Dounreay Site Restoration Ltd

# AN ASSESSMENT OF THE RADIOLOGICAL IMPACTS OF PROPOSED ATMOSPHERIC AND LIQUID RADIOACTIVE WASTE DISPOSALS FROM DOUNREAY

## 2009

Dounreay Site Restoration Ltd

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# CONTENTS

## GLOSSARY

The glossary is contained in the DSRL paper:

**RSA Application (09) Glossary -** GLOSSARY OF TERMS USED IN THE DOCUMENTS APPLYING FOR AN AUTHORISATION TO DISPOSE OF RADIOACTIVE WASTES ON OR FROM THE PREMISES AT DOUNREAY, CAITHNESS

# 1 INTRODUCTION

This report, presents an assessment of the potential radiation doses to the public as a result of proposed discharges from the Dounreay site in Caithness, taking account of disposal estimates and the 2003 habits data (Ref 1).

The RSA Application guides SEPA to granting an authorisation based on a site limit for gaseous discharge. However, PC CREAM has a limitation of only being able to model up to 5 aerial discharge points in a single assessment. To accommodate PC CREAM this assessment retains the extant RSA groupings as defined in the Schedule 4 tables 2 to 7 of the Certificate of Authorisation RSA/N/V02/50010/99.

## 1.1 Environmental Radiological Assessments

Environmental radiological assessments seek to define an upper estimate of the level of risk associated with planned discharges of radionuclides. The movement of radionuclides through the environment, from the point of discharge to the point at which a dose is received by a human receptor, can be simulated by mathematical modelling. Such modelling is generally undertaken by considering the transport of material through the environment based upon the conditions pertaining at the time of release. Where adequate data is available the assessment makes use of realistic parameter values. Where data are unavailable or are considered to be uncertain, conservative assumptions are made such that the parameter value selected will tend to lead to an overestimate of likely dose. This conservative approach aims to ensure that the public and the environment are protected from excessive risk.

The purpose of the assessments undertaken, and presented below, are to estimate the maximum potential doses that could be received by members of the public as a result of proposed atmospheric and marine discharges of radionuclides. These assessments will provide information on the possible consequences of proposed discharge levels and will thereby assist the decision-making process associated with establishing permitted discharge levels.

## 1.2 Assessment Methodology

The principal component of the assessment methodology is the PC CREAM computer code. This code was developed by the National Radiological Protection Board [Ref 2] and was based upon a report commissioned and published by the European Commission (EC) [Ref 3]. PC CREAM has been widely used across Europe to determine potential radiological impacts of routine discharges.

The availability of data was such that there was no basis for altering the basic default values used by the Assessor module other than the basic meteorological wind data and therefore the other modules were not implemented in this study. This is considered to represent a conservative approach as the default values used in PC CREAM Assessor are deliberately selected to ensure that doses tend to be overestimated rather than underestimated. This conservative approach was continued through the remainder of the study for example, in selecting default consumption rates where habit data is not available.

PC CREAM provides results in terms of annual individual committed effective dose (referred to simply as individual dose) and collective effective dose equivalent (referred to as collective dose) to the defined population of interest.

## 2 ASSESSMENT OF ATMOSPHERIC DISCHARGES

The PC CREAM model was implemented using the site selection option for Dounreay, which automatically implements the atmospheric assessment module for Dounreay. The following sections describe the input data required by the code.

### 2.1 Discharge point data

Releases of radionuclides to atmosphere take place through a large number of stacks and vents across the Dounreay site. For the purposes of the current RSA authorisation these stacks and vents are combined into 5 stack groups, to align with the limitations of PC CREAM[1], and this approach has been adopted for the present study. The five stack groups are:

- Dounreay Fast Reactor (DFR) – where releases from a number of sources are combined and released via a single stack, RSA/N/V02/50010/99 Schedule 4 Table 4.3;
- East Minor Sources (EMS) – where several small releases occur from separate buildings, RSA/N/V02/50010/99 Schedule 4 Table 4.6;;
- Fuel Cycle Area (FCA) – where a number of separate sources discharge to atmosphere via a single stack, RSA/N/V02/50010/99 Schedule 4 Table 4.4. This stack is to be replaced by two 30m stacks located to the North and South. The assessment is not compromised since the FCA Stack is modelled at 30m and is therefore treated in the same way as the WMS and EMS stacks;
- Prototype Fast Reactor (PFR)/PFR Minor Sources – where discharges occur from the PFR reactor and other nearby sources via a number of stacks, RSA/N/V02/50010/99 Schedule 4 Table 4.2 and 4.7; and,
- West Minor Sources (WMS) – where a number of sources discharge separately to atmosphere, RSA/N/V02/50010/99 Schedule 4 Table 4.5.

The representative stacks have been defined as shown in Table 1. The release heights have been selected from the available values in the main PC CREAM module. A ground level release has been specified for the EMS and WMS as the stacks for these minor sources are relatively low and will be subject to building wake effects which have the general effect of reducing effective release height. The value of 30 m for the release heights for the other three stacks has been selected as this is the next height available below the actual stack heights. The selection of a lower stack height is moderately conservative in that it will tend to increase the predicted ground level concentrations and therefore will result in conservative estimates of radiation dose. For collective dose assessment a single release height is specified for all 5 stack groups and a 30 metre level release was used.

Detailed modelling of the dispersion of radionuclides from each individual source at the actual stack heights has not been undertaken. There are two factors that make such detailed calculations impractical. Firstly, PC CREAM requires the 'effective height' to be provided (i.e. the actual height plus allowance for the plume rise due to vertical momentum due to the efflux velocity and buoyancy due to the efflux temperature being greater than that of the ambient air) and the data describing the emissions in terms of velocity and temperature is not available. Secondly, the source groups comprise a number of individual

[1] PC CREAM has a limitation of only allowing 5 release points (stacks) to be modelled at any one time. The 5 groupings adopted for the assessment are logical in the comparison of stack height, location and discharge.

sources that operate intermittently and it is not possible to define representative average release conditions. The approach taken is conservative and will tend to lead to an overestimation of possible concentrations, thereby ensuring that the public is protected against excessive doses.

**Table 1: Representative stack locations**

| Stack Group | Distance (m) from Ref. Stack | Bearing ° from N from Ref. Stack | Modelled release height | Comments |
|---|---|---|---|---|
| **DFR** Table 4.3 Group | (The Ref. Stack) | (The Ref. Stack) | 30 m | All stack locations and receptor points are determined by distance and compass bearing from the DFR stack. |
| **EMS** Table 4.6 Group | 530 m | 82° | 0 m | The location of this stack has been determined as the building with the highest emission rate of the EMS. A ground level release has been conservatively defined for this stack group as, although most of the EMS releases occur between 10 m and 20 m above ground level, some are located at or near ground level and will be affected by building wake effects. |
| **FCA** Table 4.4 Group | 329 m | 64° | 30 m | This is the main FCA stack. This stack is 55 m high but an effective release height of 30 m has been adopted as a conservative assumption in the absence of sufficient data to calculate a minimum effective stack height. |
| **PFR** Table 4.2 and 4.7 Group | 586 m | 239° | 30 m | This stack group has been defined as being located at the site of the main PFR stack. The main PFR stack is 40 m high but an effective release height of 30 m has been adopted as a conservative assumption in the absence of sufficient data to calculate a minimum effective stack height. The PFR Minor Source stacks are included here and fit in with the height of 30m, the significant minor source emissions being from stacks above 30m. |
| **WMS** Table 4.5 Group | 308 m | 223° | 0 m | This stack group has been defined as being located at the site of the building with the highest emission rate of the WMS. A ground level release has been conservatively defined for this stack group as, although the average release height is around 10 m above ground level, the sources are likely to be affected by building wake effects. |

## 2.2 Dose calculation parameters

All individual dose calculations were undertaken for the 1st and 50th year (i.e. the assessment assumes that the same level of discharge has taken place for 49 years prior to the year for which the assessment is made, thereby allowing for an accumulation of activity in the surrounding environment). Collective doses are calculated with a truncation time of 500 years and for the populations of both the United Kingdom and the European Union. All predicted doses are calculated as effective dose as given in ICRP 103 [Ref 4].

## 2.3 Radionuclide releases

The following radionuclide release rates (Tables 2 and 3) are the maximum expected releases from the various stack groups.

**Table 2: Current radionuclide discharge limits (Bq/yr)**

| EXTANT ATMOSPHERIC DISCHARGE LIMITS (Bq/yr) | | | | | | |
|---|---|---|---|---|---|---|
| Extant Groupings (as defined in RSA/N/V02/50010/99 Schedule 4) | | | | | | |
| **Radionuclide** | Table 4.4 | Table 4.2 & 4.7 | Table 4.3 | Table 4.6 | Table 4.5 | Extant Total Bq/yr |
| alpha | 9.80E+08 | 6.06E+06 | 1.00E+07 | 1.37E+07 | 3.00E+05 | 1.01E+09 |
| beta | 4.50E+10 | 5.15E+07 | 1.50E+09 | 3.71E+08 | 7.50E+07 | 4.7E+10 |
| H-3 | 2.00E+12 | 1.07E+13 | 4.50E+12 | N/A | 1.00E+10 | 1.72E+13 |
| Kr-85 | 3.00E+15 | 4.00E+12 | 4.00E+08 | 1.00E+12 | N/A | 3.00E+15 |
| I-129 | 1.10E+09 | N/A | N/A | N/A | N/A | 1.10E+09 |

**Table 3: Proposed radionuclide discharge limits (Bq/yr)**

| PROPOSED ATMOSPHERIC DISCHARGE LIMITS | | | | | | |
|---|---|---|---|---|---|---|
| Extant Groupings (as defined in RSA/N/V02/50010/99 Schedule 4) | | | | | | |
| Radionuclide | Table 4.4 | Table 4.2 & 4.7 | Table 4.3 | Table 4.6 | Table 4.5 | **Proposed Need Bq/yr** |
| alpha | 6.48E+06 | 1.28E+05 | 3.00E+05 | 3.70E+05 | 1.10E+04 | **7.28E+06** |
| beta | 1.46E+09 | 7.80E+08 | 7.00E+08 | 1.70E+06 | 4.00E+04 | **2.94E+09** |
| H-3 | 5.13E+11 | 7.50E+13 | 2.70E+12 | 2.00E+10 | 1.01E+10 | **7.82E+13** |
| Kr-85 | 0.00E+00 | 5.69E+14 | 3.00E+12 | 4.00E+12 | 0.00E+00 | **5.76E+14** |
| I-129 | 1.00E+09 | N/A | N/A | N/A | N/A | **1.00E+09** |

(These proposed limits are as defined in the application accompanying document "Estimated Releases of Radioactivity to the Environment and the Uncertainty Related to the Estimates".)

All discharges identified as alpha are assumed to be plutonium 239 (Pu-239) and all discharges identified as beta are assumed to be caesium 137 (Cs-137). This approach is commonly adopted in such assessments as a conservative assumption as these radionuclides typically result in the highest doses per unit of activity released.

## 2.4 Critical Group

The Critical Group is defined as "That group of the public most exposed, by virtue of their habits, to any impact of radioactive discharges". A critical group has not been specifically defined for atmospheric discharges although it is assumed that the public is exposed to all pathways.

## 2.5 Exposure pathways

The exposure pathways available to PC CREAM and analysed by this assessment for adults, children (nominally aged 10 years) and infants (nominally aged 1 year) were:

- Consumption of cow meat
- Consumption of cow liver

- Consumption of sheep meat
- Consumption of sheep liver
- Consumption of green vegetables
- Consumption of root vegetables
- Consumption of grain
- Consumption of fruit
- Inhalation of radionuclides in the plume
- External gamma irradiation from airborne radionuclides
- External beta irradiation from airborne radionuclides
- External gamma irradiation from deposited radionuclides
- External beta irradiation from deposited radionuclides
- Inhalation of resuspended radionuclides

Although there are no dairy farms in the surrounding area the consumption of cow's milk has been included in the assessment as it is possible that such activities may occur in the future. However, a farm producing goat's milk has been identified. The milk produced is consumed locally. Therefore, separate calculations have been undertaken for the consumption of goat's milk and goat's milk products (Section 2.9).

## 2.6 Receptor locations

PC CREAM permits up to five receptor locations to be specified. Dose calculations have been made for these locations. The nearest four receptor locations were identified and were used in this study. The locations of these receptors provide a good distribution around the site, from due east to south west of the Reference Stack. The smallholding at Shebster is also included to allow an estimate of the dose accrued from the goat's milk to be made. The receptor locations are given in Table 3 below, relative to the Reference Stack.

**Table 3: Receptor locations (Relative to the Ref. Stack)**

| Receptor | Easting | Northing | Distance | Bearing |
|---|---|---|---|---|
| Residence at Buldoo | 99810 | 67160 | 1200 m | 91° |
| Cottages to the south of the A836 near Vulcan entrance | 99060 | 66200 | 1074 m | 155° |
| Residence to the south of the A836 identified as Isauld | 98120 | 65300 | 1938 m | 195° |
| Isauld House | 97405 | 65795 | 1832 m | 221° |
| Goat's Farm at Shebster | 00100 | 64000 | 4100m | 143° |

## 2.7 Meteorological data

Meteorological data has been prepared (Table 4) based upon information derived from two sources. Wind direction data collected at Dounreay between 2007 and 2008 has been

analysed and a frequency analysis undertaken to establish an average wind rose for the site. However, PC CREAM requires meteorological data to be provided which specifies wind direction, atmospheric stability (typically in terms of Pasquill stability categories) and frequency of rainfall in specified stability conditions. Additional meteorological data was therefore purchased from the UK Meteorological Office for the nearest available monitoring station with reliable data, namely Kirkwall. Because wind direction will vary significantly between Dounreay (on a north facing coast) and Kirkwall (situated centrally within a group of islands) the on-site wind direction data is considered to be the most appropriate data to use for this parameter. However, the frequency of rainfall and stability conditions is unlikely to be significantly different and therefore the data from Kirkwall for these parameters is considered to be a reasonable basis for the assessment. The meteorological data provided to PC CREAM was as follows:

**Table 4: Meteorological data (Dounreay wind direction, Kirkwall stability analysis)**

| Wind direction | | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind Frequency | | 0.0857 | 0.0949 | 0.1082 | 0.0806 | 0.0833 | 0.0595 | 0.0432 | 0.0400 | 0.0458 | 0.1181 | 0.1344 | 0.1065 |
| Stability class | Class Frequency | | | | | | | | | | | | |
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0.003 | 2.57E-04 | 2.85E-04 | 3.25E-04 | 2.42E-04 | 2.50E-04 | 1.78E-04 | 1.30E-04 | 1.20E-04 | 1.37E-04 | 3.54E-04 | 4.03E-04 | 3.19E-04 |
| C | 0.016 | 1.37E-03 | 1.52E-03 | 1.73E-03 | 1.29E-03 | 1.33E-03 | 9.52E-04 | 6.91E-04 | 6.39E-04 | 7.32E-04 | 1.89E-03 | 2.15E-03 | 1.70E-03 |
| D | 0.7 | 6.00E-02 | 6.64E-02 | 7.57E-02 | 5.64E-02 | 5.83E-02 | 4.16E-02 | 3.02E-02 | 2.80E-02 | 3.20E-02 | 8.27E-02 | 9.41E-02 | 7.45E-02 |
| E | 0.041 | 3.51E-03 | 3.89E-03 | 4.44E-03 | 3.30E-03 | 3.41E-03 | 2.44E-03 | 1.77E-03 | 1.64E-03 | 1.88E-03 | 4.84E-03 | 5.51E-03 | 4.37E-03 |
| F/G | 0.056 | 4.80E-03 | 5.31E-03 | 6.06E-03 | 4.51E-03 | 4.66E-03 | 3.33E-03 | 2.42E-03 | 2.24E-03 | 2.56E-03 | 6.62E-03 | 7.53E-03 | 5.96E-03 |
| C-rain | 0.002 | 1.71E-04 | 1.90E-04 | 2.16E-04 | 1.61E-04 | 1.67E-04 | 1.19E-04 | 8.64E-05 | 7.99E-05 | 9.15E-05 | 2.36E-04 | 2.69E-04 | 2.13E-04 |
| D-rain | 0.184 | 1.58E-02 | 1.75E-02 | 1.99E-02 | 1.48E-02 | 1.53E-02 | 1.09E-02 | 7.94E-03 | 7.35E-03 | 8.42E-03 | 2.17E-02 | 2.47E-02 | 1.96E-02 |

The data is presented as required by PC CREAM i.e. wind into sector. This is 180 degrees out from standard wind reporting.

## 2.8 Ingestion rates

The specification of ingestion rates is typically achieved by reference to the findings of habits data of the eating habits of the population living in the vicinity the site. In 2003 a Radiological Habits Survey of the Dounreay area was undertaken by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) on behalf of the Scottish Environment Protection Agency (SEPA). The report produced following this survey [Ref 1] provided much of the data concerning ingestion rates for adults. Where the CEFAS report did not provide adequate information for the PC CREAM code this was substituted by default PC CREAM values. The survey included only a few children and no infants. In order to provide data for these groups the ratios of adult to child and adult to infant consumption rates given in the CEFAS report were used.

Two sets of ingestion rates were specified for modelling purposes, the first to represent a conservative average for the surrounding population (see Table 5, designated as the average critical group rate in the CEFAS report) and the second rate to represent the upper bounding worst case (see Table 6).

The CEFAS study did not provide data for consumption of cow or sheep liver or grain. Therefore, a decision was taken to adopt the PC CREAM default average for the critical group ingestion rate and to adopt the PC CREAM critical group rate for the upper bounding estimate. The results of the CEFAS study on the consumption of milk consider only goat's milk. It is not possible to separate out these results and so, in order to provide data for consumption of cow's milk and cow's milk products, a decision was taken to adopt the PC CREAM default values for average consumption rates and critical consumption rates. (The

potential doses arising from consumption of goat's milk and goat's milk products are assessed separately in Section 2.9).

**Table 5: Average critical group ingestion rates[1]**

| | Ingestion Rates (Kg/yr) | | | |
|---|---|---|---|---|
| **Pathway** | **Adult** | **Child** | **Infant** | **Data Source** |
| Cow's meat [2] | 42 | 29 | 8 | CEFAS Habits Survey |
| Cow's milk (l/yr) | 95 | 110 | 120 | PC CREAM average |
| Cow's milk products | 20 | 15 | 15 | PC CREAM average |
| Cow liver | 1.00 | 0.5 | 0.2 | PC CREAM average |
| Sheep meat | 15 | 7.5 | 1.5 | CEFAS Habits Survey |
| Sheep liver | 2.00 | 0.5 | 0.2 | PC CREAM average |
| Green veg | 126 | 63 | 25 | CEFAS Habits Survey |
| Root veg [3] | 234 | 163 | 78 | CEFAS Habits Survey |
| Grain | 50.0 | 45.0 | 15.0 | PC CREAM average |
| Fruit [4] | 125 | 75 | 50 | CEFAS Habits Survey |

1 Assumes all products produced locally
2 Includes consumption of venison
3 Includes potatoes
4 Includes all fruits grown locally

**Table 6: Upper bounding extreme critical group ingestion rates**

| | Ingestion Rates (Kg/yr) | | | |
|---|---|---|---|---|
| **Pathway** | **Adult** | **Child** | **Infant** | **Data Source** |
| Cows meat | 83 | 58 | 17 | CEFAS Habits Survey |
| Cow's milk (l/yr) | 240 | 240 | 320 | PC CREAM critical |
| Cow's milk products | 60 | 45 | 45 | PC CREAM critical |
| Cow liver | 10 | 5.0 | 2.25 | PC CREAM critical |
| Sheep meat | 34 | 17 | 3.4 | CEFAS Habits Survey |
| Sheep liver | 10 | 5.0 | 2.5 | PC CREAM critical |
| Green veg | 167 | 84 | 34 | CEFAS Habits Survey |
| Root veg | 280 | 195 | 93 | CEFAS Habits Survey |
| Grain | 100 | 75.0 | 30.0 | PC CREAM critical |
| Fruit | 155 | 93 | 62 | CEFAS Habits Survey |

All assumptions as for Table 5 apply to Table 6

## 2.9 Doses arising from consumption of goat's milk and milk products

As noted above, there would not be any significant doses expected from the consumption of cow's milk or milk products as there are no dairy farms in the vicinity of the Dounreay site. However, there is a farm approximately 4 km to the south west of the site where goat's milk is produced and consumed in very high quantities. It was considered that this case should be specifically modelled.

PC CREAM does not include goat's milk as a pathway, but information on the transfer coefficients indicates that concentrations of most radionuclides in goat's milk and associated products would be higher than would be expected in cow's milk and associated products. The equations used in PC CREAM [Ref 3] show a direct correlation between transfer coefficients, concentrations in milk and dose. Therefore, if each nuclide-specific dose calculated by PC CREAM for cow's milk and cow's milk products is multiplied by the nuclide specific ratio of the fodder-goat's milk transfer coefficient to the fodder-cow's milk transfer coefficient then the result will provide an estimate of the dose via the goat's milk pathways. The transfer coefficients used are shown in Table 17 along with the nuclide-specific doses arising from an annual 1TBq release of each radionuclide. The doses predicted for goat's milk and milk products are therefore provided by multiplying the cow's milk dose by the ratio of the transfer coefficients and the release rate in TBq/yr.

The values in Tables 7 and 8 below were used in the PC CREAM model for goat's milk and goat's milk product ingestion rates for a location 4 km south east of Dounreay. Default cow's milk ingestion rates are shown in italics for comparison purposes and the goat's milk products ingestion rates are therefore effectively equal to those used by PC CREAM for cow's milk products.

**Table7: Average critical group ingestion rates**

| | **Ingestion Rates (l/yr)** | | | |
|---|---|---|---|---|
| **Pathway** | **Adult** | **Child** | **Infant** | **Data Source** |
| Goat's milk | 220 | 220 | 292.6 | CEFAS Habits Survey |
| *Cow's milk* | *95* | *110* | *120* | *PC CREAM Average* |
| Goat's milk products | 20 | 15 | 15 | PC CREAM Average |

**Table 8: Extreme upper bounding ingestion rates**

| | **Ingestion Rates (l/yr)** | | | |
|---|---|---|---|---|
| **Pathway** | **Adult** | **Child** | **Infant** | **Data Source** |
| Goat's milk | 226 | 226 | 301 | CEFAS Habits Survey |
| *Cow's milk* | *240* | *240* | *320* | *PC CREAM Critical* |
| Goat's milk products | 60 | 45 | 45 | PC CREAM Critical |

## 2.10 Occupancy rates, inhalation rates, etc

Occupancy rates were also obtained from the CEFAS study and certain other parameters, including inhalation rates, were adopted from the PC CREAM default parameter values. These data values are given in Tables 9 and 10 below.

**Table 9: Occupancy rates**

| | Occupancy | Fraction Indoors | Location factor for cloud gamma | Location factor for deposited gamma |
|---|---|---|---|---|
| **Critical Group rate** | 8346 h/yr | 0.8 | 0.2 (default value) | 0.1 (default value) |
| **Upper bounding rate** | 8500 h/yr | 0.8 | 0.2 (default value) | 0.1 (default value) |

**Table10: Inhalation rates**

| | Inhalation rate ($m^3$/yr |
|---|---|
| **Adult** | 7,300 |
| **Child** | 5,500 |
| **Infant** | 1,900 |

# 3 ASSESSMENT OF MARINE DISCHARGES

As for the atmospheric discharges the PC CREAM model was implemented using the site selection option for Dounreay, which automatically implements the marine assessment module for Scottish Waters with the regional compartment defined as being Scottish Waters East. A local marine compartment is also automatically defined and the default values were accepted in the absence of alternative information. The following sections describe the input data required by the code.

## 3.1 Dose calculation parameters

As with the atmospheric assessment the individual dose calculations were undertaken for the 1$^{st}$ and 50th year and collective doses are calculated with a truncation time of 500 years, for the UK and European Union populations.

## 3.2 Radionuclide releases

The following radionuclide discharge limits (Table 11) are the proposed and extant release limits to the marine environment.

**Table 11: Proposed and Extant marine discharge limits**

| | Proposed Limits (Bq/yr) | Extant Limits (Bq/yr) |
|---|---|---|
| Total alpha | 3.67E+09 | 1.10E+11 |
| Total beta (Excl. tritium) | 2.73E+12 | 4.37E+12 |
| Total Sr-90 | 2.74E+11 | 7.70E+11 |
| Total Cs-137 | 1.27E+12 | 1.07E+12 |
| Total Na-22 | 1.30E+10 | 1.80E+12 |
| Total H-3 | 1.02E+14 | 6.9E+12 |
| Total Am-241 | 1.50E+07 | N/A |

## 3.3 Critical Groups

The Critical Group is defined as “That group of the public most exposed, by virtue of their habits, to any impact of radioactive discharges”. There are 4 critical groups identified for discharges to the marine discharges:

- ingestion of marine food products;
- beach occupancy (includes dog walkers and bait collectors);;
- geo occupancy; and
- handling of fishing gear.

### 3.4 Exposure Pathways

All exposure pathways available to PC CREAM were analysed by this assessment for adults, children and infants. The pathways assessed are:

- Consumption of fish
- Consumption of crustaceans
- Consumption of molluscs
- External gamma irradiation from radionuclides in sediment
- External beta irradiation from radionuclides in sediment
- External gamma irradiation from radionuclides in fishing gear
- External beta irradiation from radionuclides in fishing gear
- Inhalation of seaspray

### 3.5 Ingestion Rates

Ingestion data was obtained from the CEFAS report and is shown in Table 12 below. However, it should be noted that PC CREAM assumes that infants do not consume crustaceans or molluscs. This omission from PC CREAM is not considered significant in this study in the light of the very small doses that are predicted for adults and children.

**Table 12: Ingestion rates**

| | Average rates | | | Extreme rates | | |
|---|---|---|---|---|---|---|
| **Adult** | **Fish[1]** | **Crustaceans** | **Molluscs** | **Fish** | **Crustaceans** | **Molluscs** |
| Total consumption (kg/yr) | 22.8 | 8.9 | 0.5 | 39.5 | 14 | 0.7 |
| From within survey area (kg/yr) | 22.8 | 4.45 | 0.5 | 39.5 | 7 | 0.7 |
| Fraction from inside area | 1 | 0.5 | 1 | 1 | 0.5 | 1 |
| From outside survey area (kg/yr) | 0 | 4.45 | 0 | 0 | 7 | 0 |
| Fraction from outside area | 0 | 0.5 | 0 | 0 | 0.5 | 0 |
| **Child** | | | | | | |
| Total consumption | 22.8 | 5.7 | 0 | 22.8 | 5.7 | 0 |
| From within survey area (kg/yr) | 22.8 | 2.85 | 0 | 22.8 | 2.85 | 0 |
| Fraction from inside area | 1 | 0.5 | 1 | 1 | 0.5 | 1 |
| From outside survey area (kg/yr) | 0 | 2.85 | 0 | 0 | 2.85 | 0 |
| Fraction from outside area | 0 | 0.5 | 0 | 0 | 0.5 | 0 |
| **Infant** | | | | | | |
| Total consumption | 0 | 0 | 0 | 0 | 2.9[2] | 0 |
| From within survey area (kg/yr) | 0 | 0 | 0 | 0 | 1.45 | 0 |
| Fraction from inside area | 1 | 0.5 | 1 | 1 | 0.5 | 1 |
| From outside survey area (kg/yr) | 0 | 0 | 0 | 0 | 1.45 | 0 |
| Fraction from outside area | 0 | 0.5 | 0 | 0 | 0.5 | 0 |

**1 Salmon are excluded from consumption figures. All other fish assumed to be from the local area thus ensuring a conservative dose assessment. The habits survey indicates that all fish are caught outside the regional area.**

**2 Although identified in the habits survey this result is not considered credible and has been set to zero. PC Cream does not accept a non zero consumption.**

### 3.6 Occupancy Rates

Occupancy data was obtained from the CEFAS report and is shown in Table 13 below. The value of 530 hours per year beach occupancy was identified in the CEFAS report [Ref 1] as the mean exposure time over sand and rock for the maximum exposed critical group. The highest recorded exposure time was 780 hours per year. There is no separate data for the occupancy of Geos but a value of 25 hours per year is given in the 'Radioactivity in Food and the Environment, 2001' report [Ref 5] and has not been modified. It should also be noted that it has been assumed that dose rates within Geos are a factor of 10 greater than dose rates on the open beach area [Ref 6].

Table 13: Occupancy rates

| Critical Group | Occupancy | Fraction of time in local compartment | Fraction of time in regional compartment |
|---|---|---|---|
| Average occupancy over sand and rock | 530 h/yr | 1 | 0 |
| Extreme occupancy over sand and rock | 780 h/yr | 1 | 0 |
| Average critical group Geo occupancy | 25 h/yr | 1 | 0 |
| Fishing gear handling | 1500 h/yr | 1 | 0 |

### 3.7 Inhalation

For the inhalation pathway it is assumed that the individual is located 10 m from the coast and that all of the time spent near the coast is in the immediate vicinity of the discharges – both assumptions are conservative. Inhalation rates are the same as those used for the atmospheric assessment.

# 4 RESULTS & DISCUSSION

## 4.1 Individual Dose from Atmospheric Discharges

The individual doses modelled are summarised in Table 14. These results should be considered in the light of the public dose limit of 1000 µSv/yr and the generally applied dose constraint of 300 µSv/yr for members of the public for planned discharges [Ref 4].

**Table 14: Summarised individual doses for atmospheric discharges (excluding component for goat's milk and assuming cow's milk consumption)**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| **Critical Group definition** | | **Average** | **Extreme** |
| **Receptor** | | **Dose (µSv/yr)** | **Dose (µSv/yr)** |
| Residence at Buldoo | Infant | 6.1 | 14.0 |
| | Child | 7.1 | 14.0 |
| | Adult | 5.9 | 11.0 |
| Residence to south of A836 opposite the Vulcan access road | Infant | 3.4 | 7.3 |
| | Child | 3.6 | 6.7 |
| | Adult | 3.2 | 5.8 |
| Residence to the south of the A836 identified as Isauld | Infant | 1.3 | 2.6 |
| | Child | 1.3 | 2.3 |
| | Adult | 1.2 | 2.1 |
| Isauld House | Infant | 1.2 | 2.6 |
| | Child | 1.3 | 2.3 |
| | Adult | 1.2 | 2.1 |
| Goat's Farm. Smallholding in Shebster | Infant | 0. 73 | 1.6 |
| | Child | 0. 80 | 1.5 |
| | Adult | 0. 71 | 1.3 |
| **Maximum** | Infant | 6.1 | 14.0 |
| | Child | 7.1 | 14.0 |
| | Adult | 5.9 | 11.0 |
| **Max as % of dose constraint** | Infant | 2.0 | 4.67 |
| | Child | 2.4 | 4.67 |
| | Adult | 2.0 | 3.67 |

A review of the results in Appendix 1 shows that the critical group dose is dominated by the Iodine 129 discharge and the dispersion of this radionuclide in the terrestrial environment

## 4.2 Collective Dose from Atmospheric Discharges

There is no dose limit or regulatory guidance on acceptable levels for collective dose. However, it is generally considered that releases of radionuclides which give rise to doses below 1 man Sv can be considered to have negligible consequences in terms of population impacts. The collective dose results shown in Table 15 should be assessed in comparison to this.

**Table 15: Summarised collective doses (man Sv) for modelled atmospheric cases**

| At Proposed Discharge limit | |
|---|---|
| **UK collective dose** | 0.023 man Sv |
| **EU collective dose** | 0.12 man Sv |

It may be seen from the results that the assessed dose for the proposed future discharge limits is well below 1 man Sv. (Note: as collective dose calculations are undertaken for large populations there is no variation from the use of different critical group definitions.)

### 4.3 Individual Dose from Consumption of Goat's Milk and Milk Products

Table 16 summarises the doses that could be received by individuals consuming very large quantities of goat's milk and milk products at a distance of 4 km south east of the Dounreay site. The subsequent Table 16 provides the detailed results by nuclide.

**Table 16: Average critical group doses (µSv/yr) from goat's milk and milk products for proposed discharge limits**

| Infant | Milk dose | Milk products | T coeff Goat | T coeff Cow | Goat's Milk | Goat's Products | Total |
|---|---|---|---|---|---|---|---|
| H-3 | 1.31E-01 | 2.80E-03 | 3.20E-01 | 1.50E-02 | 2.79E+00 | 5.97E-02 | 2.85E+00 |
| I-129 | 3.59E-01 | 0.00E+00 | 4.30E-01 | 1.00E-02 | 1.55E+01 | 0.00E+00 | 1.55E+01 |
| Cs-137 | 4.62E-03 | 2.50E-03 | 1.00E-01 | 7.90E-03 | 5.85E-02 | 3.16E-02 | 9.01E-02 |
| Pu-239 | 1.90E-07 | 1.00E-07 | 9.40E-06 | 1.10E-06 | 1.62E-06 | 8.55E-07 | 2.48E-06 |
| **TOTAL** | | | | | | | **1.84E+01** |
| Child | Milk dose | Milk products | T coeff Goat | T coeff Cow | Goat's Milk | Goat's Products | |
| H-3 | 4.40E-02 | 1.30E-03 | 3.20E-01 | 1.50E-02 | 9.39E-01 | 2.77E-02 | 9.66E-01 |
| I-129 | 2.20E-01 | 1.60E-01 | 4.30E-01 | 1.00E-02 | 9.46E+00 | 6.88E+00 | 1.63E+01 |
| Cs-137 | 2.80E-03 | 2.00E-03 | 1.00E-01 | 7.90E-03 | 3.54E-02 | 2.53E-02 | 6.08E-02 |
| Pu-239 | 8.80E-08 | 6.60E-08 | 9.40E-06 | 1.10E-06 | 7.52E-07 | 5.64E-07 | 1.32E-06 |
| **TOTAL** | | | | | | | **1.74E+01** |
| Adult | Milk dose | Milk products | T coeff Goat | T coeff Cow | Goat's Milk | Goat's Products | |
| H-3 | 3.47E-02 | 1.40E-03 | 3.20E-01 | 1.50E-02 | 7.41E-01 | 2.99E-02 | 7.71E-01 |
| I-129 | 1.25E-01 | 1.20E-01 | 4.30E-01 | 1.00E-02 | 5.38E+00 | 5.16E+00 | 1.05E+01 |
| Cs-137 | 3.47E-03 | 3.60E-03 | 1.00E-01 | 7.90E-03 | 4.40E-02 | 4.56E-02 | 8.95E-02 |
| Pu-239 | 8.11E-08 | 8.10E-08 | 9.40E-06 | 1.10E-06 | 6.93E-07 | 6.92E-07 | 1.38E-06 |
| **TOTAL** | | | | | | | **1.14E+01** |

The equivalent dose for the average critical group, at the same location, from the consumption of cow's milk and cow's milk products are:

- Infant 0.38 µSv/yr
- Child 0.29 µSv/yr
- Adult 0.20 µSv/yr

The highest predicted dose is for infants consuming goat's milk, at a ratio of 1.33 of the adult consumption rate (Ref. 1). Doses at this level would not be expected to result in any detectable health or environmental impacts.

It should be noted that the infant group is not identified within the habits survey and therefore is a theoretical group. The only identified group is the adult group and the maximum dose for this group is 11.4µSv/yr.

**Table 17: Estimated maximum doses due to ingestion of goat's milk and goat's milk products**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| | **Critical group** | **Average** | |
| **Infant** | Dose (µSv/yr) | 18.4 | |
| | % of dose constraint | 6.13 | |
| **Child** | Dose (µSv/yr) | 17.4 | |
| | % of dose constraint | 5.80 | |
| **Adult** | Dose (µSv/yr) | 11.4 | |
| | % of dose constraint | 3.80 | |

## 4.4 Individual Dose from Marine Discharges

The individual doses modelled are summarised in Tables 18 to 21 below, and it can be seen that maximum doses due to the discharge of liquid effluent into the sea are low, at less than 1% of the 300µSv dose constraint. The consequences of exposure at this level would be negligible. The main results are:

- External exposure and inhalation of seaspray during occupancy of the beach (at 530 hours per year) will result in doses below 0.02% of the 300 µSv dose constraint.
- External exposure and inhalation of seaspray during occupancy of Geos (at 25 hours per year) will result in doses below 0.01% of the 300 µSv dose constraint.
- Exposure during the handling of fishing gear (at 1500 hours per year) will result in doses below 0.02% of the 300 µSv dose constraint.

Doses to members of the public from marine discharges are therefore very low based on the conservative assumptions adopted in this study.

Tables 18 to 21 summarise the 4 critical group doses attributable to discharges to the marine environment.

**Table 18: Summarised individual doses for ingestion of marine food products**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| | | **Total dose (µSv/yr)** | |
| | | Average | Extreme |
| Annual dose | Adult | 0.015 | 0.026 |
| Annual dose | Child | 0.010 | 0.01 |
| Annual dose | Infant[1] | 0 | 0 |
| % of dose constraint | Adult | 0.005% | 0.009% |
| % of dose constraint | Child | 0.003% | 0.003% |
| % of dose constraint | Infant | 0% | 0% |

**1 Infants are not identified as consumers of marine food products**

**Table 19: Summarised individual doses for exposure during beach occupancy**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| | | **Total dose (µSv/yr)** | |
| | | Average | Extreme |
| Annual dose | Adult | 0.021 | 0.031 |
| Annual dose | Child | 0.021 | 0.031 |
| Annual dose | Infant | 0.021 | 0.031 |
| % of dose constraint | Adult | 0.007% | 0.01% |
| % of dose constraint | Child | 0.007% | 0.01% |
| % of dose constraint | Infant | 0.007% | 0.01% |

**Table 20: Summarised individual doses for exposure during Geo occupancy**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| | | **Total dose (µSv/yr)** | |
| | | Average | Extreme |
| Annual dose | Adult | 0.01 | 0.01 |
| Annual dose | Child | 0.01 | 0.01 |
| Annual dose | Infant | 0.01 | 0.01 |
| % of dose constraint | Adult | 0.003% | 0.003% |
| % of dose constraint | Child | 0.003% | 0.003% |
| % of dose constraint | Infant | 0.003% | 0.003% |

**Table 21: Summarised individual doses for handling of fishing gear**

| At Proposed Discharge limit | | | |
|---|---|---|---|
| | | **Total dose (µSv/yr)** | |
| | | Average | Extreme |
| Annual dose | Adult | 0.0005 | 0.031 |
| Annual dose | Child | 0.0005 | 0.031 |
| Annual dose | Infant[1] | 0 | 0 |
| % of dose constraint | Adult | <0.001% | 0.01% |
| % of dose constraint | Child | <0.001% | 0.01% |
| % of dose constraint | Infant | 0 | 0 |

1 Infants are not credible fishing net handlers

## 4.5 Collective Dose from Marine Discharges

**Table 22: Summarised collective doses (man Sv) for the modelled marine cases**

| At Proposed Discharge limit | |
|---|---|
| **UK collective dose** | 0.012 manSv |
| **EU collective dose** | 0.041 manSv |

## 5 CONCLUSIONS

The maximum possible exposure of the public as a result of emissions at the proposed site discharge limits is well within safe levels. Even when the extremely conservative assumption is made that a single individual receives a dose of 32.5 µSv from all pathways, at the upper bounding estimates of exposure rates, individual doses remain within the dose constraint of 300µSv/yr. Any realistic exposure pattern (e.g. not including local production of cow's milk) would result in doses that are very low and would therefore not be expected to result in any observable consequences at either an individual or a population level.

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