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Abstract

Probabilistic dose assessments for accidental atmospheric releases of tritium and activation products as well as releases under normal operation conditions were performed for the sites of Greifswald, Germany, and Cadarache, France. Additionally, aquatic releases were considered for both sites. No country specific rules were applied and the input parameters were adapted as far as possible to those used within former ITER studies to have a better comparison to site independent dose assessments performed in the frame of ITER. The main goal was to complete the generic data base with site specific values. The agreement between the results from the ITER study on atmospheric releases and the two sites are rather good for tritium, whereas the ITER reference dose values for the activation product releases are often lower, than the maximum doses for Greifswald and Cadarache. However, the percentile values fit better to the deterministic approach of ITER. Within all scenarios, the consequences of aquatic releases are in nearly all cases smaller than those from comparable releases to the atmosphere (HTO and steel). This rule is only broken once in case of accidental releases of activated steel from Cadarache. However, the uncertainties associated with the aquatic assessments are rather high and a better data base is needed to obtain more realistic and thus more reliable dose values.

Dosisabschätzungen für Greifswald und Cadarache

Zusammenfassung

Im Rahmen von Fusionsstudien wurden Dosisabschätzungen für Freisetzungen von Tritium und Aktivierungsprodukten während des Routinebetriebs und nach potentiellen Unfällen für die beiden Standorte Greifswald, Deutschland, und Cadarache, Frankreich, durchgeführt. Es wurden sowohl Freisetzungen in die Atmosphäre als auch in die Hydrosphäre berücksichtigt. Es wurden keine länderspezifischen Vorschriften angewendet. Die Eingabeparameter wurden soweit wie möglich an diejenigen früherer ITER Studien angepaßt. Die Ergebnisse wurden mit Dosisabschätzungen, die im Rahmen von ITER für standortunabhängige Standorte gewonnen wurden, verglichen und zwar mit dem Ziel, die Datenbasis mit standortabhängigen Werten zu erweitern. Die Übereinstimmung zwischen den Ergebnissen der ITER-Studie über atmosphärische Freisetzungen und den zwei Standorten ist relativ gut für das Radionuklid Tritium, dagegen sind die in der ITER-Studie berichteten maximalen Dosen für Freisetzungen von Aktivierungsprodukten in die Atmosphäre teilweise deutlich geringer als diejenigen, die für Cadarache und Greifswald berechnet wurden. Dagegen stimmen die Perzentilwerte besser mit den deterministische Rechnungen überein. Die Ergebnisse der Freisetzungen in die Hydrosphäre konnten nicht mit Referenzwerten aus der ITER-Studie verglichen werden. Allerdings lagen sie sowohl für Greifswald als auch für Cadarache in den meisten Fällen deutlich unter denjenigen der Freisetzungen in die Atmosphäre. Ein einziges Freisetzungsszenario für Cadarache (Aktivierungsprodukte) durchbrach diese Regel. Allerdings besitzen die Ergebnisse der hydrologischen Modelle noch eine breite Unsicherheitsmarge. Deshalb sollte die verwendete Datenbasis verbessert werden, um realistischere Dosisabschätzungen durchführen zu können.

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1. Introduction

In view of the public acceptance and the licensing procedure of projected fusion reactors, the release of tritium and activation products during normal operation as well as after accidents is a significant safety aspect. One of the important concept aims for a fusion device like ITER is to minimise the potential off-site consequences to the public from potential accidental releases as well as for releases under normal conditions. There are several possibilities to achieve this goal e.g. active safety systems, passive safety systems and reduction of in-plant inventories. To provide the relevant information to the designers dose calculations have been performed only for unit release source terms which can be easily scaled if realistic source terms become available. Individual dose values for the two possible ITER sites Greifswald and Cadarache were calculated. Additionally, dose assessments with nuclide specific source terms were performed for aquatic releases from both sites.

At present, the data base of the computer system COSYMA is being improved with respect to updated foodchain information and dose conversion factors /GSF94/. The implementation of the new data was completed by the end of this year, and calculations for one source term were performed to compare the new and the old version. Whenever the differences in the results would be significant, new assessments for all scenarios would be requested. However, this is not the case as as the intercomparison of the results show (Table 18).

2. Model description

2.1 Atmospheric releases

2.1.1 Tritium models

The computer program UFOTRI /RAS90/ and /RAS93/ for assessing the consequences of accidental tritium releases has been used for the dose assessments. Processes such as the conversion of tritium gas (HT) into tritiated water (HTO) in the soil, reemission after deposition and the conversion of HTO into organically bound tritium (OBT) are considered. For atmospheric dispersion and deposition calculations (dry and wet) the trajectory model MUSEMET /STR81/ implemented in UFOTRI was used. During the time period of the first few days, all the relevant transfer processes between the compartments of the biosphere (atmosphere, soil, plants, animals) are described dynamically. A first order compartment model calculates the longer term pathways of tritium in the foodchains. In its newest version all the exchange processes (atmosphere-soil; atmosphere-plant) are based on resistance approaches and will be re-evaluated dependent on the prevailing environmental conditions. A simple photosynthetic submodule, which calculates the actual transfer rate of HTO in plant water into organically bound tritium, improved the results for the ingestion pathways. Additionally, UFOTRI allows for probabilistic assessments of the tritium impact in the environment.

Releases under normal operation conditions have been performed with the model NORMTRI /RAS93b/. The doses from inhalation and skin absorption are calculated dependent on the mean tritium concentration in air above ground within one year. The tritium concentrations in foodstuffs are derived from both, the mean HTO concentrations in air and the HTO concentration in precipitation water, with the relative air humidity as the steering factor. Deposited tritium HT/HTO (HT is converted rapidly into HTO) will be reemitted again into the atmosphere and dispersed again during the selected time period. NORMTRI is based on a statistical Gaussian atmospheric dispersion model (ISOLA V /HUE90/). This means, for all different dispersion situations during the considered time period, a double Gaussian distribution of the released radionuclides is assumed for the activity concentration in the plume. The data file, covering one year, contains meteorological parameters, such as wind speed, wind direction, stability class and rain intensity, in hourly values.

2.1.2 Activation product models

Calculations for accidental released activation products were performed with a special version of the program system COSYMA /COS90/ (subsystem NL), including extended data sets for activation products. For atmospheric dispersion and deposition calculations (dry and wet) the trajectory model MUSEMET implemented in COSYMA and UFOTRI was used. It was assumed, that the nuclides which appear in aerosol form have a mean diameter of 1 mμ AMAD, and the corresponding dry deposition velocity is set to be 1.0 E-3 m/s (see also Table 12). To have a rough estimation of the radiological impact from nuclides not yet implemented in COSYMA, a simplified program version has been generated which allows dose assessments for about 290 nuclides, however for potential EDE only. In this version, the ingestion pathway is modelled by a set of equations from the German regulatory guidelines /BUN90/, which allow only a rough estimation of the ingestion dose. The doses by ingestion of contaminated foodstuffs are calculated assuming the local production and consumption method; that means, all foodstuffs are consumed in the grid element where they are harvested / produced.

The program system COSYMA has been applied also for releases under normal operation conditions. To that purpose, the trajectory model has been replaced by the statistical Gaussian atmospheric model ISOLA V, also used within NORMTRI.

To improve the data base of COSYMA, new data sets for activation products have been made available by /GSF94/. However, as long as the existing and the new nuclide dependent data are not consistent, the final dose assessments for activation products has to be postponed to the end of this year.

2.2 Aquatic releases

Several models were used to assess the releases of tritium and activation products from the two sites of Cadarache and Greifswald. As both are different - Greifswald is located close to the Baltic see and Cadarache close to a river - mainly two models were applied. A version of the lake model LAKECO together with a simplified box model was chosen to calculate the concentration in water and fish assuming a release into the Greifswaldener Bodden, whereas the 2D model COASTOX was applied to calculate dilution factors and thus concentrations in the water. The dose model H-dose uses then the activity concentrations in water and fish - if available - to calculate the doses by the ingestion pathways. If the concentration in fish is not provided by the previous models, H-DOSE calculates it by its own submodel.

The use of a specially developed box type model was necessary, as LAKECO is only validated for caesium and strontium. Additionally, input data for the complicate foodchain module was not available, thus the simpler box model is based on concentration factors. The comparison of this model with LAKECO for the two radionuclides caesium and strontium may give an idea which uncertainties are involved by applying such a simple model. However, as the present data base can not be improved in short time, the use of more complex models is restrained, as the uncertainties will enter the model implicitly by using input data with large bounds of uncertainties.

Also, as the hydrological information on the river Serre Poncon close to Cadarache did not meet the requirements of COASTOX. Therefore, this 2-D model was only used to define the possible range of dilution factors at a distance of 1 kilometer from the release point. These factors were obtained by using simulations of a part of the Rhine river where detailed data on the river bed topography was available. Nevertheless, this can be regarded as a first approximation of the status of the river Serre Poncon close to Cadarache.

2.2.1 Lake models LAKECO and simple box type model LAKE

The box-type model LAKECO, developed by KEMA, Arnhem, The Netherlands /HEL95/, is used for predicting the behaviour of radionuclides in lakes and reservoirs. It calculates the concentration of the activity in the water column, in sediments and in the biota dynamically. It is divided into an abiotic part, describing the change of the activity concentrations in the water/soil column by means of linear differential equations of first order and a biotic part predicting the transfer throughout the aquatic food chain.

The processes which are taken into account are: particle scavenging/sedimentation, molecular diffusion, enhanced migration of radionuclides in solution due to physical and biological mixing processes, particle reworking - also by physical and biological means - and the downward transfer of radionuclides in the seabed as a result of sedimentation. In sediments both the fractions of solved and dissolved radionuclides are modelled. To predict the transfer throughout the aquatic food chains, a complex dynamic model taking into account the position of the different species in the food web, has been developed. The dynamic uptake-model for the food chains is based upon studies on mercury in fish /VRI89/. Concentrations in fish were provided for predatory and prey fish (such as the herring, the most common fish in the Greifswaldener Bodden).

nuclide	fresh water	brackish water
HTO	1	1
Cr	200	400
Mn	400	550
Fe	200	1000
Co	300	300
Ni	100	300
Mo	10	10
Sr	2	4
Cs	800	50
Ta	100	100

Table 1: Concentration factor (Bq/kg / Bq/l) of tritium and activation products for fresh and brackish water

Sensitivity analysis showed that the distribution coefficient water suspended matter, and the concentration factor water phytoplankton are the most sensitive parameters. Less sensitive were the reworking rate, and the biological half life of the aquatic organisms. To improve the predictive power and the flexibility of LAKECO, new submodels to assess these sensitive parameters were implemented. The result is that the modified model LAKECO-B has more environmental parameters, like the potassium concentration in the lake water as input, but less model specific parameters. Thus, LAKECO-B has become an aquatic model where tuning is nearly impossible as environmental input parameters control the model.

The simplified 2-box model LAKE is built in a comparable manner to LAKECO but neglecting all interactions with the bottom sediments and the foodweb. A similar approach as the concentration factor was used (see Table 1), however it was introduced in the model in a different way. The concentration factor is defined as the activity concentration in fish flesh compared to that in water assuming equilibrium conditions /TIL83/. In the model LAKE however, this concentration factor was used as biological half-life, which defines the retention time of the activity in fish. Under routine conditions (equilibrium) both approaches result in the same activity concentration in fish. Under a pulsed release, the concentration in fish is rapidly raising and then declining with time, dependent on the concentration factor (here biological half-life). This shall avoid an overestimation for the pulsed release conditions. However, the instantaneous equilibrium may also cause an overestimation of the dose which had to be proved in the comparison exercise with LAKECO.

2.2.2 River model COASTOX

The two-dimensional model COASTOX [7, 9] uses the depth averaged Navier Stokes equations to calculate the velocity field in rivers, lakes and reservoirs generated from the combined influence of discharge, wind and bottom friction. The steady state approximation without advection terms and the system of the unsteady shallow water equation are used. The same approach as in RIVTOX is applied to simulate the radionuclide exchange in the system: solution - suspended sediments - bottom depositions. The 2-D advection-diffusion equations and the equations of flow dynamics are solved numerically by using the finite difference methods. Necessary input to COASTOX are the geometrical data of the river/lake bed in a sufficient fine spatial resolution.

2.2.2 Dose model H-DOSE

Based on the concentration in water, in sediments and in fish, the computer code H-DOSE /RAS95/ calculates the dose from 4 different exposure pathways:

- Consumption of foodstuffs contaminated by irrigation (root vegetables, leafy vegetables, milk and milk products, meat and meat products)
- Consumption of contaminated drinking water
- Consumption of contaminated fish
- External radiation from the borderline of the river or lake.

If the activity concentration in fish is not provided, H-DOSE has an integrated submodel to calculate this value by using the concentration factor approach. However, as this approach is only valid for equilibrium conditions, reduction factors were introduced, which take into account for the non-equilibrium conditions /TIL83/. Rather simple approaches have been used mainly in accordance with the German Regulatory Guidelines [STO94]. Only the effective committed dose equivalent is assessed.

3. Release scenarios

3.1 Atmospheric releases

Individual doses together with the contribution of the 5 pathways inhalation (IH), inhalation from resuspension (IHR) irradiation from cloud (CL) and ground (GR) and ingestion (IG) have been calculated for the Most Exposed Individual (MEI) at several distances from the source.

3.1.1 Meteorological data for Greifswald and Cadarache

The Energiewerke Nord (EWN), maintaining the site of Greifswald, have provided meteorological data for one year covering the period from 20.03.1994 - 19.03.95. The following parameters were made available on an hourly basis:

- Wind speed (100 m height)
- Wind direction (100 m height)
- Rain intensity (10 m height)
- Stability class (Pasquill - Gifford)
- Irradiation balance
- Temperature (2 m and 100 m height)
- Relative humidity

Testing of the original data file shows that several hours of the meteorological data were missing:

• Wind speed (100 m height)	> 300 hrs
• Wind direction (100 m height)	> 300 hrs
• Rain intensity (10 m height)	complete
• Stability class	> 1200 hrs
• Irradiation balance	> 50 hrs
• Temperature (2 m and 100 m height)	> at least one T was available
• Relative humidity	> 40 hrs

There was no problem to complete the data for precipitation, irradiation, temperature and humidity. The small gaps were closed by simple interpolation between the last and the first hour with data. The missing data for wind speed and wind direction concentrated in the period from 10.09.94 - 21.09.94 where no data were present in the meteorological file. This gap was closed with 3 hourly records of the station Greifswald published in the European Weather Report /EUW95/. Further missing data were interpolated by using the first and the last hour with recorded values. If the gap was greater than 3 hours, the values were determined by using a random generator. Again, the interval for the random generator was set by the first and the last 'good' data. When evaluating the stability classes it was detected, that not only more than 1200 hours were missing, but that also the stability classes for night conditions were questionable. The wrong and missing stability classes were corrected by using the irradiation balance and the wind speed according to /KTA-1508/.

As the UFOTRI code requests the incoming solar irradiation, the irradiation balance was manipulated to obtain the necessary values. This was solved by using the temperature and the cloud cover /BLU86/. The cloud cover itself was not available at the site of Greifswald and was estimated by using the stability class, wind speed and time of the day. This procedure is in principle the inverse of the determination of the stability class according to /KLU69/, but now with the cloud cover as unknown variable.

The 'Centre d'etudes de Cadarache', part of the CEA, provided meteorological data for the three years 1991, 1992 and 1993. The meteorological values were recorded every 3 hours for most of the parameters, except the rain intensity (daily basis). In contrary to the request, the stability class was not included and the solar irradiation was provided for the year 1994 only. Furthermore, the irradiation measurements were performed on a daily basis only. The following parameters were made available:

- Wind speed (10 m height, every 3 hours)
- Wind direction (10 m height, every 3 hours)
- Rain intensity (10 m height, every 24 hours)
- Stability class (not included)
- Irradiation balance (daily values from another year)
- Temperature (2 m height, every 3 hours)
- Relative humidity (10 m height, every 3 hours

As the UFOTRI code requests the meteorological data on an hourly basis, the data from Cadarache had to be converted into the appropriate form. But this caused a lot of problems what gives rise to doubts that the data are reliable for deterministic calculations. However, as in this study only probabilistic calculations were performed, the conversion was performed in the following way:

- The wind speed recorded every 3 hours was simply copied to the two hours following the time of the measurements. In case of missing values in the original data base, the wind speed was interpolated in the same manner as for the station Greifswald.
- The wind direction recorded every 3 hours was interpolated for the two hours following the time of the measurements. Again the procedure was the same as applied for Greifswald by using the first and the last hour with recorded values together with a random generator to account for the wind fluctuations over this period of missing data.
- The temperature was linearly interpolated between the three hourly records. There was no larger gap which required special attempt.
- The relative humidity was treated in the same manner as the temperature by linear interpolation between the three hourly records. Again, there was no larger gap which required special attempt.
- The precipitation was available only on a daily basis. This is especially a problem for the assessment of the releases of activation products, as the maximum weather sequence is normally linked to heavy rain during the release hour /LIT/. This fact prevented to introduce a simple uniform distribution of the rain intensity over the 24 hour period. The relative humidity was chosen as a guide for dividing the rain intensity over the day. Whenever the relative humidity was high (>95 %) a fraction of the daily rain was related to this hour. And again this amount was not set to a uniform value but distributed randomly. This procedure was done by hand, as also the changing wind direction and the increasing wind speed (both indication of the passing rain band) was taken into account. As this attempt was made only for the three hourly values in the original data set, an interpolation scheme was necessary. This was performed by using simply a random generator to take the variability of the rain intensity into account. This procedure seemed

to be appropriate for a passing front, but is rather questionable for a thunder storm during summer times. However, this fact was considered as far as possible by the interactive procedure of selecting the rain intensity.

- As the stability class was not included in the data it was generated artificially. Unfortunately, the data base was not complete enough to use the same scheme as for Greifswald. Therefore the proposal from /LIT/ was selected, which use the wind speed, cloud cover, hour of the day and month of the year. But the necessary cloud cover was not available and substituted by the interpolated rain. Also this approach had to be corrected by manual procedures.
- The solar radiation represented a very special problem. The values were available on a daily basis for 1994 together with the remark that they do not significantly differ from year to year. This might be true for the mean value but is obviously not correct for an individual day. Nevertheless, the daily irradiation was distributed over all hours with the sun above the horizon, by using the angel of the sun above the horizon as measure. The higher the angel, the greater the fraction of the daily value sorted into this hour. To account for the rain events, the solar irradiation was halved whenever an hour contained any rain.

Again it has to be mentioned that interpolated meteorological data can not be used for deterministic assessments, but the main sources for mis-interpretations were removed. This includes combinations of rain and stable atmospheric conditions as well as rain and high solar irradiation. Nevertheless there seems to be a need to obtain a complete data set without the above reported shortcomings, to have a better feeling for the reliability of the assessments. The year 1991 was selected for all the assessments, however the years 1992 and 1993 were used for special investigations about the possible range of uncertainties involved (see chapter 4.2.5).

3.1.2 Release scenarios for tritium (accidents and effluents)

Probabilistic calculations for accidental release conditions were performed for each chemical form of tritium, HT and HTO. Two different release heights - 10 m with building wake effects and 100 m without any influence from the building were considered. Normal operation conditions were investigated for HT and HTO assuming a release via a stack only. One year of hourly meteorological data from the sites of Greifswald and Cadarache was used as the basis of the dose assessments. The main input parameters for the accidental release scenarios are shown in Table 2, those for the normal operation conditions are presented in Table 3. The 'MOL' set of dispersion parameters was applied /BUL72/ for all calculations. The sampling scheme is shortly described in the Appendix; it was also used for the activation products.

parameter	value
released quantity	3.7 E+14 Bq/hr
chemical form	HTO / HT
individual dose for the	Most Exposed Individual
building dimensions (h x w)	40m x 100m
release duration	1 hr
washout coefficient (w)	w = A*I**B (1/s)
with rain intensity I	in mm/hr
coefficient A	9.0 E-05 (hr s/mm)
coefficient B	0.6
breathing rate	2.66 E-4 m**3/s
skin absorption rate	1.60 E-4 m**3/s
ingestion rate vegetables	45 kg/year
ingestion rate root vegetables	85 kg/year
ingestion rate grain products	95 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
dose conversion factor inhalation HT	6.8 E-16 Sv/Bq
dose conversion factor inhalation HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion OBT	4.0 E-11 Sv/Bq
shielding inhalation + skin (bounding)	1.0

Table 2: Input parameters for the accidental release scenarios, (HTO/HT)

parameter	value
released quantity	1 GBq/year
chemical form	HTO / HT
building dimensions (h x w)	no influence
relative humidity	70 %
air humidity	9 g/m**3
release duration	1 year
washout coefficient (w)	w = A*I**B (1/s)
with rain intensity I	in mm/hr
coefficient A	9.0 E-05 (hr s/mm)
coefficient B	0.6
breathing rate	2.66 E-4 m**3/s
skin absorption rate	1.60 E-4 m**3/s
ingestion rate vegetables	45 kg/year
ingestion rate root vegetables	85 kg/year
ingestion rate grain products	95 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
dose conversion factor inhalation HT	6.8 E-16 Sv/Bq
dose conversion factor inhalation HTO	1.6 E-11 Sv/Bq
dose conversion factor ingestion HTO	4.0 E-11 Sv/Bq
dose conversion factor ingestion OBT	1.6 E-11 Sv/Bq
shielding inhalation + skin	1.00

Table 3: Input parameters for the routine release scenarios, (HTO/HT)

3.1.3 Activation product releases conditions (accidents and effluents)

Calculations have been performed for a corrosion source term from the ITER-ESECS study /ESECS/. This source term was applied to have a basis for intercomparison with results presented there. As for tritium, the same meteorological data set as well as the same weather sequences were used. In case of an accidental release, calculations were performed only for the vegetation period, as the early dose appears to differ not dramatically from summer to winter (see /RAS92/). Under normal operation conditions, the same assumption were applied as for the tritium scenario.

The basic input parameters have been adapted as far as possible to those used for the tritium scenarios (see Table 4 and Table 5).

parameter	value
source term	1 g of activated steel
individual dose for the	Most Exposed Individual
release height	10 m or 100 m
building dimensions (h x w)	40m x 100m
release duration	1 hr
washout coefficient (w)	w = A*I**B (1/s)
with rain intensity I	in mm/hr
coefficient A (nobel gas)	0.0 (hr s/mm)
coefficient B (nobel gas)	0.0
coefficient A (aerosol)	8.0 E-05 (hr s/mm)
coefficient B (aerosol)	0.8
coefficient A (iodine elemental)	8.0 E-05 (hr s/mm)
coefficient B (iodine elemental)	0.6
coefficient A (iodine organic)	8.0 E-07 (hr s/mm)
coefficient B (iodine organic)	0.6
coefficient A (iodine aerosol)	8.0 E-05 (hr s/mm)
coefficient B (iodine aerosol)	0.8
deposition velocity (nobel gas)	0.0 m/s
deposition velocity (aerosol)	0.001 m/s
deposition velocity (iodine elemental)	0.01 m/s
deposition velocity (iodine organic)	0.0005 m/s
deposition velocity (iodine aerosol)	0.001 m/s
dose conversion factors	nuclide dependent
ingestion rate vegeta. (root + grain)	180 kg/year
ingestion rate leafy vegetables	45 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
shielding factor	1.0

Table 4: Input parameters for the activation product accidental release scenarios

parameter	value
source term	1 g of activated steel
individual dose for the	Most Exposed Individual
release height	100 m
building dimensions (h x w)	no influence
release duration	1 year
washout coefficient (w)	w = A*I**B (1/s)
with rain intensity I	in mm/hr
coefficient A (nobel gas)	0.0 (hr s/mm)
coefficient B (nobel gas)	0.0
coefficient A (aerosol)	8.0 E-05 (hr s/mm)
coefficient B (aerosol)	0.8
coefficient A (iodine elemental)	8.0 E-05 (hr s/mm)
coefficient B (iodine elemental)	0.6
coefficient A (iodine organic)	8.0 E-07 (hr s/mm)
coefficient B (iodine organic)	0.6
coefficient A (iodine aerosol)	8.0 E-05 (hr s/mm)
coefficient B (iodine aerosol)	0.8
deposition velocity (nobel gas)	0.0 m/s
deposition velocity (aerosol)	0.001 m/s
deposition velocity (iodine elemental)	0.01 m/s
deposition velocity (iodine organic)	0.0005 m/s
deposition velocity (iodine aerosol)	0.001 m/s
dose conversion factors	nuclide dependent
ingestion rate vegeta. (root + grain)	180 kg/year
ingestion rate leafy vegetables	45 kg/year
ingestion rate meat	75 kg/year
ingestion rate milk	110 kg/year
shielding factor	1.0

Table 5: Input parameters for the activation product effluent release scenarios

3.2 Aquatic release scenarios

3.2.1 Site description for Greifswald and Cadarache

Greifswald is located at the border of the 'Bodden of Greifswald' opposite of the isle of Rügen at the coast of the Baltic Sea. The Bodden can be characterised as follows:

- area 514 km^2
- mean depth 5.6 m
- water volume 2.88 E+9 m^3
- water exchange rate 1700 m^3 /s
- salt content 10 per mill

Only one dilution factor will be calculated by the models as the water exchange rate with the Baltic Sea and the water volume does not change significantly over a year.

Cadarache is located close to the river Serre Poncon, which will be used for the liquid discharges from the projected power plant. There are three important discharge regimes, which can be characterised as :

- annual low 2.5 m^3/s
- annual high 2000 m^3/s
- annual mean 200 m^3/s

These discharge rates together with the relative dilution rates obtained from the application of COASTOX, define the effective dilution rates of the released radionuclides. The relative dilution rate varies with the location of the source in the river bed geometry but can be set to about 10% of the total water volume at the distance of 1 kilometer from the release point. This value was also used within other studies /RAS92/. As calculations with COASTOX have shown, that the dispersion and thus the dilution rate is relatively high for very low discharge rates, the annual low was not altered. The increase in the dilution with lower discharge rate is caused by the greater influence of the bottom inhomogenities. This is especially the case under conditions of a highly reduced discharge like the annual low for the river Serre Poncon. The following dilution factors were used:

- annual low 2500 / s
- annual high 2.0 E+5 /s
- annual mean 2.0 E+4 /s

3.2.2 Releas conditions

The conditions for the aquatic discharges were adapted as far as possible to the ones for the atmospheric releases. Thus, the released quantities (accidental, effluents) and main consumption rates remain unchanged. The differences and additional assumptions are summarised in the following:

- consumption rate of fish 30 kg (meat reduced by 30 kg)
- consumption of drinking water 365 l
- irrigation (accidental) 1 event of 5 mm / m^2
- irrigation (effluents) 20 events of 5 mm / m^2
- distance from the release point 1000 m

4. Results of dose calculations for releases into the atmosphere

The presentation of the probabilistic results concentrate on the individual dose values for the MEI at three distances (500 m, 1000 m, 2000m), as those distances may represent the proposed site boundaries for ITER. The probability of occurrence of for the maximum dose calculated in each individual distance is given by the probability of the corresponding weather sequence. The percentiles give the percentage of the weather sequences, which resulted in concentration / dose values equal or lower than this value. The assessment of the collective dose has been omitted due to two reasons:

1. The collective dose is not included in the German licensing procedure
2. No population density distribution was available for both sites

To get an idea about the representativeness of the probabilistic scheme, dose calculations were performed for every 4800 hours of the vegetation period for one release scenario. This is identical to the probabilistic case with a release from the building (10 m). Additionally, the percentiles can be compared with dose values obtained in an ITER study for a generic site /ESECS/.

Two different types of doses have been obtained. The individual early dose is defined as the result from the first week exposure and a 50 years integration time. The exposure pathways are the external exposure from the passing cloud (CL), the first week external exposure from the ground (GR), the internal exposure from inhalation + skin absorption (IH) from the passing cloud and the internal exposure from inhalation + skin absorption from the reemitted tritium (IHR) during the first week; the ingestion pathways (IG) are not considered. The individual effective dose equivalent (EDE) is defined as the result from chronic exposure and a 50 years integration time. The exposure pathways are the external exposure from the passing cloud and the ground, the internal exposure from inhalation + skin absorption from the passing cloud, the internal exposure from inhalation + skin absorption from reemitted tritium and the internal exposure from the ingestion of contaminated foodstuffs.

4.1 Greifswald

4.1.1 Doses from accidentally released tritium

4.1.1.1 Dose to the MEI from accidental HTO-releases

Two different scenarios with release heights of 10 and 100 m have been investigated. The probability distribution of the individual early doses and of the EDEs for the vegetation period are shown in Table 6 and Table 7. For the 10 m release scenario, the values for the individual early doses amount in general only about 10 % to 30 % of those from the EDE at the same probabilities; the lower fractions are coupled to lower probabilities. For the 100 m release, the early dose is much lower as the plume has not always touched the ground surface due to the narrow plume geometry at stable atmospheric stratification. The early doses for this scenario are mostly coupled to stability classes C and D, whereas the stability class F dominated the early dose for the 10 m release case. The reemitted HTO contributes only to a small fraction to the total dose for the MEI at these 3 distances. The highest doses were obtained for the nearest distance range what is obvious for releases near to the ground level.

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	1.25	4.59	0.57	2.03	0.198	0.70
99	1.25	4.17	0.57	1.82	0.186	0.65
95	0.69	3.16	0.31	1.38	0.107	0.46
90	0.63	2.95	0.28	1.17	0.100	0.40
50	0.09	0.95	0.04	0.36	0.013	0.12
mean	0.18	1.26	0.08	0.52	0.025	0.17

Table 6: Individual doses (mSv) for the MEI at several distances (HTO, 10 m), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 10 m release height

The doses from the 10 m release height are always higher than those from the stack of 100m. The highest doses for the stack releases are coupled to rain events while those for the 10 m release case are caused by weather conditions without rain.

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	8.2E-2	2.22	7.3E-2	1.11	8.4E-2	0.40
99	2.4E-2	0.43	4.4E-2	0.28	7.7E-2	0.17
95	1.1E-2	0.19	1.5E-2	0.20	1.8E-2	0.13
90	9.8E-3	0.15	1.0E-2	0.19	1.6E-2	0.11
50	3.1E-3	0.03	6.6E-3	0.05	4.3E-3	0.04
mean	4.1E-3	0.06	7.7E-3	0.08	7.1E-3	0.05

Table 7: Individual doses (mSv) for the MEI at several distances (HTO, 100 m), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 100 m release height

To assess the early dose for a whole year, additional probabilistic assessments were performed covering the whole period of 8760 hours. This was limited to the release height of 10m as no large differences between summer and winter periods were expected. The results are presented in Table 8. Comparing the early dose values from Table 6, the difference is small and mostly in the range of 10%. The Tables also show, that the early doses from the vegetation period are sometimes slightly higher, which is due to the fact that situations with low wind speed and stable stratification appear more often in the summer time period.

percentile	500 m	1000 m	2000 m
	early	early	early
max	1.24	0.57	0.183
99	1.23	0.55	0.151
95	0.60	0.26	0.085
90	0.51	0.22	0.078
50	0.11	0.04	0.013
mean	0.21	0.09	0.027

Table 8: Early doses (mSv) for the MEI at several distances (HTO, 10 m, year), accidental release conditions, 1 year period, 1g (3.7 E+14 Bq) HTO / hr, 10 m release height

4.1.1.2 Dose to the MEI from accidental HT-releases

The early doses from an HT-release are dominated by the reemitted HTO activity. As for HTO, the 10 m release conditions show the highest doses in the vicinity of the plant (see Table 9 and 10). Ingestion is the dominating pathway whereas the early dose is always less than 10 % of the EDE. The dose values for the elevated release (100 m) are lower by more than one order of magnitude than for a comparable release near ground level (10 m).

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	3.2 E-3	0.437	1.5 E-3	0.198	5.4 E-4	0.061
99	2.6 E-3	0.389	1.3 E-3	0.177	4.4 E-4	0.059
95	1.4 E-3	0.251	6.3 E-4	0.117	2.3 E-4	0.037
90	8.5 E-4	0.191	4.4 E-4	0.087	1.7 E-4	0.032
50	2.8 E-4	0.025	1.1 E-4	0.010	4.9 E-5	0.003
mean	4.2 E-4	0.056	1.9 E-4	0.025	7.5 E-5	0.008

Table 9: Individual doses (mSv) for the MEI at several distances (HT, 10 m), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HT / hr, 10 m release height

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	2.9E-4	0.030	1.7E-4	2.7E-2	1.4E-4	2.6E-2
99	6.8E-5	7.6E-3	7.9E-5	1.3E-2	8.7E-5	2.3E-4
95	2.0E-5	3.2E-3	3.5E-5	4.4E-3	2.8E-5	6.2E-3
90	1.8E-5	2.6E-3	2.7E-5	3.2E-3	2.7E-5	4.6E-3
50	-	8.7E-4	1.2E-5	2.0E-3	1.4E-5	1.6E-3
mean	8.1E-6	1.2E-3	1.5E-5	2.2E-3	1.5E-5	2.5E-3

Table 10: Individual doses (mSv) for the MEI at several distances (HT, 100 m), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HT / hr, 100 m release height

The probabilistic assessments over the whole period of 8760 hours are shown in Table 11. Again, only the release height of 10m was considered. Compared to the early dose values from Table 9, the differences are now higher than for the HTO scenario. Especially the lower percentiles are overestimated for the vegetation season. The reason for this may be the different behaviour of HT in summer and winter. As the microbiological activity is reduced in winter, the conversion into HTO and thus the reemission of HTO, which dominates the early dose, is strongly reduced.

percentile	500 m	1000 m	2000 m
	early	early	early
max	3.0E-3	1.4E-3	5.7E-4
99	2.3E-3	9.1E-4	3.5E-4
95	7.9E-4	3.5E-4	1.3E-4
90	5.9E-4	2.6E-4	1.0E-4
50	1.5E-4	6.6E-5	2.6E-5
mean	2.4E-4	1.1E-4	4.3E-5

Table 11: Early doses (mSv) for the MEI at several distances (HT, 10 m, year), accidental release conditions, 1 year period, 1g (3.7 E+14 Bq) HT / hr, 10 m release height

4.1.1.3 Comparison of accidental HTO- and HT-releases with ITER reference values

Reference dose limits from dose assessments for a generic site were published as a draft recently /ESECS/. Two main dose criteria and several doses 'for information only' are presented in chapter 3 of this report. The two reference dose values can be characterised as:

- Design basis accident: early dose, elevated release (100 m), worst weather conditions
- Beyond design basis accident: early dose, ground release (10 m), average weather conditions

The four additional sequences which are for information only can be shortly described as follows:

- Ground worst 1: early dose, ground release (10 m), worst weather conditions
- Elevated worst: chronic dose with ingestion, elevated release (100 m), worst weather conditions
- Ground worst 2: chronic dose with ingestion, ground release (10 m), worst weather conditions
- Ground average: chronic dose with ingestion, ground release (10 m), average weather conditions

The doses for the MEI at 1 km distance are listed below:

type	design basis	beyond design	ground worst 1	elevated worst	ground worst 2	ground average
HTO	0.06	0.1	0.96	0.9	4.03	1.04
HT	2.5 E-4	4.4 E-4	6.8 E-3	0.018	0.31	0.024

Table 12: Individual doses (mSv) for the MEI at 1 km distance (ITER-reference), accidental release conditions, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height

When comparing these deterministic cases with assessments under probabilistic conditions, four percentiles may be adequate. The maximum or the 95% percentile represent worst case weather, whereas the mean or 50% percentile should be adequate for the average weather. Those values were summarised in Table 13 and 14 for the 'design' cases and the 'information' cases, respectively. When comparing the different results, the generic doses are almost higher than the ones obtained for Greifswald. Most of the related dose values agree better than within a factor of 2. This indicates on the one hand that the generic assessments are performed sufficiently correct or, on the other hand, that the site of Greifswald fits well with the conditions assumed for a future ITER location.

type	design basis elevated worst		beyond design basis ground average	
	max	95%	mean	50%
HTO	0.073	0.015	0.078	0.037
HT	1.7E-4	3.5E-5	1.9 E-4	1.2 E-4

Table 13: Individual doses (mSv) for the MEI at 1 km distance from probabilistic calculations comparable to ITER design cases, accidental release conditions, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height

type	ground worst 1		elevated worst		ground worst 2		ground average	
	max	95%	max	95%	max	95%	mean	50%
HTO	0.57	0.31	1.11	0.20	2.02	1.38	0.52	0.36
HT	1.5 E-3	6.3E-4	2.7E-2	4.4E-3	0.198	0.117	0.025	0.01

Table 14: Individual doses (mSv) for the MEI at 1 km distance from probabilistic calculations comparable to ITER 'information' cases, accidental release conditions, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height

4.1.1.4 Comparison of probabilistic accidental calculations with deterministic calculations

To that purpose, 4800 individual weather sequences, covering the whole vegetation period of the basic year used for Greifswald were analysed. Early doses and EDEs were calculated for the 10 m release case and the radionuclide HTO. As for the probabilistic mode, a frequency distribution of the dose values was evaluated. The comparison of both methods is presented in Table 15.

The differences between the probabilistic and the complete data set are very small for the maximum early dose (about 10%) and also moderate for the EDE (some 20%). When comparing the 95% percentile, a value which can be used in the German licensing procedure, the differences nearly vanish. In general, the differences for all percentiles are always less than 20%, except the 90% percentile of the early dose. Nevertheless, this indicates, that the probabilistic approach is applicable if percentile values are requested. However it is not guaranteed that the maximum weather sequence is covered by the sampling scheme.

percentile	early		EDE	
	probabilistic	4800 WAs	probabilistic	4800 WAs
max	0.57	0.65	2.03	2.5
99	0.57	0.54	1.82	1.86
95	0.31	0.29	1.38	1.38
90	0.28	0.18	1.17	1.10
50	0.04	0.03	0.36	0.41
mean	0.08	0.07	0.52	0.51

Table 15: Comparison of individual doses (mSv) for the MEI at 1 km distance calculated with the probabilistic mode and the complete data set (HTO, 10 m), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 10 m release height

4.1.2 Dose to the MEI from routine tritium releases

4.1.2.1 HTO and HT effluents

Dose calculations were performed for unit releases of both chemical forms HT and HTO. Results were documented for 18 distances and presented in Table 16 and 17 together with the contribution of the individual pathways. The main contribution to the dose is related to the ingestion pathways for both chemical forms of tritium. For HTO, the importance of the reemission process increases with distance. The reemission of HTO plays an important role for HT-releases only close to or farther down the release point. It is not so important at the interdmediate distances up to several kilometers as this is the region where the plume touches the ground and therefore the ingestion pathways are enhanced due to the greater amount of deposited HT from the primarily plume. The maximum of the EDE appears in the vicinity of the release point for the HTO-release, whereas the HT-release shows the maximum at about 700 m distance from the stack. This is due to the different responses of the two chemical forms of tritium to precipitation. HTO is deposited close to the stack because its washout rate is quite high. But HT-gas is not affected by rain, thus no wet deposition occurs at all. The individual dose values from HT-releases are about 40 times lower than for the HTO-releases. At farther distances, this difference is reduced due to the enhanced depletion of the HTO plume in contrast to the HT plume. The average deposition rate differs between the two chemical forms by about a factor of 10 with HTO as the one with the higher deposition velocity. The contribution of the exposure pathway direct inhalation of HT is negligibly small for all distances.

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	1.76	96.65	1.59	8.11E-12
210.0	0.00	0.00	4.25	93.57	2.18	6.34E-12
320.0	0.00	0.00	9.44	88.15	2.41	5.21E-12
500.0	0.00	0.00	19.05	78.30	2.66	5.25E-12
680.0	0.00	0.00	23.49	73.87	2.64	5.39E-12
1000.0	0.00	0.00	26.44	70.92	2.64	4.99E-12
1500.0	0.00	0.00	27.22	69.78	2.99	4.00E-12
2000.0	0.00	0.00	29.69	66.25	4.06	3.14E-12
3200.0	0.00	0.00	28.56	67.06	4.38	1.87E-12
5000.0	0.00	0.00	26.36	68.19	5.46	1.06E-12
6800.0	0.00	0.00	24.59	69.06	6.35	7.04E-13
10000.0	0.00	0.00	21.09	72.76	6.15	4.12E-13
15000.0	0.00	0.00	20.58	71.62	7.80	2.47E-13
20000.0	0.00	0.00	19.56	71.92	8.51	1.76E-13
32000.0	0.00	0.00	17.97	73.65	8.38	1.06E-13
46000.0	0.00	0.00	18.75	70.79	10.45	7.19E-14
68000.0	0.00	0.00	18.45	69.91	11.63	4.55E-14
100000.0	0.00	0.00	17.57	71.07	11.36	2.71E-14

Table 16: Individual doses (Sv/yr) for the MEI at various distances from routine releases of HTO, normal operation conditions, 1.0 E+09 Bq tritium per year, 100m release height

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	0.02	83.83	16.16	3.65E-14
210.0	0.00	0.00	0.02	88.64	11.34	5.54E-14
320.0	0.00	0.00	0.03	92.20	7.78	8.50E-14
500.0	0.00	0.00	0.03	94.50	5.46	1.24E-13
680.0	0.00	0.00	0.04	95.06	4.90	1.39E-13
1000.0	0.00	0.00	0.04	95.08	4.88	1.32E-13
1500.0	0.00	0.00	0.04	92.10	7.86	1.10E-13
2000.0	0.00	0.00	0.04	91.46	8.50	8.73E-14
3200.0	0.00	0.00	0.04	90.85	9.12	5.25E-14
5000.0	0.00	0.00	0.03	88.86	11.11	3.11E-14
6800.0	0.00	0.00	0.03	85.45	14.52	2.13E-14
10000.0	0.00	0.00	0.03	84.70	15.27	1.29E-14
15000.0	0.00	0.00	0.03	83.72	16.25	8.24E-15
20000.0	0.00	0.00	0.02	83.01	16.96	6.18E-15
32000.0	0.00	0.00	0.02	82.70	17.27	4.04E-15
46000.0	0.00	0.00	0.02	81.50	18.48	3.02E-15
68000.0	0.00	0.00	0.02	80.67	19.30	2.11E-15
100000.0	0.00	0.00	0.02	80.39	19.59	1.36E-15

Table 17: Individual doses (Sv/yr) for the MEI at various distances from routine releases of HT, normal operation conditions, 1.0 E+09 Bq tritium per year, 100m release height

4.1.2.2 Comparison of the results with the ITER-reference dose values

Within the ESECS-report, the chronic dose to the MEI from an annual discharge of 3.7 10^{14} Bq per year was estimated to 0.02 mSv per year at a distance of 1 km from the release point. This value was based on pessimistic assumptions for the meteorological data. The present dose value at 1 km distance was evaluated to 0.002 mSv per year per 3.7 10^{14} Bq of HTO released, which is a factor of 10 less than the ITER reference value. One significant reason for this discrepancy may be the location of Greifswald close to the seashore. This causes in general higher wind speeds and thus higher dilution factors as assumed in the ITER-study.

4.1.3 Results for accidental activation product releases into the atmosphere

4.1.3.1 Accidental release of steel

The source term for the release of activated steel is listed in Table 18. The early dose and the EDE for both release conditions, 10 m and 100 m height, are presented in Table 19 and Table 20, respectively. Calculations with the new data base for activation products were performed only for the 10 m release scenario. As two different but consistent data sets of ingestion factors, derived from the foodchain model FARMLAND /FAR95/ and ECOSYS /GSF94/ were present in the new model version of COSYMA, two results were presented in Table 19. The comparison with the old version shows, that there is no necessity to repeat the calculations as the results for the ESECS source term differ not significantly. There is no greater difference than a factor of 2 for all comparable percentiles. Especially in view of the overall uncertainty associated with predictions of foodchain models, this agreement of the old and the new data base is sufficient.

NO.	NUCLIDE	Bq
37	CR- 51	0.23200E+11
39	MN- 54	0.51700E+10
40	MN- 56	0.72100E+11
41	FE- 55	0.32700E+11
42	FE- 59	0.27200E+09
45	CO- 57	0.74900E+10
46	CO- 58M	0.95300E+10
47	CO- 58	0.77300E+10
48	CO- 60M	0.13500E+11
49	CO- 60	0.28500E+10
51	NI- 57	0.57400E+09
99	MO- 99	0.23000E+10
101	TC- 99M	0.20100E+10
233	TA-182	0.26600E+09

Table 18: Source term for 1g of Steel 316SS from corrosion process (from /ESECS/, fluence of 1MWa/m^2)

The highest dose is associated with a weather sequence with rain in the beginning for both release scenarios. As the ingestion dose and the dose from the ground irradiation are dominating this special source term, the EDE is always much higher than the early dose. The relatively high difference between the early dose from ground level and stack release is due to the influence of the inhalation pathway which is dominating for this source term. For releases from stacks, the air concentration is rather low at 1 km distance and thus the inhalation dose is also low. The reason can be found again in the narrow plume geometry and the plume centerline in 100 m height and not in 10 m height as for the release out of the building. The plume geometry is not of great importance for the higher percentiles of the EDE, as wet deposition is the dominating factor for transferring contamination to the soil. Wet deposition depends on the rain intensity and the activity concentration integrated over the vertical plume spread.

percentile	old model version		new model version	
	early	EDE	EDE (FARMLAND)	EDE (ECOSYS)
max	3.4E-2	9.5E-1	9.4E-1	1.4E+0
99	2.6E-2	4.6E-1	2.7E-1	3.8E-1
95	8.7E-3	1.5E-1	1.8E-1	2.5E-1
90	7.8E-3	1.3E-1	1.5E-1	2.1E-1
50	9.3E-4	1.6E-2	1.7E-2	2.4E-2
mean	2.4E-3	5.7E-2	4.4 E-2	6.2E-2

Table 19: Individual doses (mSv) for the MEI at 1 km distance calculated with the new and the old ingestion data set (steel, 10 m), accidental release conditions, vegetation period, 1g of steel / hr, 10 m release height

percentile	1000 m	
	early	EDE
max	6.6E-3	7.3E-1
99	1.8E-3	1.1E-1
95	7.4E-4	2.8E-2
90	3.8E-4	1.2E-2
50	1.9E-4	3.1E-3
mean	2.7E-4	8.0E-3

Table 20: Individual doses (mSv) for the MEI at 1 km distance (steel, 100 m), accidental release conditions, vegetation period, 1g of steel / hr, 100 m release height

4.1.3.2 Comparison of the results with preliminary results of the ITER exercise

As for the tritium release case, dose assessments for a generic site were published recently /ESECS/. The definitions of the ITER doses are equivalent to those described in chapter 4.1.2 of this report. The dose values are listed for the whole range of possible results, defined by the upper bound (UB - upper bound at 1 or 3 Mwa/m^2 considering all cases studies), lower bound (LB - lower bound at 0.3, 1 or 3 Mwa/m^2) considering all cases studied) and the best estimate (BE - best estimate at 1MWa/m^2). The doses from ITER at 1 km distance are can be found in Table 21:

type	design basis	beyond design	ground worst 1	elevated worst	ground worst 2	ground average
316SS UB	1.8E-3	3.9E-3	5.5E-2	1.7E-1	1.5E-0	6.5E-2
316SS BE	1.8E-3	3.9E-3	3.4E-2	1.7E-1	1.5E-0	6.5E-2
316SS LB	3.7E-4	4.0E-4	5.0E-3	6.0E-3	1.5E-1	6.0E-3

Table 21: Individual doses (mSv) for the MEI at 1 km distance (ITER-reference), accidental release conditions, 1g of steel / hr, 10 m or 100 m release height, upper and lower bound included

Again these values will be compared with dose values from the probabilistic calculations. The maximum or the 95% percentile represent worst case weather, whereas the mean or 50% percentile should be adequate for the average weather of ITER. Those values can be summarised in Table 22 and Table 23 for the 'design' cases and the 'information' cases, respectively.

type	design basis elevated worst		beyond design basis ground average	
	max	95%	mean	50%
steel	6.6E-3	7.4E-4	2.4E-3	9.3E-4

Table 22: Individual doses (mSv) from steel for the MEI at 1 km distance from probabilistic calculations comparable to ITER design cases, accidental release conditions, 1g steel / hr, 10 m or 100 m release height

type	ground worst 1		elevated worst		ground worst 2		ground average	
	max	95%	max	95%	max	95%	mean	50%
steel	6.5E-1	1.1E-1	7.2E-1	2.8E-2	9.5E-1	1.5E-1	4.7E-2	1.6E-2

Table 23: Individual doses (mSv) from steel for the MEI at 1 km distance from probabilistic calculations comparable to ITER 'information' cases, accidental release conditions, 1g of steel / hr, 10 m or 100 m release height

The agreement of the ITER and the Greifswald doses from accidental releases of activation products is not as good as for the tritium scenarios. The results from Greifswald differ from those of ITER, dependent on the percentile selected from the probabilistic calculations. As the results fit very well for tritium, the ITER worst case for activation products (low wind speed, low turbulence and 1.3 mm/h of rain in the release hour) might not completely covers the boundary of possible activation product release scenarios. The precipitation in the first hour of the worst case for Greifswald was 7.8 mm/h, which is reflected in the maximum doses for the scenarios design basis, elevated worst and ground worst 1. However, the 95% percentiles of these scenarios are close (ground worst 1) or lower (design basis, elevated worst) than the ITER dose values.

4.1.4 Results for activation product effluents

The same source term as for the accidental case has been applied also for effluents. The release duration was now set to 1 year. The release height is again 100 m, the same height as for the tritium releases under normal operation conditions. All the release conditions are close to those for the tritium releases. The EDE for the MEI at 1 km distance is presented in Table 24. As for tritium, the collective dose has been omitted. The evaluation program of the normal operation module allows to break down the dose into the contribution of pathways and nuclides. This shows the groundshine as the dominating pathway, followed by ingestion. The most important nuclide is Co-60 followed by Mn-54. These observations can be in general also transferred to the results of the accidental release, only the percentages may differ.

NUCLIDE	CL %	GR %	IH %	IG %	IHR %	EDE (SV)	% OF T
CR- 51	0.36	46.79	4.12	48.52	0.21	1.78E-09	0.39
MN- 54	0.09	88.52	0.88	10.41	0.10	4.79E-08	10.46
MN- 56	61.13	21.91	14.37	2.59	0.00	1.96E-09	0.43
FE- 55	0.00	0.00	3.60	95.93	0.46	1.54E-08	3.35
FE- 59	0.25	38.12	3.29	58.12	0.22	1.26E-09	0.27
CO- 57	0.05	67.03	5.57	26.72	0.64	1.64E-08	3.57
CO- 58M	0.00	0.00	83.36	16.55	0.09	1.23E-11	0.00
CO- 58	0.24	63.04	3.64	32.78	0.30	2.97E-08	6.47
CO- 60M	9.93	90.02	0.00	0.05	0.00	4.74E-12	0.00
CO- 60	0.02	83.95	2.51	13.19	0.33	3.29E-07	71.79
NI- 57	7.04	26.93	11.36	54.62	0.05	1.42E-10	0.03
MO- 99	0.94	20.67	20.62	57.61	0.15	3.37E-10	0.07
TC- 99M	34.56	51.56	10.13	3.75	0.01	6.08E-12	0.00
TC- 99	0.00	0.00	1.99	97.74	0.27	2.28E-20	0.00
TA-182	0.02	6.54	0.94	92.40	0.09	1.44E-08	3.15
TOTAL	0.31	76.61	2.59	20.18	0.31	4.58E-07	100.00

Table 24: Individual doses from effluents (Sv/yr) for the MEI at 1 km distance (steel, 100 m), normal operation release conditions, period of one year, 1g of steel / yr, 100 m release height

4.2 Cadarache

4.2.1 Doses from accidentally released tritium

As for Greifswald, probabilistic assessments were performed to obtain the individual dose values for the MEI at 3 distances (500 m, 1000 m, 2000m), as those distances may represent the proposed site boundaries for ITER. No value for the collective dose is given. All the other input parameters except those of the meteorological data were identical to those used for Greifswald, which means that no country typical ingestion or breathing rates were applied.

4.2.1.1 Dose to the MEI from accidental HTO-releases

Two different scenarios with release heights of 10 and 100 m were investigated. The probability distribution of the individual early doses and of the EDEs for the vegetation period are shown in Table 25 and 26. In general, the values do not differ significantly from those of Greifswald. This may be an indication that the data preparation was rather successful. However this is not a proof especially for the higher percentiles. A more global discussion about the reliability of the data can be found in the chapters 3.1.1 and 4.2.5.

The overall behaviour of the dose values differs not significantly from those of Greifswald. For the 10 m release scenario, the values for the individual early dose amount in general only about 10 to 30 % of those of the EDE at comparable probabilities; the lower fractions are coupled to lower probabilities. For the 100 m release, the early dose is much lower as the plume has not always touched the ground surface due to the narrow plume geometry at stable atmospheric stratification. The reemitted HTO contributes only to a small fraction to the total dose for the MEI at these 3 distances. The highest doses were obtained for the nearest distance range which is obvious for releases near to the ground level.

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	1.25	6.90	0.56	2.95	0.26	1.14
99	1.25	5.50	0.54	2.24	0.19	0.98
95	1.25	5.01	0.52	2.08	0.18	0.69
90	1.23	4.68	0.50	1.89	0.10	0.60
50	0.09	1.05	0.03	0.33	0.01	0.12
mean	0.40	2.06	0.16	0.78	0.04	0.24

Table 25: Individual doses (mSv) for the MEI at several distances (HTO, 10 m, Cadarache), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 10 m release height

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	5.9E-2	1.8E+0	3.8E-2	9.6E-1	3.6E-2	4.0E-1
99	5.9E-2	7.6E-1	3.2E-2	4.6E-1	3.6E-2	2.8E-1
95	3.9E-2	4.8E-1	2.4E-2	3.1E-1	3.3E-2	1.4E-1
90	2.1§-2	3.2E-1	1.7E-2	1.9E-1	3.0E-2	1.3E-1
50	2.9E-3	3.2E-2	8.7E-3	7.4E-2	4.9E-3	8.1E-2
mean	8.5E-3	1.3E-1	1.1E-2	1.1E-1	1.2E-2	7.9E-2

Table 26: Individual doses (mSv) for the MEI at several distances (HTO, 100 m, Cadarache), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 100 m release height

The doses from the 10 m release height are always higher than those from the stack of 100m. The highest doses for the stack releases are coupled to rain events, as this is an effective procedure to deposit contamination even if the plume has not reached the ground. The maximum weather sequence which caused the highest doses for the 10 m release case can be an artifact of the meteorological data preparation as it includes a rain event coupled with relatively high solar irradiation. However, this combination is due to the use of the solar irradiation from another year and does not necessarily represent reality. Calculations over one year were not performed as the artificial content of the data set prevents such sophisticated investigations.

4.2.1.2 Dose to the MEI from accidental HT-releases

The early doses from an HT-release are dominated by the reemitted HTO activity. As for HTO, the 10 m release conditions show the highest doses in the vicinity of the plant (see Tables 27 and 28). The contribution from the ingestion is the dominating pathway whereas the early dose is always less than 10 % of the EDE. The dose values from the elevated release (100 m) are lower by more than one order of magnitude compared to related release near ground level (10 m).

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	3.9E-3	5.2E-1	1.5E-3	2.3E-1	9.4E-4	1.0E-1
99	2.4E-3	4.9E-1	1.3E-3	2.1E-1	7.8E-4	8.2E-2
95	2.4E-3	4.8E-1	1.2E-3	2.0E-1	5.7E-4	6.3E-2
90	2.2E-3	4.4E-1	1.1E-3	1.9E-1	5.4E-4	4.4E-2
50	2.2E-4	3.1E-2	1.0E-4	1.1E-2	4.4E-5	4.1E-3
mean	6.3E-4	1.4E-1	3.1E-4	5.6E-2	1.5E-4	1.4E-2

Table 27: Individual doses (mSv) for the MEI at several distances (HT, 10 m, Cadarache), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HT / hr, 10 m release height

percentile	500 m		1000 m		2000 m	
	early	EDE	early	EDE	early	EDE
max	2.3E-4	2.3E-2	1.8E-4	1.9E-2	1.2E-4	1.3E-2
99	2.3E-4	2.1E-2	1.7E-4	1.3E-2	1.2E-4	1.3E-2
95	1.1E-4	1.0E-2	1.0E-4	8.9E-3	9.3E-5	1.1E-2
90	8.1E-5	7.2E-3	5.7E-5	6.7E-3	8.5E-5	1.1E-2
50	1.0E-5	1.0E-3	2.5E-5	3.2E-3	2.0E-5	1.5E-3
mean	3.0E-5	3.0E-3	3.2E-5	3.8E-3	3.2E-5	4.0E-3

Table 28: Individual doses (mSv) for the MEI at several distances (HT, 100 m, Cadarache), accidental release conditions, vegetation period, 1g (3.7 E+14 Bq) HT / hr, 100 m release height

Calculations over one year were not performed as the artificial data set prevents such sophisticated investigations.

4.2.1.3 Comparison of accidental HTO- and HT-releases with ITER reference values

The comparison with the ITER reference cases was prepared in the same way as for Greifswald. The maximum or the 95% percentile represent worst case weather, whereas the mean or 50% percentile should be adequate for the average weather of ITER. These values are summarised in Table 29 and 30 for the 'design' cases and the 'information' cases, respectively. When comparing these results with Table 12 which contains the generic dose assessments, there is no large discrepancy between both assessments. Most of the related dose values agree better than within a factor of 2. The tables also show that the values from Cadarache are slightly higher than those from Greifswald. However, a more detailed analysis is not possible due to the artificial background of the meteorological data base.

type	design basis elevated worst		beyond design basis ground average	
	max	95%	mean	50%
HTO	3.8E-2	2.4E-2	1.6E-1	3.0E-2
HT	1.8E-4	1.0E-4	3.1E-4	1.0E-4

Table 29: Individual doses (mSv) for the MEI at 1 km distance from probabilistic calculations for Cadarache, comparable to ITER design cases, accidental release conditions, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height

type	ground worst 1		elevated worst		ground worst 2		ground average	
	max	95%	max	95%	max	95%	mean	50%
HTO	5.6E-1	5.2E-1	9.6E-1	3.1E-1	2.9E+0	2.1E+0	7.8E-1	3.3E-1
HT	1.5E-3	1.2E-3	1.9E-2	8.9E-3	2.3E-1	2.0E-1	5.6E-2	1.1E-2

Table 30: Individual doses (mSv) for the MEI at 1 km distance from probabilistic calculations from Cadarache comparable to ITER 'information' cases, accidental release, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height

4.2.2 Dose to the MEI from routine tritium releases

4.2.2.1 HTO and HT effluents

The basic input parameters are identical to those used for Greifswald. The overall behavior is close to that observed for Greifswald. Also the dose values are closer together as for the accidental conditions. This can be attributed to the fact that the solar irradiation is not considered in the normal operation mode. Therefore any inconsistencies related to this parameter were omitted.

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	0.84	97.44	1.72	2.23E-11
210.0	0.00	0.00	5.35	92.38	2.27	1.74E-11
320.0	0.00	0.00	11.47	85.87	2.65	1.39E-11
500.0	0.00	0.00	26.64	69.95	3.42	1.12E-11
680.0	0.00	0.00	29.27	67.70	3.04	1.02E-11
1000.0	0.00	0.00	30.74	66.13	3.13	8.62E-12
1500.0	0.00	0.00	28.78	67.27	3.95	7.29E-12
2000.0	0.00	0.00	29.83	66.11	4.06	6.06E-12
3200.0	0.00	0.00	29.95	65.43	4.62	3.79E-12
5000.0	0.00	0.00	28.83	65.32	5.86	2.14E-12
6800.0	0.00	0.00	27.94	65.35	6.70	1.36E-12
10000.0	0.00	0.00	26.94	65.22	7.84	7.66E-13
15000.0	0.00	0.00	26.34	64.40	9.26	4.49E-13
20000.0	0.00	0.00	26.40	63.60	10.00	3.12E-13
32000.0	0.00	0.00	25.97	62.31	11.71	1.77E-13
46000.0	0.00	0.00	25.31	61.40	13.28	1.11E-13
68000.0	0.00	0.00	24.49	60.48	15.03	6.24E-14
100000.0	0.00	0.00	24.46	59.49	16.05	3.14E-14

Table 31: Individual doses (Sv/yr) for the MEI at various distances from routine releases of HTO, Cadarache, normal operation conditions, 1.0 E+09 Bq tritium per year, 100m release height

DISTANCE (M)	CL%	GR%	IH%	IG%	IHR%	EDE (SV)
145.0	0.00	0.00	0.02	87.16	12.82	1.64E-13
210.0	0.00	0.00	0.03	90.65	9.32	2.75E-13
320.0	0.00	0.00	0.03	92.68	7.28	3.53E-13
500.0	0.00	0.00	0.03	93.72	6.24	3.64E-13
680.0	0.00	0.00	0.04	93.67	6.29	3.41E-13
1000.0	0.00	0.00	0.04	93.40	6.56	2.92E-13
1500.0	0.00	0.00	0.04	92.82	7.14	2.26E-13
2000.0	0.00	0.00	0.04	90.22	9.74	1.81E-13
3200.0	0.00	0.00	0.04	89.22	10.74	1.21E-13
5000.0	0.00	0.00	0.04	87.01	12.95	7.37E-14
6800.0	0.00	0.00	0.03	85.62	14.34	4.98E-14
10000.0	0.00	0.00	0.03	83.98	15.99	3.04E-14
15000.0	0.00	0.00	0.03	82.28	17.69	1.99E-14
20000.0	0.00	0.00	0.03	79.80	20.17	1.50E-14
32000.0	0.00	0.00	0.03	80.11	19.87	9.79E-15
46000.0	0.00	0.00	0.02	77.44	22.54	7.02E-15
68000.0	0.00	0.00	0.02	78.25	21.72	4.72E-15
100000.0	0.00	0.00	0.03	77.55	22.42	2.85E-15

Table 32: Individual doses (Sv/yr) for the MEI at various distances from routine releases of HT, Cadarache, normal operation conditions, 1.0 E+09 Bq tritium per year, 100m release height

The highest doses were obtained for the near range and the release of HTO (see Table 31 and 32). Doses from HT-releases are typically 40 times lower than those from HTO. Except for the near range, HT doses are much more lower as the HT plume has not reached the ground yet and HT is not affected by rain whereas HTO is. In the far range the difference is closer to 20.

4.2.2.2 Comparison of the results with the ITER-reference dose values

Within the ESECS-report, the chronic dose to the MEI from an annual release of 3.7 10^{14} Bq per year was estimated to 0.02 mSv per year at a distance of 1 km from the release point /ESECS/. This value was based on pessimistic assumptions about the meteorological data. The present dose value for Cadarache at 1 km distance was evaluated to 0.004 mSv per year per 3.7 10^{14} Bq of HTO released, which is a factor of 5 less than the ITER reference value. Again it seems that the assumptions made within the ITER study are rather conservative.

4.2.3 Results for accidental activation product releases into the atmosphere

4.2.3.1 Accidental release of steel

Calculations have been performed for the same source term of activated steel as listed in Table 18 in chapter 4. Dose calculations were performed for two release conditions (10m and 100m release height). The basic input parameters were the same as used for the Greifswald scenarios (see Table 4 chapter 3.1.2). The early dose and the EDE for both release conditions, 10 m and 100 m height, are presented in Table 33 and 34, respectively.

percentile	1000 m	
	early	EDE
max	1.7E-2	1.2E+0
99	1.6E-2	2.9E-1
95	1.6E-2	2.7E-1
90	1.5E-2	2.6E-1
50	1.0E-3	1.7E-2
mean	4.6E-3	8.9E-2

Table 33: Individual doses (mSv) for the MEI at 1 km distance (steel, 10 m, Cadarache), accidental release, vegetation period, 1g of steel / hr, 10 m release height

For both release scenarios, the highest dose is caused by a weather sequence with rain in the beginning. As the two exposure pathways ingestion and irradiation from the ground surface dominate the doses integrated over 50 years, the EDE is always much higher than the early dose without ingestion. The relatively high difference between the early dose from ground level and from stack release is due to the influence of the inhalation pathway which becomes dominant for the early dose. For releases from stacks, the air concentration is rather low at 1 km distance and thus the inhalation dose is also low too. The reason is again the narrow plume geometry and the plume centerline at 100 m height. The plume geometry is not so important for the higher percentiles of the EDE, as the wet deposition becomes here the dominating factor for transferring activity to the soil. The dose values are in general slightly higher as those obtained for Greifswald. However, the difference is almost in the range of a factor of 2 which might have its reason in the preparation of the meteorological data. Such a relatively small difference can not be attributed to a certain phenomenon, as the meteorological sampling scheme also causes a certain variation in the results. But the much higher number of hours with low wind speeds at Cadarache might be one explanation for the observed difference.

percentile	1000 m	
	early	EDE
max	8.6E-3	9.6E-1
99	1.8E-3	1.2E-1
95	1.1E-3	1.7E-2
90	1.0E-3	9.1E-3
50	2.7E-4	4.4E-3
mean	3.8E-4	9.9E-3

Table 34: Individual doses (mSv) for the MEI at 1 km distance (steel, 100 m, Cadarache), accidental release, vegetation period, 1g of steel / hr, 100 m release height

4.2.3.2 Comparison of the results with preliminary results of the ITER exercise

The dose assessments for a generic site, published recently in /ECNES/ and listed in Table 18 in chapter 4.1.3.2, were compared with the results obtained for Cadarache. The definitions of the doses are equivalent to those described in chapter 4.1.2.2 of this report. Again these values will be compared with dose values from the probabilistic calculations. The maximum or the 95% percentile represent worst case weather, whereas the mean or 50% percentile should be adequate for the average weather of ITER. These values were summarised in Table 35 and 36 for the 'design' cases and the 'information' cases, respectively.

type	design basis elevated worst		beyond design basis ground average	
	max	95%	mean	50%
steel	8.6E-3	1.8E-3	8.9E-3	1.7E-3

Table 35: Individual doses (mSv) from steel for the MEI at 1 km distance from probabilistic calculations comparable to ITER design cases, accidental release conditions, 1g steel / hr, 10 m or 100 m release height

type	ground worst 1		elevated worst		ground worst 2		ground average	
	max	95%	max	95%	max	95%	mean	50%
steel	6.5E-1	1.1E-1	9.1E-1	1.7E-2	1.2	2.7E-1	8.9E-2	1.7E-2

Table 36: Individual doses (mSv) from steel for the MEI at 1 km distance from probabilistic calculations comparable to ITER 'information' cases, accidental release conditions, 1g of steel / hr, 10 m or 100 m release height

The comparison of the doses values of ITER and Cadarache shows similar agreements and discrepancies as for ITER and Greifswald. First of all the agreement is not as good as for the tritium scenarios. The results of the activation product release from Cadarache, which are even higher than those from Greifswald, differ from those of ITER again dependent on the percentile selected from the probabilistic calculations. The maximum dose values obtained for Cadarache are often higher by a factor of 2 to 5 than those of ITER Beneath the uncertainties in the meteorological data preparation, discussed already before, the question may arise, whether the ITER worst case for activation products (low wind speed, low turbulence and 1.3 mm/h of rain in the release hour) really covers the boundary of possible scenarios. The precipitation during the worst case for Cadarache was 7.3 mm/h and thus, together with the worst case of Greifswald, higher than assumed for ITER. However, the 95% percentiles are in most cases comparable high or lower than those obtained for the generic site of ITER. This observation is in particular related to the dose values of the two reference scenarios: design basis and beyond design basis.

4.2.4 Results for activation product effluents

The same source term as for the accidental case has been applied for effluents; only the release duration was now set to 1 year. The release height is 100 m, the same height as for the tritium releases under normal operation conditions. All the release conditions are identical as for Greifswald which were listed in Table 5 in chapter 3.1.3. The EDE for the MEI at 1 km distance is presented in Table 37. As before, the collective dose has been omitted.

The groundshine is the dominant exposure pathway, followed by ingestion of contaminated foodstuffs. The by far dominating nuclide is Co-60 followed by Mn-54. These observations were similar to those observed for Greifswald. The only significant difference can be observed in the EDE from Cadarache, which is about 2 times higher than for Greifswald. Apart from the problems of the meteorological data base, the greater number of situations with low wind speed combined with stable atmospheric stratification may be the reason for this result.

NUCLIDE	CL %	GR %	IH %	IG %	IHR %	EDE (SV)	% OF T
CR- 51	0.36	43.27	4.10	52.08	0.19	2.73E-09	0.41
MN- 54	0.09	87.09	0.94	11.78	0.10	6.89E-08	10.28
MN- 56	61.93	20.66	14.56	2.85	0.00	2.85E-09	0.43
FE- 55	0.00	0.00	3.36	96.24	0.40	2.51E-08	3.75
FE- 59	0.25	34.78	3.24	61.54	0.20	1.95E-09	0.29
CO- 57	0.05	64.01	5.73	29.60	0.61	2.42E-08	3.62
CO- 58M	0.00	0.00	82.27	17.64	0.08	1.88E-11	0.00
CO- 58	0.24	59.72	3.72	36.03	0.28	4.43E-08	6.61
CO- 60M	10.23	89.71	0.00	0.06	0.00	4.71E-12	0.00
CO- 60	0.02	82.11	2.64	14.90	0.32	4.76E-07	71.00
NI- 57	6.89	24.43	11.10	57.54	0.04	2.21E-10	0.03
MO- 99	0.92	18.63	20.03	60.28	0.14	5.28E-10	0.08
TC- 99M	35.79	49.54	10.49	4.17	0.01	8.94E-12	0.00
TC- 99	0.00	0.00	2.39	97.33	0.28	1.08E-19	0.00
TA-182	0.02	5.70	0.88	93.32	0.08	2.35E-08	3.50
TOTAL	0.31	74.10	2.69	22.59	0.30	6.70E-07	100.00

Table 37: Individual doses from effluents (Sv/yr) for the MEI at 1 km distance (steel, 100 m, Cadarache), normal operation release conditions, 1 year, 1g of steel / yr, 100 m release height

4.2.5 Special investigations for Cadarache

There were 3 years with meteorological data provided for Cadarache. The year 1991 was chosen for the main investigations. To get an idea about the variability of the results with changing years, also 1992 and 1993 were processed. There were the same difficulties with the missing data and the resolution of 3 hours only. However, the preparation was performed in the same way as described in chapter 3.1.1. Again one has to mention that the quality of the data prevent a detailed investigation, therefore, only one release situation for HTO (10 m release height, summer) and activation products (10 m release height, summer) was considered. The differences are shown in Table 38 and 39.

percentile	1991		1992		1993	
	early	EDE	early	EDE	early	EDE
max	0.56	2.95	0.56	2.73	0.58	2.97
99	0.54	2.24	0.54	2.54	0.57	2.82
95	0.52	2.08	0.52	2.04	0.51	2.13
90	0.50	1.89	0.51	2.00	0.50	1.95
50	0.03	0.33	0.12	0.95	0.03	0.49
mean	0.16	0.78	0.18	0.99	0.13	0.78

Table 38: Individual doses (mSv) for the MEI at 3 years (HT0, 10 m, Cadarache), accidental release, vegetation period, 1g (3.7 E+14 Bq) HTO / hr, 10 m release height

percentile	1991		1992		1993	
	early	EDE	early	EDE	early	EDE
max	1.7E-2	1.2E+0	1.8E-2	9.1E-1	1.7E-2	9.6E-1
99	1.6E-2	2.9E-1	1.6E-2	7.1E-1	1.7e-2	4.8E-1
95	1.6E-2	2.7E-1	1.5E-2	2.9E-1	1.5e-2	2.9E-1
90	1.5E-2	2.6E-1	1.5E-2	2.6E-1	1.5E-2	2.6E-1
50	1.0E-3	1.7E-2	4.1E-3	6.9E-2	9.5E-4	1.6E-2
mean	4.6E-3	8.9E-2	5.5E-3	1.1E-1	3.9E-3	7.9E-2

Table 39: Individual doses (mSv) for the MEI at 3 years (activated steel, 10 m, Cadarache), accidental release, vegetation period, 1g / hr, 10 m release height

The maximum doses agree very well within the three years for the releases of tritium and activation product. Also the 90% and 95% percentiles show no significant differences. However all the other comparable values differ up to a factor of 4. The reason for the agreement of the maxima seems to be the weather sequences which result in the highest doses. For activation product releases, these sequences contains always rainfall in the first hour of an intensity of about 7 to 8 mm/h. For releases of HTO, the solar irradiation and the atmospheric stratification is comparable. The differences in the 50% percentiles and the mean may be associated with the number of low wind speeds, however, it can be also an artifact from the processing of the meteorological data. Nevertheless, this comparison shows, that the overall agreement for two of the main important doses values, the maximum and the 95% percentile, is rather good. Therefore one can draw the conclusions, that the probabilistic assessments for Cadarache are rather reliable, in particular when regarding the great problems with the meteorological data. But it has to be mentioned that it seems to be not possible with the present data base to perform deterministic calculations to obtain so called 'realistic worst case scenarios' /RAS92/.

5. Aquatic releases

Only the effective dose from the consumption of contaminated foodstuffs was calculated for the aquatic releases. This covers the consumption of fish (IGF), of irrigated foodstuffs including milk and beef (IGI) and of drinking water (IGD). The intake of drinking water should be regarded as a very conservative contribution as the assumption was made that the concentration in the river water is identical to the concentration in drinking water. This is not the fact for most applications, as drinking water is taken out from bank infiltration areas or from ground water. Both processes cause a more or less high dilution of the activity. However, models which describe these transfer processes are not part of the present hydrological models and therefore this conservative assumption was taken.

5.1 Greifswald

5.1.1 Doses from accidental aquatic discharges

As mentioned in the model description, the complex code LAKECO could not be used for the present source term. Therefore, a comparison between the complex lake model LAKEKO and the simple one, which has been used for the assessment of radionuclides other than Sr and Cs, was performed and the results can be found in Table 40. As explained in chapter 2.2, the advanced model lacks in data about activation products. Nevertheless the concentration factor approach seems to be the second best, at least, if detailed information about the food web is missing /TIL83/. But as explained in the model description of LAKE, the equilibrium concentration is only reached if the water concentration remains constant till infinity. This avoids the overestimation of the activity concentration in fish and thus the dose under accidental conditions in comparison to models which use the direct equilibrium between water and fish also here /OVE95/. The difference between the time integrated concentrations (TIC) in fish calculated with the complex model LAKECO and the 2-Box model LAKE is very high for this exercise. Reasons for higher TICs from LAKECO can be related to the contribution from the sediments, which act as a secondary source for the activity concentration in water. However, the most important reason for the differences is the application of a complex foodweb, but again based on literature values and assumptions, which also cause a different behaviour of the predatory and prey fish (such as the herring, the most common fish in the Greifswaldener Bodden). This use of the foodweb submodel produces - under equilibrium conditions - a concentration factor of 427 for Cs and the prey fish which is about 10 times higher as the one found in the literature and used in the simple model LAKE. This indicates that also the use of complex models without appropriate data is not recommendable.

nuclide	LAKEKO		LAKE
	TIC-prey.	TIC predatory	TIC fish
Sr- 90	9.1	18.2	0.074
Cs-137	13.6	29.1	0.925

Table 40: Comparison of the time integrated concentration (TIC over 3 years) in prey and predatory fish (Bq/kg wet weight) from an accidental discharge of 1.0E+09 Bq of Sr-90 and Cs-137 into the Greifswaldener Bodden, calculated by the two different models LAKECO and LAKE, dose from fish consumption only

Tables 41 and 42 show the results from releases into the Greifswaldener Bodden of 1g of HTO and activated steel, respectively.

nuclide	dose
HTO	4.9E-6

Table 41: Individual dose (mSv) for the MEI from an accidental discharge of 1g of HTO into the Greifswaldener Bodden, dose from fish consumption only

The dominating radionuclide of the activation product source term is Co-60 which is in accordance with the results from atmospheric releases. Doses for HTO and activation products are of a similar order of magnitude.

NO.	NUCLIDE	dose	% of Total
37	CR- 51	1.8E-08	0.27
39	MN- 54	5.3E-07	7.98
40	MN- 56	1.3E-08	0.19
41	FE- 55	7.0E-07	10.55
42	FE- 59	1.4E-08	0.21
45	CO- 57	2.7E-07	4.07
47	CO- 58	3.4E-07	5.13
49	CO- 60	4.6E-06	69.23
51	NI- 57	6.1E-10	0.01
98	MO- 99	4.7E-09	0.07
99	Tc- 99m*	1.3E-07	1.97
233	TA-182	1.8E-08	0.28
	total	6.6E-06	

Table 42: Individual doses (mSv) for the MEI from an accidental discharge of 1g of activated steel into the Greifswaldener Bodden, dose from fish consumption only (* = with contribution of Tc-99)

5.1.2 Doses from routine aquatic discharges

It is assumed for routine release conditions, that the concentrations in fish and water are in equilibrium just from the beginning of the release in January the first. Additionally, the water concentration in the Bodden has reached equilibrium with the activity discharged and the fresh water exchanged by the Baltic Sea. The doses obtained under these conditions do not differ from those obtained for the accidental scenario. The reason can be found in the model structure of the computer code LAKE and the fast mixing with uncontaminated water from the Baltic Sea. In other words, the fish 'finds' the same time integrated activity concentration in water for both the accidental and the routine case. This together with the assumption of an instantaneously reached equilibrium water-fish, and with the use of a biological half-life instead of a concentration factor are reasons for the observed results. Again the differences between the simple and the complex models (see Table 43) can be explained by the use of different concentration factors, which are calculated by LAKECO or taken from the literature (see discussion in chapter 5.1.1).

nuclide	LAKEKO		LAKE
	TIC-prey	TIC predator	TIC fish
Sr- 90	1.5	5.8	0.074
Cs-137	17.1	65.7	0.925

Table 43: Comparison of the time integrated concentration (TIC over 1 year) in prey and predatory fish (Bq/kg wet weight) from a routine discharge of 1.0E+09 Bq of Sr-90 and Cs-137 into the Greifswaldener Bodden, calculated by the two different models LAKECO and LAKE, dose from fish consumption only

The Tables 44 and 45 show the results from routine releases into the Greifswaldener Bodden of 1g of HTO and activated steel, respectively.

nuclide	dose
HTO	4.9E-6

Table 44: Individual doses (mSv) for the MEI from an accidental discharge of 1g of HTO into the Greifswaldener Bodden, dose from fish consumption only

As for the accidental scenario, Co-60 is identified as the dominating radionuclide of this activation product source term. Again, this is in accordance with the results from atmospheric releases. Doses for HTO and activation products are of similar order of magnitude and equal to those from the accidental scenario. The explanation is mentioned above.

NO.	NUCLIDE	dose	% of Total
37	CR- 51	1.8E-08	0.27
39	MN- 54	5.3E-07	7.98
40	MN- 56	1.3E-08	0.19
41	FE- 55	7.0E-07	10.55
42	FE- 59	1.4E-08	0.21
45	CO- 57	2.7E-07	4.07
47	CO- 58	3.4E-07	5.13
49	CO- 60	4.6E-06	69.23
51	NI- 57	6.1E-10	0.01
98	MO- 99	4.7E-09	0.07
99	Tc- 99m*	1.3E-07	1.97
233	TA-182	1.8E-08	0.28
	total	6.6E-06	

Table 45: Individual doses (mSv) for the MEI from a routine discharge of 1g of activated steel into the Greifswaldener Bodden (release duration 1 year), dose from fish consumption only (* = with contribution of Tc-99)

5.2 Cadarache

5.2.1 Doses from accidental aquatic discharges

Table 46 (tritium) and Table 47 (activated steel) show the results from the accidental releases in the river Serre Poncon under mean discharge conditions. These numbers have to be multiplied by a factor of 10 and 0.1 to obtain the doses under annual low and under annual high discharge conditions, respectively.

nuclide	IGI	IGD	IGF	dose
HTO	63.94	34.78	1.28	1.6E-02

Table 46: Individual doses (mSv) for the MEI at 1 km distance from an accidental discharge of 1g of tritium as HTO (mean discharge, Cadarache), dose from ingestion only

nuclide	IGI	IGD	IGF	dose	% of tot.
Cr- 51	72.21	15.01	12.78	5.1E-06	.68
Mn- 54	33.73	5.81	60.46	5.5E-05	7.37
Mn- 56	87.66	1.29	11.06	8.0E-07	.11
Fe- 55	62.74	4.85	32.41	9.4E-05	12.42
Fe- 59	75.56	10.39	14.06	4.0E-06	.54
Co- 57	49.99	5.95	44.06	3.4E-05	4.49
Co- 58	59.68	9.77	30.56	6.4E-05	8.50
Co- 60	45.82	4.66	49.52	3.7E-04	49.39
Ni- 57	72.68	26.38	.94	1.1E-06	.14
Mo- 99	45.36	54.35	.29	2.3E-06	.31
Tc- 99m*	98.25	1.00	.75	6.1E-05	8.12
Ta-182	98.44	.61	.95	6.0E-05	7.93
Total	57.25	4.92	37.83	7.5E-04	

Table 47: Individual doses (mSv) for the MEI at 1 km distance from an accidental discharge of 1g of activated steel (mean discharge, Cadarache), dose from ingestion only (* = with contribution of Tc-99)

The highest contribution to the dose from activated steel results from the consumption of irrigated food (IGI) and of fish (IGF), both with about an equal weight. The most important nuclide is again identified as Co-60, which is responsible for about half of the total dose. This picture is different for HTO, which shows the IGI and the IGD as main contributor to the dose. This can be explained by two approaches applied. One reason is the use of an equilibrium model for tritium and the other can be found in the concentration factor for fish which is only 1 and thus much lower as for most of the activation products of the present source term.

5.2.2 Doses from routine aquatic discharges

Table 48 and 49 show the results from the routine releases in the river Serre Poncon for tritium and activated steel, respectively. As mentioned in the definition of the scenario (chapter 2) only one discharge regime, the mean, is assumed throughout the year.

nuclide	IGI	IGD	IGF	dose
HTO	9.23	87.55	3.22	6.2E-04

Table 48: Individual doses (mSv) for the MEI at 1 km distance from routine discharges of 1g of tritium as HTO (Cadarache), dose from ingestion only

nuclide:	IGI	IGD	IGF	dose	% of tot.
Cr- 51	6.22	50.65	43.13	1.5E-07	.45
Mn- 54	1.20	8.66	90.14	3.7E-06	11.14
Mn- 56	25.29	7.78	66.93	1.3E-08	.04
Fe- 55	3.86	12.52	83.62	3.6E-06	10.05
Fe- 59	7.19	39.44	53.37	1.1E-07	.32
Co- 57	2.23	11.63	86.14	1.7E-06	5.18
Co- 58	3.32	23.42	73.26	2.7E-06	7.99
Co- 60	2.03	8.42	89.55	2.1E-05	61.56
Ni- 57	10.40	86.52	3.09	3.3E-06	.10
Mo- 99	2.63	96.86	.51	1.3E-07	.39
Tc- 99m*	73.98	14.86	11.16	4.1E-07	1.23
Ta-182	62.94	14.58	22.48	2.5E-07	.75
Total	2.77	11.05	86.18	3.3E-05	

Table 49: Individual doses (mSv) for the MEI at 1 km distance from routine discharges of 1g of activated steel (Cadarache), routine release conditions, dose from ingestion only (* = with contribution of Tc-99)

The results of both HTO and activated steel differ from those of the accidental scenarios. Activated steel shows the consumption of fish as the highest individual contribution to the dose. This is due to the fact, that there remains more time during a release duration of one year to establish an equilibrium between the activity concentration in water and fish. This is expressed in the model as concentration factor with values for all activation product nuclides greater than 1 (see Table 1). Again, the most important nuclide is identified as Co-60, which is responsible for more than half of the total dose. Drinking water becomes the by far most important pathway for the routine discharge scenario of HTO.

6. Conclusions

Probabilistic dose assessments for accidental atmospheric releases of tritium and activation products as well as releases under normal operation conditions were performed for the sites of Greifswald, Germany, and Cadarache, France. Additionally, aquatic releases were considered for both sites. The results were compared to site independent dose assessments performed in the frame of the ITER study. The agreement between the results from the ITER study on atmospheric releases and the two sites are rather good for tritium, whereas the ITER reference dose values for the activation product releases are often lower, than the maximum values from Greifswald and Cadarache (see chapters 4.1.1.3 and 4.1.2.2 for Greifswald chapters 4.2.1.3 and 4.2.2.2 for Cadarache and Tables 50 and 51 in this chapter for the design basis scenarios). However, the appropriate percentiles fit better to the ITER reference dose values for steel.

location	**HTO** design basis elevated worst		**HTO** beyond design basis ground average		**HT** design basis elevated worst		**HT** beyond design basis ground average	
	max	95%	mean	50%	max	95%	mean	50%
ITER*	6.0E-2		1.0E-1		2.5E-4		4.4E-4	
Greifswald	7.3E-2	1.5E-2	7.8E-2	3.7E-2	1.7E-4	3.5E-5	1.9E-4	1.2E-4
Cadarache	3.8E-2	2.4E-2	1.6E-1	3.0E-2	1.8E-4	1.0E-4	3.1E-4	1.0E-4

Table 50: Comparison of individual doses (mSv) for the MEI at 1 km distance from probabilistic calculations for accidental releases of tritium from Greifswald and Cadarache with ITER design cases, accidental release conditions, 1g (3.7 E+14 Bq) / hr, 10 m or 100 m release height (* only one deterministic reference value calculated for ITER)

location	design basis elevated worst		beyond design basis ground average	
	max	95%	mean	50%
ITER UB *	1.8E-3		3.9E-3	
ITER BE *	1.8E-3		3.9E-3	
ITER LB *	3.7E-4		4.0E-4	
Greifswald	6.6E-3	7.4E-4	2.4E-3	9.3E-4
Cadarache	8.6E-3	1.8E-3	8.9E-3	1.7E-3

Table 51: Comparison of individual doses (mSv) from accidental releases of steel for the MEI at 1 km distance from probabilistic calculations for Greifswald and Cadarache with ITER design cases, accidental release conditions, 1g steel / hr, 10 m or 100 m release height (* UB - upper bound, BE - best estimate, LB - lower bound)

In most scenarios, the doses from Cadarache are higher than those observed for Greifswald. Besides the problems with the meteorological data of the site from Cadarache, which were discussed in chapter 3.1.1, the higher number of hours with low wind speeds may be the major reason for the in general higher doses from this site. This seems to be the case especially for the lower probabilities. The maximum doses, in particular those with the exposure pathway ingestion, agree rather well, indicating that there is always one weather sequence in a year which causes high doses, nearly independent from the site characteristics.

The comparison of the doses from normal operation releases of HTO shows that the results for both sites are far below the ITER reference value for HTO (see Table 52). As ITER does not present doses for routine emissions of HT and activation products, the sites can be only compared to each other. Again, Cadarache shows higher doses, which was also found for the accidental release scenarios.

location	HTO	HT	activation products
ITER	2.0E-2	-	*
Greifswald	2.0E-3	4.9E-5	2.3E-4
Cadarache	3.2E-3	1.1E-4	6.7E-4

Table 52: Comparison of individual doses (mSv/yr) from normal operation releases of tritium or steel for the MEI at 1 km distances for Greifswald and Cadarache with the ITER design case, routine release conditions, 1g tritium or steel / hr, 100 m release height (* assumption that there is no major release of activation products)

Table 53 summarises the results from the discharges into the Greifswaldener Bodden and the river Serre close to Cadarache. Doses of accidental releases from Cadarache vary by a factor of 10 around the mean (which is reported here), dependent on the annual low and annual high discharge rates. Even the lowest dose values are higher than those from Greifswald which can be explained mainly due to the following two facts:

- Different exposure pathways (only fish for Greifswald)
- higher dilution rates in the Greifswaldener Bodden

	Greifswald		Cadarache	
	accidental	routine	accidental	routine
HTO (1 g)	4.9E-06	4.9E-06	1.6E-2	6.2E-04
steel (1 g)	6.6E-06	6.6E-06	7.5E-4	3.3E-05

Table 53: Doses (mSv) from aquatic releases (mean value for Cadarache)

Within all scenarios, the consequences of aquatic releases are in nearly all cases smaller than those from comparable releases to the atmosphere (HTO and steel). This rule is only broken once in case of accidental releases of activated steel from Cadarache. There, the doses from aquatic releases under worst case conditions - annual low - exceed those released into the atmosphere under design basis conditions. However, the uncertainties associated with the aquatic assessments are rather high and a better data base is needed to obtain more realistic and thus more reliable dose values.

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APPENDIX

Probabilistic sampling scheme

The consequences of a postulated release of radioactive material will vary considerably with the conditions pertaining at the time of the accidental release, in particular with the prevailing meteorological conditions, the season, the location and habits of population. For any given release, therefore, there will be a spectrum of possible consequences, each having different probabilities of occurrence determined by the environmental characteristics of the release location and its surroundings. To estimate the full spectrum of consequences of an accidental release a computer code should calculate all possible sequences of weather (a weather sequence is defined by its starting time in the weather record) which may occur during this period. Thus several thousands of different weather sequences had to be considered. In practice, time and computer effort prevent such an action. Therefore, a reduced number of weather sequences representing the full spectrum of atmospheric conditions at the site under consideration had to be selected.

The meteorological record includes (against others) wind speed, wind direction, rainfall and atmospheric stability category in hourly values for a given period (in our example for the whole vegetation period, 4800 hours). For each of the 4800 possible weather sequences the trajectory of the plume will be calculated and evaluated according to the following criteria:

- initial wind direction (12 classes)
  - 12 30° sectors
- travel time T up to the 20 km radius from the release point (3 classes)
  - $0 < T <= 2h$
  - $2\,h < T <= 5\,h$
  - $T > 5\,h$
- precipitation I, found during the travel time to reach 20 km (4 classes)
  - $I = 0$ mm
  - 0 mm < I <=. 1 mm
  - 1 mm < I <=. 3 mm
  - $I > 3$ mm

In this way 144 different classes of weather conditions are obtained together with their probability of occurrence which will be determined from the number of weather sequences sorted in each class divided by the total number of weather sequences. For the calculations one weather sequence of each class will be chosen randomly. Thus 144 weather sequences with their probability of occurrence may represent the vegetation period, however uncertain due to the chosen sampling scheme.