)
I131	4,2 (-2)	1,31(-1) (d)	1,73(-1)
I133	-	3,9 (-1)	3,9 (-1)
Aerosols	3,0 (-5)	1,3 (-5)	4,3 (-5)

(a) annual production of hydrogenated waste = 10.000 Nm^3/y

(b) activity of hydrogenated waste = 300 Ci/Nm^3

(c) release < 1 Ci/y for noble gases and < 1(-3) Ci/y for iodine isotopes

(d) for the design case, the releases from the ventilation are assumed to be filtered. The filters of the ventilation, being in "series" with the filters of the TEG, give an additional DF of 10 for iodine and 100 for aerosols released from the TEG.

RADIOLOGICAL ASSESSMENT FOR THE CRITICAL INDIVIDUAL DUE TO NOBLE GASES RELEASES (mrem/y)
(INLAND SITE = COASTAL SITE)

Isotope	Real Case (a)		Design Case (b),(c)	
	Total Body	Skin	Total Body	Skin
Kr85	-	8.1 (-3)	1,1 (-3)	8,2 (-2)
Kr85m	-	-	3,5 (-3)	7,0 (-3)
Kr87	-	1.4 (-3)	1,2 (-2)	2,7 (-2)
Kr88	4.2 (-3)	4.9 (-3)	8,5 (-2)	9,8 (-2)
Xe133	9.9 (-3)	2.0 (-2)	1,2 (-1)	2,4 (-1)
Xe133m	-	-	-	3,0 (-3)
Xe135	1.6 (-3)	3.1 (-3)	3,3 (-2)	6,2 (-2)
TOTAL (mrem/y)	1.6 (-2)	3.8 (-2)	2,5 (-1)	5,2 (-1)
TOTAL (μSv/y)	1.6 (-1)	3.8 (-1)	2,5 (0)	5,2 (0)

(a) - Hydrogenated gaseous waste production = 10.000 Nm^3/y with gross gaseous activity = 30 Ci/Nm^3

- Ventilation activity = 5 (-7) Ci/m^3

(b) - Hydrogenated gaseous waste production = 10.000 Nm^3/y with gross gaseous activity = 300 Ci/Nm^3
- Ventilation activity = 1(-5) Ci/m^3

(c) - For hydrogenated gaseous waste production = 24000 Nm^3/y, with gross gaseous activity = 300 Ci/Nm^3) and ventilation activity = 1(-5) Ci/m^3, the total body and skin doses become respectively equal to 5,6 mrem/y (56μSv/y) and 11,7 mrem/y (117μSv/y).

RADIOLOGICAL ASSESSMENT OF IODINE AND PARTICULATES ROUTINE ATMOSPHERIC RELEASES - REAL CASE (A)

Isotope	Discharge (Ci/y)* from		Doses to Adult Critical Individual (mrem / yr)							
	TEG	VENT	Bone	Liver	Thyroïd	Kidneys	Lungs	GI-LLI	total body	Skin
I 131	4,2(-2)	6,6(-2)	5,2(-3)	7,3 (-3)	1,3 (0)	1,2 (-2)	2,9 (-4)	2,1 (-3)	4,3 (-3)	3,6 (-4)
I 133	-	2,0(-1)	8,5(-5)	1,3 (-4)	1,6 (-2)	2,1 (-4)	2,4 (-5)	1,1 (-4)	5,6 (-5)	2,9 (-5)
Cs 137	1,5(-4)	3,3(-5)	2,5(-4)	2,9(-4)	1,0 (-4)	1,7 (-4)	1,2 (-4)	1,1 (-4)	2,3 (-4)	1,2 (-4)
Co 60	1,5(-4)	3,3(-5)	2,2(-4)	2,2(-4)	2,2 (-4)	2,2 (-4)	2,8 (-4)	2,6 (-4)	2,2 (-4)	2,5 (-4)
C 14	4,6(0)	8,0(-1)	5,4(-1)	1,1(-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	-
H 3	-	1,5(2)	-	6,6(-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	-
Total mrem/y			5,5(-1)	1,2(-1)	1,4 (0)	1,3 (-1)	1,2 (-1)	1,2 (-1)	1,2 (-1)	8,0 (-4)
Total µSv/y			5,5(0)	1,2(0)	1,4 (1)	1,3 (0)	1,2 (0)	1,2 (0)	1,2 (0)	8,0 (-3)

(A) see table T 10.1 - 10.000 Nm^3/y and 30 Ci/Nm^3

RADIOLOGICAL ASSESSMENT OF ROUTINE IODINE AND PARTICULATES ATMOSPHERIC RELEASES - DESIGN CASE (B)

Isotope	Discharge (Ci/y) from		Doses to Adult Critical Individual (mrem / yr)							
	TEG	VENT	Bone	Liver	Thyroïd	Kidneys	Lungs	GI-LLI	total body	Skin
I 131	4,2(-2)	1,31(-1)	6,2(-3)	8,7 (-3)	1,5 (0)	1,5 (-2)	3,5 (-4)	2,6 (-3)	5,1 (-3)	4,2 (-4)
I 133	-	3,9(-1)	1,7(-4)	2,5 (-4)	3,1 (-2)	4,1 (-4)	4,7 (-5)	2,1 (-4)	1,1 (-4)	5,7 (-5)
Cs 137	1,5(-5)	6,5(-6)	2,5(-5)	3,1(-5)	1,1 (-5)	1,8 (-5)	1,3 (-5)	1,1 (-5)	2,4 (-5)	1,3 (-5)
Co 60	1,5(-5)	6,5(-6)	2,3(-5)	2,3(-5)	2,3 (-5)	2,3 (-5)	2,9 (-5)	2,8 (-5)	2,4 (-5)	2,7 (-5)
C 14	4,6(0)	8,0(-1)	5,4(-1)	1,1(-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	1,1 (-1)	-
H 3	-	1,5(2)	-	6,6(-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	-
Total mrem/y			5,5(-1)	1,3(-1)	1,6 (0)	1,3 (-1)	1,2 (-1)	1,2 (-1)	1,2 (-1)	5,2 (-4)
Total µSv/y			5,5(0)	1,3(0)	1,6 (1)	1,3 (0)	1,2 (0)	1,2 (0)	1,2 (0)	5,2 (-3)

(B) see table T 10.4 - 10.000 Nm^3/y and 300 Ci/Nm^3

- Table 14 -

RADIOLOGICAL ASSESSMENT OF IODINE AND PARTICULATES ROUTINE ATMOSPHERIC RELEASES - DESIGN CASE (C)

Isotope	Discharge (Ci/y) from		Doses to Adult Critical Individual (mrem / yr)							
	TEG	VENT	Bone	Liver	Thyroïd	Kidneys	Lungs	GI-LLI	total body	Skin
I 131	1,2(0)	1,31(-1)	7,7(-2)	1,1 (-1)	1,9 (1)	1,8 (-1)	4,4 (-3)	3,2 (-2)	6,4 (-2)	5,3 (-3)
I 133	-	3,9(-1)	1,7(-4)	2,9 (-4)	3,1 (-2)	4,1 (-1)	4,6 (-5)	2,2 (-4)	1,1 (-4)	5,6 (-5)
Cs 137	3,6(-5)	6,5(-6)	3,7(-5)	4,5(-5)	1,6 (-5)	2,6 (-5)	1,9 (-5)	1,6 (-5)	3,5 (-5)	1,9 (-5)
Co 60	3,6(-5)	6,5(-6)	3,4(-5)	3,4(-5)	3,4 (-5)	3,4 (-5)	4,3 (-5)	4,1 (-5)	3,4 (-5)	3,9 (-5)
C 14	4,6(0)	8,0(-1)	3,4(-1)	6,8(-2)	6,8 (-2)	6,8 (-2)	6,8 (-2)	6,8 (-2)	6,8 (-2)	-
H 3	-	1,5(2)	-	6,6(-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	6,6 (-3)	-
Total mrem/y			4,2(-1)	1,8(-1)	1,9 (1)	6,6 (-1)	7,9 (-2)	1,1 (-1)	1,4 (-1)	5,4 (-3)
Total µSv/y			4,2(0)	1,8(0)	1,9 (2)	6,6 (0)	7,9 (-1)	1,1 (0)	1,4 (0)	5,4 (-2)

(C) See table T10 - 3. -24.000 Nm^3/y and 300 Ci/Nm^3

WHOLE BODY COLLECTIVE DOSES DUE TO NOBLE GASES RELEASES (Man-Rem/y)

IN-LAND SITE

ISOTOPE	REAL CASE (a)	DESIGN CASE (b)	DESIGN CASE (c)
^{85}Kr	2,6 (-3)	2,6 (-2)	3,6 (-2)
^{85m}Kr	4,3 (-3)	8,6 (-2)	8,6 (-2)
^{87}Kr	1,5 (-2)	3,0 (-1)	3,0 (-1)
^{88}Kr	1,1 (-1)	2,1 (0)	2,1 (0)
^{133}Xe	2,4 (-1)	2,9 (0)	1,26 (2)
^{135m}Xe	8,5 (-4)	1,6 (-2)	6,91 (-2)
^{135}Xe	4,1 (-2)	8,2 (-1)	8,2 (-1)
Total (Man-Rem/y)	4,1 (-1)	6,3 (0)	1,29 (2)
Total (Man-Sv/y)	4,1 (-3)	6,3 (-2)	1,29 (0)

COASTAL SITE

TOTAL	REAL CASE (a)	DESIGN CASE (b)	DESIGN CASE (c)
Man-Rem/y	2,1 (-1)	3,2 (0)	6,5 (1)
Man-Sv/y	2,1 (-3)	3,2 (-2)	6,5 (-1)

(a) - 10.000 Nm^3/y and 30 Ci/Nm^3 - T10.1
(b) - 10.000 Nm^3/y and 300 Ci/Nm^3 - T10.4
(c) - 24.000 Nm^3/y and 300 Ci/Nm^3 - T10.

COLLECTIVE DOSES DUE TO ATMOSPHERIC RELEASES OF C14, H3 IODINE AND AEROSOLS - IN-LAND SITE -

1. I131 Thyroïd collective dose

CASE	EXPOSURE PATHWAYS		TOTAL COLLECTIVE DOSE	
	Inhalation (Man.Rem/y)	Ingestion (Man.Rem/y)	(Man.Rem/y)	(Man.Sv/y)
Real (a)	1,14	72,6	73,7	0,74
Design (b)	1,29	82,5	83,8	0,84
Design (c)	14,6	931	946	9,5

(a) Real case = 10.000 Nm^3/y from TEG and 30 Ci/Nm^3 (total gases)

(b) Design case = 10.000 Nm^3/y from TEG and 300 Ci/Nm^3 (total gases)

(c) Design case = 24.000 Nm^3/y from TEG and 300 Ci/Nm^3 (total gases)

2. TOTAL BODY COLLECTIVE DOSES

CASE	Isotope	EXPOSURE PATHWAYS			TOTAL COLLECTIVE DOSE	
		Inhalation (Man.Rem/y)	Ingestion (Man.Rem/y)	Ground Contamination (Man.Rem/y)	(Man.Rem / y)	(Man.Sv / y)
Real(a)	C14	3,2 (-2)	3,0 (-1)	--	3,3 (-1)	3,3 (-3)
	H3	5,9 (-2)	2,3 (-1)	--	2,9 (-1)	2,9 (-3)
	I131	1,9 (-3)	1,3 (-1)	7,3 (-3)	1,4 (-1)	1,4 (-3)
	I133	2,6 (-4)	---	5,8 (-4)	8,4 (-4)	8,4 (-6)
	Co60	4,3 (-6)	1,8 (-4)	5,6 (-3)	5,8 (-3)	5,8 (-5)
	Cs137	9,8 (-5)	2,7 (-3)	2,7 (-3)	5,5 (-3)	5,5 (-5)
	Total	9,3 (-2)	6,6 (-1)	1,6 (-2)	7,7 (-1)	7,7 (-3)
Design (b)	C14	3,2 (-2)	3,0 (-1)	--	3,3 (-1)	3,3 (-3)
	H3	5,9 (-2)	2,3 (-1)	--	2,9 (-1)	2,9 (-3)
	I131	2,3 (-3)	1,6 (-1)	8,7 (-3)	1,7 (-1)	1,7 (-3)
	I133	5,1 (-4)	---	1,1 (-3)	1,6 (-3)	1,6 (-5)
	Co60	4,3 (-7)	1,8 (-5)	5,6 (-4)	5,8 (-4)	5,8 (-6)
	Co137	9,8 (-6)	2,7 (-4)	2,7 (-4)	5,5 (-4)	5,5 (-6)
	TOTAL	9,4 (-2)	6,9 (-1)	1,1 (-2)	8,0 (-1)	8,0 (-3)
Design (c)	C14	1,9 (-2)	3,0 (-1)	--	3,2 (-1)	3,2 (-3)
	H3	5,9 (-2)	2,3 (-1)	--	2,9 (-1)	2,9 (-3)
	I131	2,6 (-2)	1,7 (0)	9,9 (-2)	1,9 (0)	1,9 (-2)
	I133	5,1 (-4)	--	1,1 (-3)	1,6 (-3)	1,6 (-5)
	Co60	5,9 (-7)	2,4 (-5)	7,6 (-4)	7,8 (-4)	7,8 (-6)
	Co137	1,3 (-5)	3,6 (-4)	3,6 (-4)	7,3 (-4)	7,3 (-6)
	TOTAL	1,1 (-1)	2,3 (0)	1,0 (-1)	2,51 (0)	2,51(-2)

COLLECTIVE DOSES DUE TO THE INGESTION OF DRINKING WATER FOR THE IN-LAND REFERENCE SITE (MAN.REM/Y) - (MAN.Sv/Y)

ISOTOPE i	REAL CASE		DESIGN CASE	
	Whole body (Man.Rem/y)	Thyroïd (Man.Rem/y)	Whole body (Man.Rem/y)	Thyroïd (Man.Rem/y)
Mn54	2,2 (-3)		5,0 (-3)	
Co58	1,4 (-2)		3,3 (-2)	
Co60	1,9 (-2)		4,0 (-2)	
Sr90	2,1 (-1)		4,9 (-1)	
I131	1,1 (-3)	6,3 (-1)	3,1 (-3)	1,8 (0)
Cs134	9,4 (-1)		2,24 (0)	
Cs137	5,7 (-1)		1,4 (0)	
H3	1,57 (1)	1,57 (1)	1,57 (1)	1,57 (1)
TOTAL (Man.Rem/y)	1,75 (1)	1,63 (1)	1,99 (1)	1,75 (1)
TOTAL (Man.Sv/y)	1,75 (-1)	1,63 (-1)	1,99 (-1)	1,75 (-1)

COLLECTIVE DOSES DUE TO FISH INGESTION FOR THE

FOR THE IN-LAND REFERENCE SITE (MAN.REM/Y) - (MAN.Sv/Y)

ISOTOPE i	REAL CASE		DESIGN CASE	
	Whole body (Man.Rem/y)	Thyroïd (Man.Rem/y)	Whole body (Man.Rem/y)	Thyroïd (Man.Rem/y)
Mn54	5,8 (-4)		1,3 (-3)	
Co58	8,0 (-4)		1,9 (-3)	
Co60	5,4 (-4)		1,2 (-3)	
Sr90	3,2 (-3)		7,6 (-3)	
I131	2,4 (-3)	1,75 (0)	7,0 (-3)	4,0 (0)
Cs134	1,02(0)		2,42 (0)	
Cs137	6,0 (-1)		1,43(0)	
H3	7,2 (-3)	7,2 (-3)	7,2 (-3)	7,2 (-3)
TOTAL (Man.Rem/y)	1,63 (0)	1,76 (0)	3,88 (0)	4,0 (0)
TOTAL (Man.Sv/y)	1,63 (-2)	1,76 (-2)	3,88 (-2)	4,0 (-2)

COLLECTIVE DOSES DUE TO THE INGESTION OF MILK CONTAMINATED BY WATERING AND IRRIGATION PROCESSES

ISOTOPE	Whole body dose (man. Rem/y)		Thyroïd dose (man. Rem/y)	
	Real case	Design Case	Real case	Design Case
Co58	7,7 (-4)	1,9 (-3)		
Co60	6,2 (-4)	1,4 (-3)		
Sr90	4,6 (-3)	1,1 (-2)		
I131	2,7 (-2)	7,8 (-2)	1,52 (1)	4,37 (1)
Cs134	3,0 (-1)	7,1 (-1)		
Cs137	1,8 (-1)	4,4 (-1)		
H3	2,82 (0)	2,82 (0)	2,82 (0)	2,82 (0)
TOTAL (Man.Rem/y)	3,3 (0)	4,1 (0)	1,8 (1)	4,65 (1)
TOTAL (Man.Sv/y)	3,3 (-2)	4,1 (-2)	1,8 (-1)	4,65 (-1)

T19.2

COLLECTIVE DOSES DUE TO THE INGESTION OF MEAT CONTAMINED BY WATERING AND IRRIGATION PROCESSES

Isotope	Whole body dose (Man Rem/y)		Thyroïd dose (Man Rem/y)	
	Real case	Design case	Real case	Design case
Co58	3,5 (-3)	8,5 (-3)		
Co60	3,5 (-3)	7,6 (-3)		
Sr90	1,7 (-3)	4,1 (-3)		
I131	1,4 (-3)	3,9 (-3)	7,6 (-1)	2,2 (0)
Cs134	5,9 (-2)	1,4 (-1)		
Cs137	3,8 (-2)	9,1 (-2)		
H3	1,68 (0)	1,68 (0)	1,68 (0)	1,68 (0)
Total (Man Rem/y)	1,79 (0)	1,94 (0)	2,44 (0)	3,88 (0)
Total (Man Sv/y)	1,8 (-2)	1,9 (-2)	2,4 (-2)	3,9 (-2)

COLLECTIVE DOSES DUE TO THE INGESTION OF IRRIGATED PRODUCTS (*)

FOR THE IN-LAND REFERENCE SITE (Man Rem/y - Man SV/y)

ISOTOPE	Real case		Design case	
	Total body (Man Rem/y)	Thyroïd (Man Rem/y)	Total body (Man Rem/y)	Thyroïd (Man Rem/y)
H3	5,4 (0)	5,4 (0)	5,4 (0)	5,4 (0)
Co58	9,8 (-3)		2,4 (-2)	
Co60	1,1 (-2)		2,4 (-2)	
Sr90	1,1 (-1)		2,6 (-1)	
I131	1,8 (-3)	9,6 (-1)	5,1 (-3)	2,8 (0)
Cs134	5,0 (-1)		1,2 (0)	
Cs137	3,0 (1)		7,2 (-1)	
TOTAL (Man.Rem/y)	6,3 (0)	6,4 (-2)	7,6 (0)	8,2 (0)
TOTAL (Man.Sv/y)	6,3 (-2)	6,4 (-2)	7,6 (-2)	8,2 (-2)

(*) i.e. : Fruits, vegetables and grains

COLLECTIVE DOSES DUE TO LIQUID RELEASES FROM THE IN-LAND REFERENCE SITE FOR THE REAL CASE

- SUMMARY -

Exposure pathway	Collective whole body dose (Man.Rem/y)	Main isotopes contribution (%)	Collective thyroïde dose (Man.Rem/y)	Main isotopes contribution (%)
Drinking water	1,75 (1)	H3 (90), Cs134,Cs137, Sr90	1,63 (1)	H3(96), I131(4)
Fish	1,63 (0)	Cs134 (63), Cs137 (37)	1,76 (0)	I131 (99)
Watering and irrigation products :				
- milk	3,3 (0)	H3 (85), Cs134, Cs137	1,8 (1)	I131 (84), H3 (16)
- meat	1,79 (0) } 1,14 (1)	H3 (94), Cs134, Cs137	2,44 (0) } 2,68 (1)	H3 (69), I131 (31)
- vegetables + fruits + grains	6,3 (0)	H3 (86), Cs134, Cs137 Sr90	6,4 (0)	H3 (84), I131 (16)
Total (Man.Rem/y)	3,05 (1)		4,49 (1)	
Total (Man.Sv/y)	3,1 (-1)		4,5 (-1)	

COLLECTIVE DOSES DUE TO THE INGESTION OF SEA WATER FISHES, CRUSTACEAS AND MOLLUSCS (steady release rate, t ≥ 50 years).

ISOTOPE	REAL CASE (Man.Rem/y)		DESIGN CASE (Man.Rem/y)	
	WHOLE BODY	THYROID	WHOLE BODY	THYROID
H3	5,9(-3)	5,9(-3)	5,9(-3)	5,9(-3)
Co58	1,2(-3)		2,9(-3)	
Co60	1,9(-3)		4,0(-3)	
Sr90	2,2(-4)		5,3(-4)	
I131	5,8(-4)	3,3(-1)	1,7(-3)	9,6(-1)
Cs134	1,2(-2)		2,9(-2)	
Cs137	1,0(-2)		2,5(-2)	
Total Man.Rem/y	3,2(-2)	3,4 (-1)	6,9(-2)	9,7(-1)
Total Man.Sv/y	3,2(-4)	3,5(-3)	6,9(-4)	9,7(-3)

COLLECTIVE DOSES ASSESSMENT IN THE REAL CASE

CONTRIBUTION OF THE MAIN EXPOSURE PATHWAYS (Man.Rem/y)

EXPOSURE PATHWAYS	Whole body		Thyroïd	
	In-land	Coastal	In-land	Coastal
Liquid releases				
- Drinking water	1,75 (1)		1,63 (1)	
- Fish (*)	1,63 (0)	3,2 (-2)	1,76 (0)	3,4 (-1)
Irrigation and watering products				
- Milk	3,30 (0)		1,80 (1)	
- Meat	1,79 (0)		2,44 (0)	
- Fruits, vegetables, grains	6,30 (0)		6,4 (0)	
Total liquide (A)	3,05 (1)	3,2 (-2)	4,49 (1)	3,4 (-1)
Gaseous releases				
- Noble gases	4,1 (-1)	2,1 (-1)	4,1 (-1)	2,1 (-1)
- I131	1,4 (-1)	7,0 (-2)	7,4 (1)	3,7 (1)
- C14, H3, aerosols	6,3 (-1)	3,2 (-1)	6,3 (-1)	3,2 (-1)
Total gaseous (B)	1,18 (0)	6,0 (-1)	7,5 (1)	3,7 (1)
Total (A) + (B) - Liquid + gaseous	3,2 (1)	6,3 (-1)	1,2 (2)	3,7 (1)
Total (A) + (B) in Man.Sv/y	3,2 (-1)	6,3 (-3)	1,2 (0)	3,7 (-1)

(*) For the coastal site, this exposure pathway includes Fishes + crustaceas + molluscs

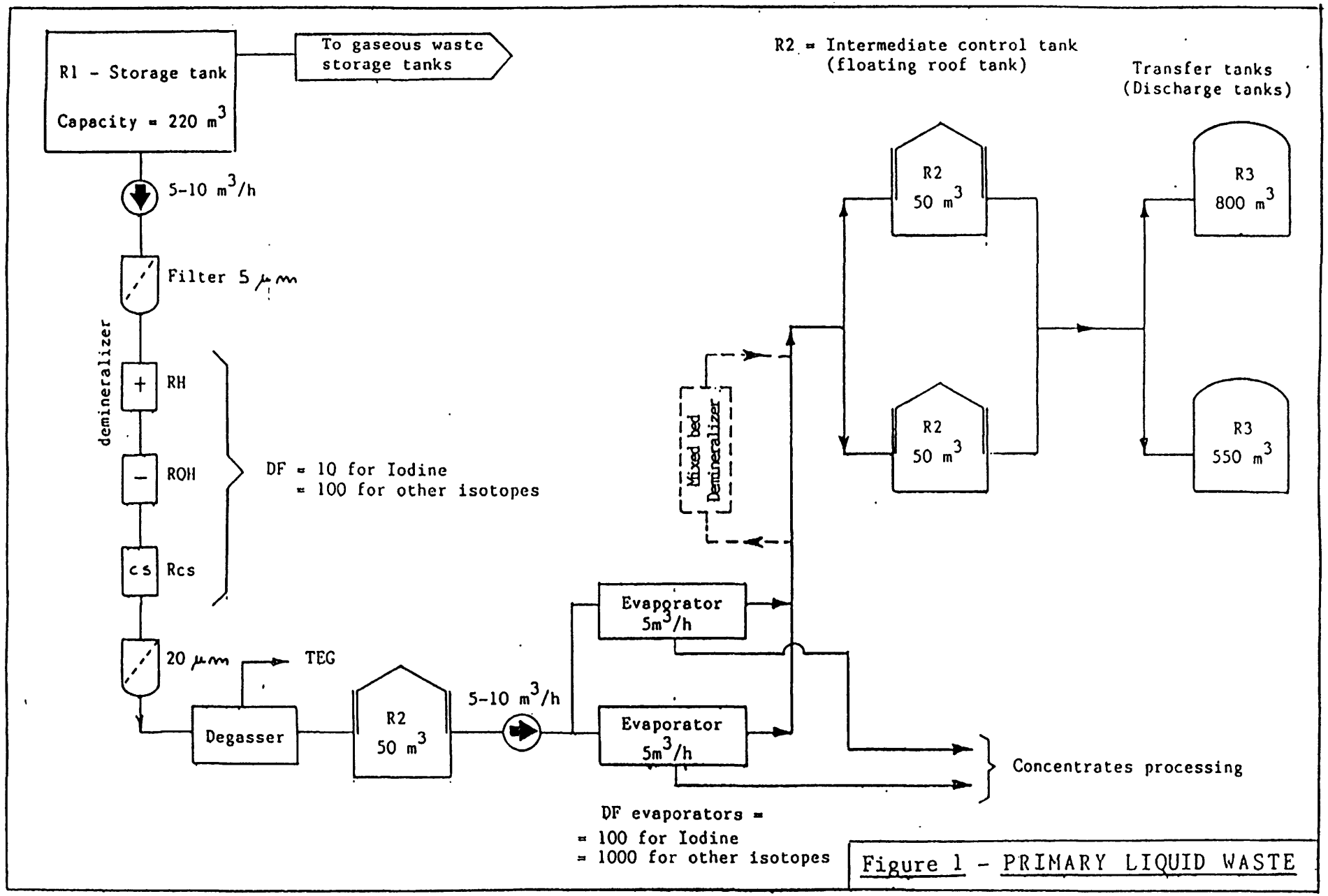


Figure 1 - PRIMARY LIQUID WASTE

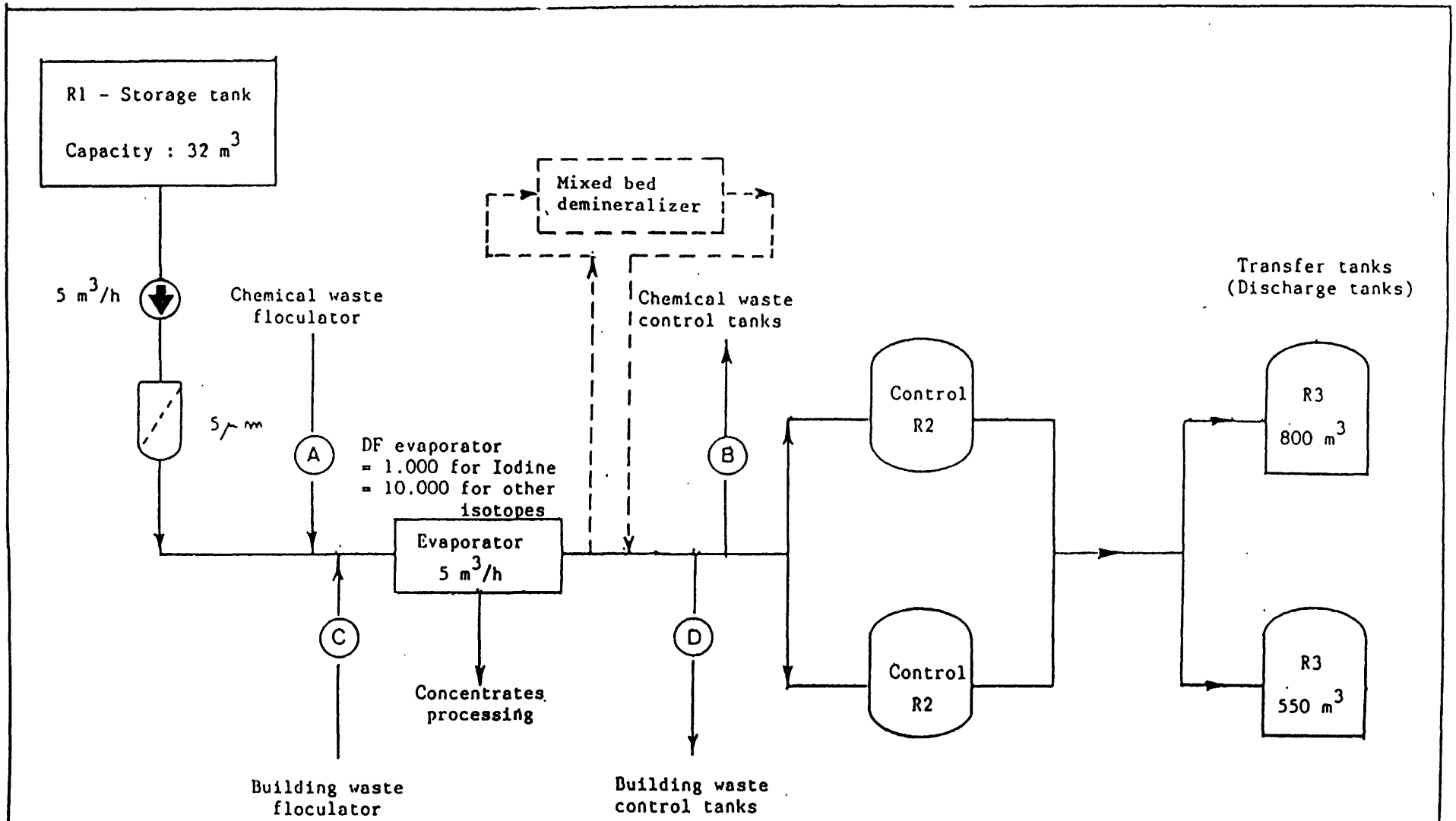
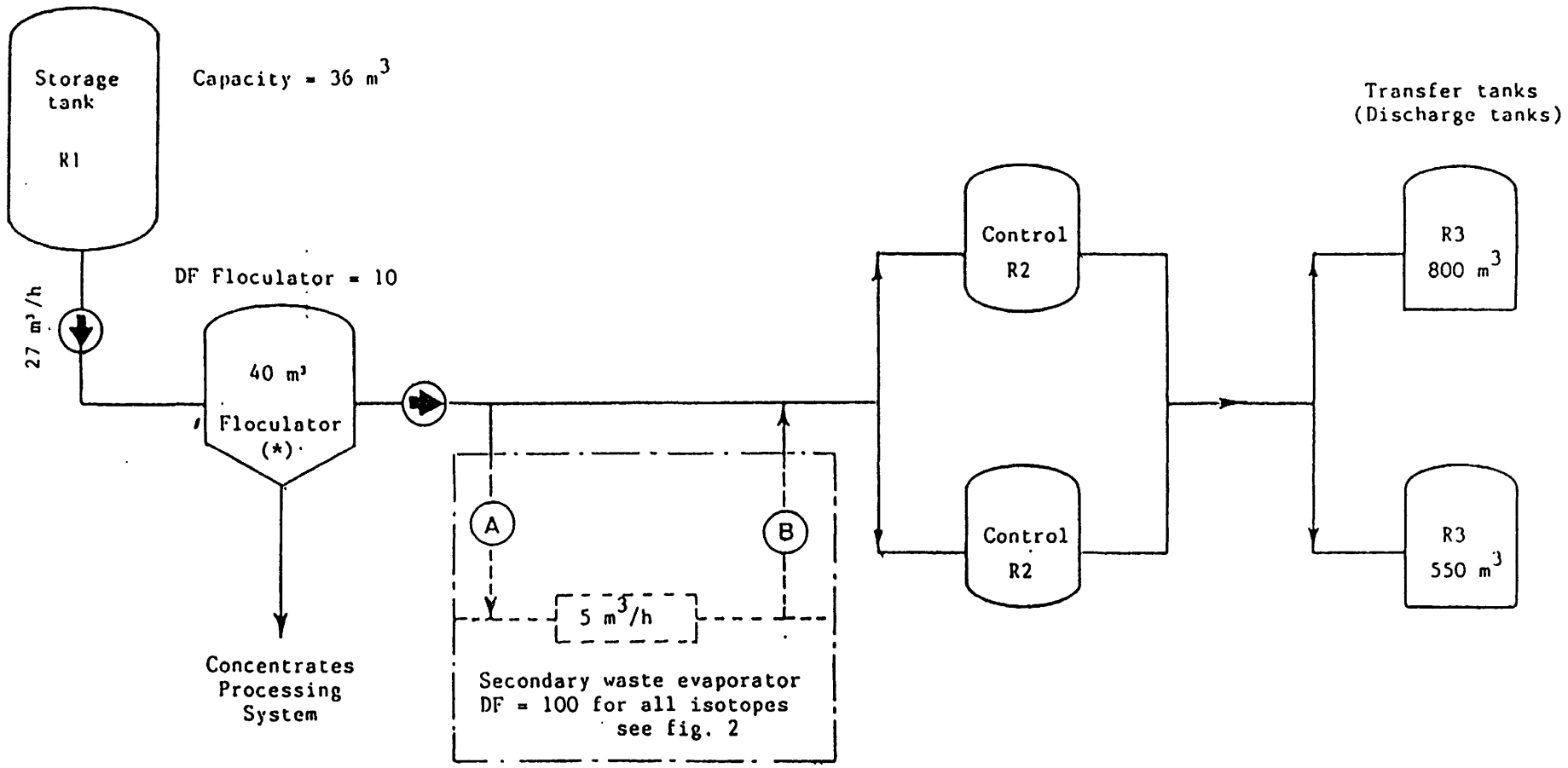
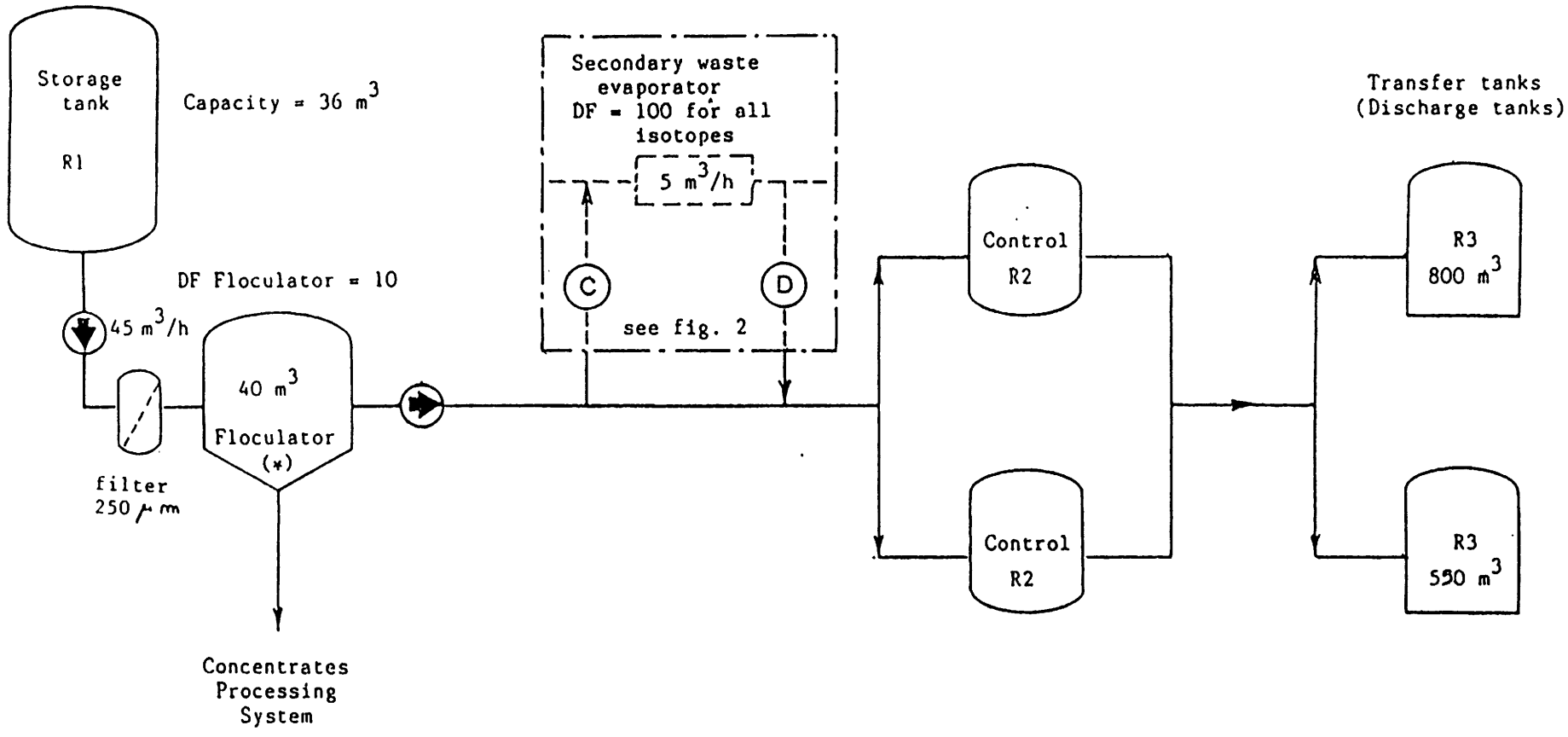


Figure 2 - SECONDARY WASTE



(*) The same floculator is used for chemical and building liquid waste

Figure 3 - CHEMICAL AND DECONTAMINATION WASTE



(*) The same floculator is used for chemical and building liquid waste

Figure 4 - BUILDING WASTE

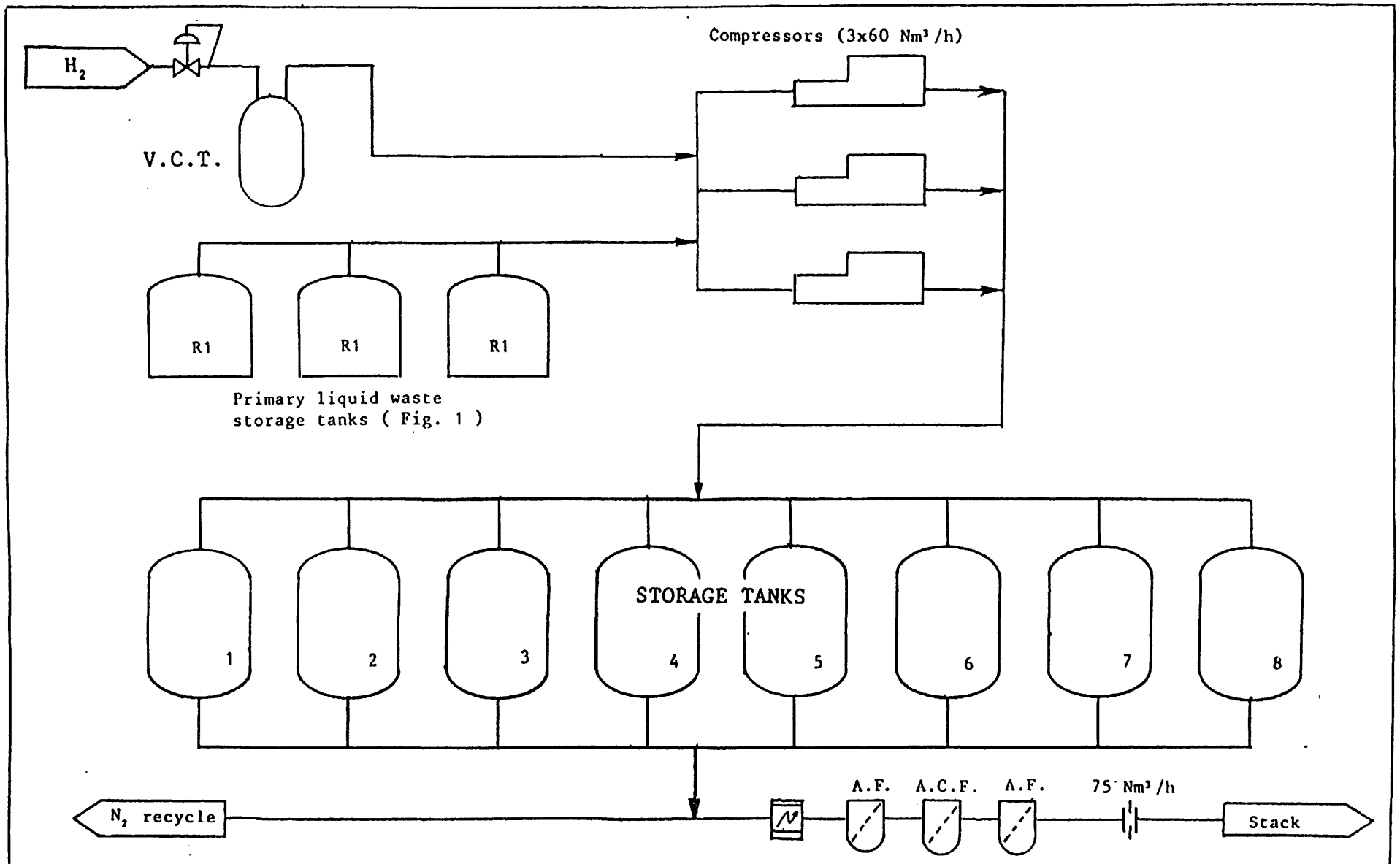


Figure 5 - HYDROGENATED GASEOUS WASTE PROCESSING SYSTEM

APPENDIX I

A1. PUBLIC DOSES ASSESSMENT METHODOLOGY - LIQUID WASTE RELEASE

A1.1. Introduction

The public doses assessment methodology is derived from USNRC Regulatory Guide 1.109 - Ref. 3.

The doses are calculated for the adult critical individual taking into account the following exposure pathways :

Ingestion

- Drinking water	:	730 l/y
- Milk	:	310 l/y
- Fruits, vegetables and grains	:	520 kg/y
- Leafy vegetables	:	64 kg/y
- Meat and poultry	:	110 kg/y
- Fish (fresh water)	:	21 kg/y

Inhalation : 8000 m^3/y

External exposure

- Swimming	:	100 h/y
- Nautical	:	1000 h/y
- Shore line recreation	:	12 h/y
- Sediments draging operations	:	1000 h/y

A1.2. Site specific parameters related to the discharge of liquid waste

The values of the parameters used in the assessment methodology are, in general, those which are recommended by ref. 3. However, some parameters are site specific.
The selected values of those parameters are listed hereafter.

River Meuse flow rate :

100 m^3/s (annual average value)

Drinking water production :

The closest drinking water production plant is located in the vicinity of Antwerpen along the Albert canal.

Due to the dilution of Meuse water by another small river (Ourthe), the volumic activity of the water, at the pumping station of the drinking water plant, is equal to 78 % of that existing in the Meuse downstream of the discharge canal of Tihange power station.

The transit time between Tihange station and the drinking water production plant is 82 days.
The average concentration of sedimentable suspended solids is 50 mg/l. Under this condition, in-situ measurements have shown that 75 % of the Fe activity, 80 % of Zr activity and 10 % of the Cs activity in the river water are absorbed on the sediments.

For the other isotopes no natural decontamination has been taken into account.

No account has been taken of the decontamination effect that occurs, for some isotope, in the drinking water production plant.

Contamination of food products by irrigation

The following irrigation rates have selected (upper limit of the actual values) :

$I = 0,013$ l/h x m² for pastures

$I = 0,023$ l/h x m² for cultures (fruits, cereals, vegetables, etc.)

It is conservatively assumed that irrigation is carried out continuously throughout the year.

A1.3. Activity - Dose relationship

On the basis of the hereabove assumption, table A1-T1 lists the dose to the organs and to the total body of the adult critical individual, which arise from the annual release of 1 TBq of each significant isotope.

Doses (mrem/Yr) (*) arising from an annual liquid discharge of 1 TBq of each Isotope - fresh water site

Exposure pathways : Ingestion and external irradiation
Critical Individual : Adult

Isotopes	ORGANS							
	Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Cr51	1,3 (-3)	1,3 (-3)	1,4 (-3)	1,4 (-3)	1,5 (-3)	2,9 (-2)	1,5 (-3)	1,6 (-3)
Mn54	3,2 (-1)	6,2 (-1)	3,2 (-1)	4,1 (-1)	3,2 (-1)	1,2 (0)	3,8 (-1)	3,8 (-1)
Fe55	8,9 (-2)	6,2 (-2)	3,2 (-7)	3,2 (-7)	3,5 (-2)	3,5 (-2)	1,4 (-2)	1,8 (-6)
Fe59	1,9 (-1)	3,5 (-1)	7,6 (-2)	7,6 (-2)	1,5 (-1)	9,7 (-1)	1,8 (-1)	8,6 (-2)
Co58	9,5 (-2)	1,4 (-1)	9,5 (-2)	9,5 (-2)	9,5 (-2)	1,0 (0)	2,0 (-1)	1,1 (-1)
Co60	4,9 (0)	5,1 (0)	4,9 (0)	4,9 (0)	4,9 (0)	7,6 (0)	5,1 (0)	5,7 (0)
Zn65	2,0 (0)	6,2 (0)	1,8 (-1)	4,0 (0)	1,8 (-1)	4,0 (0)	2,7 (0)	2,0 (-1)
Rb86	3,0 (-3)	8,1 (0)	3,0 (-3)	3,0 (-3)	3,0 (-3)	1,4 (0)	3,8 (0)	6,8 (-3)
Sr89	1,7 (+1)	3,0 (-5)	3,0 (-5)	3,0 (-5)	3,0 (-5)	2,7 (0)	4,9 (-1)	2,7 (-3)
Sr90	4,9 (+2)	1,7 (-3)	1,7 (-3)	1,7 (-3)	1,7 (-3)	1,4 (+1)	1,2 (+2)	7,0 (-3)
Zr95	6,5 (-2)	6,5 (-2)	6,5 (-2)	6,5 (-2)	6,5 (-2)	3,5 (-1)	6,5 (-2)	7,6 (-2)
Nb95	7,0 (-2)	5,7 (-2)	3,8 (-2)	5,7 (-2)	3,8 (-2)	1,1 (+2)	4,9 (-2)	4,6 (-2)
Tc99m	8,1 (-6)	2,2 (-5)	6,7 (-7)	3,2 (-4)	1,1 (-5)	1,2 (-2)	2,6 (-4)	1,3 (-6)
Mo99	3,2 (-3)	2,1 (-2)	3,2 (-3)	4,3 (-2)	3,2 (-3)	4,3 (-2)	6,5 (-3)	5,7 (-3)
Ru103	4,0 (-2)	3,0 (-2)	3,0 (-2)	7,0 (-2)	3,0 (-2)	1,2 (0)	3,5 (-2)	3,5 (-2)
Ru106	3,0 (-1)	9,7 (-2)	9,7 (-2)	4,9 (-1)	9,7 (-2)	1,2 (+1)	1,2 (-1)	1,2 (-1)
Ag110m	8,1 (-1)	8,1 (-1)	8,1 (-1)	8,1 (-1)	8,1 (-1)	3,0 (0)	8,1 (-1)	9,5 (-1)
Sb124	2,7 (-1)	5,4 (-1)	7,0 (-4)	-	2,2 (-1)	8,1 (0)	1,1 (-1)	-
I131	2,7 (-2)	3,8 (-2)	9,4 (0)	5,7 (-2)	7,3 (-3)	1,5 (-2)	2,4 (-2)	9,4 (-3)
I133	1,1 (-2)	1,5 (-2)	1,5 (0)	2,3 (-2)	5,4 (-3)	1,4 (-2)	8,4 (-3)	8,4 (-3)
Te132	2,0 (-1)	1,3 (-1)	1,4 (-1)	1,2 (0)	3,0 (-3)	5,9 (0)	1,2 (-1)	3,5 (-3)
Cs134	1,4 (+1)	3,0 (+1)	1,6 (0)	9,5 (0)	4,6 (0)	2,1 (0)	2,4 (+1)	1,8 (0)
Cs136	1,2 (0)	4,9 (0)	5,7 (-2)	2,7 (0)	4,0 (-1)	5,9 (-1)	3,5 (0)	6,5 (-2)
Cs137	1,8 (+1)	2,4 (+1)	2,3 (0)	9,7 (0)	4,9 (0)	2,7 (-0)	1,7 (+1)	2,7 (0)
Ba140	4,3 (-2)	7,3 (-3)	7,3 (-3)	7,3 (-3)	7,3 (-3)	8,1 (-2)	9,7 (-3)	9,2 (-3)
La140	2,5 (-2)	2,5 (-2)	2,5 (-2)	2,5 (-2)	2,5 (-2)	4,6 (-1)	2,5 (-2)	3,2 (-2)
Ce141	3,9 (-3)	3,9 (-3)	3,9 (-3)	3,9 (-3)	3,9 (-3)	8,1 (-1)	3,9 (-3)	4,6 (-3)
Ce144	2,2 (-2)	1,9 (-2)	1,6 (-2)	1,8 (-2)	1,6 (-2)	2,0 (-0)	1,6 (-2)	2,5 (-2)
H3	-	1,6 (-3)	1,6 (-3)	1,6 (-3)	1,6 (-3)	1,6 (-3)	1,6 (-3)	6,2 (-5)

(*) Note : To convert mrem/y into μSv/y, multiply the above values by 10.

Doses (mrem/Yr) (*) arising from an annual liquid discharge of 1 TBq of each Isotope - coastal site

Exposure pathways : Ingestion and external irradiation
Critical Individual : Adult

Isotopes	ORGANS							
	Bone	Liver	Thyroid	Kidneys	Lungs	GI-LLI	Total body	Skin
Cr51	5,1 (-4)	5,1 (-4)	7,6 (-4)	6,2 (-4)	1,1 (-3)	1,0 (-1)	9,2 (-4)	6,2 (-4)
Mn54	1,5 (-1)	6,7 (-1)	1,5 (-1)	3,0 (-1)	1,5 (-1)	1,8 (0)	2,5 (-1)	1,8 (-1)
Fe55	3,9 (0)	2,6 (0)	-	-	1,5 (0)	1,5 (0)	6,2 (-1)	-
Fe59	5,9 (0)	1,4 (+1)	3,0 (-2)	3,0 (-2)	4,0 (0)	4,6 (+1)	5,4 (0)	3,5 (-2)
Co58	4,3 (-2)	8,6 (-2)	4,3 (-2)	4,3 (-2)	4,3 (-2)	9,5 (-1)	1,4 (-1)	4,9 (-2)
Co60	2,4 (0)	2,5 (0)	2,4 (0)	2,4 (0)	2,4 (0)	4,9 (0)	2,7 (0)	2,7 (0)
Zn65	1,2 (+1)	3,8 (+1)	8,4 (-2)	2,6 (+1)	8,4 (-2)	2,4 (+1)	1,8 (+1)	9,7 (-2)
Rb86	1,0 (-3)	4,6 (-2)	1,0 (-3)	1,0 (-3)	1,0 (-3)	1,0 (-2)	2,2 (-2)	1,2 (-3)
Sr89	3,8 (-1)	2,5 (-6)	2,5 (-6)	2,5 (-6)	2,5 (-6)	5,9 (-2)	1,1 (-2)	3,0 (-6)
Sr90	9,2 (-1)	5,9 (-4)	5,9 (-4)	5,9 (-4)	5,9 (-4)	2,7 (-1)	2,3 (0)	7,0 (-4)
Zr95	3,0 (-2)	3,0 (-2)	3,0 (-2)	3,0 (-2)	3,0 (-2)	1,2 (0)	3,0 (-2)	3,1 (-2)
Nb95	4,9 (-2)	3,2 (-2)	1,5 (-2)	3,2 (-2)	3,2 (-2)	1,1 (+2)	2,5 (-2)	1,8 (-2)
Tc99m	2,1 (-5)	2,1 (-5)	2,1 (-5)	2,3 (-5)	2,1 (-5)	1,2 (-4)	2,3 (-5)	2,3 (-5)
Mo99	4,6 (-4)	7,8 (-3)	4,6 (-4)	1,8 (-2)	4,6 (-4)	1,8 (-2)	1,9 (-3)	5,1 (-4)
Ru103	2,0 (-2)	1,2 (-2)	1,2 (-2)	4,3 (-2)	1,2 (-2)	9,5 (-1)	1,6 (-2)	1,4 (-2)
Ru106	1,7 (-1)	4,6 (-2)	3,0 (-2)	2,7 (-1)	4,6 (-2)	7,8 (0)	6,2 (-2)	5,7 (-2)
Ag110m	4,6 (-1)	4,6 (-1)	3,8 (-1)	5,1 (-1)	3,8 (-1)	2,4 (+1)	4,3 (-1)	4,6 (-1)
Sb124	4,0 (-1)	7,6 (-3)	9,5 (-4)	-	3,8 (-1)	8,4 (-1)	1,6 (-1)	-
I131	1,7 (-2)	2,3 (-2)	7,0 (0)	3,8 (-2)	1,9 (-3)	7,6 (-3)	1,4 (-2)	2,3 (-3)
I133	2,7 (-3)	4,6 (-3)	6,5 (-1)	8,1 (-3)	2,7 (-4)	4,3 (-3)	1,6 (-3)	3,2 (-3)
Te132	1,7 (-2)	1,3 (-2)	1,4 (-2)	8,1 (-2)	4,6 (-3)	3,8 (-1)	1,2 (-2)	5,7 (-3)
Cs134	1,3 (0)	2,0 (0)	7,6 (-1)	1,2 (0)	8,9 (-1)	7,8 (-1)	1,8 (-1)	8,9 (-1)
Cs136	6,8 (-2)	2,2 (-2)	1,7 (-2)	1,3 (-1)	3,2 (-2)	4,1 (-2)	1,6 (-1)	1,9 (-2)
Cs137	1,8 (0)	2,1 (0)	1,2 (0)	1,5 (0)	1,2 (0)	1,2 (-0)	1,8 (0)	1,2 (0)
Ba140	1,3 (-1)	1,6 (-2)	1,6 (-2)	1,6 (-2)	1,6 (-2)	2,6 (-1)	2,4 (-2)	1,9 (-2)
La140	2,2 (-3)	2,2 (-3)	2,2 (-3)	2,2 (-3)	2,2 (-3)	3,0 (0)	2,2 (-3)	2,4 (-3)
Ce141	1,8 (-3)	1,7 (-3)	1,5 (-3)	1,6 (-3)	1,5 (-3)	6,5 (-1)	1,5 (-3)	1,7 (-3)
Ce144	2,1 (-2)	1,2 (-2)	7,8 (-3)	1,1 (-2)	7,8 (-3)	4,6 (0)	8,4 (-3)	8,9 (-3)
H3	-	6,8 (-4)	6,8 (-4)	6,8 (-4)	6,8 (-4)	6,8 (-4)	6,8 (-4)	

(*) Note : to convert mrem/y into μSv/y, multiply the above values by 10

APPENDIX 2

A2. PUBLIC DOSES ASSESSMENT METHODOLOGY-GASEOUS RELEASES

A2.1. Introduction

The public doses assessment methodology is derived from USNRC R.G.1.109 - Ref. 3.
The doses are calculated for the adult critical individual taking into account the following exposure pathways :

Ingestion

The annual ingestion rates of food products contaminated by C14, H3, iodine and aerosols are :

- Milk : 310 l/y
- Fruits, vegetables and grains : 520 kg/y
- Leafy vegetables : 64 kg/y
- Meat and poultry : 110 kg/y

Inhalation : 8000 m^3/y

A2.2. Deposition rates

- molecular iodine : $1 \cdot 10^{-2}$ m/s
- aerosols : $1 \cdot 10^{-3}$ m/s

A2.3. Site specific parameters

The atmospheric dilution factors (χ/q values) are plotted on figure A2-F1, versus the duration of the stack release supposed to occur at a constant rate.

The plotted values represent the most pessimistic values for a confidence level of 95 %.

Example :

- for a release at a constant rate during 1 hour,
  $\frac{\chi}{q} = 2,6 \cdot 10^{-5}$ (s/m^3)
- for a release at a constant rate during 1 year,
  $\frac{\chi}{q} = 3,0 \cdot 10^{-7}$ (s/m^3)

The dose-contamination conversion factors used for the critical individual are given in table :

. A2-T1 for noble gases cloud exposure
. A2-T2 for iodine and aerosols inhalation
. A2-T3 for iodine and aerosols ingestion
. A2-T2 for C14 and H3 inhalation and ingestion

DOSES - CONTAMINATION CONVERSION FACTORS FOR NOBLE GASES STACK ROUTINE RELEASES

Isotopes	γ Doses, air rad.m³/ Ci . s	β Doses, air rad.m³/Ci . s	Whole Body rem.m³/Ci . s	Skin rem.m³/Ci . s
Kr 85m	4,57 (-2)	6,25 (-2)	4,82 (-2)	9,72 (-2)
Kr 85	5,46 (-4)	6,19 (-2)	5,67 (-4)	4,31 (-2)
Kr 87	2,35 (-1)	3,27 (-1)	2,50 (-1)	5,70 (-1)
Kr 88	5,99 (-1)	9,30 (-2)	6,43 (-1)	7,40 (-1)
Kr 89	6,59 (-1)	3,37 (-1)	7,02 (-1)	1,05 (0)
Xe 131 m	5,30 (-3)	3,46 (-3)	3,46 (-3)	2,10 (-2)
Xe 133 m	1,12 (-2)	4,70 (-2)	9,55 (-3)	4,41 (-2)
Xe 133	1,21 (-2)	3,33 (-2)	1,12 (-2)	2,31 (-2)
Xe 135 m	1,28 (-1)	2,35 (-2)	1,32 (-1)	1,65 (-1)
Xe 135	7,08 (-2)	7,81 (-2)	7,41 (-2)	1,38 (-1)
Xe 137	5,75 (-2)	4,03 (-1)	6,01 (-2)	4,51 (-1)
Xe 138	3,50 (-1)	1,51 (-1)	3,73 (-1)	5,20 (-1)

IODINE AND AEROSOLS ATMOSPHERIC RELEASES

INHALATION DOSES - CONTAMINATION CONVERSION FACTORS FOR ADULT CRITICAL INDIVIDUAL

(rem.m³/Ci.s)

Isotope	ORGANS						
	Bone	Liver	Thyroïd	Kidneys	Lungs	GI Tractus	total body
Mn54	-	1,26 (0)	-	3,12 (-1)	4,44 (1)	2,46 (0)	2,00 (-1)
Fe59	3,73 (-1)	8,81 (-1)	-	-	3,23 (1)	5,97 (0)	3,35 (-1)
Co58	-	5,03 (-2)	-	-	2,95 (1)	3,78 (0)	6,58 (-2)
Co60	-	3,66 (-1)	-	-	1,89 (2)	9,04 (0)	4,70 (-1)
Sr89	9,65 (0)	-	-	-	4,44 (1)	1,11 (1)	2,77 (-1)
Sr90	3,15 (3)	-	-	-	3,05 (2)	2,29 (1)	1,94 (2)
Cs134	1,18 (1)	2,69 (1)	-	9,12 (0)	3,10 (0)	3,30 (-1)	2,31 (1)
Cs137	1,52 (1)	1,97 (1)	-	7,06 (0)	2,39 (0)	2,67 (-1)	1,36 (1)
I131	8,00 (-1)	1,14 (0)	3,78(2)	1,95 (0)	-	1,99 (-1)	6,50 (-1)
I133	2,74 (-1)	4,70 (-1)	6,83(1)	8,20 (-1)	-	2,82 (-1)	1,43 (-1)
H3*	-	1,46 (-1)	1,46(-1)	1,46 (-1)	1,46 (-1)	1,46 (-1)	1,46 (-1)
C14 *	5,5 (1)	1,1 (1)	1,1 (1)	1,1 (1)	1,1 (1)	1,1 (1)	1,1 (1)

* Note : H3 and C 14 inhalation dose - contamination factors take also into account the internal exposures due to ingestion pathways.

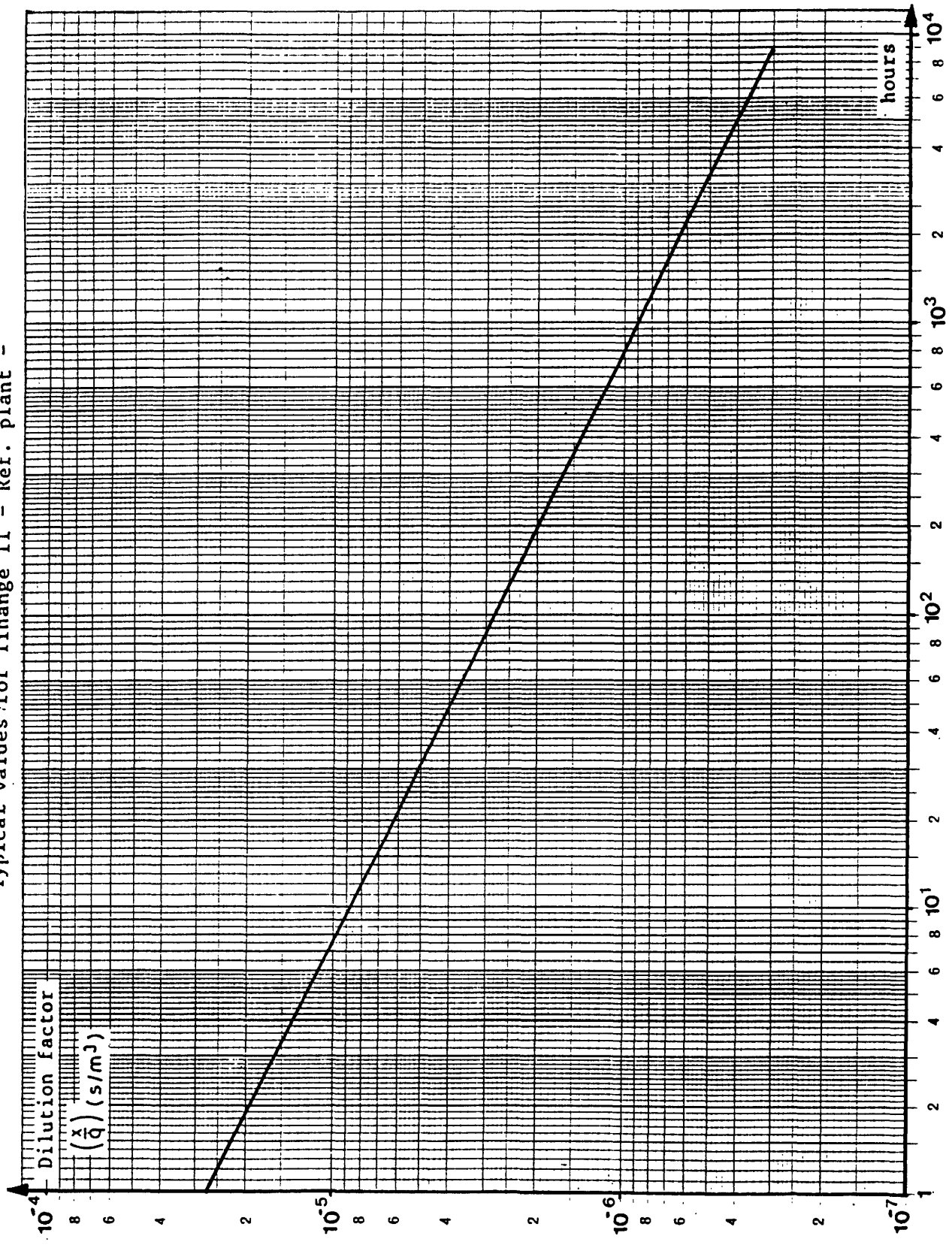
IODINE AND AEROSOLS ATMOSPHERIC RELEASES

INGESTION DOSES - CONTAMINATION CONVERSION FACTORS FOR ADULT CRITICAL INDIVIDUAL
(rem m^2/Ci)

Isotope	ORGANS							
	Bone	Liver	Thyroïd	Kidneys	Lungs	GI Tractus	total body	Skin
Mn54	4,26 (4)	5,26 (4)	4,26(4)	4,56 (4)	4,26 (4)	7,32 (4)	4,45 (4)	5,00 (4)
Fe59	1,88 (4)	3,23 (4)	8,83(3)	8,83 (3)	1,54 (4)	8,72 (4)	1,78 (4)	1,03 (4)
Co58	1,21 (4)	1,35 (4)	1,21(4)	1,21 (4)	1,21 (4)	4,10 (4)	1,53 (4)	1,42 (4)
Co60	6,88 (5)	6,95 (5)	6,88(5)	6,88 (5)	6,88 (5)	8,28 (5)	7,04 (5)	8,05 (5)
Sr89	3,52 (5)	7,16 (-1)	7,16(-1)	7,16 (-1)	7,16 (-1)	5,65 (4)	1,01 (4)	8,3 (-1)
Sr90	2,25 (7)	-	-	-	-	6,51 (5)	5,53 (6)	-
Cs134	5,09 (5)	9,14 (5)	2,16(5)	4,42 (5)	2,91 (5)	2,28 (5)	7,87 (5)	2,53 (5)
Cs137	7,44 (5)	8,97 (5)	3,27(5)	5,20 (5)	3,91 (5)	3,38 (5)	7,00 (5)	3,81 (5)
I131	4,75 (3)	6,68 (3)	1,13(6)	1,13 (4)	2,72 (2)	1,96 (3)	3,95 (3)	3,31 (2)
I133	1,15 (2)	1,71 (2)	1,94(4)	2,69 (2)	3,93 (1)	1,58 (2)	7,94 (1)	4,77 (1)

ATMOSPHERIC DILUTION FACTORS FOR STACK RELEASES

- Typical values for Tihange II - Ref. plant -



APPENDIX 3

COLLECTIVE DOSES CALCULATION

This appendix describes the methodology applied to calculate the values of the different parameters taken into account to assess the collective doses (see § 9).

A.3.1. Population distribution around the site

In order to calculate the collective doses resulting from inhalation and external irradiation, the population distribution around the reference site has been investigated within a radius of 80 km around the site (see figure A3-F1). The area considered and centered around the site has been divided into circular sector "j", each circular sector being defined by radii Rj-i (internal radius) and Rj (external radius) as indicated on figure A3-F2.
The definition of the miscellaneous sectors and the corresponding values of Rj-1, Rj are given in table A3-T1.

A.3.2. Atmospheric dilution factors

An atmospheric dilution factor $\left(\frac{\chi}{q}\right)_j$ is associated to each sector j. This factor is calculated as follows :

- each sector is divided into 4 quadrants (see fig. A3-F3,a)
- In each quadrant, 3 directions are considered (see figure A3-F3,b and directions (1), (2) and (3)) : 2 directions perpendicular to each other and the bissectrice of the so formed 90° angle.

- In each quadrant, 3 atmospheric dilution coefficient are calculated i.e. one coefficient along each direction (coefficients X1,j; X2,j and X3,j). Each coefficient XK,j is calculated at a location characterized by a radius equal
  $\frac{Rj-1 + Rj}{2}$ and corresponds to the maximum annual average value recorded on the site during a 3 years measurements compaign.
  The evolution of XK with the distance R from the reference site is plotted on fig. A3-F4.

- Each quadrant i of each sector j is then characterized by an average dilution coefficient factor calculated as :

$$\left(\frac{\chi}{q}\right)_{i,j} = \frac{1}{3}\left[X1,j + X2,j + X3,j\right]$$

- Each sector j is eventually characterized by an average atmospheric dilution coefficient defined as

$$\left(\frac{\bar{\chi}}{q}\right)_j = \frac{1}{4}\sum_{i=1}^{i=4}\left(\frac{\chi}{q}\right)_{i,j}$$

The values of Rj-1, Rj, $\left(\frac{\chi}{q}\right)_{i,j}$ and $\left(\frac{\bar{\chi}}{q}\right)_j$ are given in table A3-T1.

A.3.3. Population distribution factor

The population distribution factor F^{P}_{EXT} for external irradition and inhalation is defined by :

$$F^{P}_{EXT} = \sum_j \left(\frac{\bar{\chi}}{q}\right)_j * p_{inh,j}$$

$\left(\frac{\bar{\chi}}{q}\right)_j$ - see § A.3.2.

$p_{inh,j}$ = population of sector j exposed to external irradiation and inhalation pathways (Men). The values of $p_{inh,j}$ are listed in Table A3-T2.

From the data listed in table A3-T2, it can be seen that $F^{P}_{EXT} = 7{,}4.10^{-3}$ Men.s/m³ for the in-land reference site.

A.3.4 Inhalation doses - contamination conversion factors

$\overline{D'}^{P,inh}_{TB,i}$ = Average doses contamination conversion factor for total body inhalation from isotope i (rem.m³/Ci.s)

i = Cs137, Co60, C14, H3, I131

For this analysis, the following ages classes are taken into account :

Type of individual	Ages range (y)	% of total population
Infant	0 - 1	2
Child	1 - 10	13
Teenager	10 - 17	15
Adult	> 17	70

Therefore :

$\overline{D'}^{P,inh}_{TB,Cs137}$ = 12 (rem.m³/Ci.s)

$\overline{D'}^{P,inh}_{TB,Co60}$ = 0,52 (rem.m³/Ci.s)

$\overline{D'}^{P,inh}_{TB,C14}$ = 0,13 (rem.m³/Ci.s)

$\overline{D'}^{P,inh}_{TB,H3}$ = 0,039 (rem.m³/Ci.s)

$\overline{D'}^{P,inh}_{TB,I131}$ = 0,71 (rem.m³/Ci.s)

Note : For the thyroïd collective dosis :

$$\overline{D}'_{TB,I131}^{P,inh} = 411 \quad (rem.m^3/Ci.s)$$

A.3.5. Milk Production

The yearly milk production around the in-land reference site is plotted on fig. A3-F5. The milk ingestion exposed populations in the miscellaneous sectors around the site are listed in table A3-T3.

A.3.6. Grains, Fruits and Vegetables Production - Meat production

A.3.6.1. Grains, Fruits and Vegetables Production

The yearly grains, fruits and vegetables production in the different sectors around the site, as well as the corresponding ingestion concerned population are listed in table A3-T4.

A.3.6.2. Meat production

The yearly meat production in the different sectors around the site, as well as the corresponding ingestion concerned populations are listed in table A3-T5. A distinction is made between meat products from "Cattle grass", supposed to graze on pastures, and from porks supposed to be fed with stored feed (grains, roots etc ...).

A.3.7. Milk contamination

A.3.7.1. Pasture grass contamination

The application of the USNRC transfer models developed in R.G. 1-109 leads to the following results :

- For Cs137 : $\frac{C_d^v}{} = 1{,}11.10^2 \quad (pCi/kg/pCi/h.m^2)$

- For Co60 : $\frac{C_d^v}{} = 1{,}08.10^2 \quad (pCi/kg/pCi/h.m^2)$

$\frac{C_d^v}{}$ = contamination of the pasture grass resulting from a deposition rate of 1 pCi/h.m²

The $\frac{C_v}{d}$ values of Cs137 and Co60 being practically equal, the milk contamination will be calculated on the basis of a single value of :

$$\frac{C_v}{d} = 1{,}11.10^{2} \ (\text{pCi/kg/pCi/h.m}^{2})$$

Therefore, the contamination of the pasture grass in sector j due to the deposition of particulates is given by :

$$C_{v,j}^{i} = 1{,}14.10^{8} * Vd * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j * 1{,}11.10^{2} \ (\text{pCi/kg})$$

$C_{v,j}^{i}$ = contamination of the pasture grass in pCi/kg

Vd = aerosols deposition rate = 10^{-3} m/s

R_{tot}^{i} = total release of isotope i (Ci/y)

From § 9.1.1, $R_{tot}^{i} = K.Ri,TEG + Ri,vent$

$$C_{v,j}^{i} = 1{,}27.10^{7} * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j \qquad (1)$$

- <u>For I131</u>, the pasture grass contamination is given by :

$$\frac{C_v}{d} = 2{,}46.10^{2} \ (\text{pCi/kg/pCi/h.m}^{2})$$

For a deposition rate of 10^{-2} m/s, the grass contamination in sector j is given by

$$C_{v,j}^{i} = 1{,}35.10^{8} * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \quad (2)$$

A3.7.2. Milk contamination

The contamination of the milk produced in sector j is given by :

- For Cs137 : $$C_{m,j}^{Cs137} = 7{,}6.10^{6} * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \quad (3)$$

- For Co60 : $$C_{m,j}^{Co60} = 6{,}4.10^{5} * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \quad (4)$$

- For I131 : $$C_{m,j}^{I131} = 2{,}14.10^{7} * R_{tot}^{i} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \quad (5)$$

For I131, it is assumed that the cattle grazes on pastures during 9 months of the year and that the time elapsed between the production and the consumption of fresh milk is equal to 4 days.

A.3.8. Grains, fruits and vegetables contamination $\left(C^{i}_{L,j}\right)$

The appliation of the USNRC transfer models developed in RG 1.109 leads to the following results :

- For Cs137 : $\frac{C^{Cs137}_{L,j}}{d} = 50$ (pCi/kg/pCi/h.m²)

- For Co60 : $\frac{C^{Co60}_{L,j}}{d} = 48$ (pCi/kg/pCi/h.m²)

Those values being practically equal, one single value can be taken into account for the collective dose analysis, i.e. :

$$\frac{C^{Cs137}_{L,j}}{d} = \frac{C^{Co60}_{L,j}}{d} = 50 \text{ (pCi/kg/pCi/h.m}^2\text{)}$$

The contamination of the fruits, vegetables and grains in sector j can thus be calculated by :

$$C^{i}_{L,j} = 1{,}14.10^{8} * Vd * R^{i}_{tot} * \left(\frac{\overline{X}}{q}\right)_j * 50 \text{ (pCi/kg)}$$

$$C^{i}_{L,j} = 5{,}7.10^{6} * R^{i}_{tot} * \left(\frac{\overline{X}}{q}\right)_j \text{ (pCi/kg)} \qquad (1)$$

i = Cs137, Co60

- For I131 : $C^{I131}_{L,j} = 1{,}43.10^{7} * R^{I131}_{tot} * \left(\frac{\overline{X}}{q}\right)_j$ (pCi/kg) (2)

A.3.9. Meat contamination

The application of the models developped in réf. (3) leads to :

- For Cs137 : The contamination of beef (B) is given by :

$$C^{Cs137}_{B,j} = 2{,}54.10^{6} * R^{Cs137}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (1)$$

The contamination of pork (P) is given by :

$$C^{Cs137}_{P,j} = 1{,}14.10^{6} * R^{Cs137}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (2)$$

- For Co60 :

$$C^{Co60}_{B,j} = 8{,}26.10^{6} * R^{Co60}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (3)$$

$$C^{Co60}_{P,j} = 3{,}71.10^{6} * R^{Co60}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (4)$$

- For I131 :

$$C^{I131}_{B,j} = 2{,}64.10^{6} * R^{I131}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (5)$$

$C^{I131}_{P,j}$ is negligible compared to $C^{I131}_{B,j}$ due to the very low contamination of stored foods by I131 (i.e. short half-life isotope)

A.3.10. Contamination of food products by C14

A.3.10.1. C14 in vegetation, fruits, grains and vegetables

The concentration of C14 in the vegetation is calculated by assuming that the following equilibrium relationship applies :

$$\left.\frac{C^{14}}{\text{Natural carbon}}\right)_{\text{atmosphere}} = \left.\frac{C^{14}}{\text{Natural carbon}}\right)_{\text{vegetation}} \qquad (1)$$

Strictly, the above relationship applies to the continuous releases from the plant ventilation via the plant stack, i.e. for releases characterized by duration $\geq$ than the photosynthesis duration (4400 h/y)
For the intermittent releases from the TEG decay tanks, a fractionnal equilibrium parameter (p) has to be taken into account to calculate the vegetation contamination by C14 :

$$p = \frac{\text{total duration of releases from TEG tanks}}{\text{photosynthesis duration}} \text{ , and}$$

$$R^{C14}_{tot} = R^{C14}_{TEG} * K * p + R^{C14}_{VENT} \qquad (2)$$

R^{C14}_{TEG} = 4,6 Ci/y (see tables 12, 13 et 14)

R^{C14}_{VENT} = 0,8 Ci/y (see tables 12,13 and 14)

The p values are listed hereafter :

- Real and design cases with 10.000 Nm^3/y :

$$p = \frac{164}{4400} = 3{,}7.10^{-2}$$

- Design case with 24.000 Nm^3/y :

$$p = \frac{392}{4400} = 8{,}9.10^{-2}$$

The collective dose calculations are done with :

$p = 5.10^{-2}$ for the real case

$p = 1.10^{-1}$ for the design case (with 24.000 Nm³/y)

Taking into account the K values (§ 9.1.1), (2) can be written as :

$$R^{C14}_{tot} = 2,41 \text{ Ci/y in the real and design cases with } 10.000 \text{ Nm}^3\text{/y}$$

$$R^{C14}_{tot} = 2,64 \text{ Ci/y in the design case with } 24.000 \text{ Nm}^3\text{/y}$$

Those values being practically equal, the calculation will be performed on the basis of a single value :

$$R^{C14}_{tot} = 2,64 \text{ Ci/y} \qquad (3)$$

On the basis of a natural carbon concentration in the atmosphere equal to 0,16 g/m³ and of a natural carbon content of the vegetation equal to 0,11 (massic fraction), the vegetation C14 (grains, fruits, vegetables) contamination is given by :

$$C^{C14}_{L,j} = 2,2.10^{7} * R^{C14}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg)$$

Relationship (3) gives :

$$C^{C14}_{L,j} = 5,8.10^{7} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \quad (4)$$

A.3.10.2. C14 in meat

The meat concentration is given by :

$$C^{C14}_{B,j} = C^{C14}_{P,j} = 9,0.10^{7} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \qquad (5)$$

A.3.10.3. C14 in milk

The application of the R.G.1.109 leads to the following value of the milk contamination :

$$C^{C14}_{m,j} = 3,5.10^{7} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \quad (6)$$

A.3.11. Contamination of food products by H3

A.3.11.1. Tritium in vegetation, fruits, grains and vegetables

The H3 concentration in the vegetation is calculated on the basis of the following assumptions :

- the ratio $\frac{\text{Mass of water in plant}}{\text{Total mass of plant}} = 0,75$

- the ratio $\frac{\text{H3 concentration in plant water}}{\text{H3 concentration in atmosphere water}} = 0,5$

- the absolute humidity of the atmosphere = 4,84 g/m³ (corresponding to a temperature = 19° C and a relative humidity = 30 %)

The application of R.G.1.109 leads then to :

$$C^{H3}_{L,j} = 2,5.10^{6} * R^{H3}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/kg) \quad (1)$$

A.3.11.2. Tritium in the milk

The application of R.G.1.109 leads to :

$$C^{H3}_{m,j} = 1,25.10^{6} * R^{H3}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \quad (2)$$

A.3.11.3. Tritium in meat

The application of R.G.1.109 leads to :

$$C^{H3}_{B,j} = C^{H3}_{P,j} = 1{,}5.10^{6} * R^{H3}_{tot} * \left(\frac{\bar{X}}{q}\right)_j \quad (pCi/l) \qquad (3)$$

A.3.12. Population average dose-contamination conversion factors

A.3.12.1. Ingestion

The population average dose-contamination conversion factors are calulated by :

$$D^{\overline{Pi}}_{j,k} = \sum_{l=1}^{l=3} x1 * Q_{l,k} * D^{i}_{j,l} \qquad (1)$$

$D^{\overline{Pi}}_{j,k}$ = population average dose-contamination conversion factor for exposure of organ j due to isotope i via pathway exposure k (mrem.l/pCi.y or mrem.Kg/pCi.y)
In this study j = thyroïd and whole body

x1 = fraction of population belonging to class of ages l : x1 = adult population = 0,7
x2 = teenagers population = 0,15
x3 = children population = 0,15

$Q_{l,k}$ = annual quantity consumed via pathway K by an individual belonging to class of ages l (l/y or kg/y)
K = milk, cereals + vegetables + fruits, meat
$Q_{l,k}$ values are taken from ref. 3.

$D^{i}_{j,l}$ = dose-contamination conversion factor for exposure of organ j by isotope i for an individual belonging to class of ages l.

Example of calculation

i = I131, j = thyroïd

For k = milk

$$D_{thy,milk}^{P,I131} = 0,7 * 110 * 1,95.10^{-3} + 0,15 * 200 * 2,39.10^{-3} + 0,15 * 170 * 5.72.10^{-3} = 3,7.10^{-1}$$

(mrem.l/pCi.y)

For k = grains + fruits + vegetables (L)

$$D_{thy,L}^{P,I131} = 0,7 * 190 * 1,95.10^{-3} + 0,15 * 240 * 2,39.10^{-3} + 0,15 * 200 * 5,72.10^{-3} = 5,2.10^{-1}$$

(mrem.kg/pCi.y)

For k = meat

$$D_{thy,Meat}^{P,I131} = 0,7 * 95 * 1,95.10^{-3} + 0,15 * 59 * 2,39.10^{-3} + 0,15 * 37 * 5,72.10^{-3} = 1,8.10^{-1}$$

(mrem.kg/pCi.y)

The values of $\overline{D}^{Pi}_{j,k}$ for whole body exposure are listed hereafter (organ j = whole body)

ISOTOPE i	$\overline{D}^{Pi}_{wb,k}$ for exposure pathway k		
	k = milk mrem.l/pCi.y	k = fruits + vegetables + grains mrem.kg/pCi.y	k = meat mrem.kg/pCi.y
C14	1,3 (-4)	1,8 (-4)	5,8 (-5)
H3	1,7 (-5)	2,4 (-5)	9,1 (-6)
I131	6,5 (-4)	9,1 (-4)	3,2 (-4)
Co60	9,5 (-4)	1,32 (-3)	4,56 (-4)
Cs137	8,23 (-3)	1,28 (-2)	5,46 (-3)

A.3.12.2. Inhalation

Similarly for the inhalation, we have :

$$\overline{D}^{Pi}_{j,inh} = \sum_{l=1}^{l=3} xl * Rl * D^{i}_{j} \qquad (2)$$

$\overline{D}^{Pi}_{j,inh}$ = population average dose-contamintion conversion factor exposure of organ j due to isotope i via inhalation (rem.m³/Ci.s)

xl = see A3.12.1

Rl = inhalation rate of an individual belonging to class of ages l (m³/s)

R1 = R2 = $2,54.10^{-4}$ (m³/s) for adults and teenagers

R3 = $1,17.10^{-4}$ (m³/s) for children

D_j^i = dose-contamination conversion factor for exposure of organ j by isotope i via inhalation (rem/Ci).

The D_j^i values are taken from ref. 3.

The $D_{j,inh}^{\overline{Pi}}$ values are listed hereafter :

j = thyroïd

$D_{thy,inhal}^{\overline{P}\ I131}$ = 411 (rem.m³/Ci.s)

j = whole body

ISOTOPE i	$D_{wb,\ inh}^{\overline{Pi}}$ (rem.m³/Ci.s)
I131	7,1 (-1)
I133	1,7 (-1)
Co60	5,4 (-1)
Cs137	1,2 (+1)
C14	1,31 (-1)
H3	3,95 (-2)

COLLECTIVE DOSES

SECTORS DEFINITION AROUND THE IN-LAND REFERENCE SITE AND CORRESPONDING VALUES OF THE ATMOSPHERIC DILUTION FACTORS

Sector j (km)	Rj-1 Rj (km)	χ/q1,j (s/m³)	χ/q2,j (s/m³)	χ/q3,j (s/m³)	χ/q4,j (s/m³)	(χ/q)j(*) (s/m³)
1	0 3	1,2 (-7)	4,8 (-8)	6,4 (-8)	1,3 (-7)	9,1 (-8)
2	3 5	3,7 (-8)	1,5 (-8)	1,7 (-8)	4,0 (-8)	2,7 (-8)
3	5 10	1,7 (-8)	8,3 (-9)	9,3 (-9)	1,8 (-8)	1,3 (-8)
4	10 15	8,7 (-9)	4,0 (-9)	3,9 (-9)	7,7 (-9)	6,1 (-9)
5	15 20	4,9 (-9)	2,3 (-9)	2,1 (-9)	4,1 (-9)	3,3 (-9)
6	20 30	2,8 (-9)	1,3 (-9)	1,1 (-9)	2,1 (-9)	1,8 (-9)
7	30 40	1,4 (-9)	6,6 (-10)	6,0 (-10)	1,2 (-9)	9,7 (-10)
8	40 50	8,2 (-10)	3,8 (-10)	3,8 (-10)	6,7 (-10)	5,6 (-10)
9	50 60	5,7 (-10)	2,7 (-10)	2,6 (-10)	4,3 (-10)	3,8 (-10)
10	60 70	4,8 (-10)	2,1 (-10)	1,9 (-10)	3,8 (-10)	3,2 (-10)
11	70 80	4,1 (-10)	1,8 (-10)	1,4 (-10)	3,0 (-10)	2,6 (-10)

(*) $\left(\overline{\frac{\chi}{q}}\right)_j = \frac{1}{4} \sum_{i=1}^{i=4} \left(\frac{\chi}{q}\right)_{i,j}$

POPULATION DISTRIBUTION WITHIN A RADIUS 0-80 KM AROUND THE IN-LAND REFERENCE SITE

CALCULATION OF PARAMETERS F_{EXT}^{P} (7)

Sector j	Rj-1 Rj (km)	$\left(\frac{\chi}{q}\right)_{1,j}$ (s/m³)	$\left(\frac{\chi}{q}\right)_{2,j}$ (s/m³)	$\left(\frac{\chi}{q}\right)_{3,j}$ (s/m³)	$\left(\frac{\chi}{q}\right)_{4,j}$ (s/m³)	$\left(\frac{\chi}{q}\right)_{(6)}$ (s/m³)	p inh,j individuals
1 (1)	0 3	1,2 (-7)	4,8 (-8)	6,4 (-8)	1,3 (-7)	9,1 (-8)	1,83 (4)
2 (1)	3 5	3,7 (-8)	1,5 (-8)	1,7 (-8)	4,0 (-8)	2,7 (-8)	2,28 (4)
3 (1)	5 10	1,7 (-8)	8,3 (-9)	9,3 (-9)	1,8 (-8)	1,3 (-8)	3,14 (4)
4 (1)	10 15	8,7 (-9)	4,0 (-9)	3,9 (-9)	7,7 (-9)	6,1 (-9)	6,31 (4)
5 (2)	15 25	4,9 (-9)	2,3 (-9)	2,1 (-9)	4,1 (-9)	3,3 (-9)	3,53 (5)
6 (3)	25 50	1,4 (-9)	6,6 (-10)	6,0 (-10)	1,2 (-9)	9,7 (-10)	1,36 (6)
7 (4)	50 80	4,8 (-10)	2,1 (-10)	1,9 (-10)	3,8 (-10)	3,2 (-10)	5,62 (6) (5)

Remarks

(1) See table A3-T1

(2) For sector 15-25, the selected value is $\left(\frac{\chi}{q}\right)_{i,5}$ of sector j=5 (15 → 20) - see Table A3-T1

(3) For sector 25-50, the selected value is $\left(\frac{\chi}{q}\right)_{i,7}$ of sector j=7 (30 → 40) - see Table A3-T1

(4) For sector 50-80, the selected value is $\left(\frac{\chi}{q}\right)_{i,10}$ of sector j=10 (60 → 70) - see Table A3-T1

(5) Including the population of the district of Antwerpen, Mons and Arlon

(6) $$\left(\frac{\bar{\chi}}{q}\right)_j = \frac{1}{4} \sum_{i=1}^{i=4} \left(\frac{\chi}{q}\right)_{i,j}$$

(7) $$F_{EXT}^{P} = \Sigma \left(\frac{\bar{\chi}}{q}\right)_j * p \quad : 7{,}4\ 10^{-3}\ \text{Man.s/m}^3$$

MILK PRODUCTION WITHIN A RADUIS OF 0 - 80 KM AROUND THE IN-LAND REFERENCE SITE

Sector	Rj-1 Rj km	Sp,j (1) (ha)	Pm,j (2)(4) (l/y)	Pm,j(3)(5) (individuals)
1	0- 3	7,63(2)	3,05(6)	2,24(4)
2	3- 5	1,35(3)	5,40(6)	3,97(4)
3	5-10	6,37(3)	2,55(7)	1,87(5)
4	10-15	1,06(4)	4,24(7)	3,12(5)
5	15-20	1,49(4)	5,94(7)	4,37(5)
6	20-30	4,24(4)	1,70(8)	1,25(5)
7	30-40	5,94(4)	2,38(8)	1,75(6)
8	40-50	7,64(4)	3,06(8)	2,25(6)
9	50-60	9,34(4)	3,74(8)	2,75(6)
10	60-70	1,10(5)	4,40(8)	3,24(6)
11	70-80	1,27(5)	5,08(8)	3,74(6)

Remarks

(1) Sp,j = Area of sector j dedicated to pastures
= $0,27 * \pi * [Rj^2 - (Rj-1)^2] * 100$ (ha)

(2) Pm,j = Yearly milk production in sector j = 4.10^3 X Sp,j (l/an)

(3) pL,j = Milk ingestion concerned population in sector j
= Pm,j/136 = pm,j

(4) Actually Pm,j involves fresh milk production as well as milk products such as cheese and butter.
The fresh milk production is equal to 50% of Pm,j

(5) pm,j refers to the population concerned by ingestion of fresh milk and milk products. The population concerned by ingestion of fresh milk is equal to 50% of pm,j.

Grains (cereals), vegetables and fruits production around the In-land reference site

sector J	Rj-1 Rj (Km)	Sc,j (1) (ha)	SF+L,j(2) (ha)	PC,j (3) (Kg/y)	PF+L,j (4) (Kg/y)	PV,j (5) (Kg/y)	pv,j (6) individuals
1	0 3	7,63(2)	1,68(2)	3,05(6)	4,20(6)	4,23(6)	2,17(4)
2	3 5	1,35(3)	3,00(2)	5,40(6)	7,50(6)	7,56(6)	3,88(4)
3	5 10	6,37(3)	1,42(3)	2,55(7)	3,55(7)	3,58(7)	1,83(5)
4	10 15	1,06(4)	2,35(3)	4,24(7)	5,88(7)	5,92(7)	3,04(5)
5	15 20	1,49(4)	3,30(3)	5,96(7)	8,25(7)	8,32(7)	4,27(5)
6	20 30	4,24(4)	9,42(3)	1,70(8)	2,36(8)	2,38(8)	1,22(6)
7	30 40	5,94(4)	1,32(4)	2,38(8)	3,30(8)	3,33(8)	1,71(6)
8	40 50	7,64(4)	1,70(4)	3,06(8)	4,25(8)	4,28(8)	2,20(6)
9	50 60	9,34(4)	2,08(4)	3,74(8)	5,20(8)	5,24(8)	2,69(6)
10	60 70	1,10(5)	2,45(4)	4,40(8)	6,13(8)	6,17(8)	3,17(6)
11	70 80	1,27(5)	2,83(4)	5,08(8)	7,08(8)	7,13(8)	3,66(6)

Remarks :

(1) Sc,j = area of sector j dedicated to grains production
= $0,27 * \pi * [Rj^2 - (Rj-1)^2] * 100$ (ha)

(2) $S_{F+L,j}$ = Area of sector j dedicated to fruits and vegetables production = $0,06 * \pi * [Rj^2 - (Rj-1)^2] * 100$ (ha)

(3) Pc,j = Cereals production in sector j = $4.10^3 * Sc,j$ (Kg/y)

(4) $P_{F+L,j}$ = Fruits and vegetables production in sector j
= $2,5.10^4 * S_{F+L,j}$ (Kg/y)

(5) Pv,j = Grains, fruits and vegetables production dedicated to the population = $0,15P_{c,j} + 0,9P_{F+L,j}$ (Kg/y)

(6) pv,j = Exposed population due to ingestion of fruits, vegetables and cereals in sector j
$Pv,j/195$ (individuals)

MEAT (Beef an Pork) PRODUCTION AROUND THE IN-LAND REFERENCE SITE

Sector j (km)	Rj-1 Rj (km)	$P_{B,j}$ (1) (kg/y)	$p_{B,j}$ (2) (individuals)	$P_{P,j}$ (3) (Kg/y)	$p_{P,j}$ (4) (individuals)
1	0 - 3	1,91 (5)	2,36 (3)	7,6 (5)	5,38 (3)
2	3 - 5	3,38 (5)	4,17 (3)	1,35 (6)	1,67 (4)
3	5 - 10	1,59 (6)	1,96 (4)	6,36 (6)	7,85 (4)
4	10 - 15	2,65 (6)	3,27 (4)	1,06 (7)	1,31 (5)
5	15 - 20	3,73 (6)	4,60 (4)	1,49 (7)	1,84 (5)
6	20 - 30	1,06 (7)	1,31 (5)	4,24 (7)	5,23 (5)
7	30 - 40	1,49 (7)	1,84 (5)	5,96 (7)	7,36 (5)
8	40 - 50	1,91 (7)	2,36 (5)	7,64 (7)	9,43 (5)
9	50 - 60	2,34 (7)	2,89 (5)	9,36 (7)	1,16 (6)
10	60 - 70	2,75 (7)	3,40 (5)	1,10 (8)	1,36 (6)
11	70 - 80	3,18 (7)	3,93 (5)	1,27 (8)	1,57 (6)

(1) $P_{B,j}$ = Beef production in sector j for consumption (from cattle grass) =

$0,27 * \pi * [Rj^2 - (Rj-1)^2] * 100 * 250$ (Kg/y)

(2) $p_{B,j}$ = Exposed population due to beef ingestion in sector j = $\frac{P_{B,j}}{81}$ (individuals)

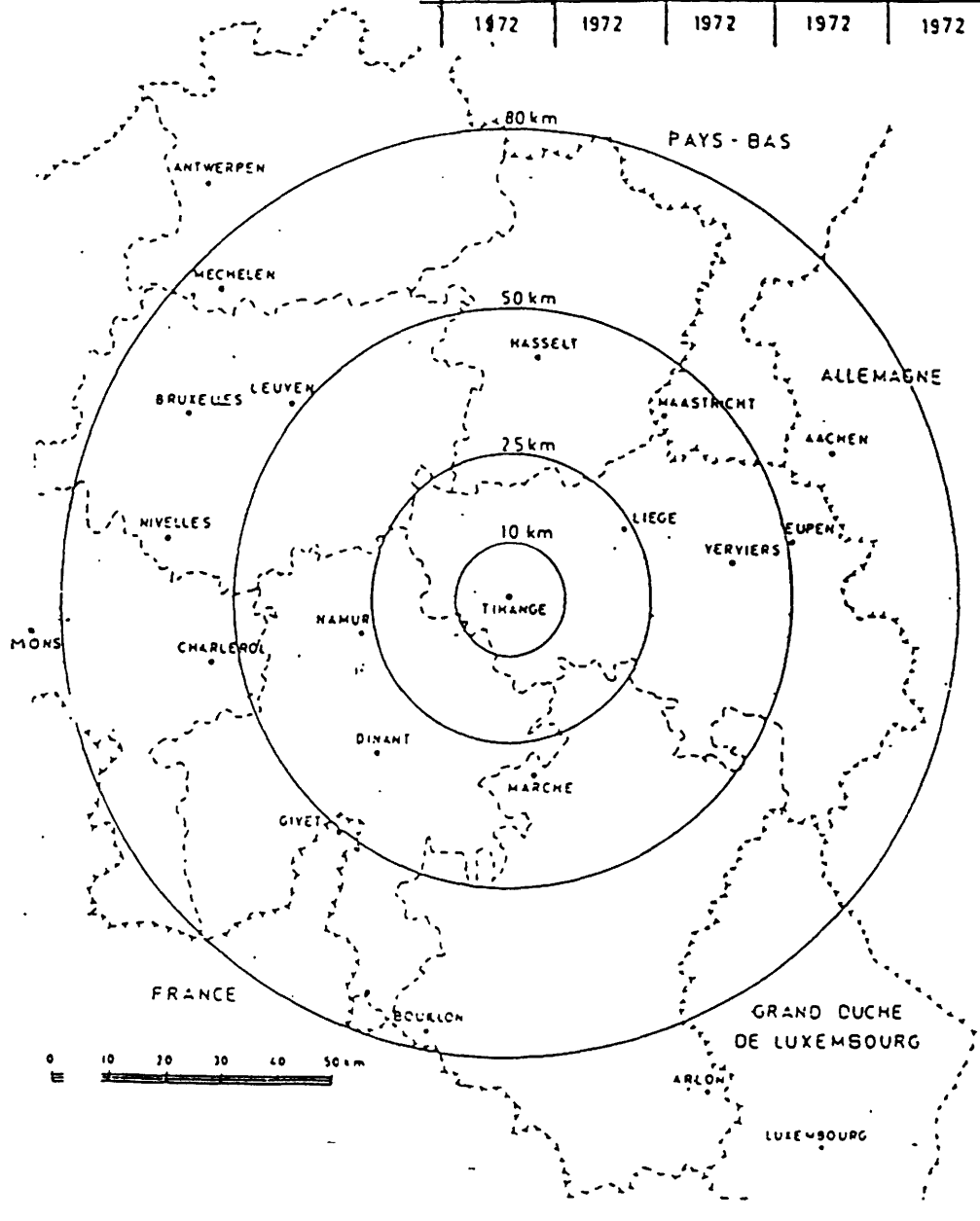
(3) $P_{P,j}$ = Porks production in sector j for consumption (from grains and cereals)

= $0,27 * \pi * [Rj^2 - (Rj-1)^2] * 100 \times 1000$ (Kg/y)

(4) $p_{P,j}$ = Exposed population due to pork ingestion in sector j = $\frac{P_{P,j}}{81}$

POPULATION DISTRIBUTION AROUND THE REFERENCE SITE (Thinge)

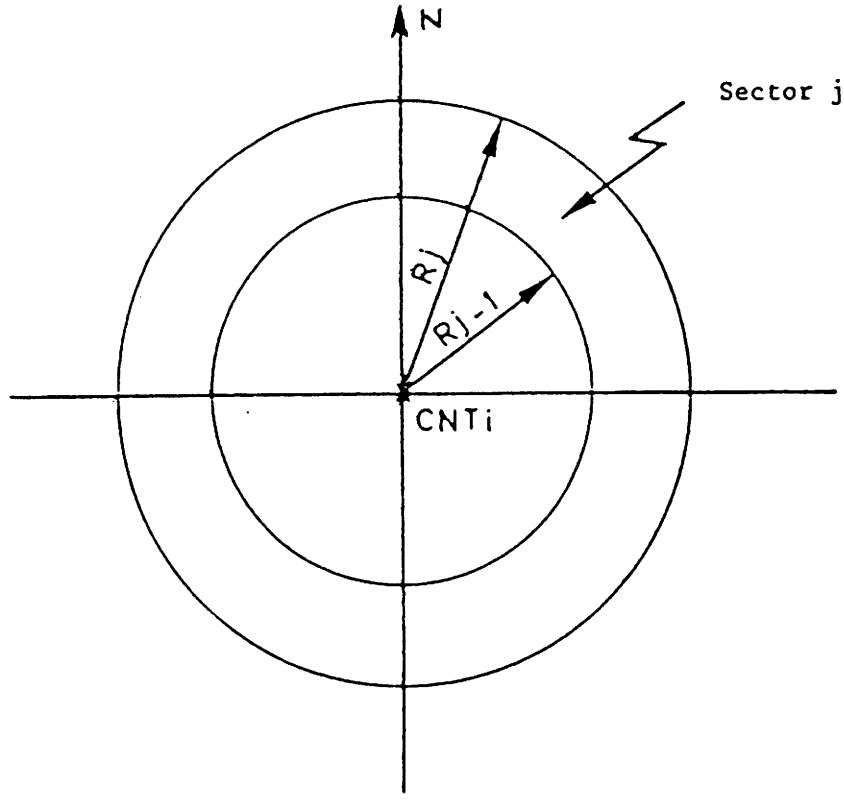
0 ↓ 3	3 ↓ 5	5 ↓ 10	10 ↓ 15	15 ↓ 25	25 ↓ 50	50 ↓ 80
18.239	22.725	31.350	63.075	353.000	1.351.000	4.409.973 *
1972	1972	1972	1972	1972	1972	1973



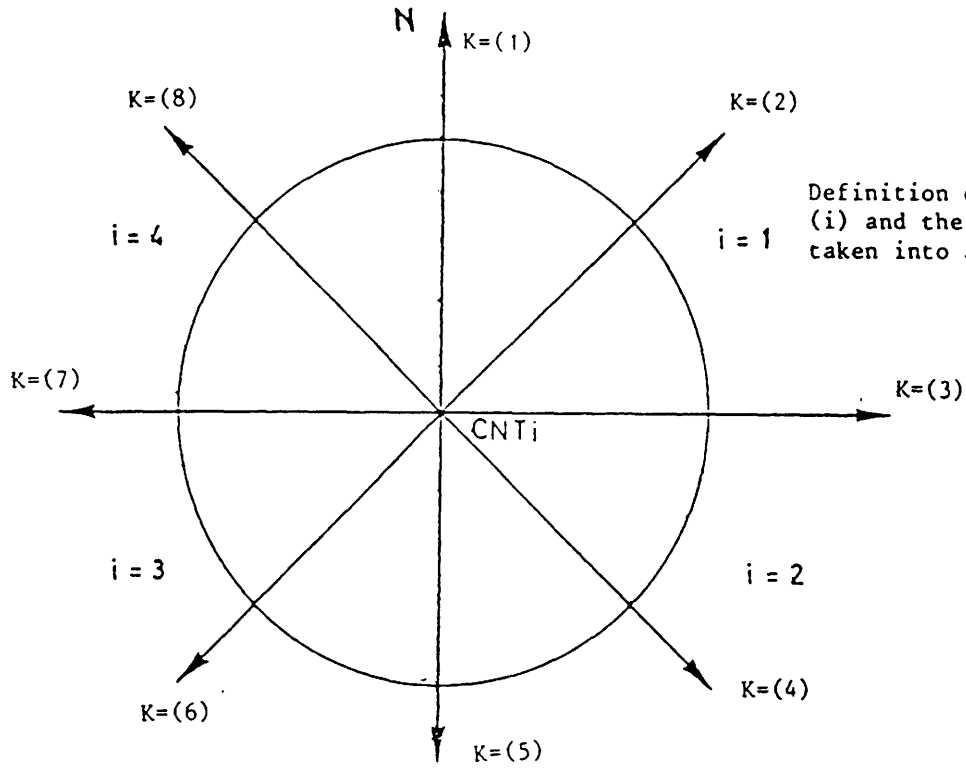
* 5.62×10^6 including the populations of district of Antwerpen, Mons and Arlon

COLLECTIVE DOSIS - SECTOR DEFINITION

AROUND THE IN-LAND REFERENCE SITE

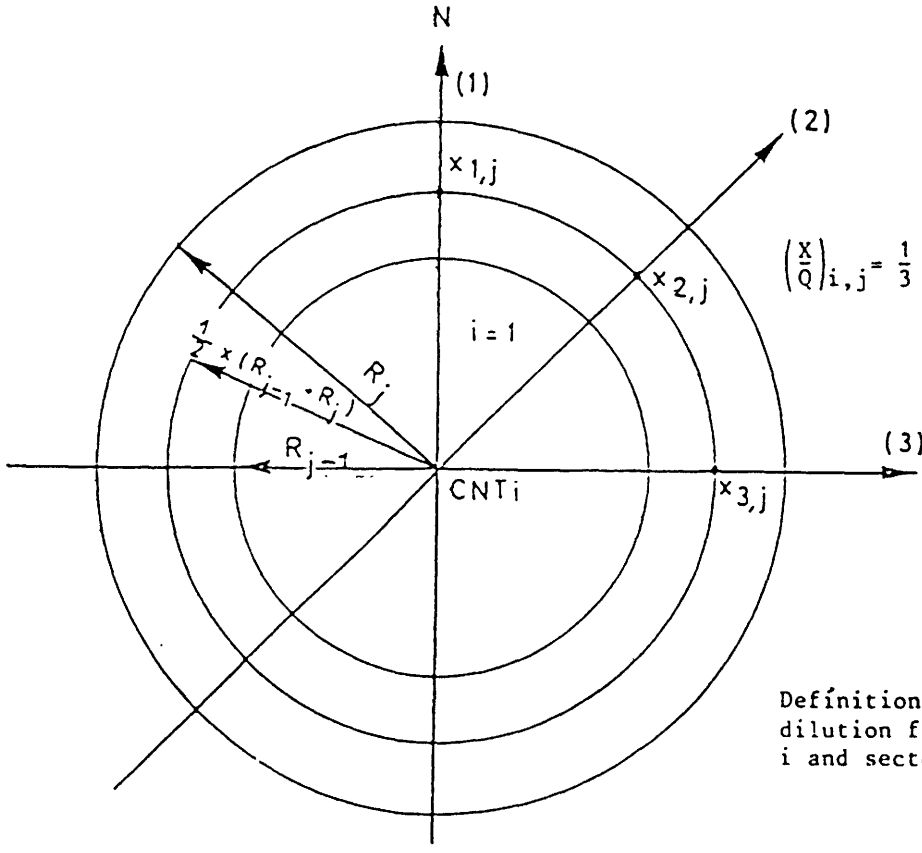


COLLECTIVE DOSIS CALCULATION



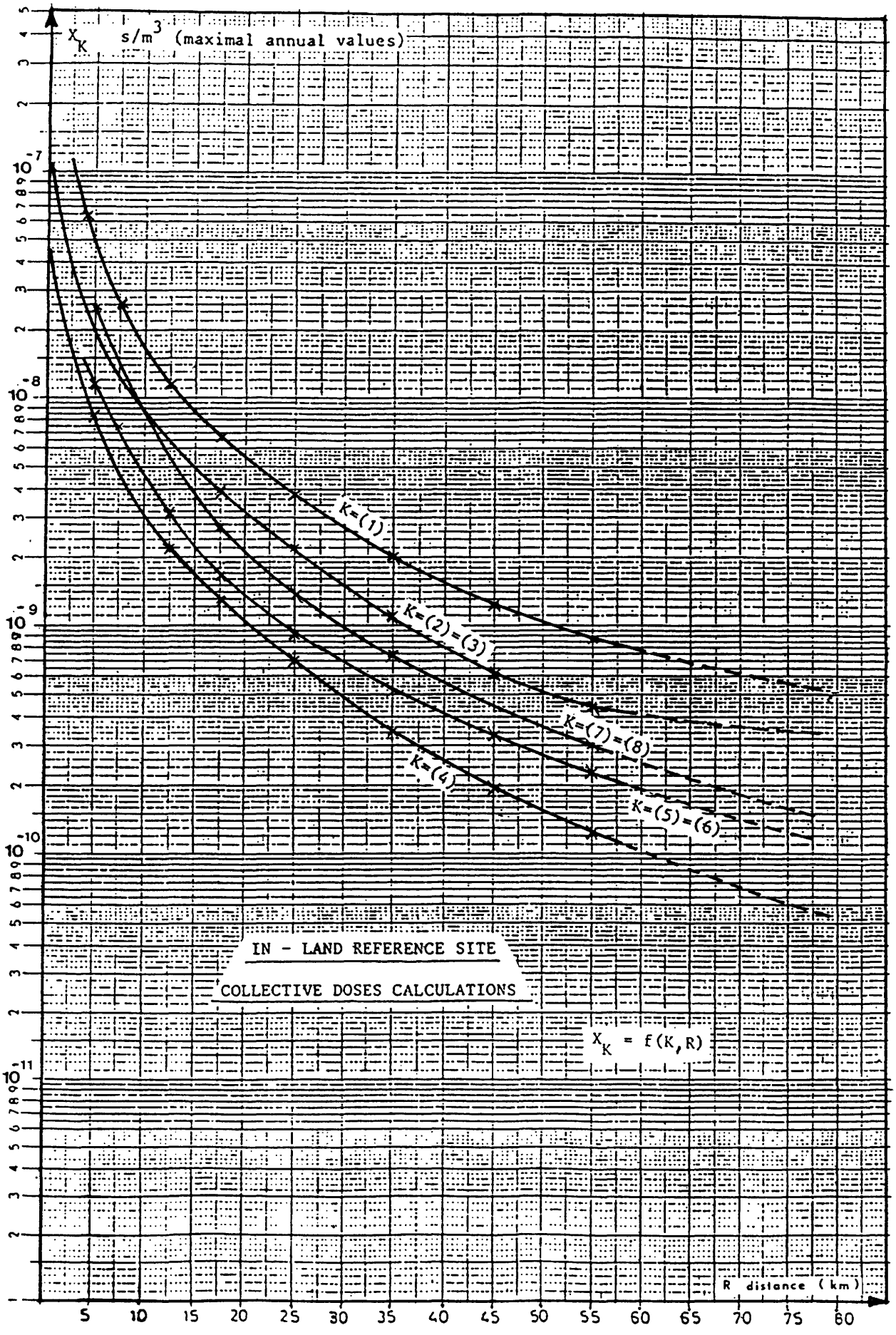
Definition of the 4 quadrants (i) and the 8 directions (K) taken into account

COLLECTIVE DOSIS CALCULATION

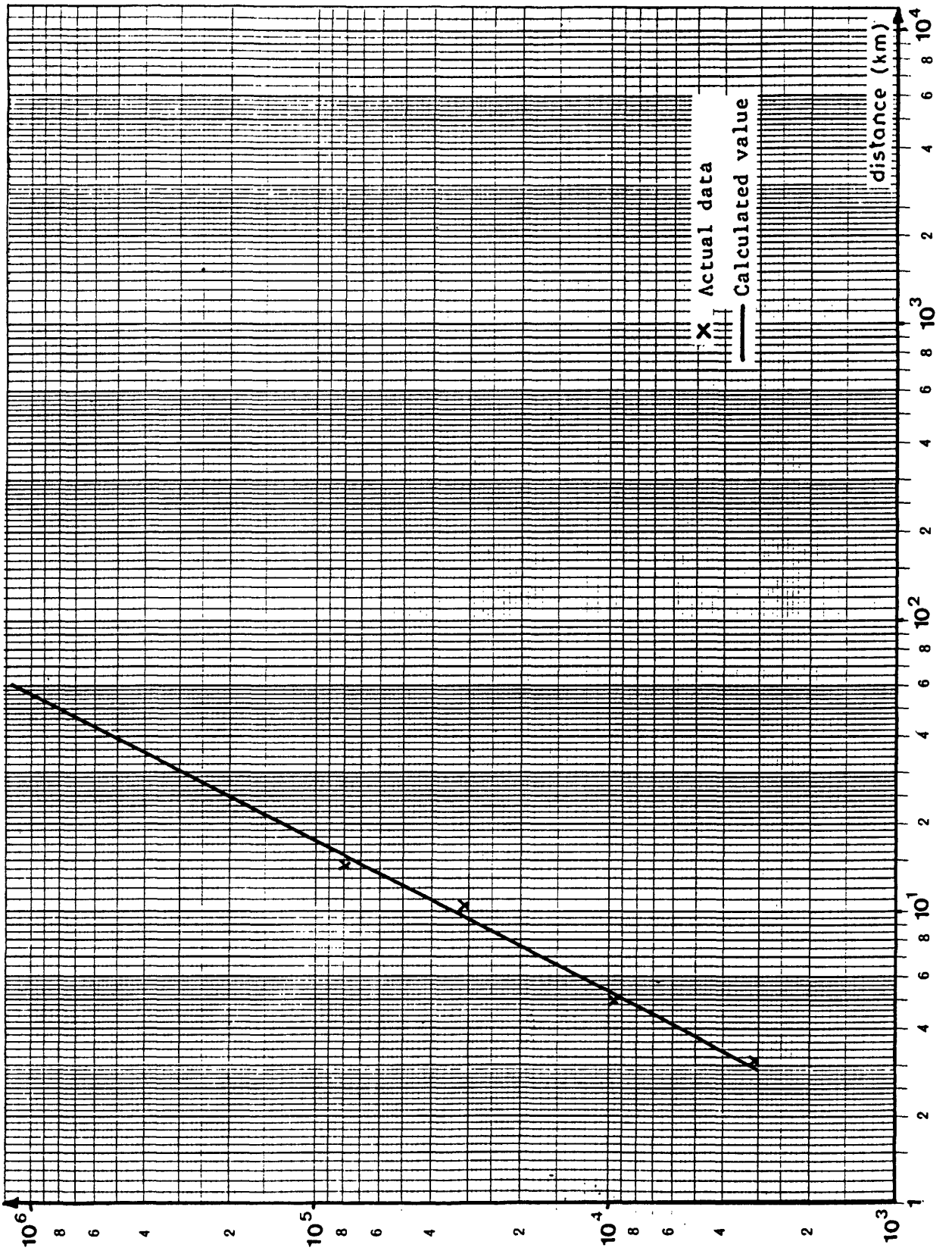


$$\left(\frac{X}{Q}\right)_{i,j} = \frac{1}{3} \left(X_{1,j} + X_{2,j} + X_{3,j} \right)$$

Definition of the atmospheric dilution factor in quadrant i and sector j


X_K s/m^3 (maximal annual values)
K=(1)
K=(2)=(3)
K=(7)=(8)
K=(4)
K=(5)=(6)
IN - LAND REFERENCE SITE
COLLECTIVE DOSES CALCULATIONS
$X_K = f(K, R)$
R distance (km)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80

INTEGRATED MILK PRODUCTION AROUND THE IN-LAND REFERENCE SITE



APPENDIX 4

COLLECTIVE DOSES DUE TO LIQUID RELEASE

A.4.1. DRINKING WATER CONTAMINATION

A.4.1.1. Antwerpen drinking water contamination

$$C^{i}_{w,A} = \frac{0,78 * 10^{12}}{10^{5} * 3,15.10^{7}} * PFi\ e^{-\lambda i.td} \qquad (1)$$

$C^{i}_{w,A}$ = Contamination of the Antwerpen area drinking water for a release of 1Ci/y of isotope i (pCi/l / Ci/y)

$0,78$ = Meuse water dilution factor

10^{12} = pCi/Ci

1.10^{5} = average Meuse flow rate at the in-land reference site (l/s)

$3,15.10^{7}$ = sec/y

PFi = natural purification factor due to interaction between isotope i and the sediments (§ 9.3.1.3).

PFi = 0,9 for Cs isotopes
PFi = 0,95 for Co, Mn and Fe isotopes
PFi = 1 fore all other isotopes

λi = decay rate of isotope i (d^{-1})

td = transit time from the site to the water preparation station = 82 days.

(1) gives $C^{i}_{w,A} = 0,25 * PFi * e^{-\lambda i.td}$ (2)

The values of $C^{i}_{w,A}$ are listed in table A4-T1

A.4.1.2. Rotterdam drinking water contamination

$$C^{i}_{w,R} = \frac{0,53 * 10^{12}}{10^{5} * 3,15.10^{7}} * PFi * \prod_{j=1}^{j=3} \left(\frac{q/vj}{q/vj + \lambda i}\right) e^{-\lambda i.td} \qquad (3)$$

$C^{i}_{w,R}$ = Contamination of the Rotterdam area drinking water for a release of 1 Ci/y of isotope i (pCi/l / pCi/kg)

0,53 = Meuse water dilution factor

10^{12}; 10^{5}; $3,15.10^{7}$, PFi, λi = see § A4.1.1.

td = 15 days

q = Meuse water make up rate in the Biesbosh reservoirs = 7.10^{5} m³/d

V1, V2, V3 = Biesbosch reservoirs capacities (see § 9.3.1.3)

$\frac{q}{V1} = 1,7.10^{-2}\ d^{-1}$; $\frac{q}{V2} = 2,0.10^{-2}\ d^{-1}$; $\frac{q}{V3} = 4,6.10^{-2}\ d^{-1}$

The values $C^{i}_{w,R}$ are listed in table A4-T1.

A.4.1.3. Collective dose due to drinking water

For the population of Antwerpen and Rotterdam, we have :

$$D^{Pi}_{Dw,j} = 10^{-3} * \overline{D}^{Pi}_{Dw,j} * \left[2.10^{6}\ C^{i}_{wA} + 1,1.10^{6}\ C^{i}_{wR}\right] \qquad (4)$$

$D^{Pi}_{Dw,j}$ = drinking water collective dose to organ j due to the release of 1Ci/y of isotope i (Man. Rem/y)

$\overline{D}^{Pi}_{Dw,j}$ = Drinking water population average dose-contamination conversion factor for organ j due to isotope i (mrem.l/pCi.y)

The methodology applied to calculate $\overline{D}^{Pi}_{Dw,j}$ is described in § A3.12.

The values of $\overline{D}^{Pi}_{Dw,j}$ are listed in table A4-T2.

10^{-3} = Rem/mRem

2.10^6; $1,1.10^6$ = populations concerned by the ingestion of drinking water in Antwerpen and Rotterdam.

The values of $\overline{D}^{Pi}_{Dw,j}$ are listed in table A4-T1.

.4.2. FISHES INGESTION

The collective dose due to a release of 1 Ci/y of each isotope i is given by :

$$D^{P,i}_{F,j} = 10^{-3} * \overline{D}^{P,i}_{F,j} * 0,32 * Fci \left[Q_B * e^{-\lambda i . \overline{tp1}} + 0,78 * Q_{NL} * e^{-\lambda i . \overline{tp2}} \right] * e^{-\lambda i t}$$

$D^{P,i}_{F,j}$ = collective dose due to fishes ingestion to organ j resulting from the release of 1 Ci/y of isotope i (Man. Rem/y)

10^{-3} = Rem/mRem

0,32 = $\frac{1 * 10^{12}}{10^5 * 3,15.107}$ (pCi/l) - See § A4.1.1.

Fci = Fresh water fishes concentration factor for isotope i (pCi/kg / pCi/l)

Q_B = fish catch along the Meuse section located between Tihange and the Dutch border Q_B = 35.000 kg/y.

0,78 = dilution factor of the Meuse water at the dutch border

Q_{NL} = fish catch in the Netherlands along the Meuse section located downstream of the dutch border Q_{NL} = 400.000 kg/y

λi = decay rate of isotope i (d^{-1})

$\overline{t_{p1}}$ = transit time of the effluents from the reference site to the mid-point of the belgian Meuse section located between the site and the dutch border. This Meuse section has a length of 40 km.
For a velocity of 1 Km/h

$$\overline{t}_{p1} = \frac{40}{2} \times \frac{1}{1} = 20 \text{ h} = 0{,}83 \text{ day}$$

$\overline{t_{p2}}$ = transit time of the effluents from the reference site to the mid-point of the dutch Meuse section. This Meuse section has a lenght of 100 km.
For a velocity of 1 km/h.

$$\overline{t}_{p2} = \left(40 + \frac{100}{2}\right) \times \frac{1}{1} = 90 \text{ h} = 3.75 \text{ days}$$

td = delay between the fish catch and the consumption, td = 7 days

$\overline{D}^{P,i}_{F,j}$ = population average dose-contamination conversion factor taking into account the ages classes mentioned in § A3.4. (mRem/pCi)

$\overline{D}^{P,i}_{F,j}$ values are listed in table A4-T2.

The value of $D^{P,i}_{F,j}$ are listed in table A3-T4.

A4.3. COLLECTIVE DOSES DUE TO INGESTION OF IRRIGATION AND WATERING CONTAMINATED PRODUCTS

A4.3.1. Milk and meat contamination calculation bases

The milk and meat contamination are calculated on the following bases :

- The cows are assumed to graze on irrigated pasture grass during 9 months per year.

- The irrigated areas are estimated to 50.000 ha located in the districts of Limburg (Belgium) and North-Brabant (Holland).

- The water used for irrigation consits of 78 % of Meuse river (dilution effect due to the Ourthe river). The transit time from the in-land site to the irrigation water pumping station is 6,6 days (§ 9.3.1.3.).

- The water consumed by the animals (watering) is supposed to be of the same quality as that used for irrigation during the grazing period.

- The stored feed and forage consumed by the animals outside of the grazing period are supposed to come from irrigated areas.

- Irrigation rate : during the growing season the irrigation rate is equal to $1,3.10^{-2}$ l/h.m² for the grass-cow-milk pathway.

A4.3.1.1. Milk contamination

The average milk contamination is given by :

$$C^i_m = C^i_{m,w} + 0,75 * C^i_{m,irr} + 0,25\ Ci_{m,SF} \quad (1)$$

C^i_m = average milk contamination (pCi/l/Ci/y)

$C^i_{m,w}$ = milk contamination due to the consumption of contaminated water by the cow (watering) (pCi/l/Ci/y)

$C^i_{m,irr}$ = milk contamination due to the consumption of contaminated grass during the grazing period (pCi/l/Ci/y)

$C^i_{m,SF}$ = milk contamination due to the consumption of stored feed outside of the grazing period (pCi/l/Ci/kg)

0,75 = fraction of the year during which the animal is grazing

0,25 = fraction of the year during which the animal consumes stored feed

$$C^i_{m,w} = 0,78\ (0,75 * Fi * C^i_w * Q^1_{AW} + 0,25 * Fi\ Q^2_{AW} * C^i_w)\ e^{-\lambda i(tp+td)} \quad (2)$$

C^i_w = contamination of the Meuse river downstream of the liquid effluents release collector

C^i_w = 0,317 (pCi/l/Ci/y)

Fi = isotope i transfer coefficient into milk (d/l) - see ref. (3)

Q^1_{AW} = animal's water daily consumption rate during the grazing period = 10 l/d

Note : the water daily consumption amounts to about 58 l/d. However, during the grazing period, most of the animal's water consumption (48 l/d) comes from the water content of the pasture grass (80 %).

Q^2_{AW} = animal's water daily consumption outside of the grazing period = 58 l/d

tp = delay between the in-land ref. site to the pumping stations for watering and irrigation = 6,6 days

td = delay between the milk production and consumption by the population = 4 days
tp + td = 254 hours

(2) gives :

$$C^i_{m,w} = 5.4 * Fi * e^{-\lambda i.254} \text{ (pCi/l/Ci/y)} \quad (3)$$

$C^i_{m,irr}$ = $Q^1_{AF} * Fi * C^i_v * e^{-\lambda i.2414}$

$C^i_{m,SF}$ = $Q^2_{AF} * Fi * e^{-\lambda i . 254}$

Q^1_{AF} = animal's grass consumption rate during the grazing period = 60 kg/d

Q^2_{AF} = animal's forage consumption rate outside of the grazing period = 50 kg/d

C^i_v = grass or forage contamination for a release of 1 Ci/y of isotope i (pCi/kg/Ci/y)
$C^i v$ is calculated according to the methodology of ref (3)

Fi; 254 = see hereabove

2.414 = delay time (in hours) including :

- . the transit time from the site to the irrigation water pumping stations (6,6 days)
- . the storage time between the forage harvest and the ingestion by the cow (90 days)
- . the delay time between milk production and consumption by the population (4 days)

The values of C^i_m are listed hereafter :

Isotope i	C^i_M (pCi/l/Ci/y)
I131	3,5 (-2)
Cs134	3,4 (-1)
Cs137	3,6 (-1)
Sr90	2,4 (-2)
Co58	2,2 (-2)
Co60	2,9 (-2)
H3	1,9 (-1)

A4.3.1.2. Meat contamination

A methodology similar to that used for the calculation of the milk contamination leads to :

$C^i_{M,W} = 4,95 * Fi * e^{-\lambda i.638}$ (1)

$C^i_{M,W}$ = Meat contamination due to water consumption (watering) (pCi/kg/Ci/y)

Fi = Isotope i transfer coefficient into meat (d/kg) - see ref. (3)

638 = transit (delay) time in hours including :

- . the transit time from the reference site to the pumping station used for watering and irrigation i.e. 6,6 days

. the time from slaughter of meat animal to consumption by the population = 20 days.

Note : For beef cattle, the values of Q^1_{AW} and Q^2_{AW} are respectively equal to 10 l/d and to 50 l/d.

$C^i_{M,irr}$ = $Q_{AF} * Fi * C^i_v * e^{-\lambda i.638}$ (2)

$C^i_{M,SF}$ = $Q_{AF} * Fi * C^i_v * e^{-\lambda i.3278}$ (3)

Q_{AF} = cattle's grass consumption rate = 50 kg/d

C^i_v = grass (or forage) contamination for a release of 1 Ci/y of isotope i (pCi/kg/Ci/y). C^i_v is calculated according to the methodology of ref (3)

638 = delay time - see hereabove (h)

3278 = delay time in hours including :

. the transit time from the plant to the irrigation pumping stations (6,6 days)

. the forage storage time between the harvest and the consumption by the cattle (90 days)

. the time from slaughter of meat animal to consumption by the population = 20 days

$C^i_{M,irr}$ = meat contamination by isotope i due to grass consumption during the irrigation period (pCi/kg/Ci/y)

$C^i_{M,SF}$ = meat contamination by isotope i due to stored feed consumption outside of the irrigation period (pCi/kg/Ci/y)

The average meat contamination due to watering, consumption of irrigated grass and stored feed is given by :

$C^i_M = C^i_{M,W} + 0,75\ C^i_{M,irr} + 0,25\ C^i_{M,SF}$ (4)

0,75 ; 0,25 = see A4.3.1.1.

The C^i_M values are listed hereafter :

Isotope i	C^i_M (pCi/kg/Ci/y)
I131	3,5 (-3)
Cs134	9,7 (-2)
Cs137	1,1 (-1)
Sr90	1,6 (-2)
Co58	2,1 (-1)
Co60	3,3 (-1)
H3	2,1 (-1)

A4.3.2. Irrigation products contamination calculation bases

The contamination of the irrigated products (fuits, vegetables and grains are calculated on the following bases :

- Irrigation period : 6 months/y
- Irrigated areas : see § A4.3.1.
- Quality of water used for irrigation : see A4.3.1.
- Irrigation rate : 2,6 . 10^{-2} l/h.m²

The C^i_L values are calculated according to the methodology of ref 3 and take the following transit (delay) times into account :

- transit time of the Meuse water from the reference site to the irrigation pumping station = 6,6 days (see § A4.3.1.);
- transit time between irrigation and harvest : 1 month
- transit time between the harvest and distribution to the population : 15 days.

The C^i_L values are listed hereafter :

Isotope i	C^i_L (pCi/kg/Ci/y)
H3	2,5 (-1)
Co58	2,0 (-1)
Co60	3,7 (-1)
Sr90	3,9 (-1)
I131	1,6 (-3)
Cs134	3,5 (-1)
Cs137	3,7 (-1)

COLLECTIVE DOSES DUE TO DRINKING WATER (AREAS OF ANTWERPEN AND ROTTERDAM) FOR A RELEASE OF 1 Ci/y OF EACH ISOTOPE - IN - LAND SITE -

ISOTOPE	CONTAMINATION OF DRINKING WATER (pCi/l/Ci/y)		COLLECTIVE DOSE MAN.REM/Y/CI/Y	
	ANTWERPEN	ROTTERDAM	WHOLE BODY	THYROID
Mn54	2,0(-1)	1,2(-1)	1,98(-1)	
Co58	1,1(-1)	4,9(-2)	1,95(-1)	
Co60	2,3(-1)	1,5(-1)	1,26(0)	
Sr90	2,5(-1)	1,7(-1)	4,87(2)	
I131	2,1(-4)	5,1(-4)	1,36(-3)	7,82(-1)
Cs134	2,3(-1)	1,3(-1)	2,24(1)	
Cs137	2,3(-1)	1,5(-1)	1,36(1)	
H3	2,5(-1)	1,7(-1)	2,62(-2)	2,62(-2)

POPULATION AVERAGE DOSE-CONTAMINATION CONVERSION FACTORS

ISOTOPE i	$\overline{D}_{DW,j}^{P,i}$ (a) (mrem.l/pCi.y)		$\overline{D}_{F,j}^{P,i}$ (b) (mrem/pCi)	
	j = whole body	j = thyroïd	j = whole body	j = thyroïd
H3	3,82(-5)	3,82(-5)	1,2(-7)	1,2(-7)
Mn54	3,71(-4)		1,2(-6)	
Co58	7,12(-4)		2,3(-6)	
Co60	2,01(-3)		6,6(-6)	
Sr90	7,09(-1)		2,3(-3)	
I131	1,39(-3)	7,97(-1)	4,5(-6)	2,6(-3)
Cs134	3,71(-2)		1,1(-4)	
Cs	2.18(-2)		6.5(-5)	

(a) DW = drinking water

(b) F = Fishes

ISOTOPE i	$\overline{D}_{m,j}^{P,i}$ (c) (mrem.l/pCi.y)		$\overline{D}_{L,j}^{P,i}$ (d) (mrem.kg/pCi.y)	
	j = whole body	j = thyroïd	j = whole body	j = thyroïd
H3	1,6 (-5)	1,6 (-5)	2,4(-5)	2,4(-5)
Co58	3,4 (-4)		4,7(-4)	
Co60	9,5 (-4)		1,3(-3)	
Sr90	3,1 (-1)		4,5(-1)	
I131	6,5 (-4)		9,1(-4)	
Cs134	1,4 (-2)	3,7 (-1)	2,2(-2)	5,2(-1)
Cs137	8,2 (-3)		1,3(-2)	

(c) m = milk
(d) L = vegetables, fruits and grains

POPULATION AVERAGE DOSE-CONTAMINATION CONVERSION FACTORS

ISOTOPE i	$\overline{D}_{M,j}^{P,i}$ (a) (mrem.kg/pCi.y)	
	j = whole body	j = thyroïd
H3	9,0 (-6)	9,0 (-6)
Co58	1,6 (-4)	
Co60	4,6 (-4)	
Sr90	1,7 (-1)	
I131	3,2 (-4)	
Cs134	9,3 (-3)	1,8 (-1)
Cs137	5,5 (-3)	

(a) M = meat

COLLECTIVE DOSES DUE TO FISH INGESTION FOR THE RELEASE OF 1 Ci/y OF EACH ISOTOPE

IN-LAND SITE

Isotope i	COLLECTIVE DOSES (Man. rem/Y/Ci/Y)	
	Whole body	Thyroïd
Mn54	5,3(-2)	
Co58	1,1(-2)	
Co60	3,6(-2)	
Sr90	7,6(0)	
I131	3,0(-3)	1,75(0)
Cs134	2,42(1)	
Cs137	1,43(1)	
H3	1,21(-5)	1,21(-5)

COLLECTIVE DOSES DUE TO MILK INGESTION FOR THE RELEASE OF 1 Ci/y OF EACH ISOTOPE

IN-LAND SITE

Isotope i	COLLECTIVE DOSES (Man.rem/Y/Ci/Y)	
	Whole body	Thyroïd
H3	4,7(-3)	4,7(-3)
Co58	1,1(-2)	
Co60	4,1(-2)	
Sr90	1,1(1)	
I131	3,4(-2)	1,9(1)
Cs134	7,1(0)	
Cs137	4,4(0)	

COLLECTIVE DOSES DUE TO MEAT INGESTION

FOR THE RELEASE OF 1 Ci/y OF EACH ISOTOPE

IN-LAND SITE

Isotope i	COLLECTIVE DOSES (Man.rem/Y/Ci/Y)	
	Whole body	Thyroïd
H3	2,8(-3)	2,8(-3)
Co58	5,0(-2)	
Co60	2,3(-1)	
Sr90	4,1(0)	
I131	1,7(-3)	9,5(-1)
Cs134	1,4(0)	
Cs137	9,1(-1)	

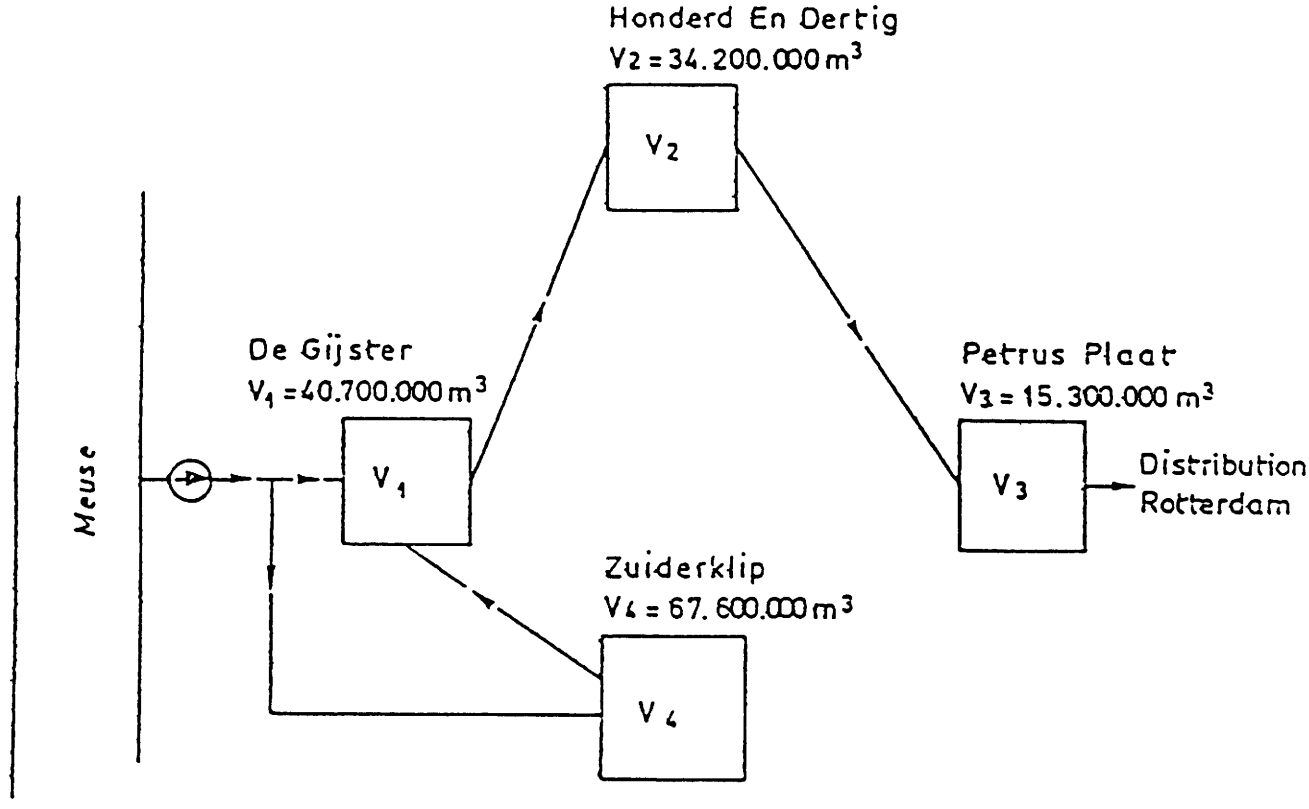
COLLECTIVE DOSES DUE TO IRRIGATED PRODUCTS (*)

INGESTION FOR THE RELEASE OF 1 Ci/y OF EACH ISOTOPE

IN-LAND SITE

Isotope i	COLLECTIVE DOSES (Man.rem/Y/Ci/Y)	
	Whole body	Thyroïd
H3	9,0(-3)	3,0(-3)
Co58	1,4(-1)	
Co60	7,2(-1)	
Sr90	2,6(2)	
I131	2,2(-3)	1,2(0)
Cs134	1,2(1)	
Cs137	7,2(0)	

(*) i.e. : vegetables, fruits and grains



STORAGE AND DISTRIBUTION OF DRINKING WATER TO ROTTERDAM

POPULATION FROM THE BIESBOSCH RESERVOIRS

APPENDIX 5

COLLECTIVE DOSES DUE TO LIQUID RELEASES FROM THE COASTAL REFERENCE PLANT

A5.1 North sea model

The coastal reference plant liquid wastes are supposed to be discharged into the western portion of the North Sea. The model used to assess the collective doses takes 3 compartments into account (see fig A5-F1) :

- The "Western North Sea" compartment
- The adjacent "East Channel" compartment
- The adjacent "Central North Sea" compartment.

The volume and the exchange rates between the compartments are given on figure A5-F1.

A5.2 Radionuclides dispersion

For a single nuclide, a mass balance on compartment i gives :

$$\frac{dAi}{dt} = \sum_{j=1}^{j=N} (Kji\ Aj - KijAi) - KiAi + Ri \qquad (1)$$

Ai = Activity of the nuclide in compartment i at time t (Ci or Bq)

Kij = Sea water exchanger rate from compartment i to compartment j (s^{-1}).

$$Kij = \frac{Rij}{Vi}$$

Rij = Massic exchange rate from compartment i to compartment j (Km^3/s - see fig A5-F1)

Vi = volume of compartment i (Km^3)

Ki = Decay rate in compartment i due to sedimentation, radioactive decay,...(s^{-1})

Ri = release rate of a given isotope into compartment i (Ci/s or Bq/s)

The volumic activity of a given isotope in compartment i is given by :

$$Ci(t) = \frac{Ai(t)}{10^{9}\ Vi} \qquad \text{(in Ci/m}^3\text{ or Bq/m}^3\text{)} \qquad (2)$$

$Ki = \lambda + \lambda si$
λ = isotope radiological decay rate (s^{-1})
λsi = isotope removal rate by sedimentation in compartment i (s^{-1}).

$$\lambda\ Si = \frac{Kd * Si}{hi\ (1 + Kd.\ Csi)} \qquad (3)$$

Kd = distribution coefficient between the sediments and the sea water (Bq/t / Bq/m³). Kd values are given in table A5-T1

Si = sedimentation rate in compartment i (t/m².s)
Si values are given in § 9.3.2.1.

hi = average depth of compartment i (m)
hi values are given in § 9.3.2.1.

Csi = suspended solids concentration in compartment i (t/m³) - see § 9.3.2.1.

Note : Relationship (1) neglects the evaporation at the sea water surface. Therefore, the activity inventory in compartment i (Ai values) is slightly overestimated in the case of tritium.

A5.3 Activity intake - Population exposure

The yearly sea products catch is listed in § 9.3.2.2.
The concentration factors of the nuclides in fishes, crustaceas and molluscs are taken from ref (8).

The isotopes yearly activity intakes by the population are given in table A5-T2.

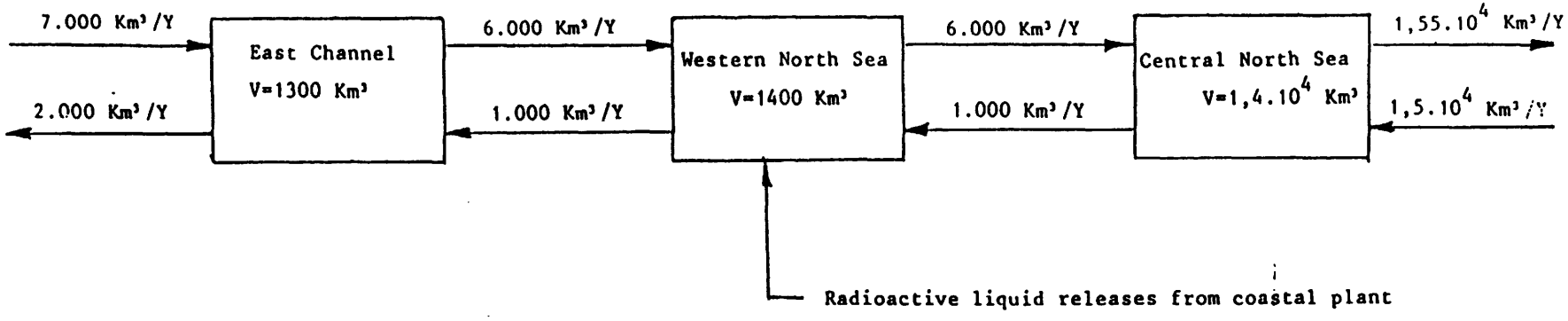
SEA WATER SEDIMENTS CONCENTRATION FACTORS (Kd)

isotope	Kd (Bq/t / Bq/ m^3)
H3	0
Co58	1(4)
Co60	1(4)
Sr90	5(2)
I 131	1(2)
Cs134	5(2)
Cs137	5(2)

INTEGRATED COLLECTIVE INGESTIONS Ic FOR A RELEASE RATE OF 1Bq/s IN THE WESTERN NORTH SEA COMPARTMENT

Isotope	Ic (Man.Bq/y / Bq/s)
H3	2,5 (0)
Co58	2,3 (2)
Co60	6,0 (2)
Sr90	7,3 (0)
I 131	5,0 (0)
Cs134	8,2 (1)
Cs137	1,2 (1)

NORTH SEA MODEL USED TO CALCULATE THE DISPERSION OF THE RADOACTIVE LIQUID EFFLUENTS DISCHARGED FROM THE COASTAL REFERENCE PLANT



European Communities – Commission

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(Volume 5)
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B. Centner

Luxembourg: Office for Official Publications of the European Communities

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