using science to create a better place

Study of historical nuclear reactor discharge data – graph annex

Better Regulation Science Programme

Science report: SC070015/SR2

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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Science at the Environment Agency

Science underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us and helps us to develop monitoring tools and techniques to manage our environment as efficiently and effectively as possible.

The work of the Environment Agency's Science Department is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

The science programme focuses on five main areas of activity:

- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive summary

The report presents the results of work undertaken by AREVA Risk Management Consulting Ltd for the Environment Agency. It presents the graphs from the investigations into levels of radioactive liquid and airborne discharge data relevant to nuclear reactor power stations that are predecessors to the four current designs proposed for future reactor plant in the United Kingdom.

Acknowledgements

AREVA Risk Management Consulting Ltd would like to acknowledge the support provided by the Environment Agency staff. We also thank the vendors and stations that provided data on discharges and operations for their work and cooperation.

Contents

1. Introduction

1.1 Background

Before any new nuclear reactor can be authorised for construction and operation in the UK, its design must be thoroughly assessed and then approved for license. The primary regulatory bodies involved in this process are the Environment Agency and the Nuclear Safety Division of the Health and Safety Executive (the NSD). The Environment Agency's regulatory role in the nuclear power industry is to regulate the operations of any new nuclear power station against the requirements of relevant legislation, such as the Radioactive Substances Act (1993) and the Environmental Protection Act (1990).

In response to a request from the UK Government (following the Energy Review in 2006), the two regulators have developed the Generic Design Assessment (GDA) process for proposed reactor designs for new nuclear power stations (HSE, 2007). The GDA will essentially determine whether reactor designs satisfy the safety, security and environmental requirements for licensing and authorisation of nuclear power stations in the UK. The regulators plan to make statements at key stages during the GDA process.

To date, four generic reactor designs have been submitted for assessment against the requirements for licensing and authorisation to operate in the UK. These generic designs are:

- the AP1000, submitted by Westinghouse;
- the European Pressurised Reactor (EPR), submitted by Electricité de France (EDF)/Areva;
- the Economic Simplified Boiling Water Reactor (ESBWR), submitted by GE-Hitachi;
- the ACR-1000, submitted by Atomic Energy of Canada Ltd (AECL).

A significant issue of interest to the Environment Agency is the potential for discharges to the environment and the accumulation of associated solid radioactive wastes from a new nuclear power station. On behalf of the Environment Agency, AREVA Risk Management Consulting Ltd has conducted this study of actual discharges at operating nuclear power stations with reactor designs that are effectively precursors to the generic designs submitted for GDA.

The output from this study will be used by the Environment Agency to inform its assessment of Best Available Technologies (BAT).

1.2 Objectives

The objective of this report is to provide stand-alone reference material on the full set of figures for the Environment Agency's internal use only. This report is not intended to be published, but can be used as backup information to the main report (SC070015/SR1).

1.3 Scope

This report presents the figures in order of reactor class.

2 Candidate reactors discharge data

2.1 Westinghouse AP1000 predecessors

The following stations have been used in this study as predecessors to the proposed new Westinghouse AP1000 reactor design:

- Seabrook-1;
- Beaver Valley;
- Byron;
- Comanche Peak;
- Sizewell B;
- Takahama.

The results for each of these are presented in the following subsections.

2.1.1 AP1000 predecessor – Seabrook-1

Charts – liquid discharges (Seabrook-1, AP1000)

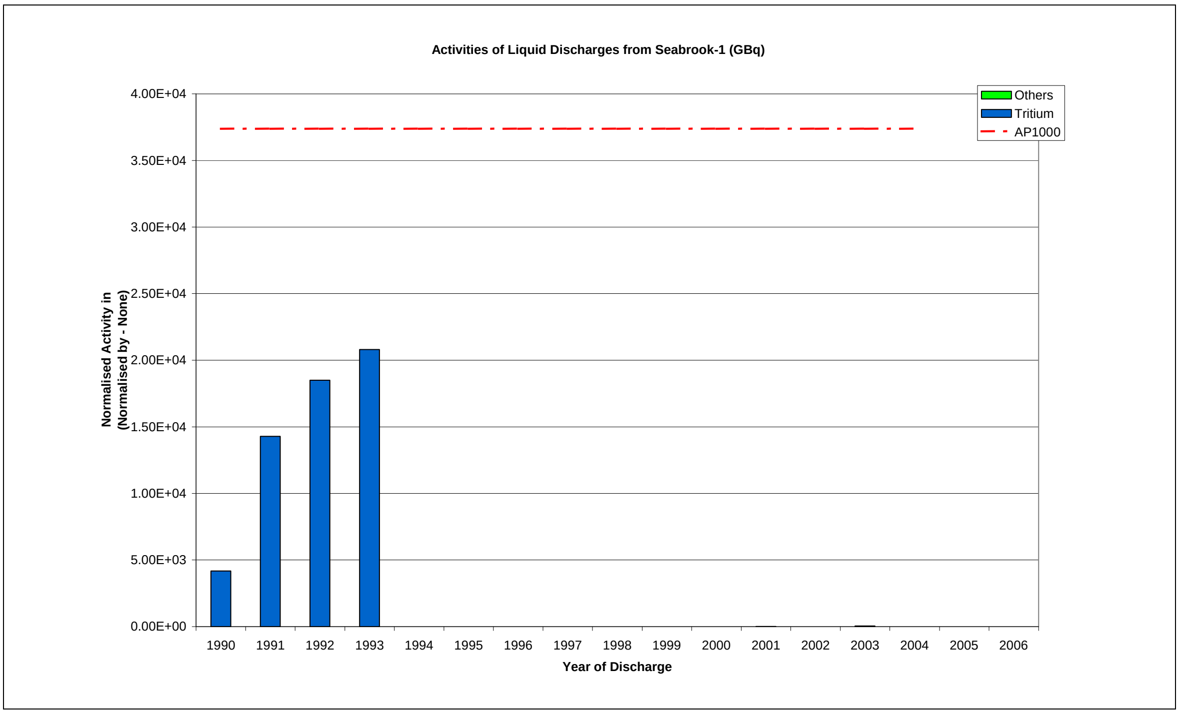

Figure 2.1 Activities of liquid discharges from Seabrook-1 (GBq).

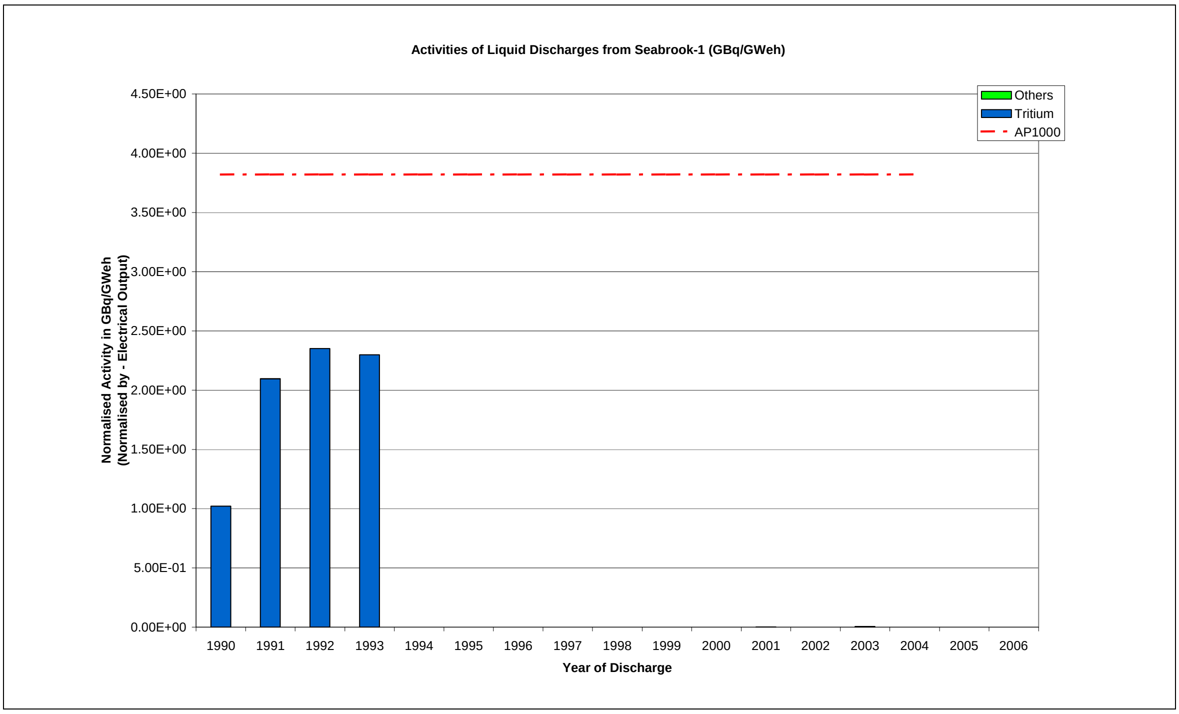

Figure 2.2 Activities of liquid discharges from Seabrook-1 (GBq/GWeh).

Charts – airborne discharges (Seabrook-1, AP1000)

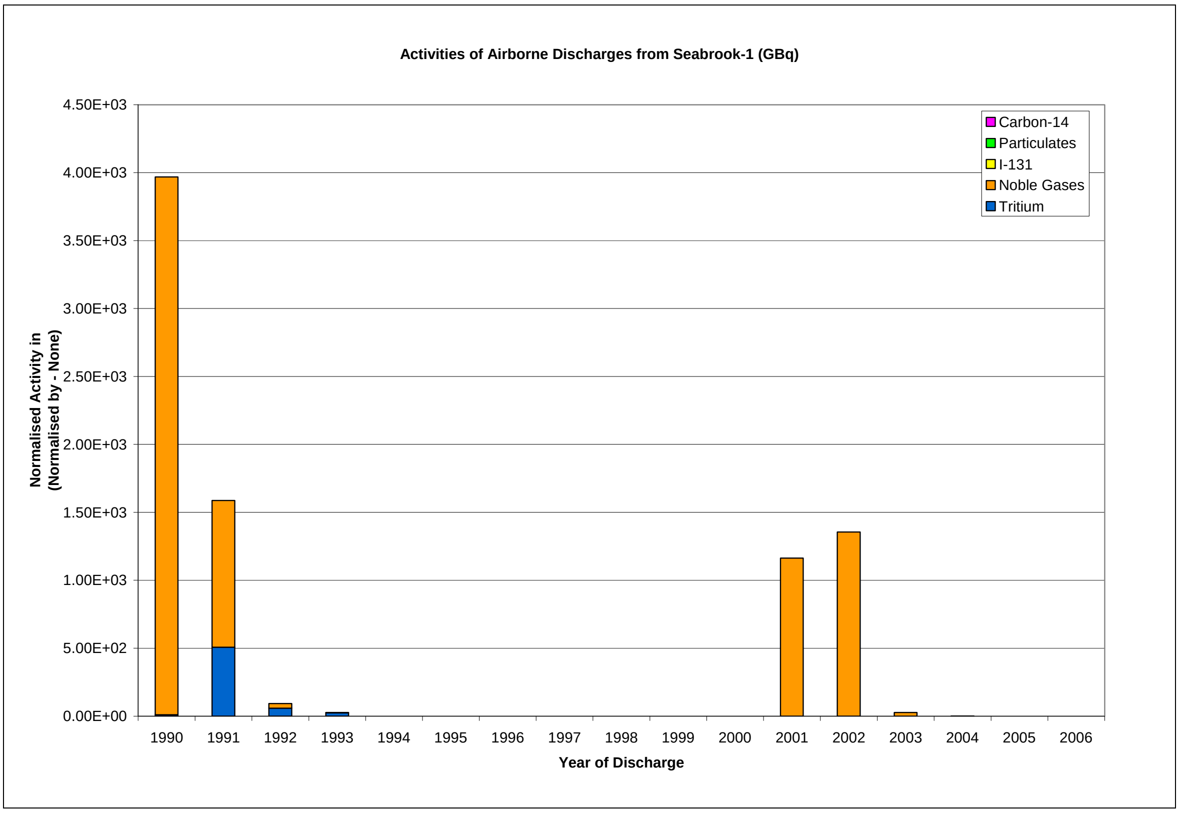

Figure 2.3 Activities of airborne discharges from Seabrook-1 (GBq).

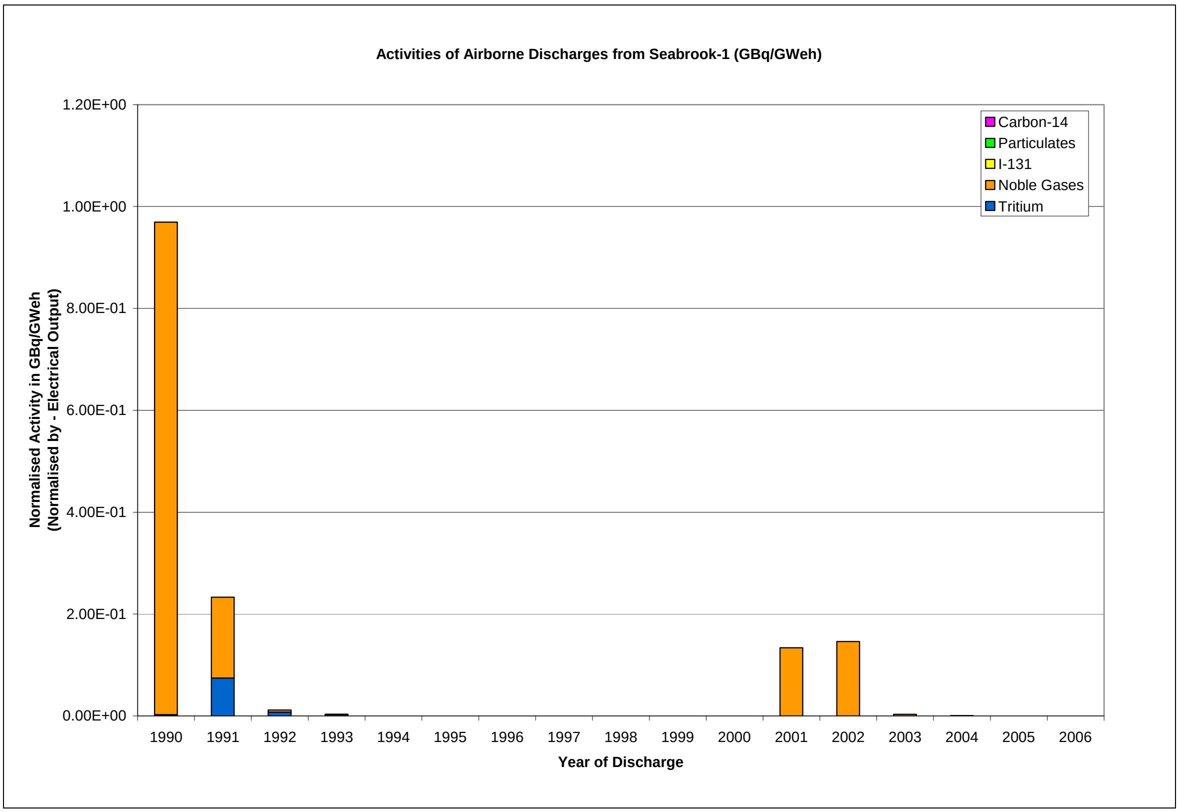

Figure 2.4 Activities of airborne discharges from Seabrook-1 (GBq/GWe).

The caveats are that:

- recorded predictions correspond to a single AP1000 unit;
- predicted activity of airborne discharges from the AP1000 is 43.1 GBq/GWeh per annum, but this is not indicated in the chart above due to the comparatively small activities of the actual discharges reported for Seabrook-1;
- data for years 2000–2004 originates from the NRC Effluents Database (NRC, 2008) which does not always report tritium discharges;
- The NRC Effluents Database (NRC, 2008) reports discharges for radioisotopes of iodine other than iodine-131 (I-132, I-133, etc) for some years. The activities of these nuclides have not been included in the data in order to produce a consistent dataset for all reactors that will allow comparisons to be made.

It should also be noted that for the above charts the following data are lacking due to current information gaps:

- liquid tritium data post-1993;
- other liquid data 1994–2000;
- airborne tritium data post-1993;
- airborne halogen data 1993–2000;
- airborne particulates data 1994–2000;
- carbon-14 data.

2.1.2 AP1000 predecessor – Beaver Valley

Charts – liquid discharges (Beaver Valley, AP1000)

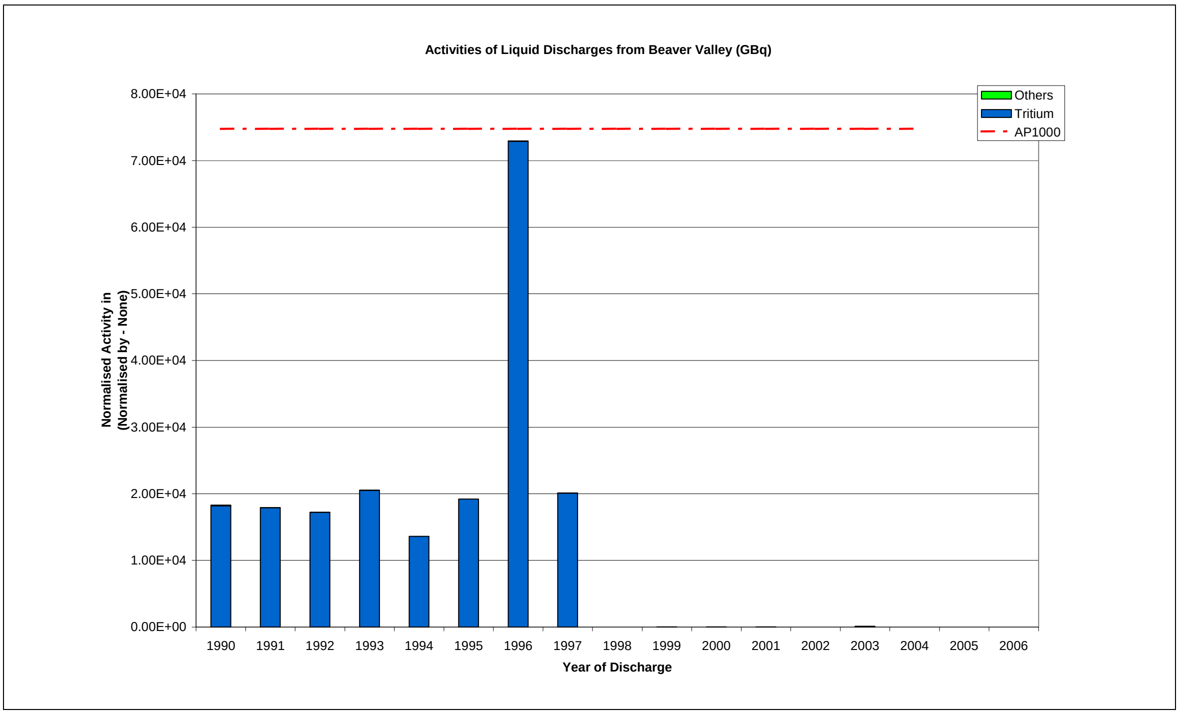

Figure 2.5 Activities of liquid discharges from Beaver Valley (GBq).

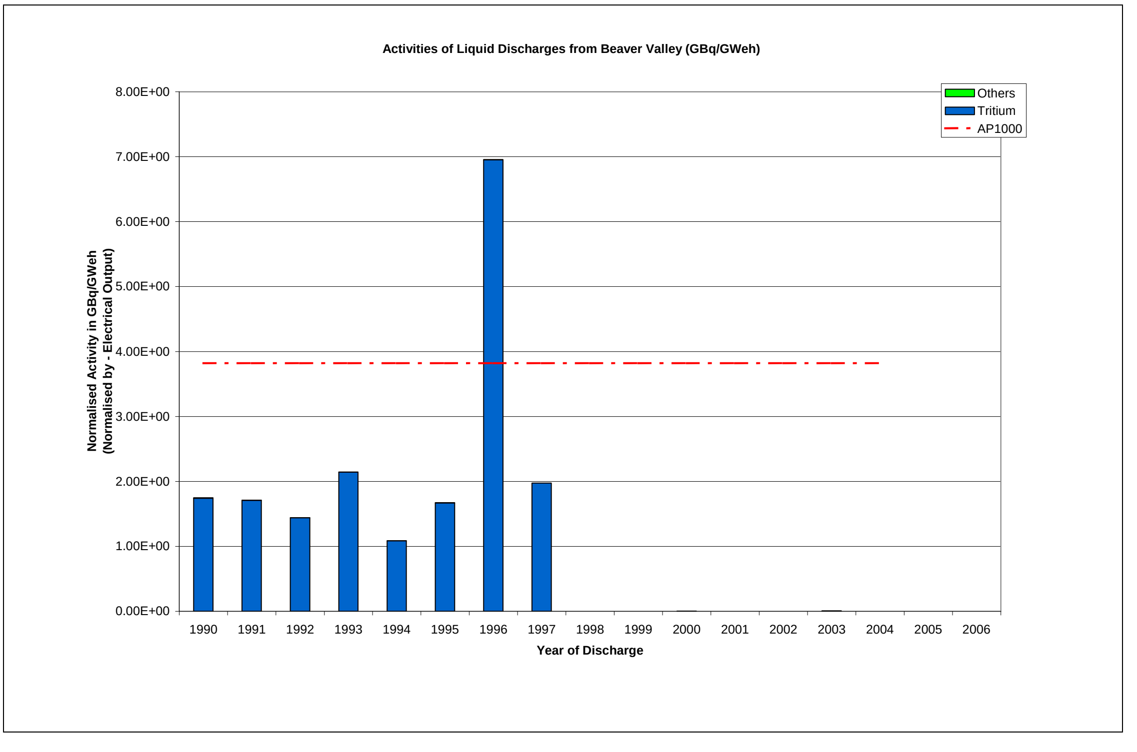

Figure 2.6 Activities of liquid discharges from Beaver Valley (GBq/GWeh).

Charts – airborne discharges (Beaver Valley, AP1000)

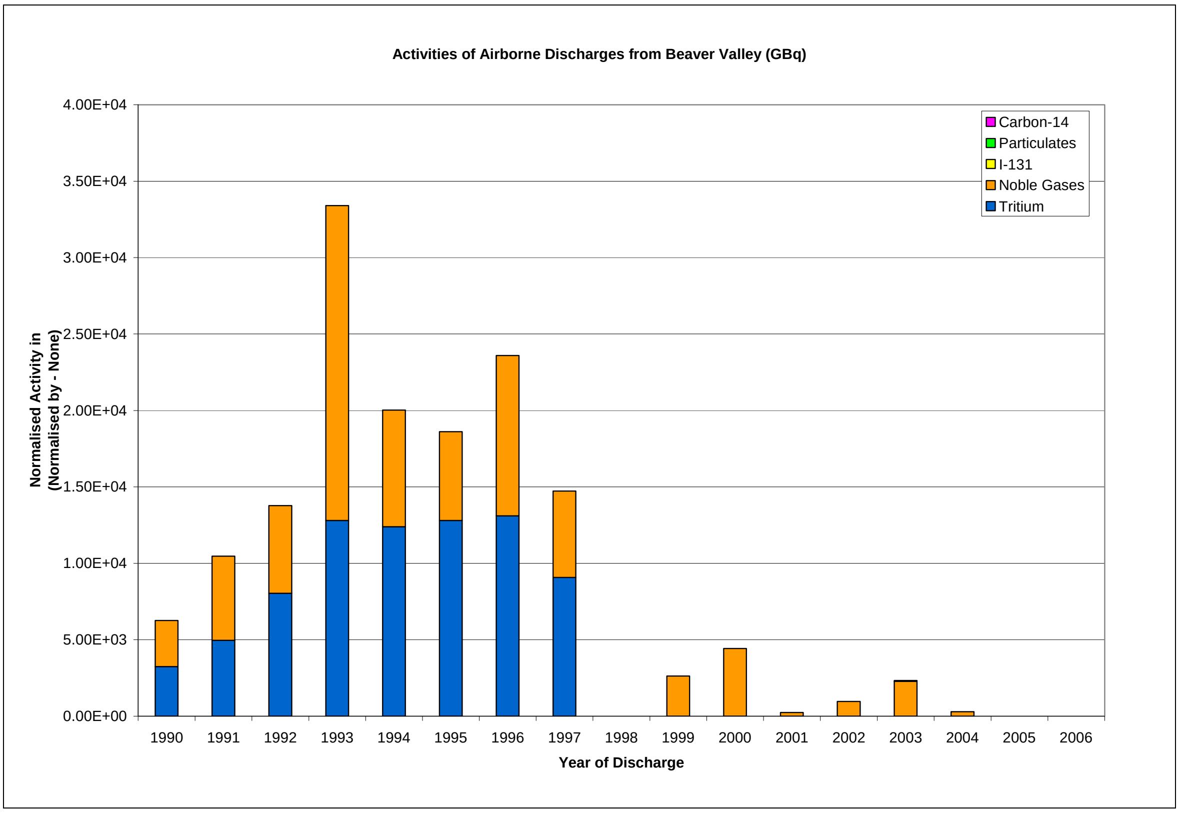

Figure 2.7 Activities of airborne discharges from Beaver Valley (GBq).

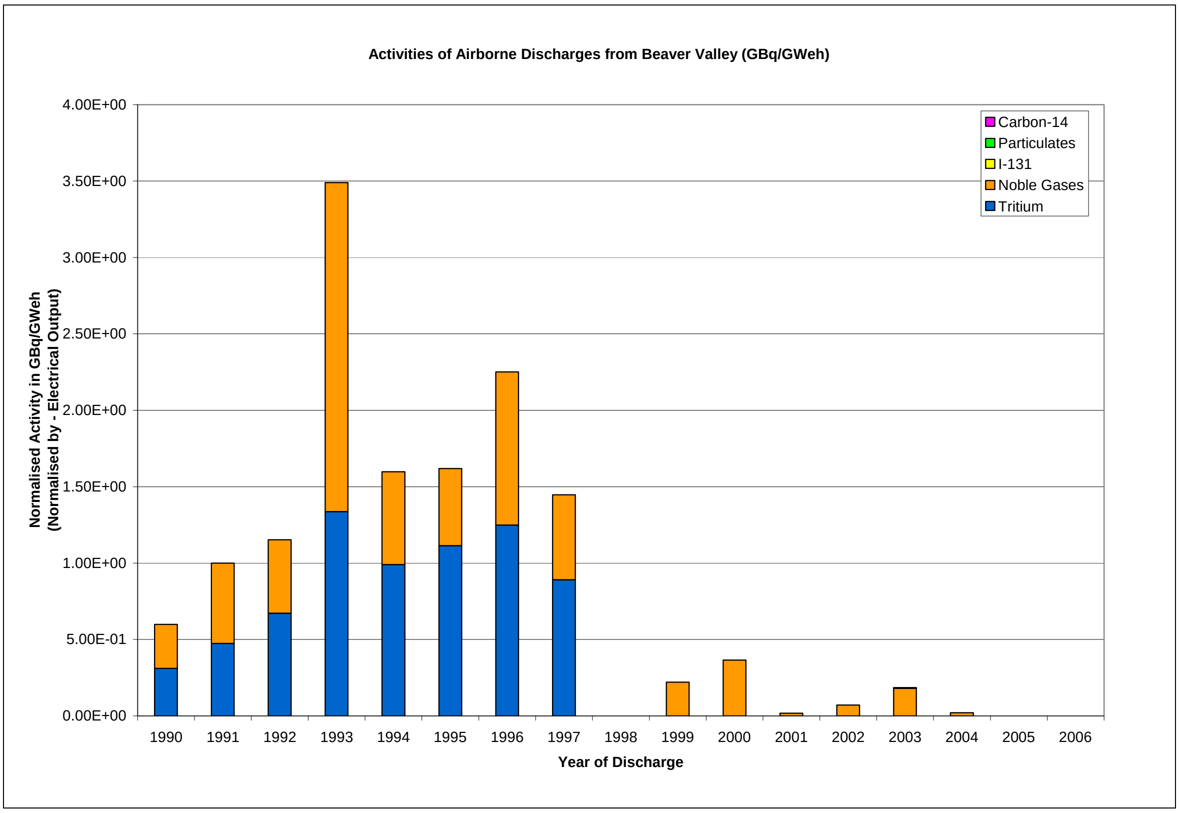

Figure 2.8 Activities of airborne discharges from Beaver Valley (GBq/GWeh).

The caveats are that:

- total airborne discharge data for the period 1990–1997 (from the UNSCEAR Report (UNSCEAR, 2000) is inconsistent with data for the period 1999–2004 (from the NRC Effluents Database (NRC, 2008), due to the absence of liquid tritium discharge reports;
- The predicted airborne discharge from the AP1000 is 43.1 GBq/GWeh per annum. This is not indicated in the chart due to the comparatively small activities of the actual discharges reported for Beaver Valley.
- The NRC Effluents Database (NRC, 2008) reports discharges for radioisotopes of iodine other than iodine-131 (I-132, I-133, etc) for some years. The activities of these nuclides have not been included in the data in order to produce a consistent dataset for all reactors that will allow comparisons to be made.

It should also be noted that for the above charts the following data are lacking due to current information gaps:

- liquid tritium data post-1998;
- other liquid data for 1998;
- airborne tritium data for 1998–2004;
- airborne noble gas data for 1998;
- airborne halogen data for 1998;
- airborne particulates data for 1998;
- carbon-14 data.

2.1.3 AP1000 predecessor – Byron

Charts – liquid discharges (Byron, AP1000)

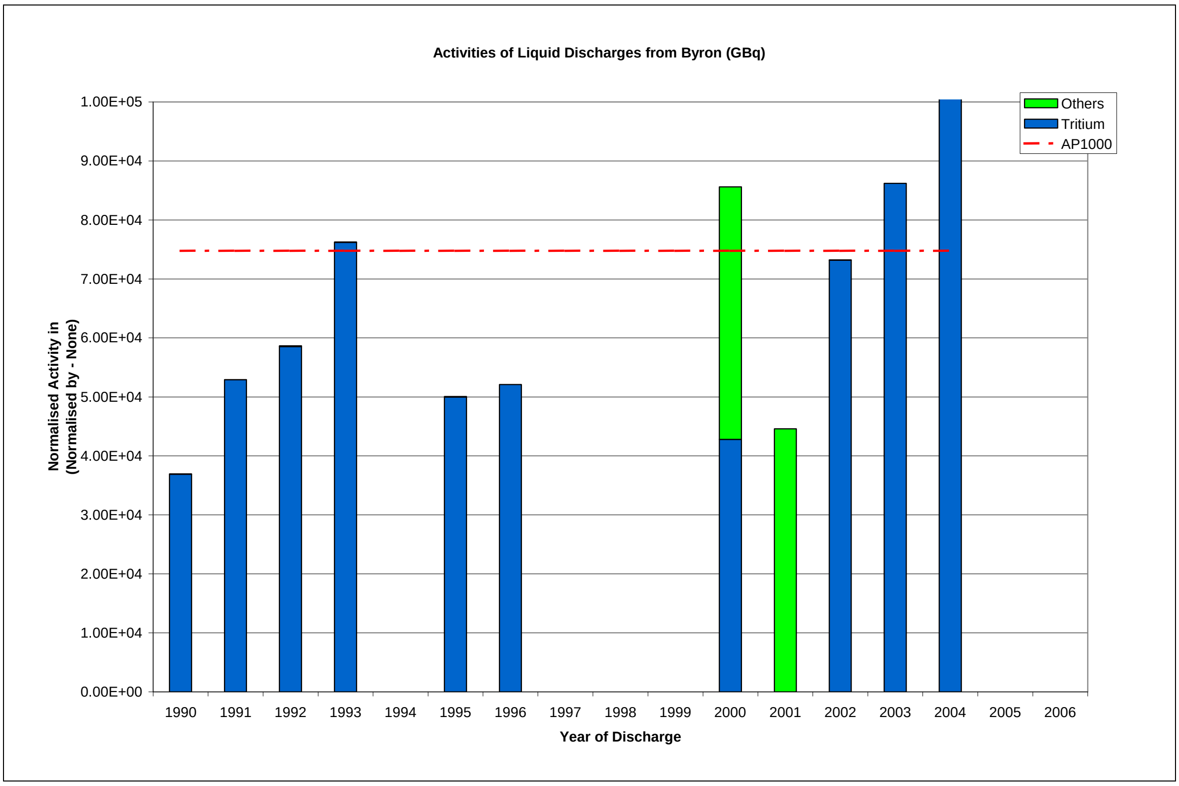

Figure 2.9 Activities of liquid discharges from Byron (GBq).

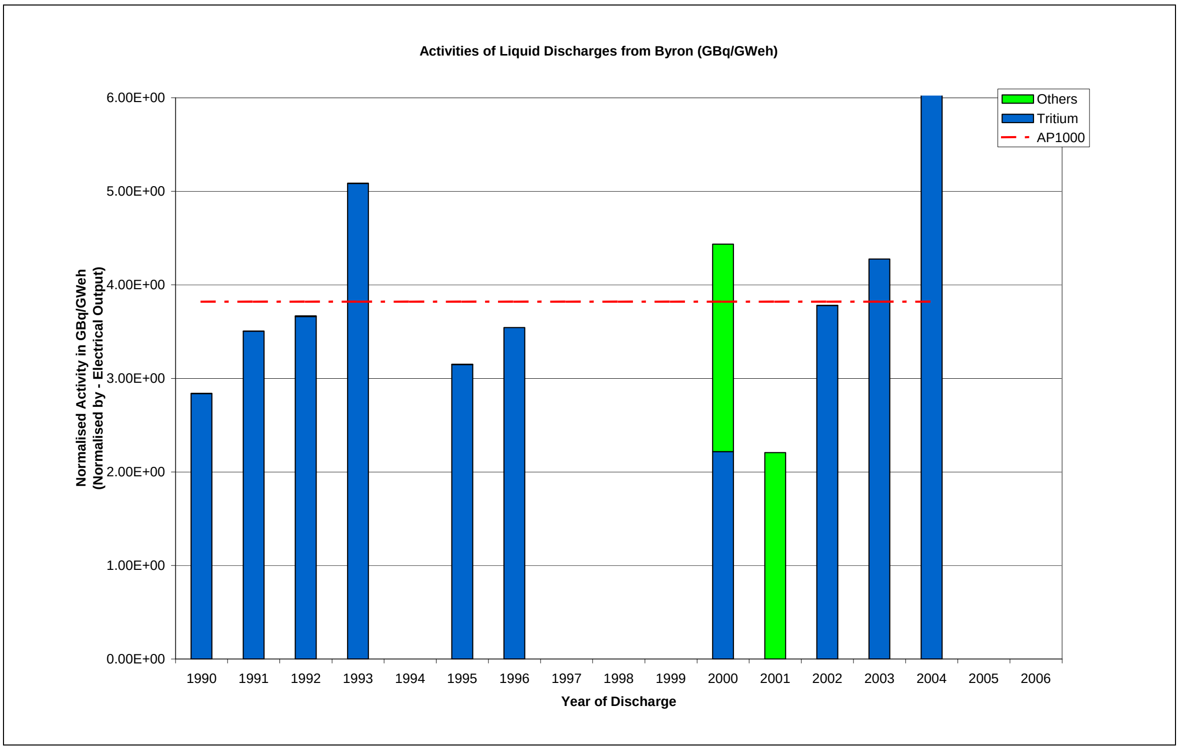

Figure 2.10 Activities of liquid discharges from Byron (GBq/GWeh).

Charts – airborne discharges (Byron, AP1000)

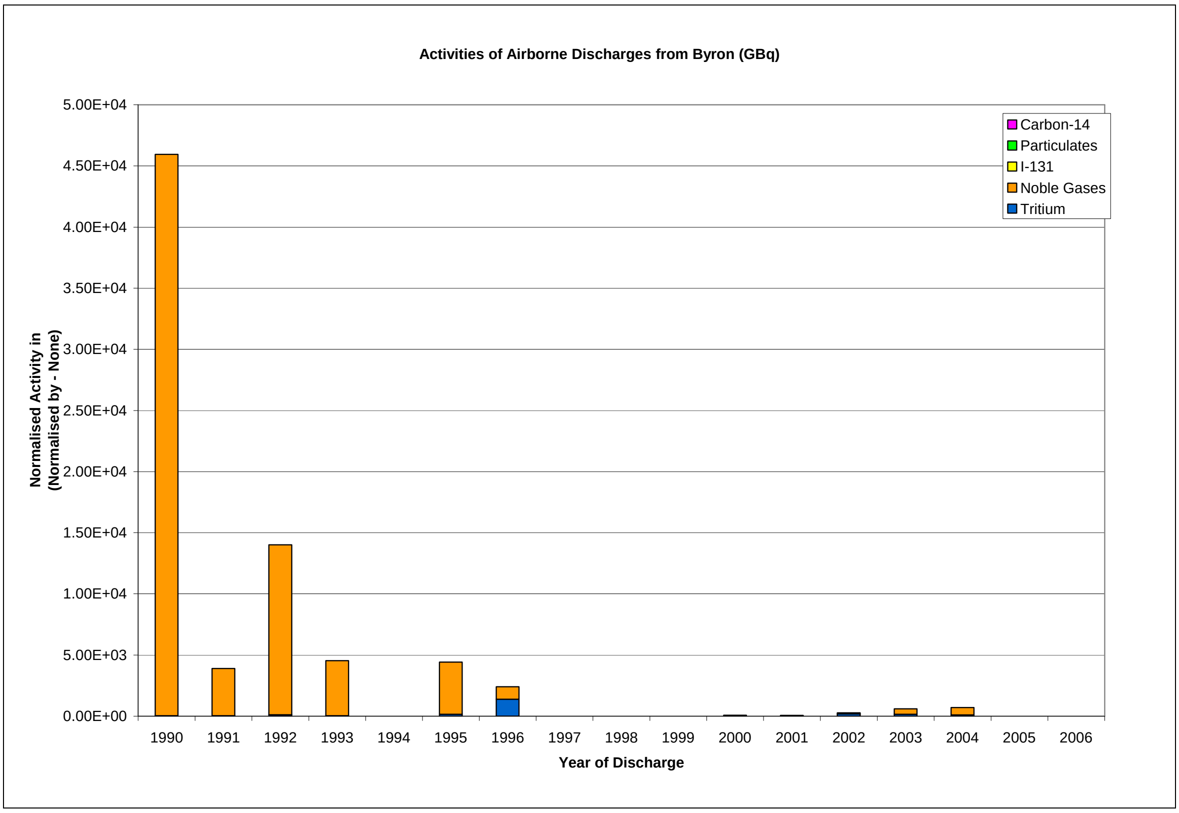

Figure 2.11 Activities of airborne discharges from Byron (GBq).

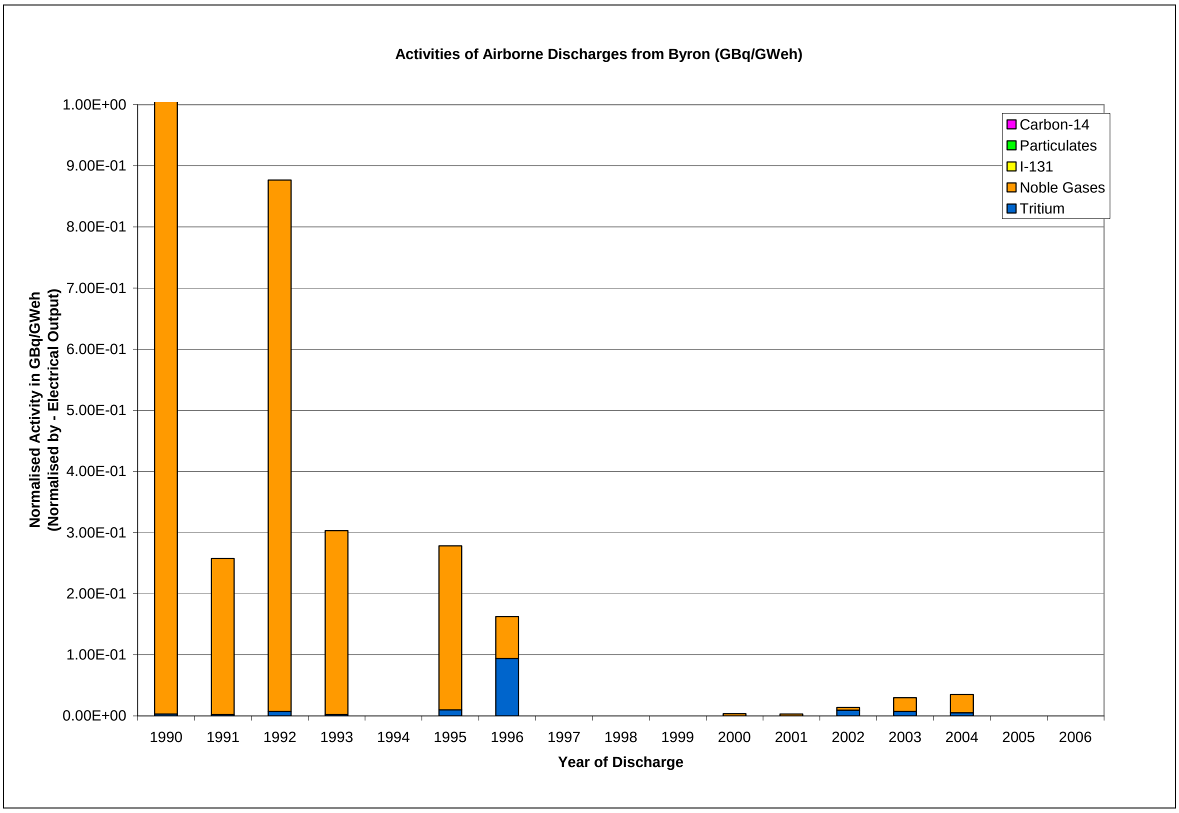

Figure 2.12 Activities of airborne discharges from Byron (GBq/GWeh).

The caveats are that:

- data for 2000–2004 originate from the NRC Effluents Database (NRC, 2008) which does not always report tritium discharges;
- the predicted airborne discharge from the AP1000 is 43.1 GBq/GWeh per annum which is not indicated in the chart due to the comparatively small activities of the actual discharges reported for Byron;
- The NRC Effluents Database (NRC, 2008) reports discharges for radioisotopes of iodine other than iodine-131 (I-132, I-133, etc) for some years. The activities of these nuclides have not been included in the data in order to produce a consistent dataset for all reactors that will allow comparisons to be made.

It should also be noted that for the above charts the following data are lacking due to current information gaps:

- carbon-14 data.

2.1.4 AP1000 predecessor – Comanche Peak

Charts – liquid discharges (Comanche Peak, AP1000)

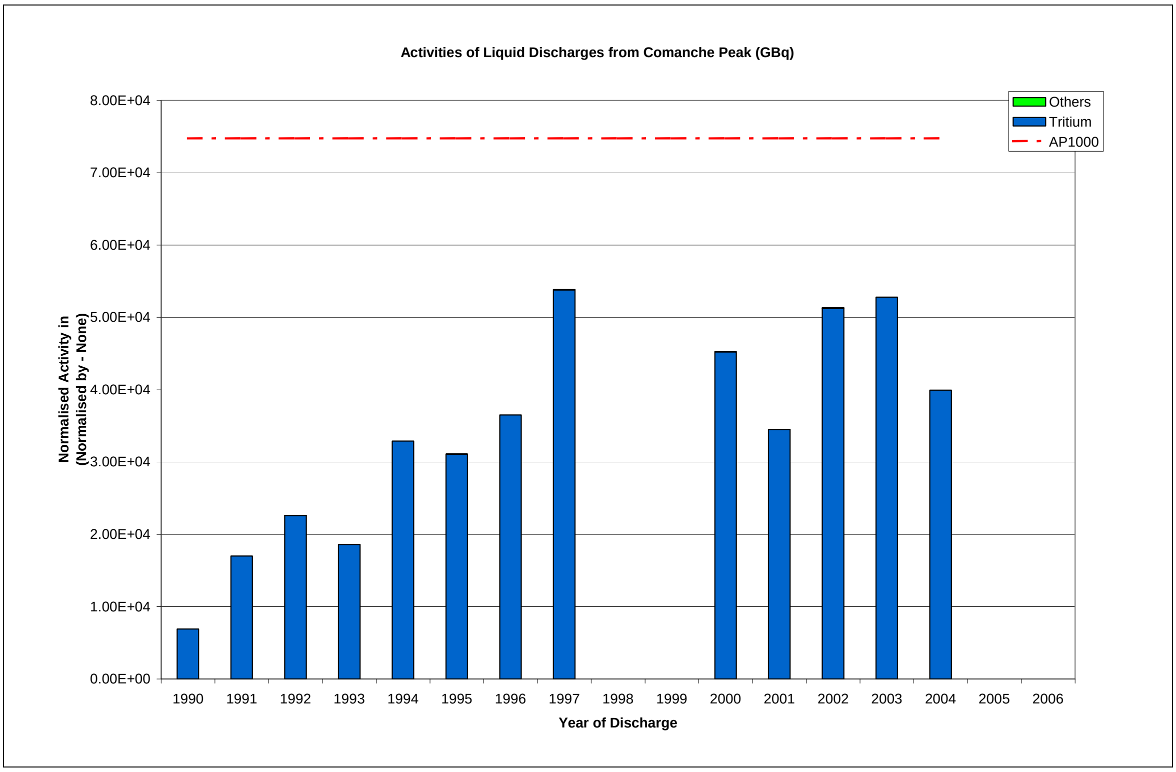

Figure 2.13 Activities of liquid discharges from Comanche Peak (GBq).

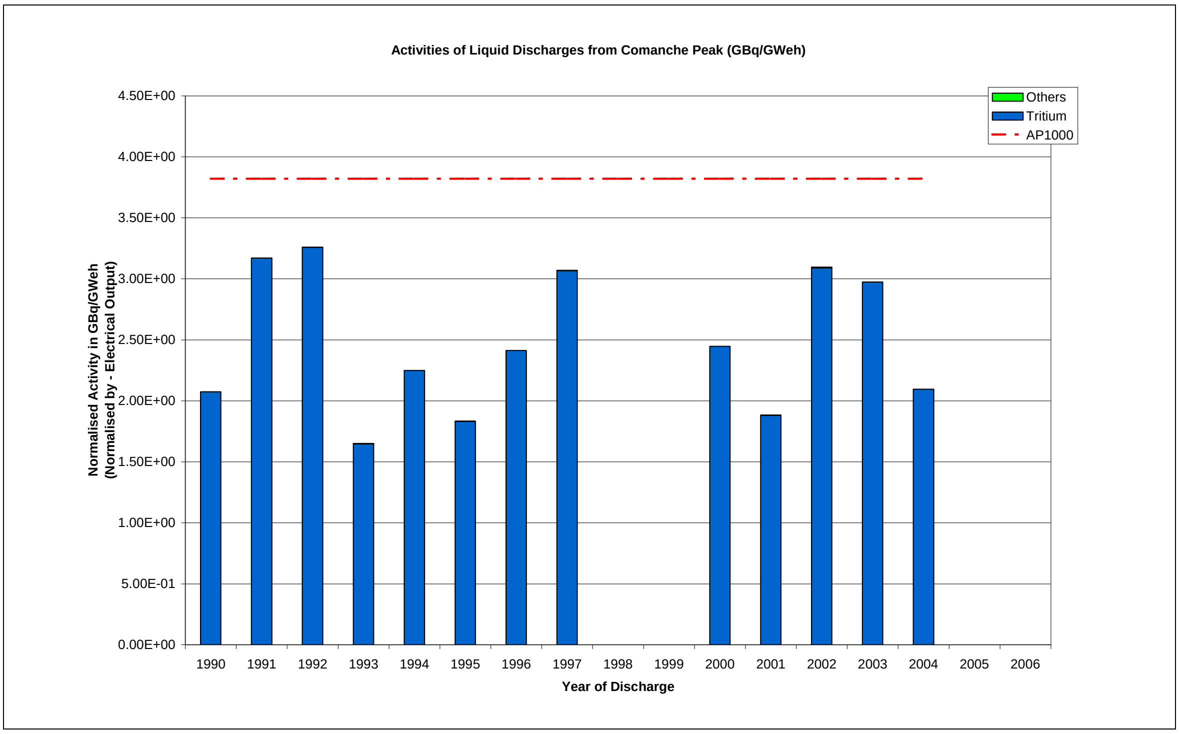

Figure 2.14 Activities of liquid discharges from Comanche Peak (GBq/GWeh).

Charts – airborne discharges (Comanche Peak, AP1000)

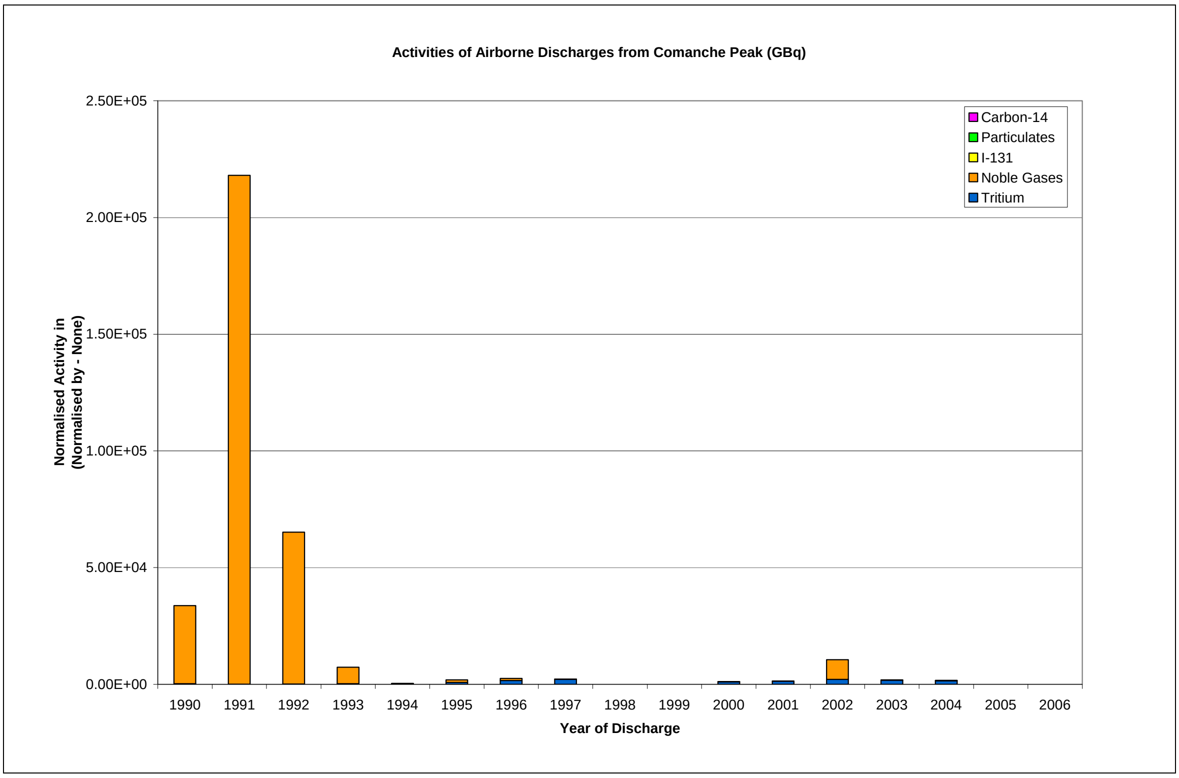

Figure 2.15 Activities of airborne discharges from Comanche Peak (GBq).

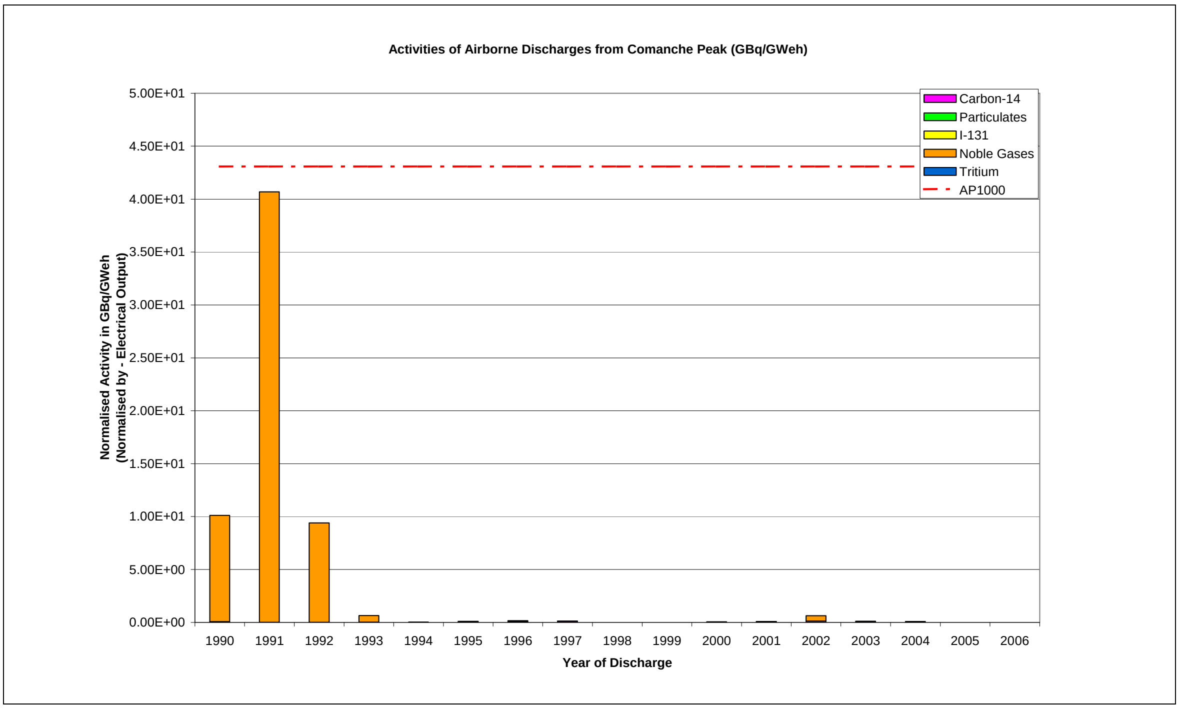

Figure 2.16 Activities of airborne discharges from Comanche Peak (GBq/GWeh).

The caveats are that:

- data for 2000–2004 correspond to Comanche Peak-1 only as no data was available for Comanche Peak-2 for those years;
- the NRC Effluents Database (NRC, 2008) reports discharges for radioisotopes of iodine other than iodine-131 (I-132, I-133, etc) for some years. The activities of these nuclides have not been included in the data in order to produce a consistent dataset for all reactors that will allow comparisons to be made.

It should also be noted that for the above charts the following data are lacking due to current information gaps:

- carbon-14 data.

2.1.5 AP1000 predecessor – Sizewell B

Charts – liquid discharges (Sizewell B, AP1000)

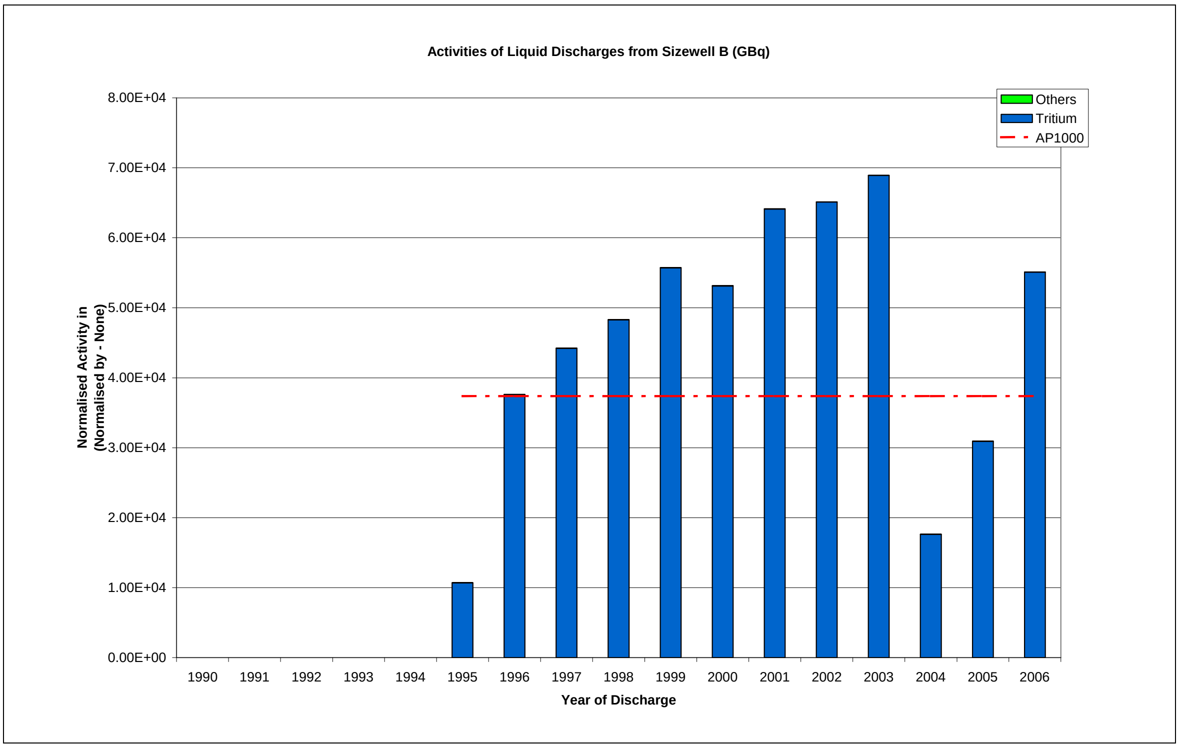

Figure 2.17 Activities of liquid discharges from Sizewell B (GBq).

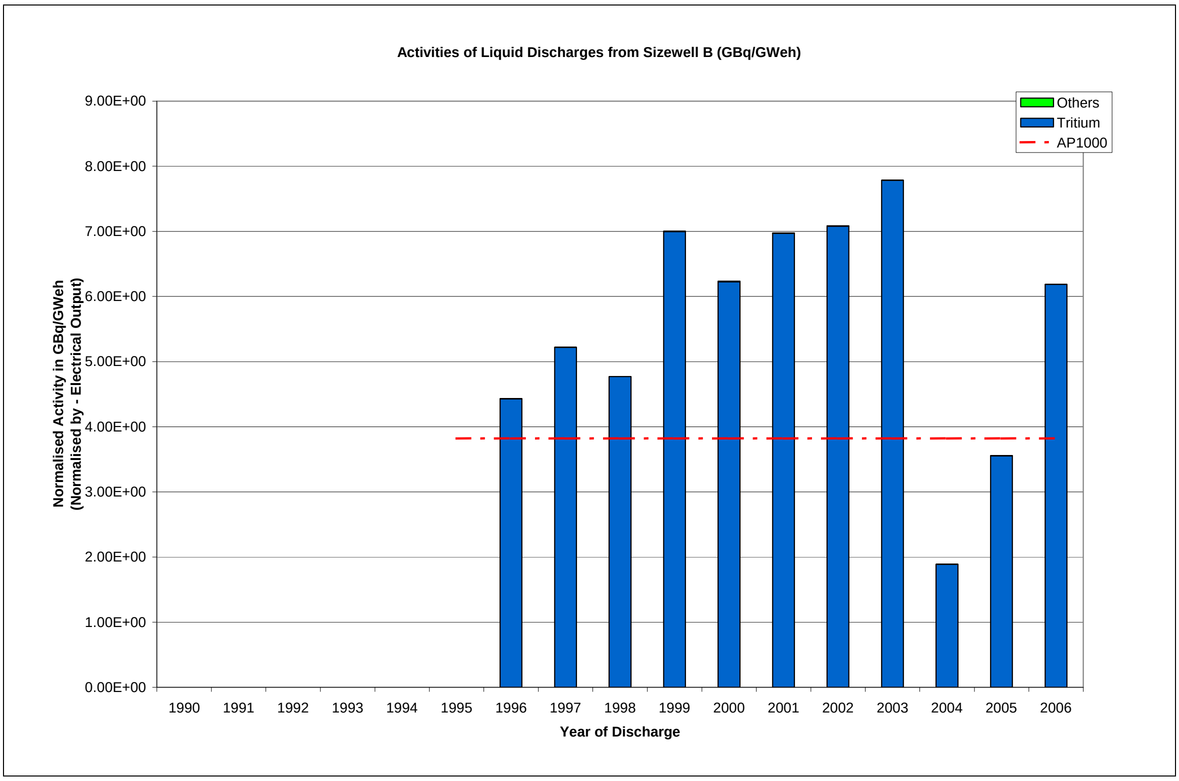

Figure 2.18 Activities of liquid discharges from Sizewell B (GBq/GWeh).

Charts – airborne discharges (Sizewell B, AP1000)

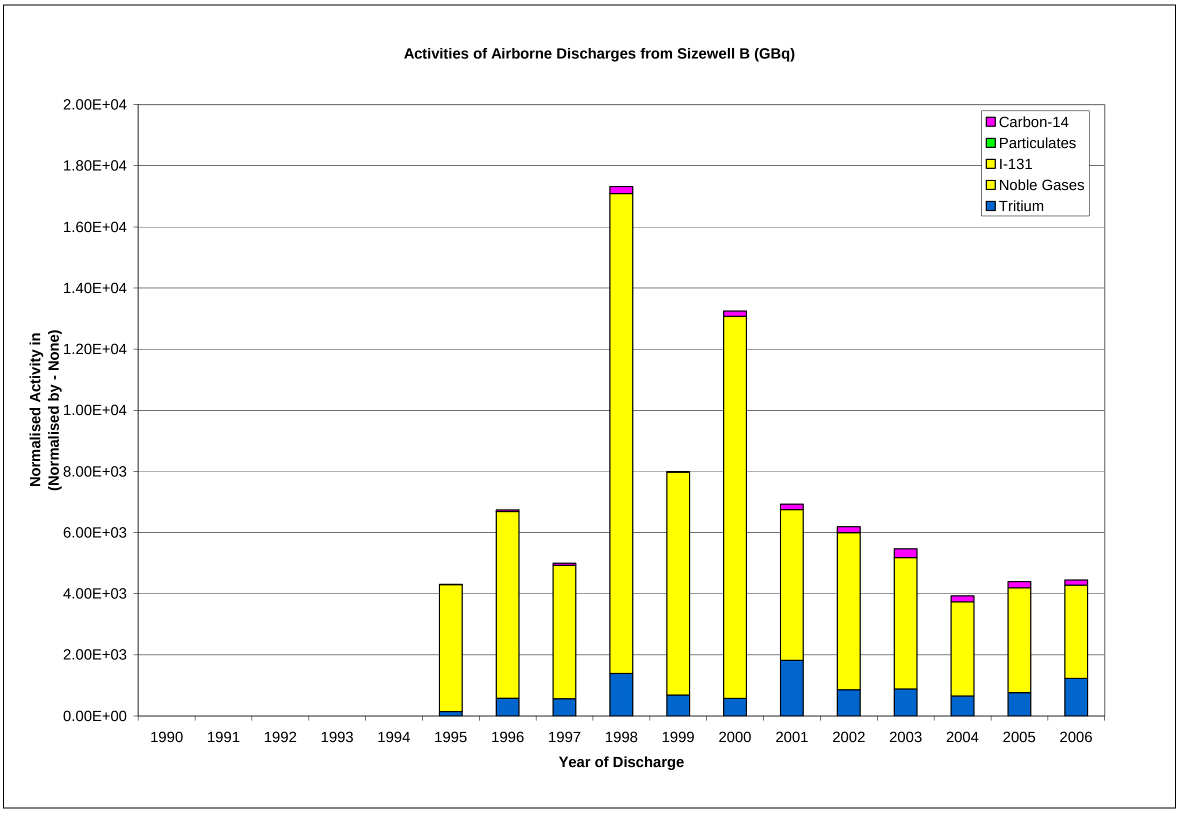

Figure 2.19 Activities of airborne discharges from Sizewell B (GBq).

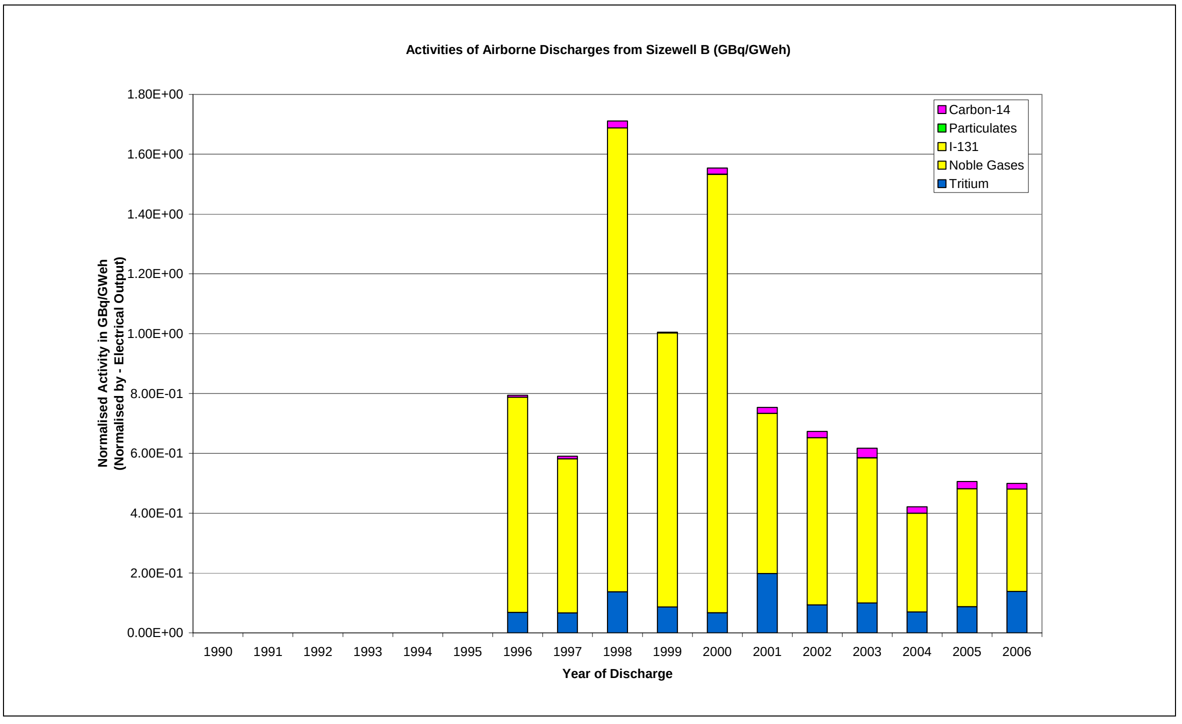

Figure 2.20 Activities of airborne discharges from Sizewell B (GBq/GWeh).

The caveats are:

- the predicted airborne discharge from the AP1000 is 43.1 GBq/GWeh per annum, which is not indicated in the above chart due to the comparatively small activities of the actual discharges reported for Sizewell B.

2.1.6 AP1000 predecessor – Takahama

Charts – liquid discharges (Takahama, AP1000)

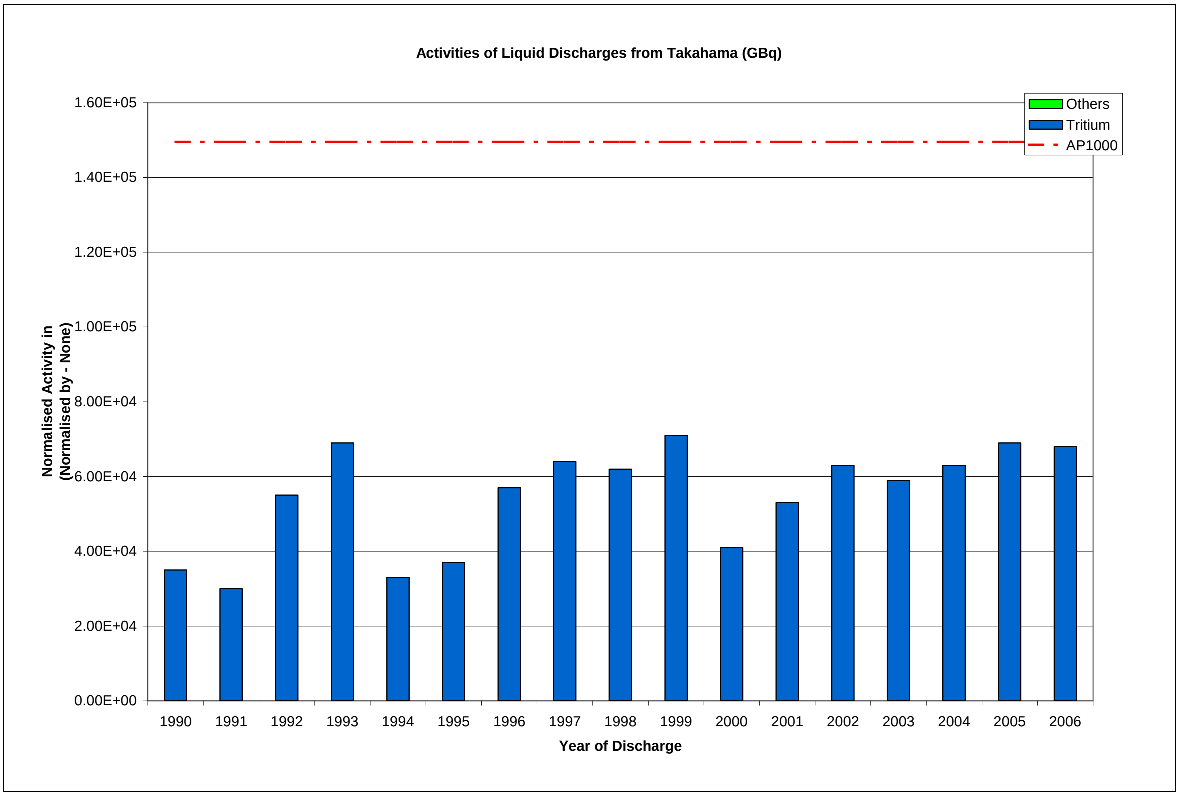

Figure 2.21 Activities of liquid discharges from Takahama (GBq).

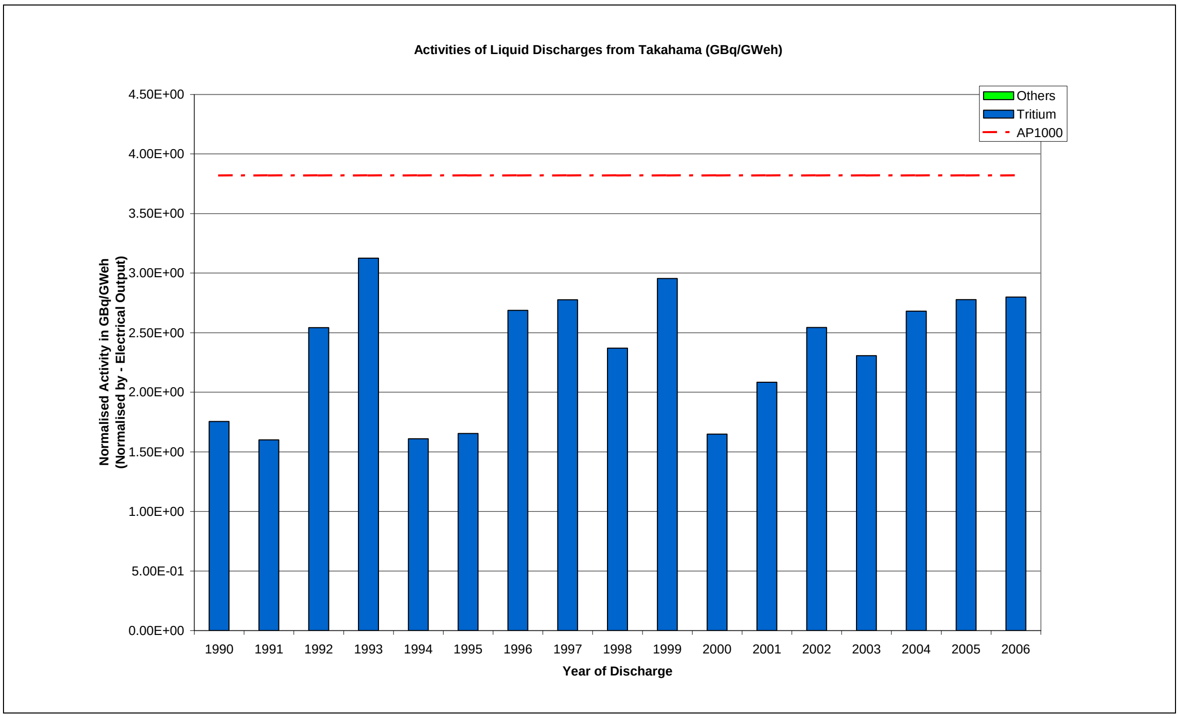

Figure 2.22 Activities of liquid discharges from Takahama (GBq/GWeh).

Charts – airborne discharges (Takahama, AP1000)

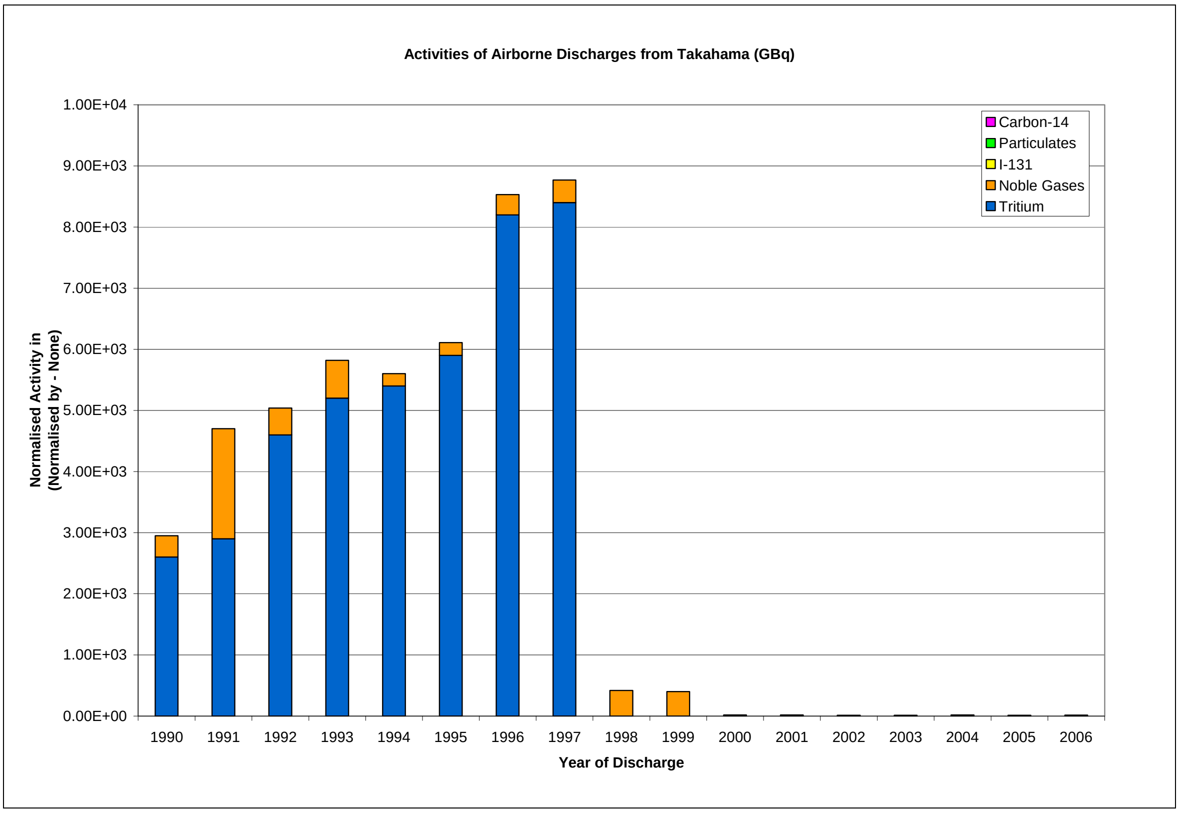

Figure 2.23 Activities of airborne discharges from Takahama (GBq).

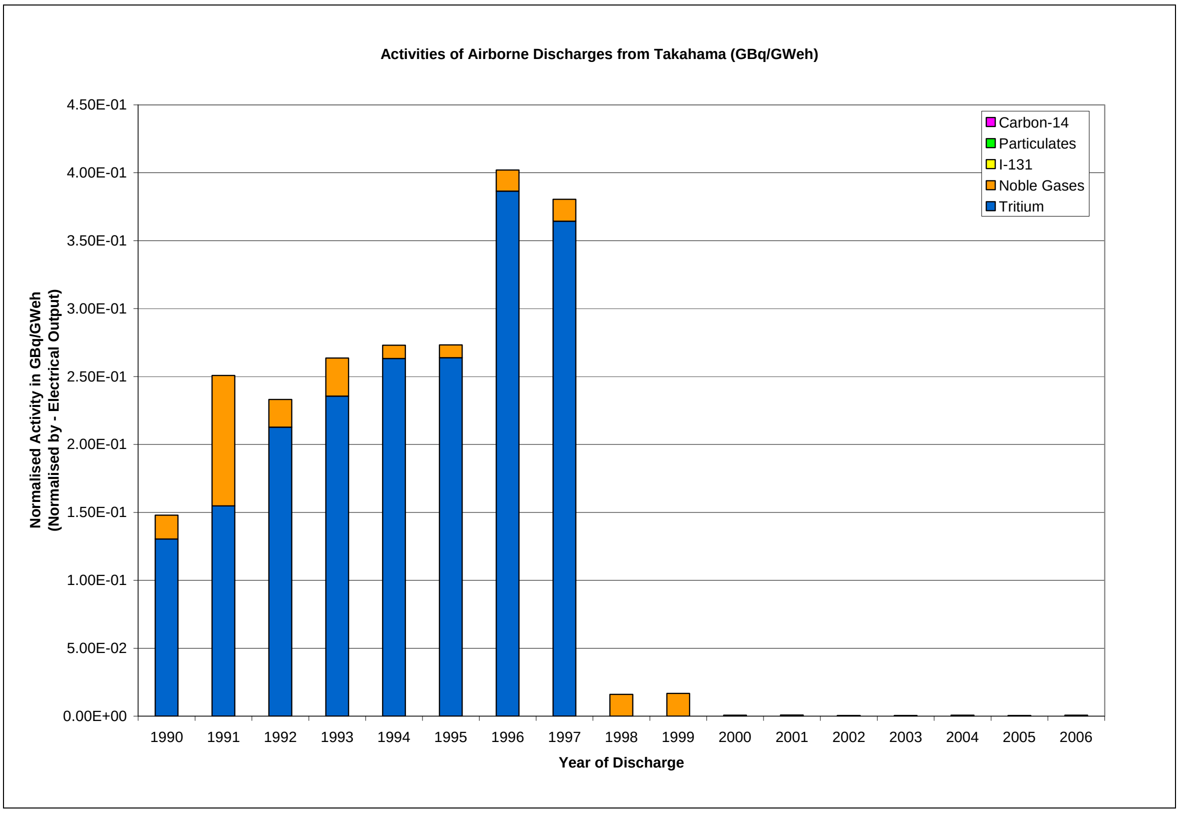

Figure 2.24 Activities of airborne discharges from Takahama (GBq/GWeh).

The caveats are that:

- the predicted electrically normalised discharge for airborne discharges from the AP1000 is 43.1 GBq/GWeh, which is not indicated in the chart above due to the comparatively small activities of the actual discharges reported for Takahama.

It should be noted that the charts above lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium data for 1998–2006;
- airborne particulates data for 1998–2006.

2.2 EDF/Areva EPR predecessors

The following stations have been used in this study as predecessors to the proposed new EDF/Areva EPR reactor design:

- Chooz;
- Civaux;
- Golfech;
- Penly;
- Neckarwestheim;
- Emsland;
- Isar-2.

The results for each of these are presented in the following subsections.

2.2.1 EPR predecessor – Chooz

Charts – liquid discharges (Chooz, EPR)

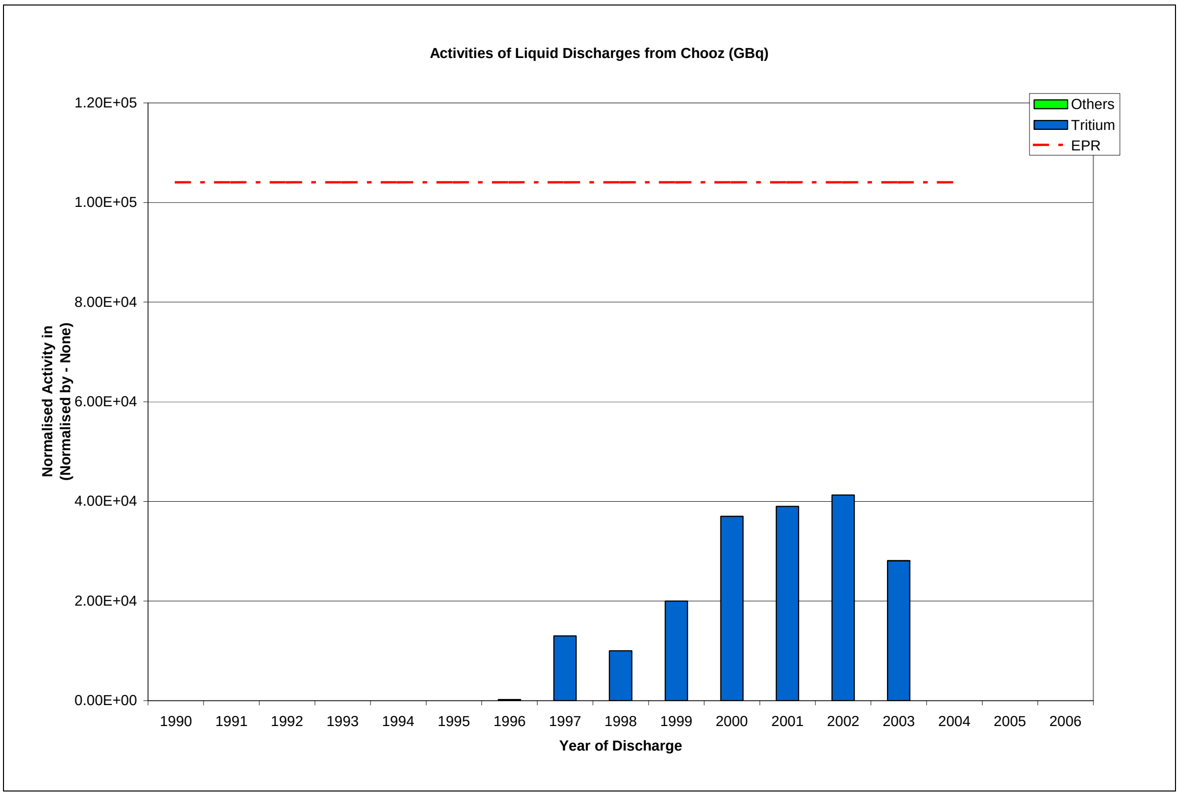

Figure 2.25 Activities of liquid discharges from Chooz (GBq).

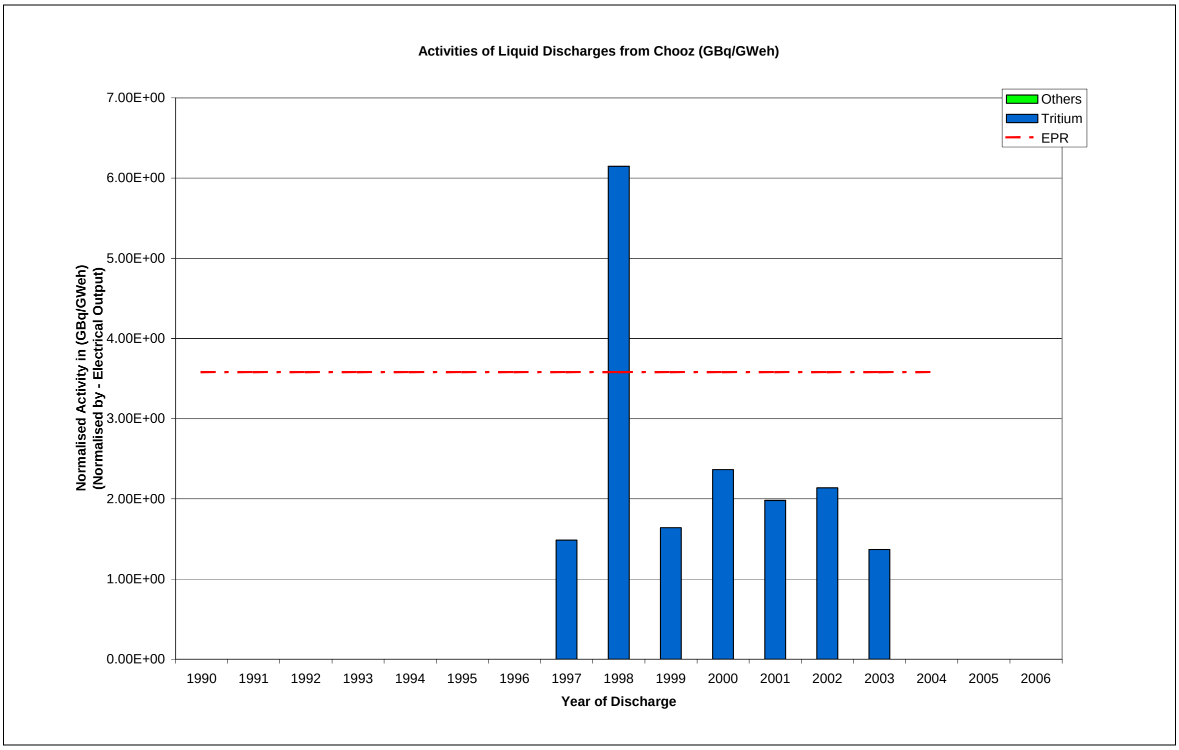

Figure 2.26 Activities of liquid discharges from Chooz (GBq/GWeh).

Charts – airborne discharges (Chooz, EPR)

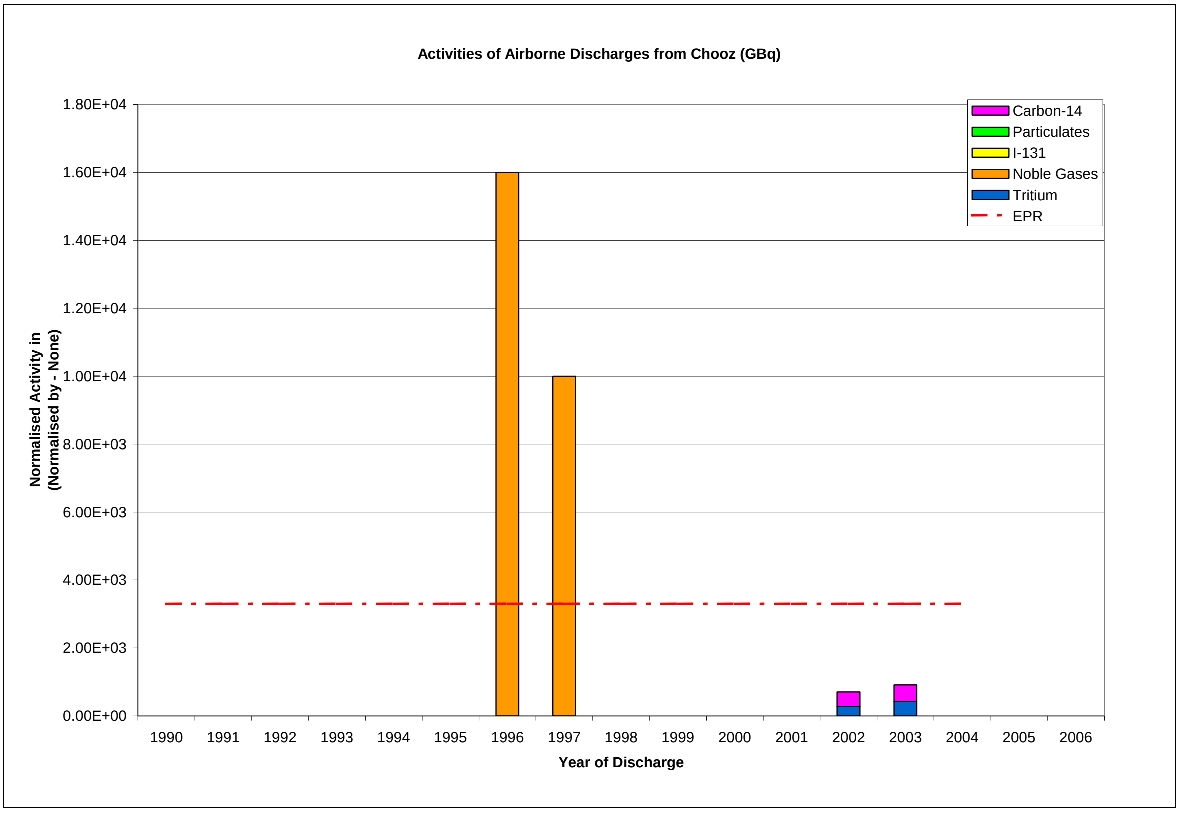

Figure 2.27 Activities of airborne discharges from Chooz (GBq).

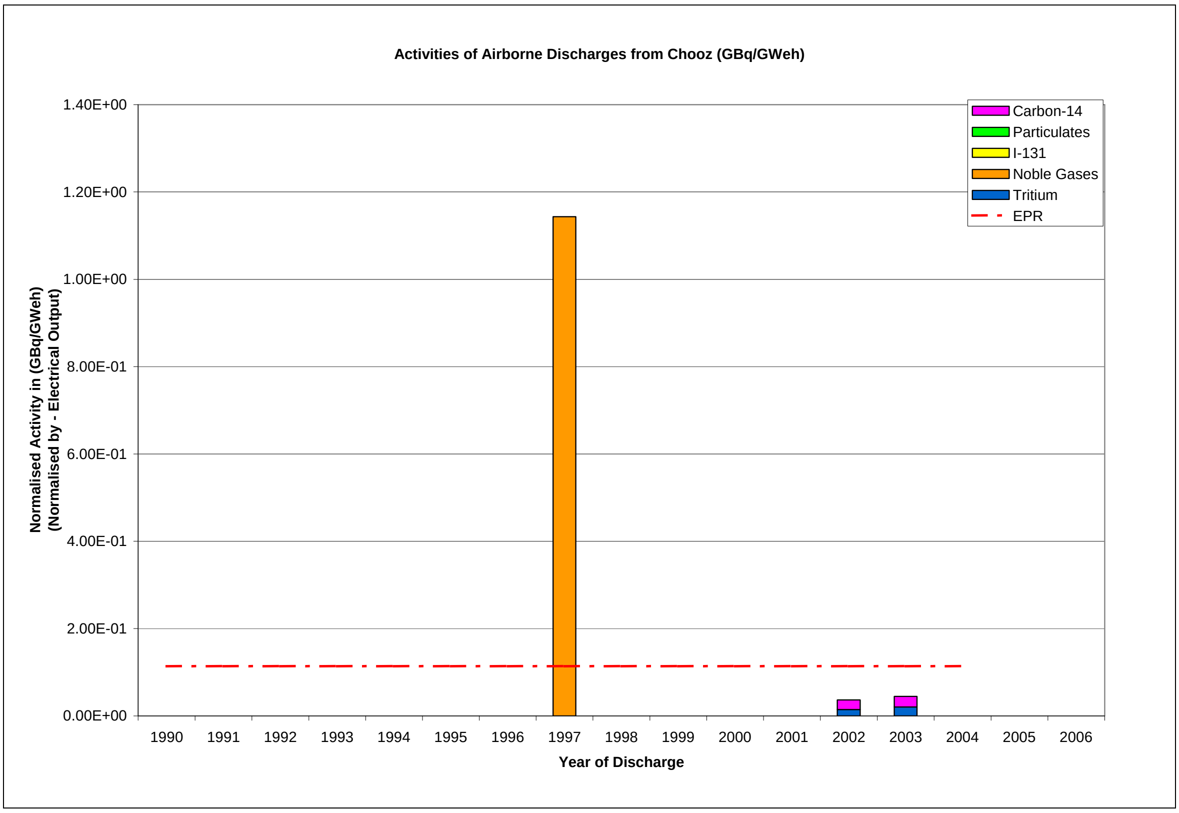

Figure 2.28 Activities of airborne discharges from Chooz (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for both Chooz B1-B2 (for 1996–1997);
- data from the UNSCEAR report combines data for 'Noble gas + tritium' and 'Particulates + iodine' for the years 1996–1997;
- between 1996 and 1999 gaseous discharges were categorised as 'Halogen + aerosol' and 'Tritium + noble gases';
- data from the EC Radiation Protection 127 document is reported for the years 2002–2003;
- with respect to Chooz, the years for which specific tritium, carbon-14 and iodine-131 information is not available (due to the main regulatory reporting obligations) are left out of the data;
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no liquid or airborne discharges could be extracted for the years 1990–1995 and 2004–2006;
- no airborne discharges could be extracted for the years 1998–2001 and 2004–2006;
- electrical and thermal output was not available for 1996.

2.2.2 EPR predecessor – Civaux

Charts – liquid discharges (Civaux, EPR)

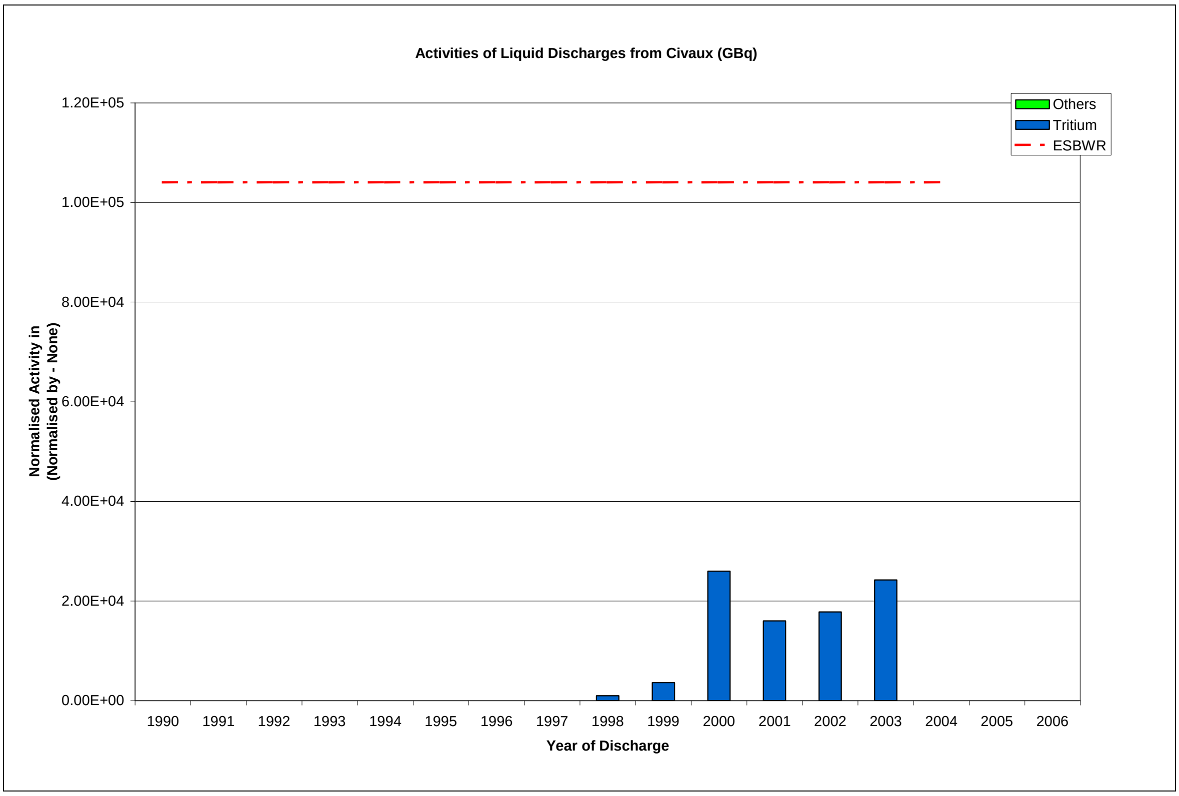

Figure 2.29 Activities of liquid discharges from Civaux (GBq).

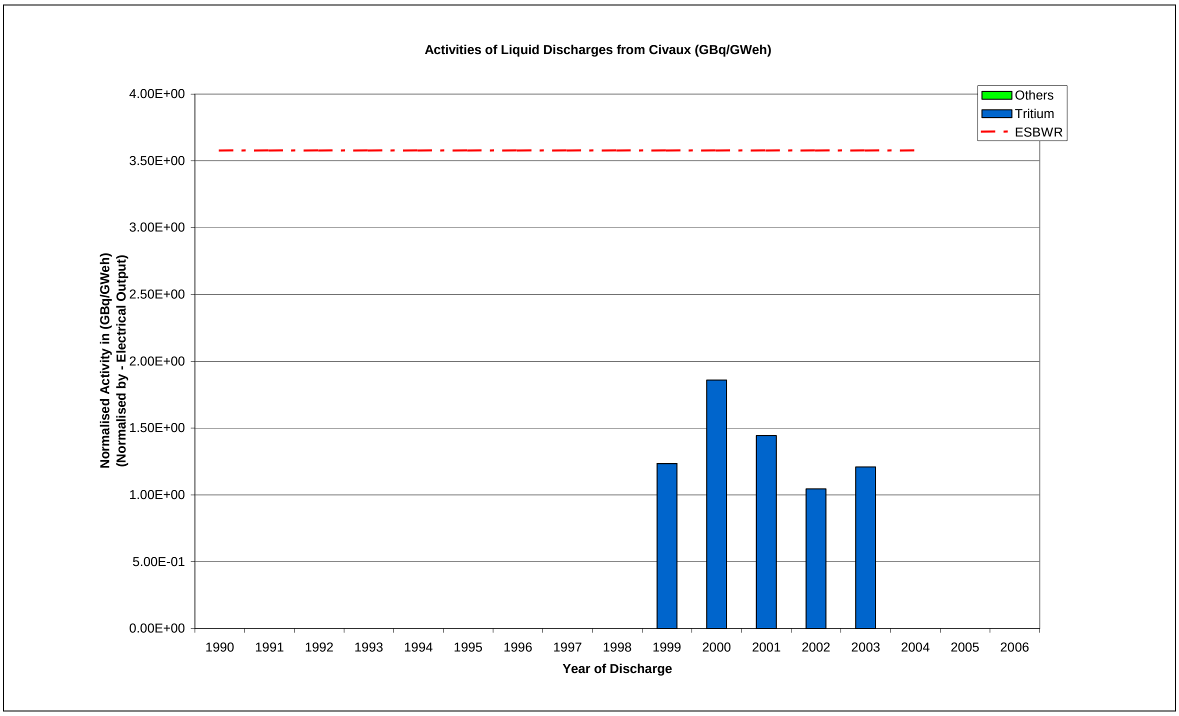

Figure 2.30 Activities of liquid discharges from Civaux (GBq/GWeh).

Charts – airborne discharges (Civaux, EPR)

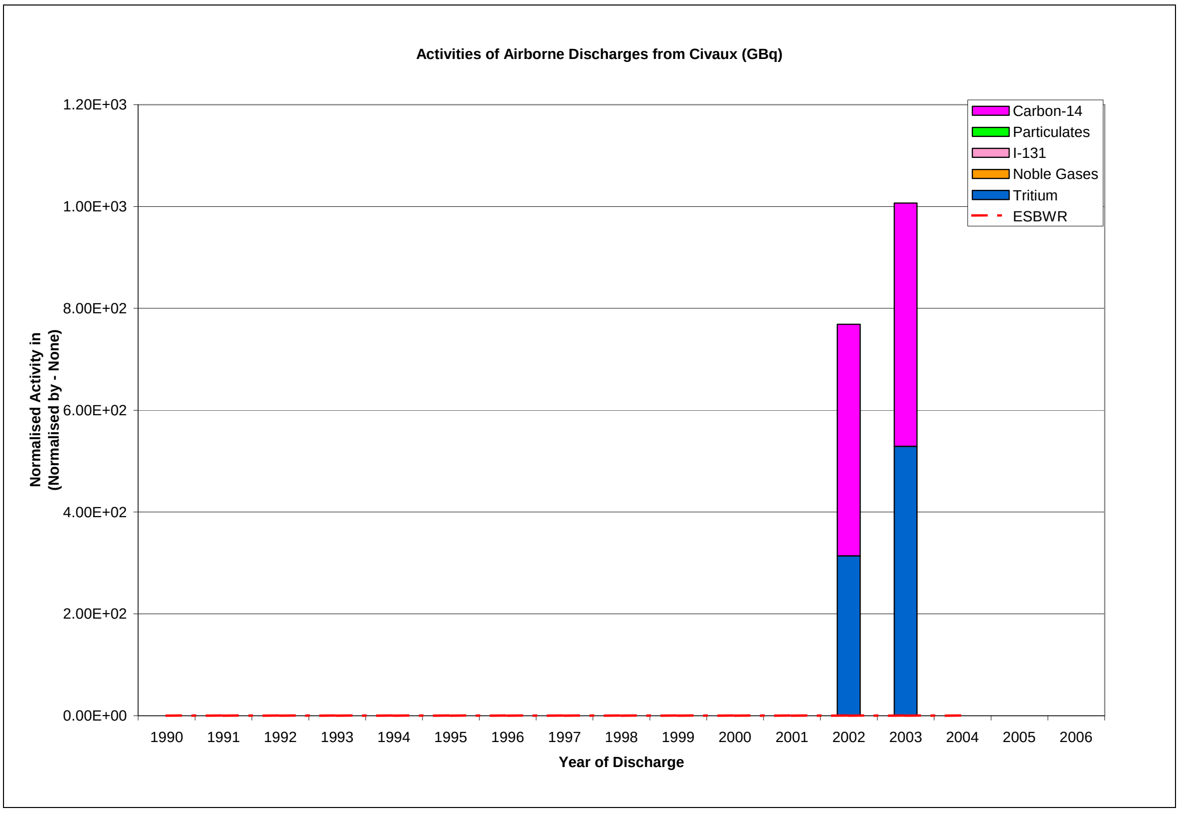

Figure 2.31 Activities of airborne discharges from Civaux (GBq).

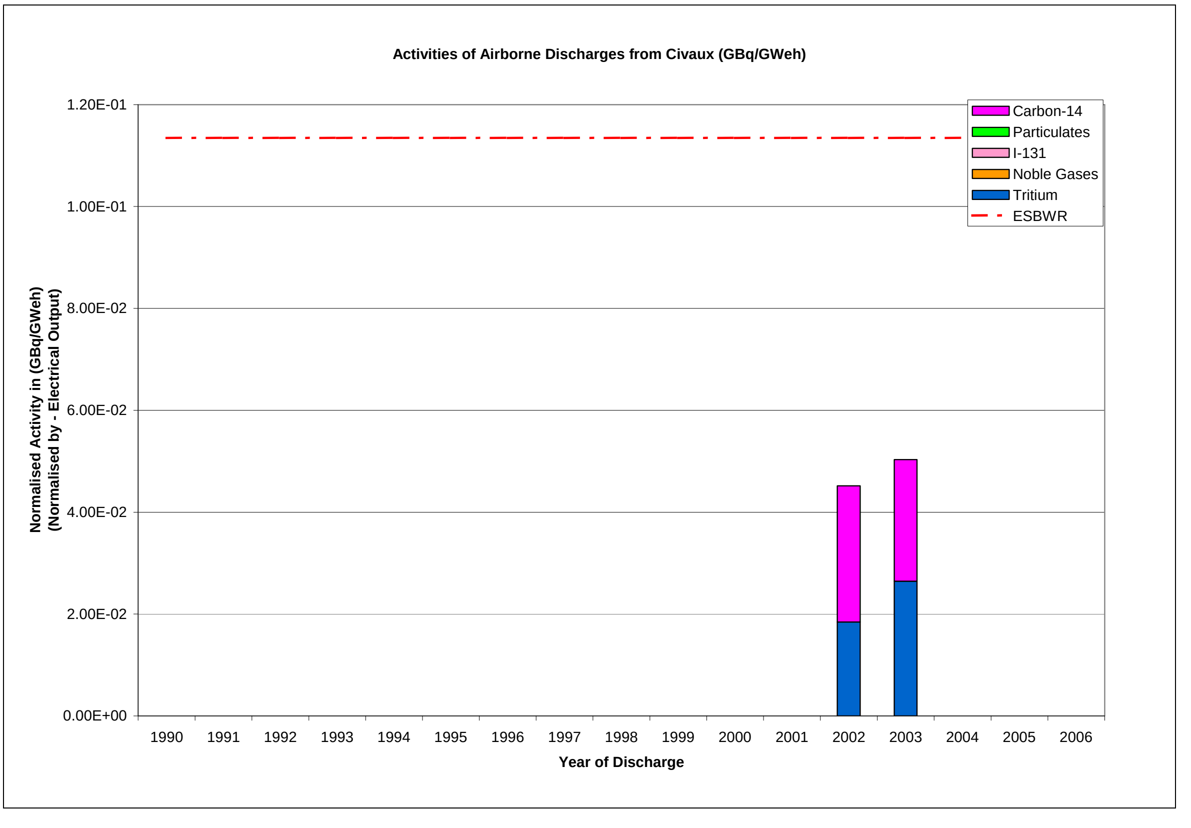

Figure 2.32 Activities of airborne discharges from Civaux (GBq/GWeh).

The caveats are that:

- data from the EC Radiation Protection 127 document are reported for the years 2002–2003;
- with respect to Civaux, the years for which specific tritium, carbon-14 and iodine-131 information is not available (due to the main regulatory reporting obligations) are left out of the table;
- the UNSCEAR (1990-1997) report does not detail any discharges (Civaux started up in 2002);
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no liquid discharges could be extracted for the years 2004–2006.

2.2.3 EPR predecessor – Golfech

Charts – liquid discharges (Golfech, EPR)

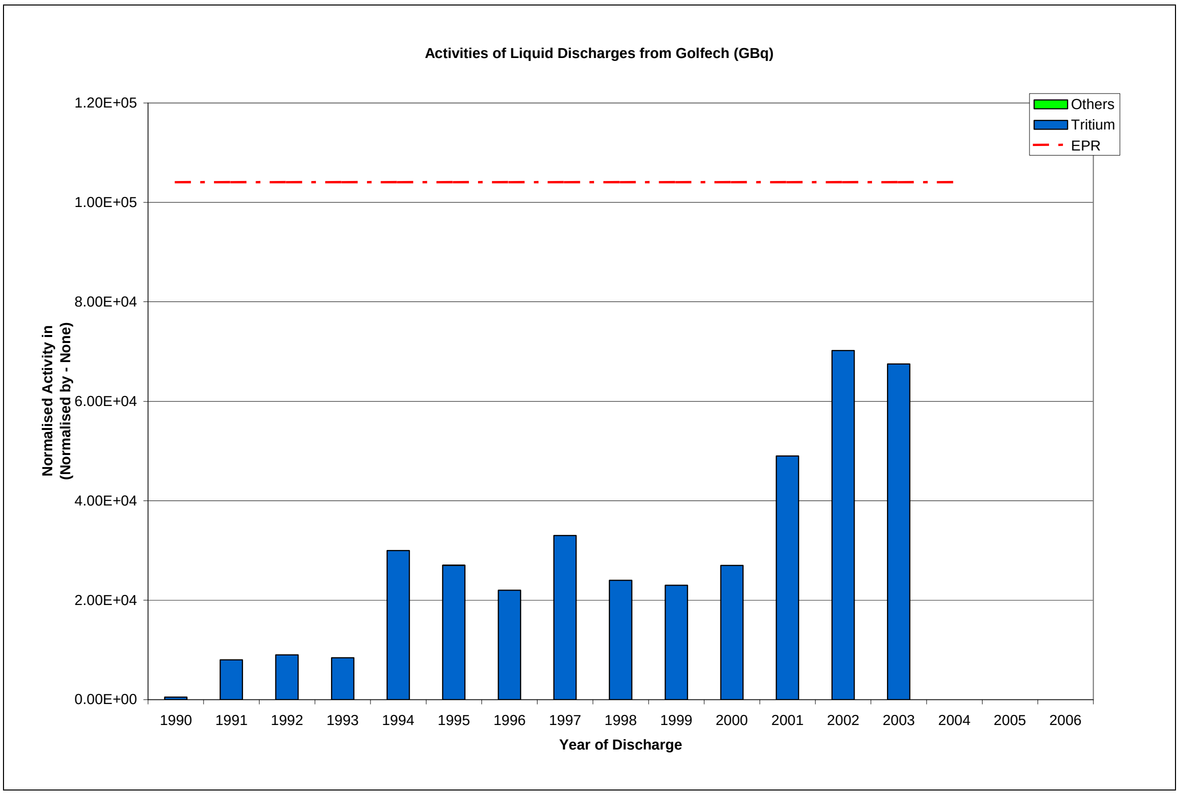

Figure 2.33 Activities of liquid discharges from Golfech (GBq).

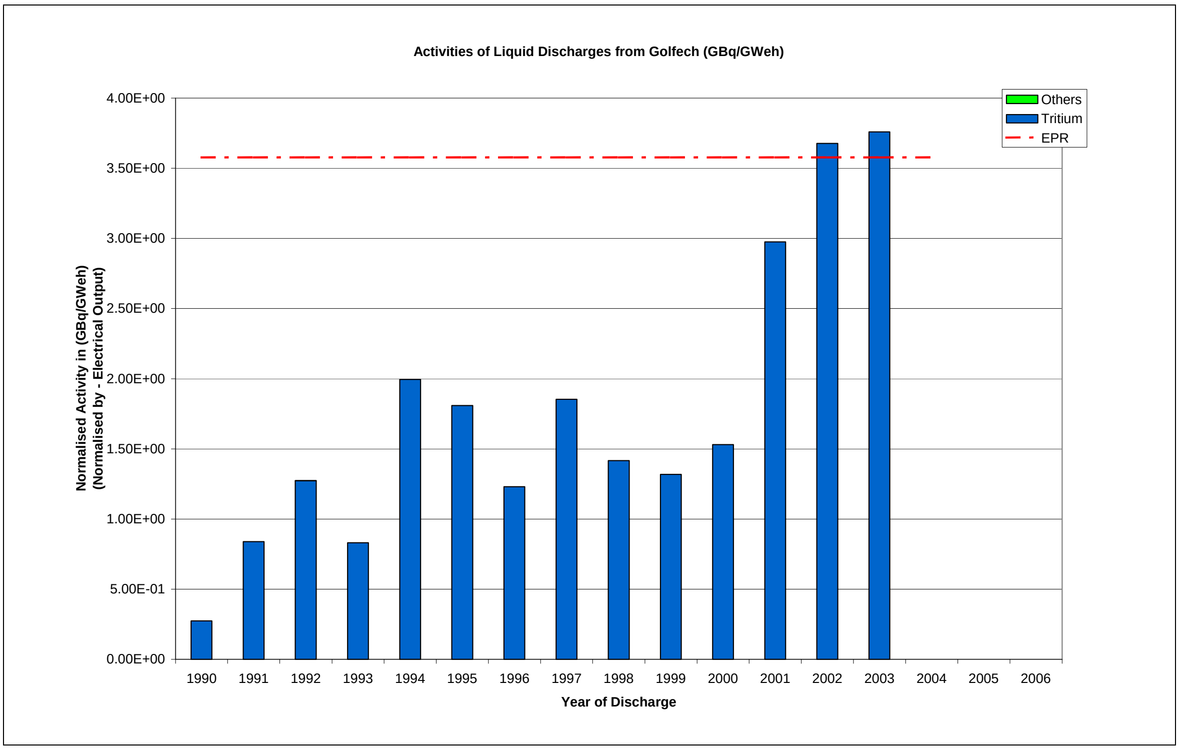

Figure 2.34 Activities of liquid discharges from Golfech (GBq/GWeh).

Charts – airborne discharges (Golfech, EPR)

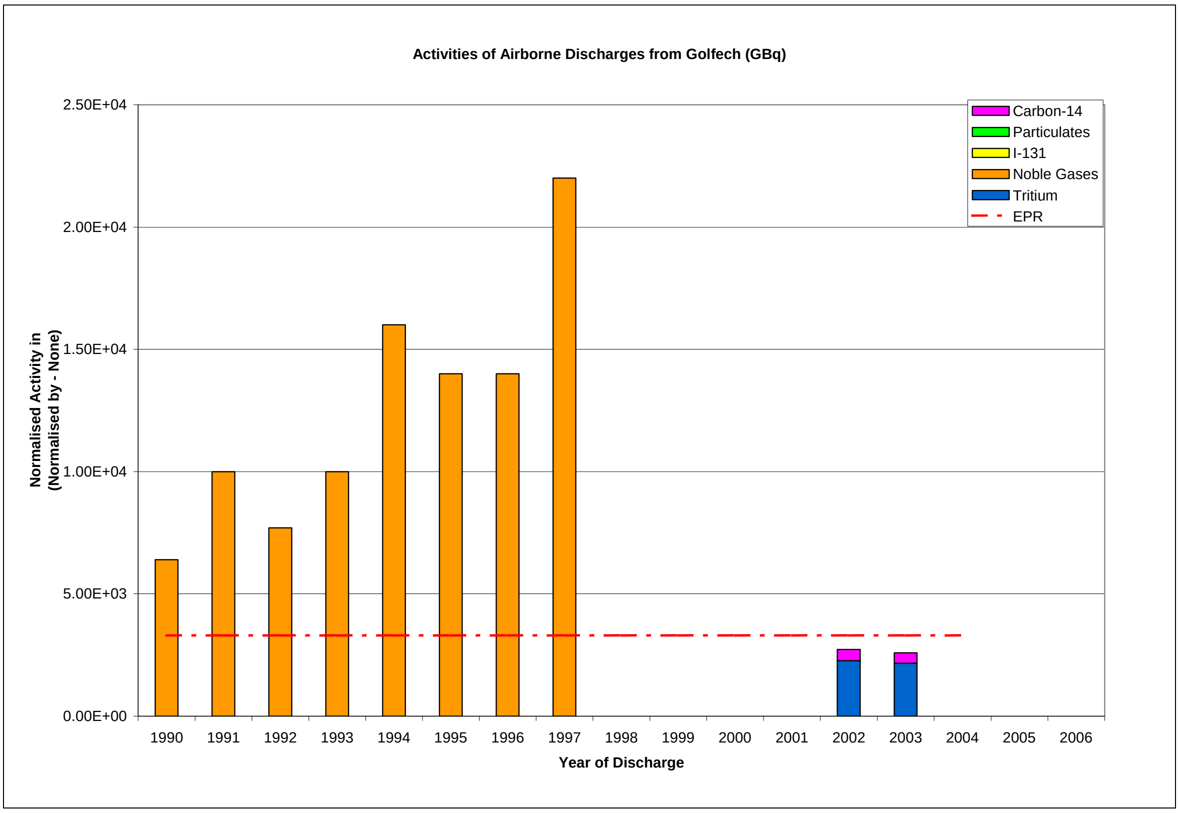

Figure 2.35 Activities of airborne discharges from Golfech (GBq).

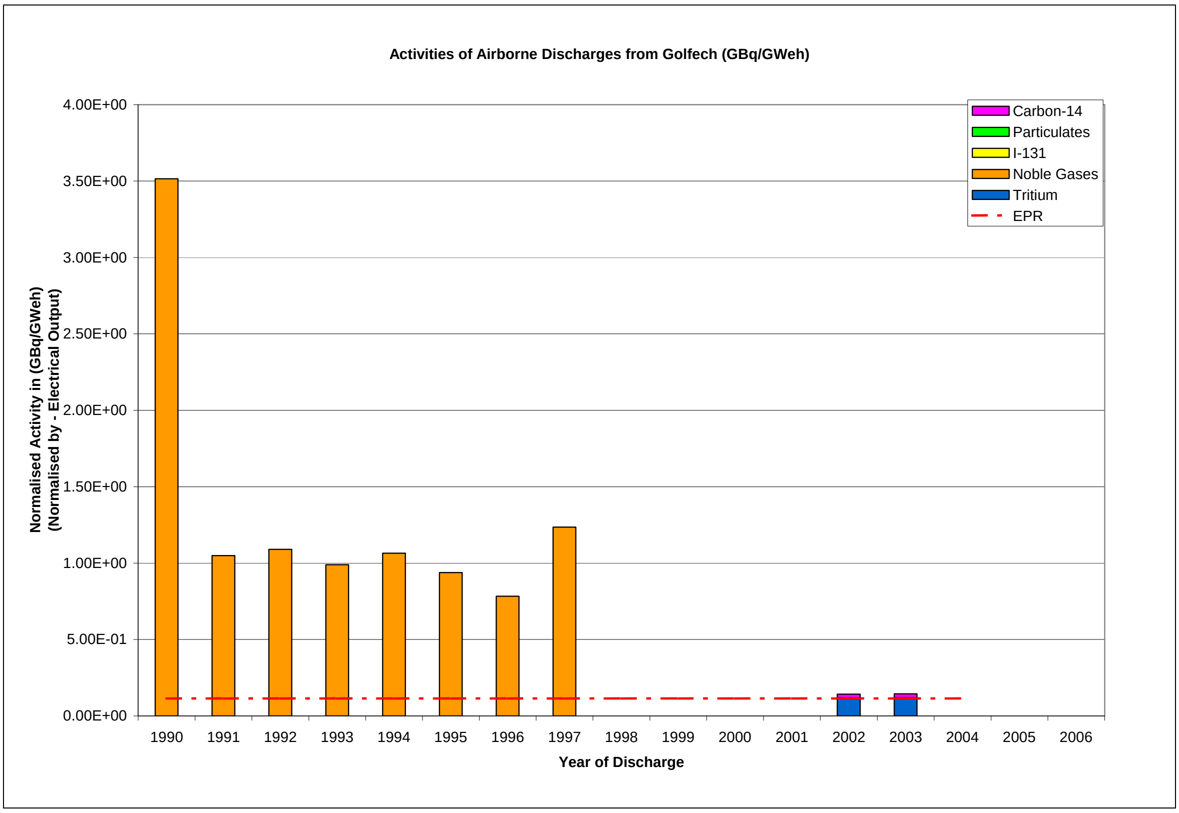

Figure 2.36 Activities of airborne discharges from Golfech (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for both Golfech-1 and -2 (for 1990–1997);
- data from the UNSCEAR report combines data for 'Noble gas + tritium' and 'Particulates + iodine' for the years 1990–1997;
- between 1998 and 1999 gaseous discharges were categorised as 'Halogen + aerosol' and 'tritium + noble gases';
- data from the EC Radiation Protection 127 document is reported for 2002–2003;
- With respect to Golfech, the years for which specific tritium, carbon-14 and iodine-131 information is not available (due to the main regulatory reporting obligations) are left out of the data;
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no liquid discharges could be extracted for 2004–2006;
- no airborne discharges could be extracted for the years 1998–2001 and 2004–2006.

2.2.4 EPR predecessor – Penly

Charts – liquid discharges (Penly, EPR)

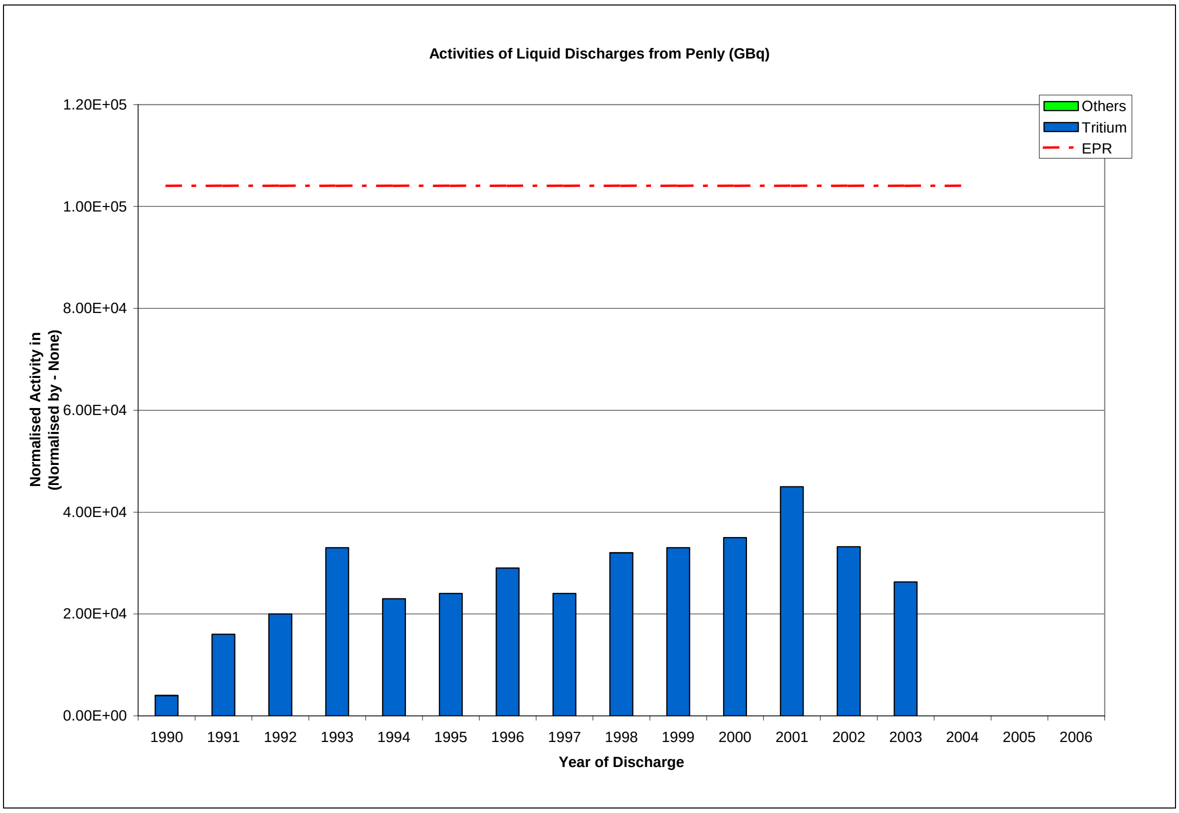

Figure 2.37 Activities of liquid discharges from Penly (GBq).

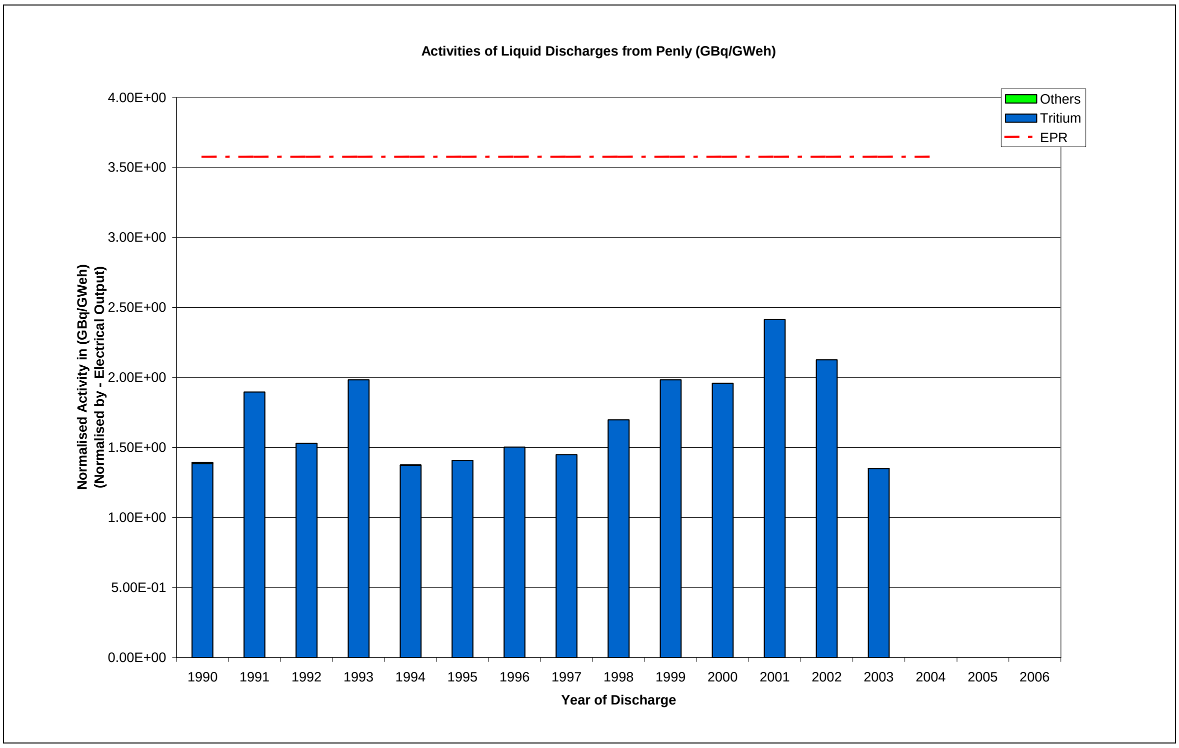

Figure 2.38 Activities of liquid discharges from Penly (GBq/GWeh).

Charts – airborne discharges (Penly, EPR)

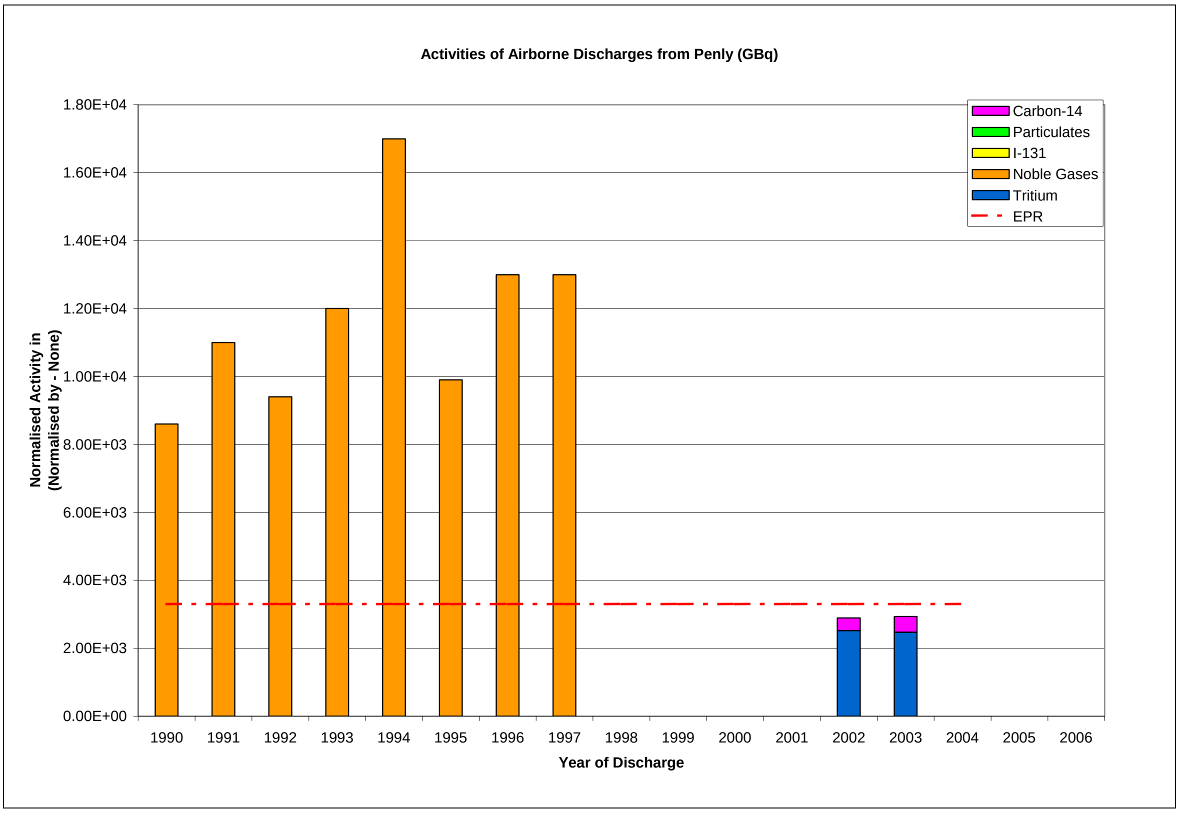

Figure 2.39 Activities of airborne discharges from Penly (GBq).

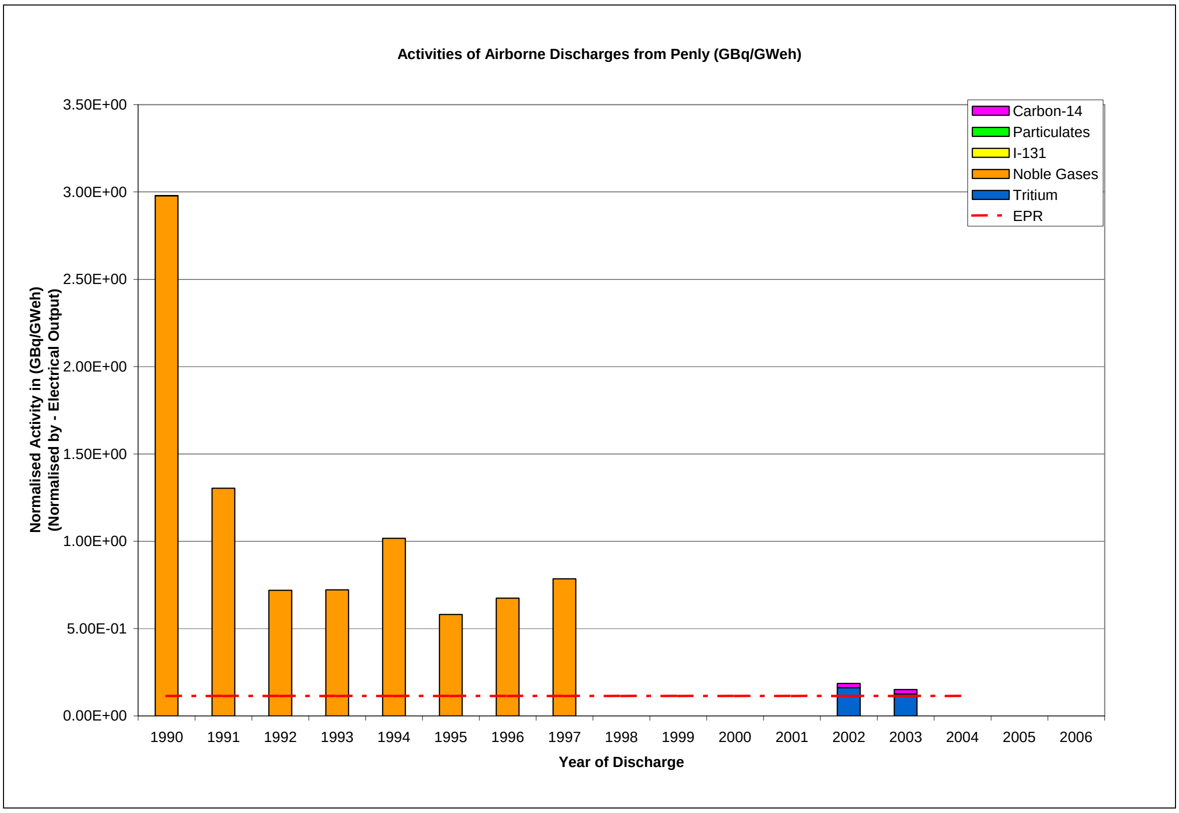

Figure 2.40 Activities of airborne discharges from Penly (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for both Penly-1 and -2 (for 1990–1997);
- airborne data from the UNSCEAR report combines data for 'Noble gas + tritium' and 'Particulates + iodine' for the years 1990–1997;
- the EC radiation report categorised gaseous discharges as 'Halogen + aerosol' and 'Tritium + Noble Gases' between 1998 and 1999;
- airborne data from the EC Radiation Protection 127 document is reported for 2002–2003;
- with respect to Penly, the years for which specific tritium, carbon-14 and iodine-131 information is not available (due to the main regulatory reporting obligations) are left out of the data;
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no liquid discharges could be extracted for 2004–2006;
- no airborne discharges could be extracted for the years 1998–2001 and 2004–2006.

2.2.5 EPR predecessor – Neckarwestheim

Charts – liquid discharges (Neckarwestheim, EPR)

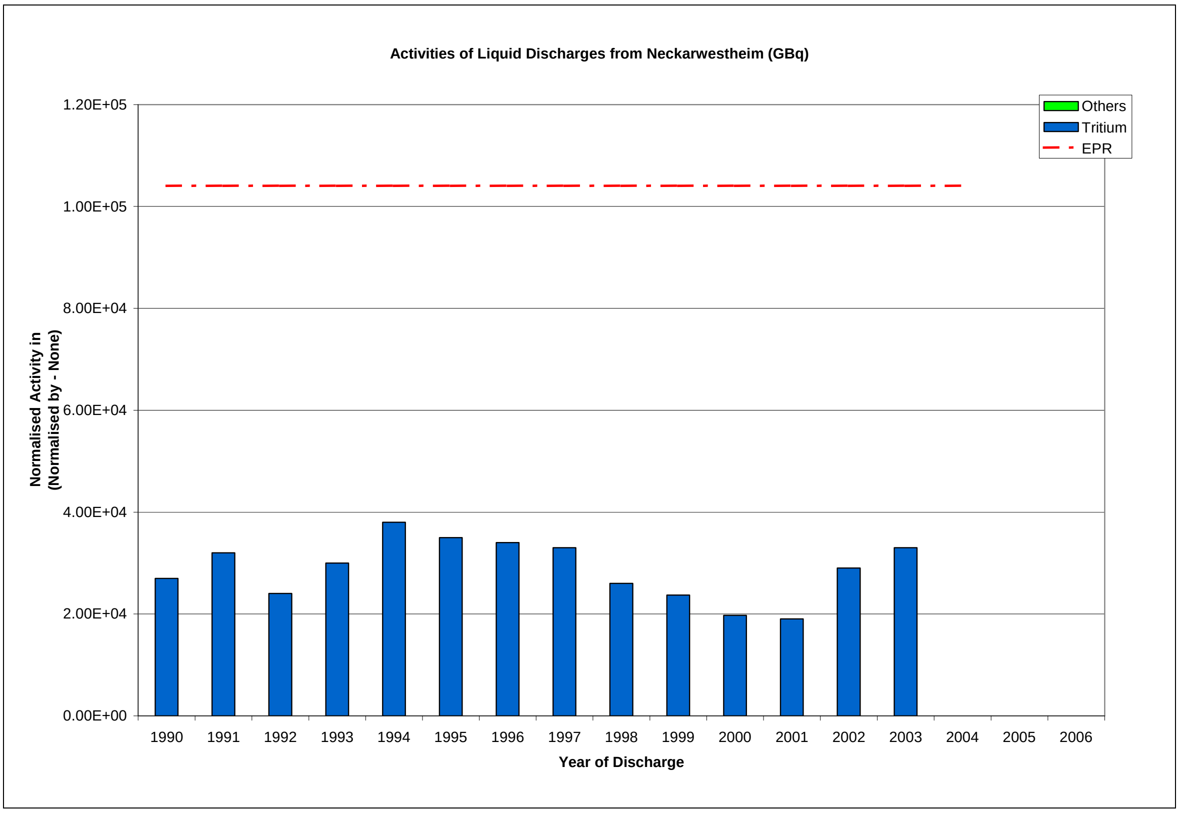

Figure 2.41 Activities of liquid discharges from Neckarwestheim (GBq).

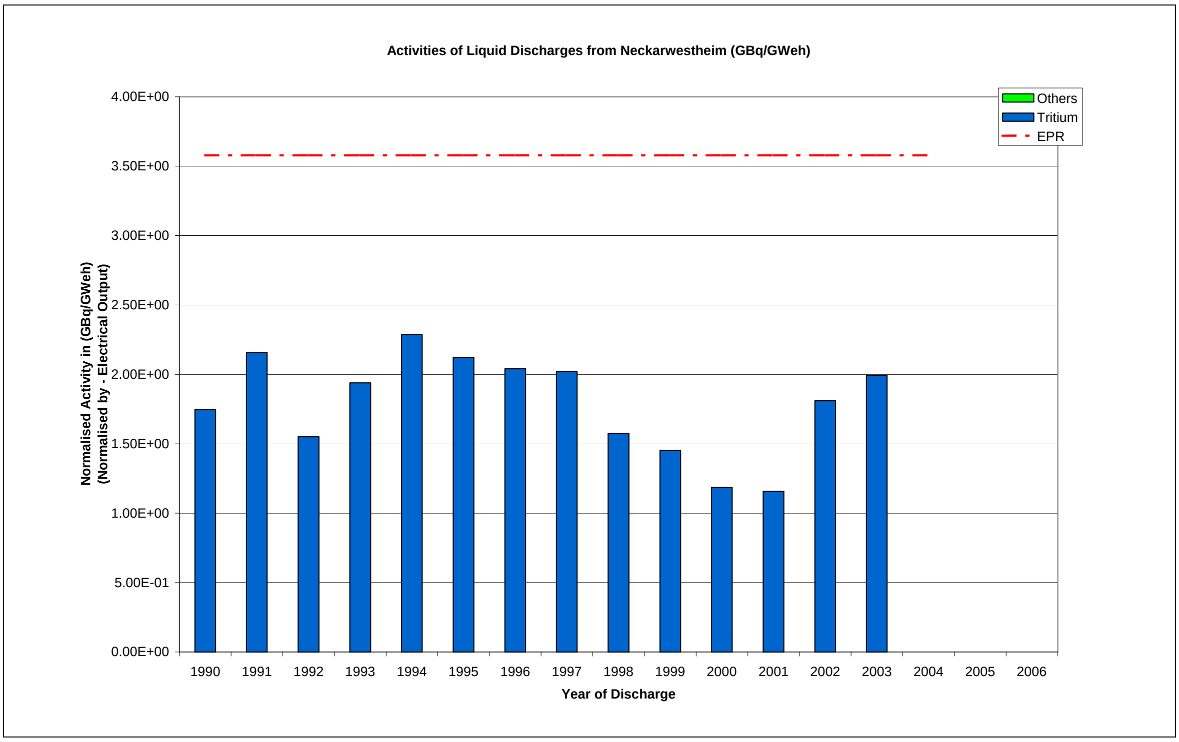

Figure 2.42 Activities of liquid discharges from Neckarwestheim (GBq/GWeh).

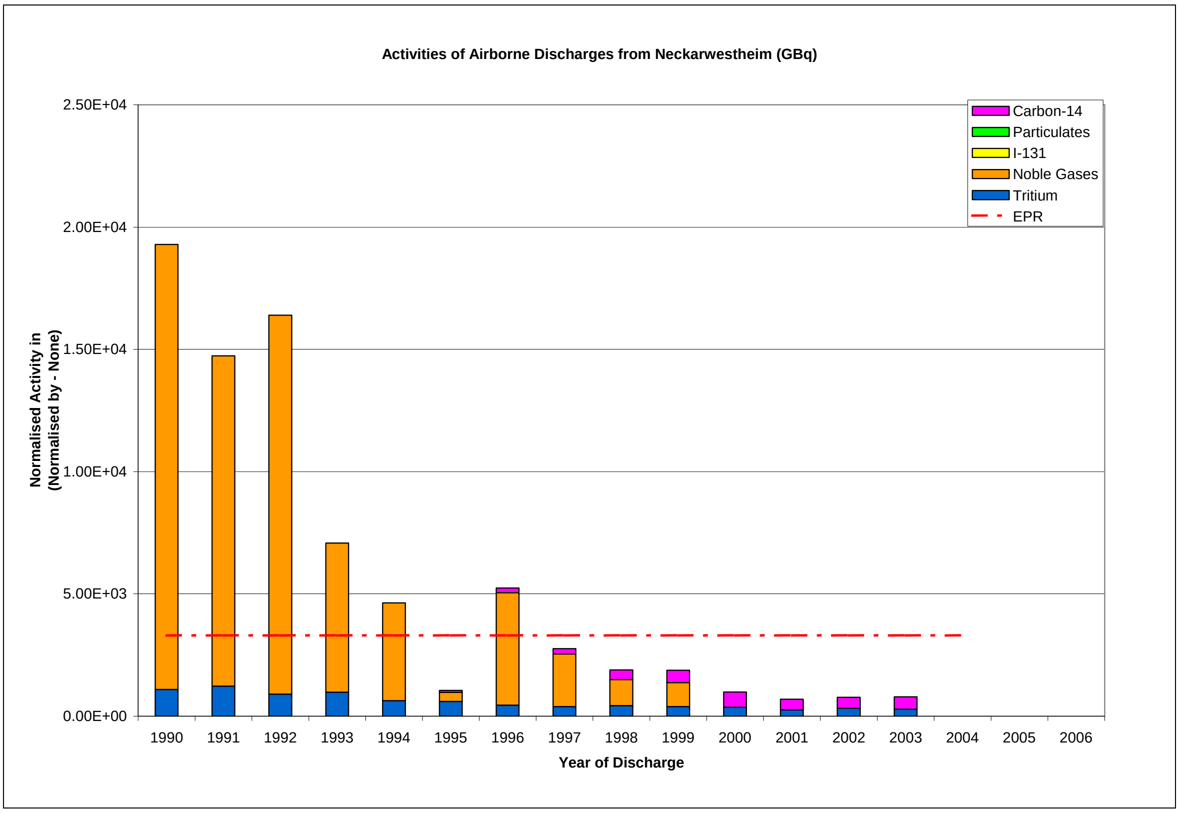

Figure 2.43 Activities of airborne discharges from Neckarwestheim (GBq).

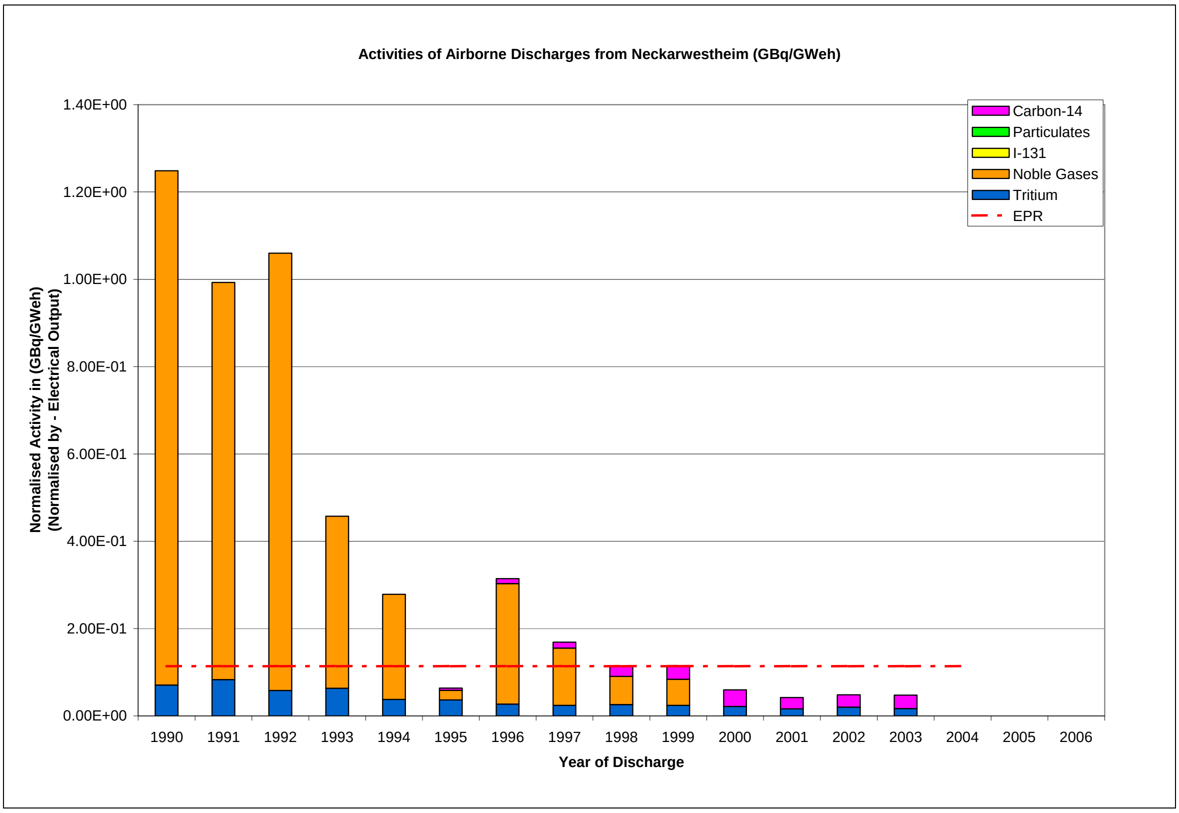

Figure 2.44 Activities of airborne discharges from Neckarwestheim (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for both Neckarwestheim-1 and -2 (for the years 1990–1997);
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no carbon-14 airborne discharges could be extracted for the years 1990–1994 and 2004–2006;
- no airborne particulates discharges could be extracted for 1998;
- no noble gas discharges could be extracted for 2000–2003;
- no liquid discharges could be extracted for 2004–2006;
- no airborne discharges could be extracted for 2004–2006.

2.2.6 EPR predecessor – Emsland

Charts – liquid discharges (Emsland, EPR)

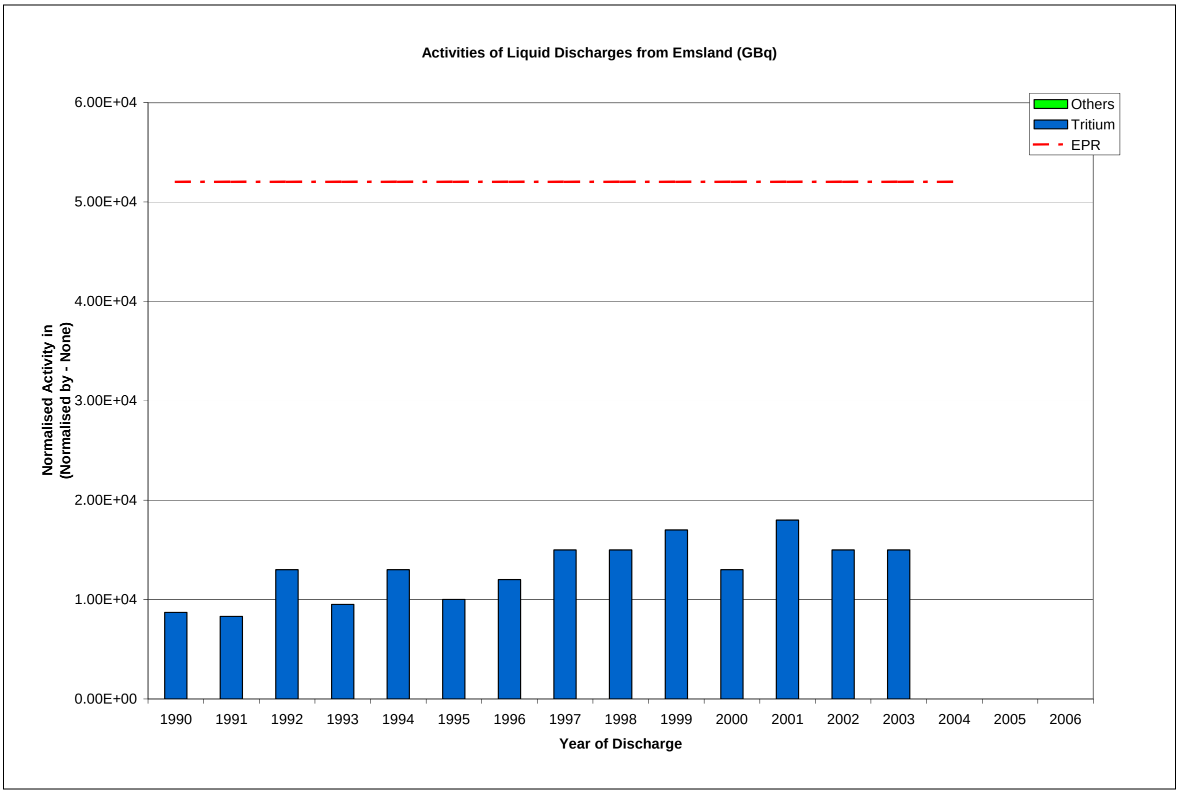

Figure 2.45 Activities of liquid discharges from Emsland (GBq).

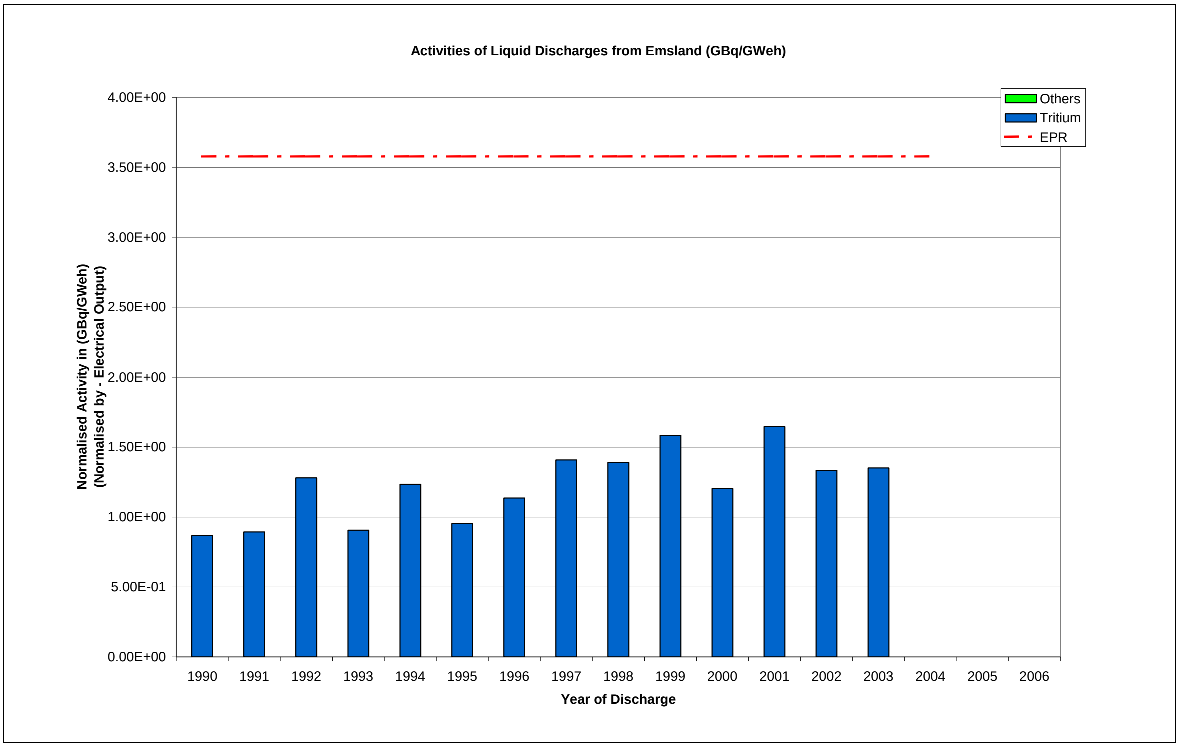

Figure 2.46 Activities of liquid discharges from Emsland (GBq/GWeh).

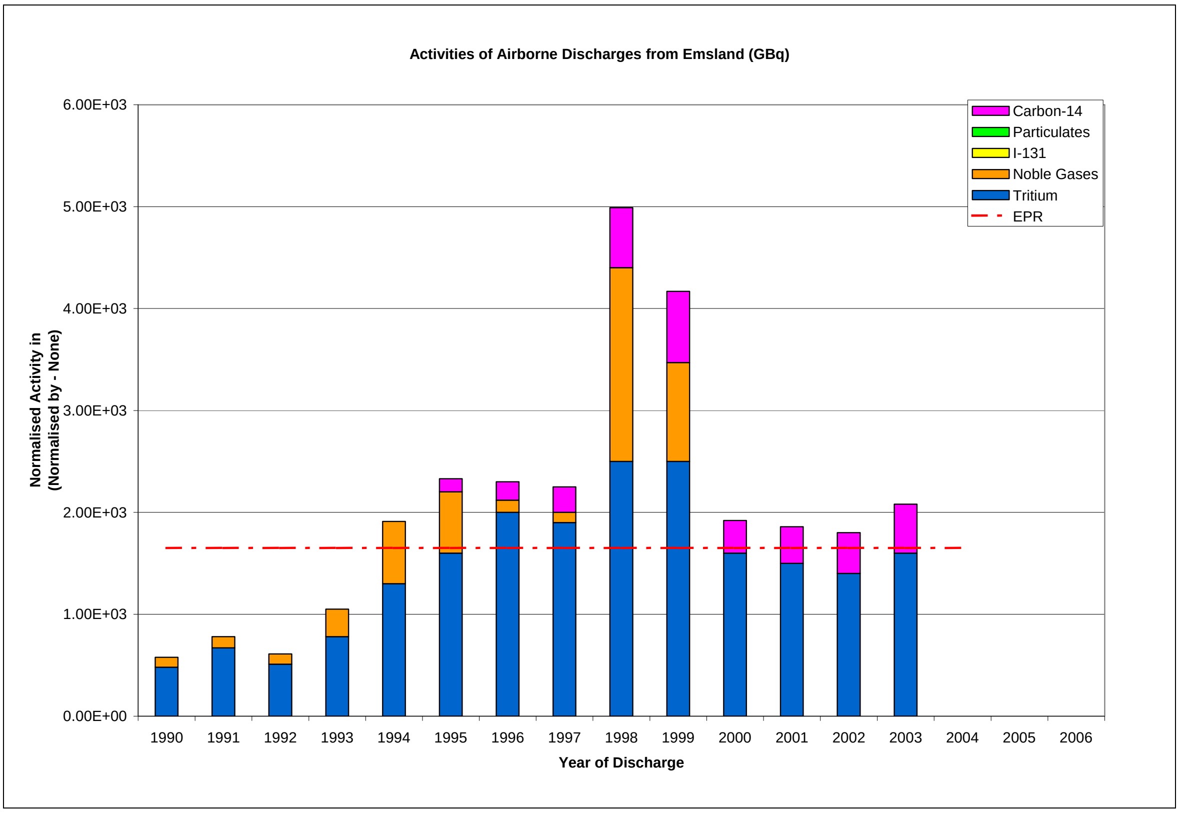

Figure 2.47 Activities of airborne discharges from Emsland (GBq).

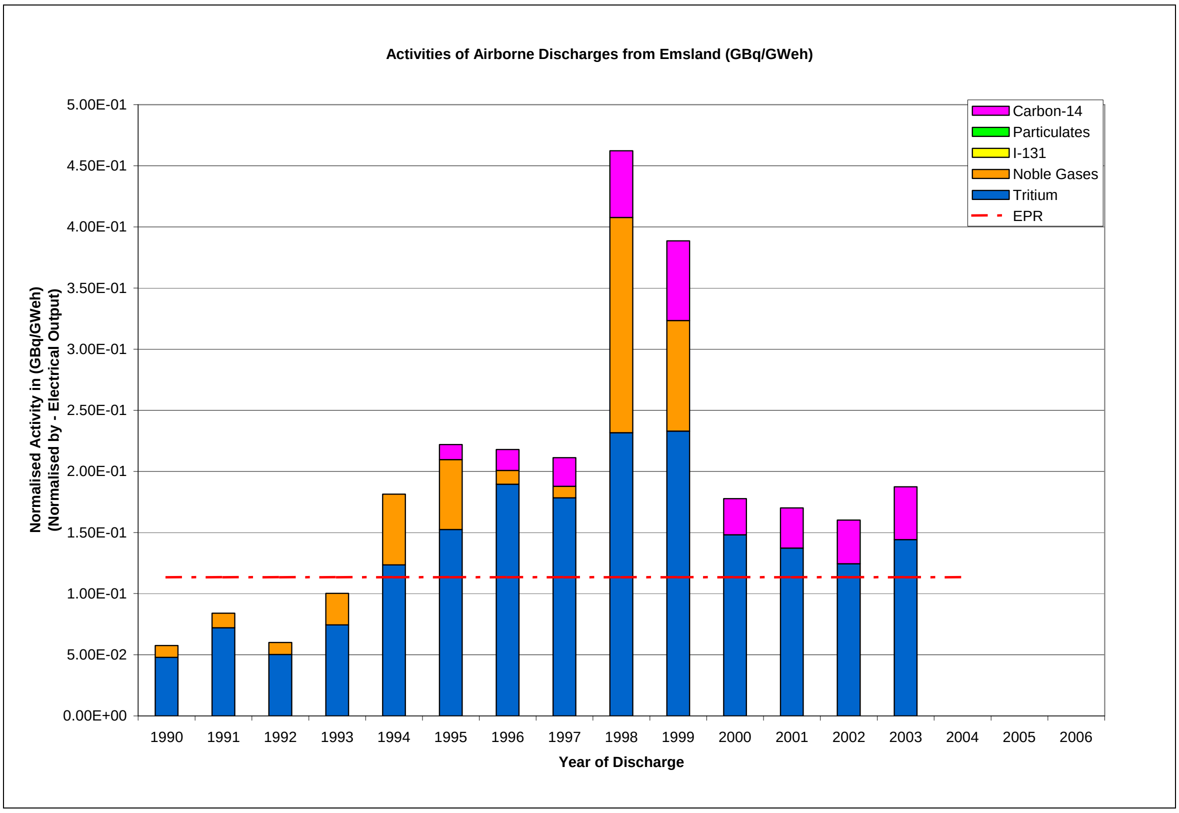

Figure 2.48 Activities of airborne discharges from Emsland (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for 1990–1997;
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no carbon-14 airborne discharges could be extracted for the years 1990–1994;
- no airborne particulates discharges could be extracted for 1998;
- no noble gas discharges could be extracted for 2000–2003;
- no halogen discharges could be extracted for 2000–2003;
- no liquid discharges could be extracted for 2004–2006;
- no airborne discharges could be extracted for 2004–2006.

2.2.7 EPR predecessor – Isar-2

Charts – liquid discharges (Isar-2, EPR)

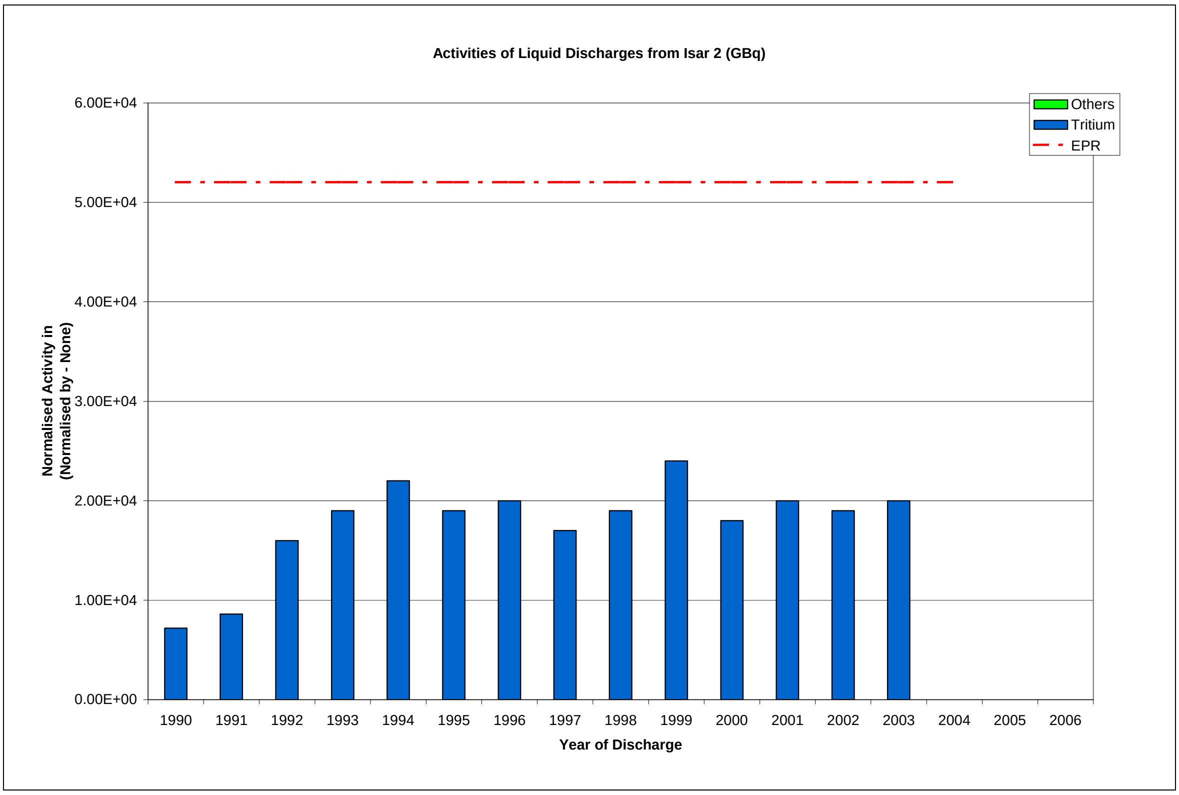

Figure 2.49 Activities of liquid discharges from Isar-2 (GBq).

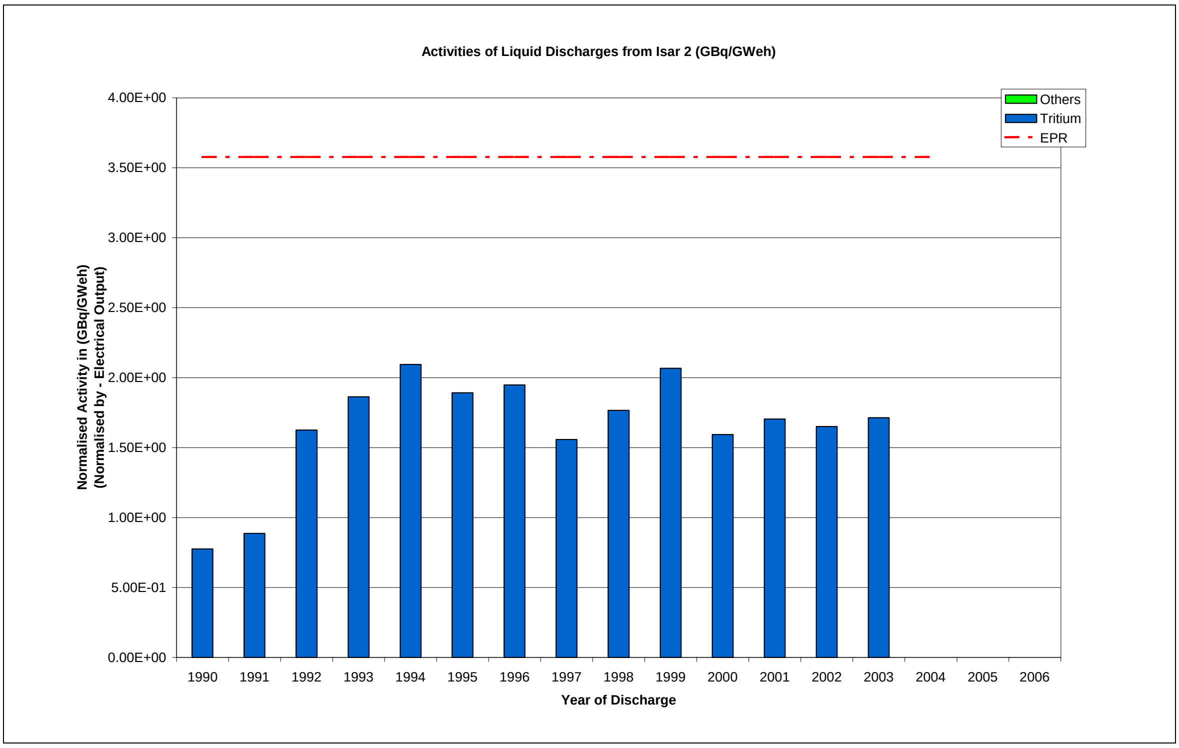

Figure 2.50 Activities of liquid discharges from Isar-2 (GBq/GWeh).

Charts – airborne discharges (Isar-2, EPR)

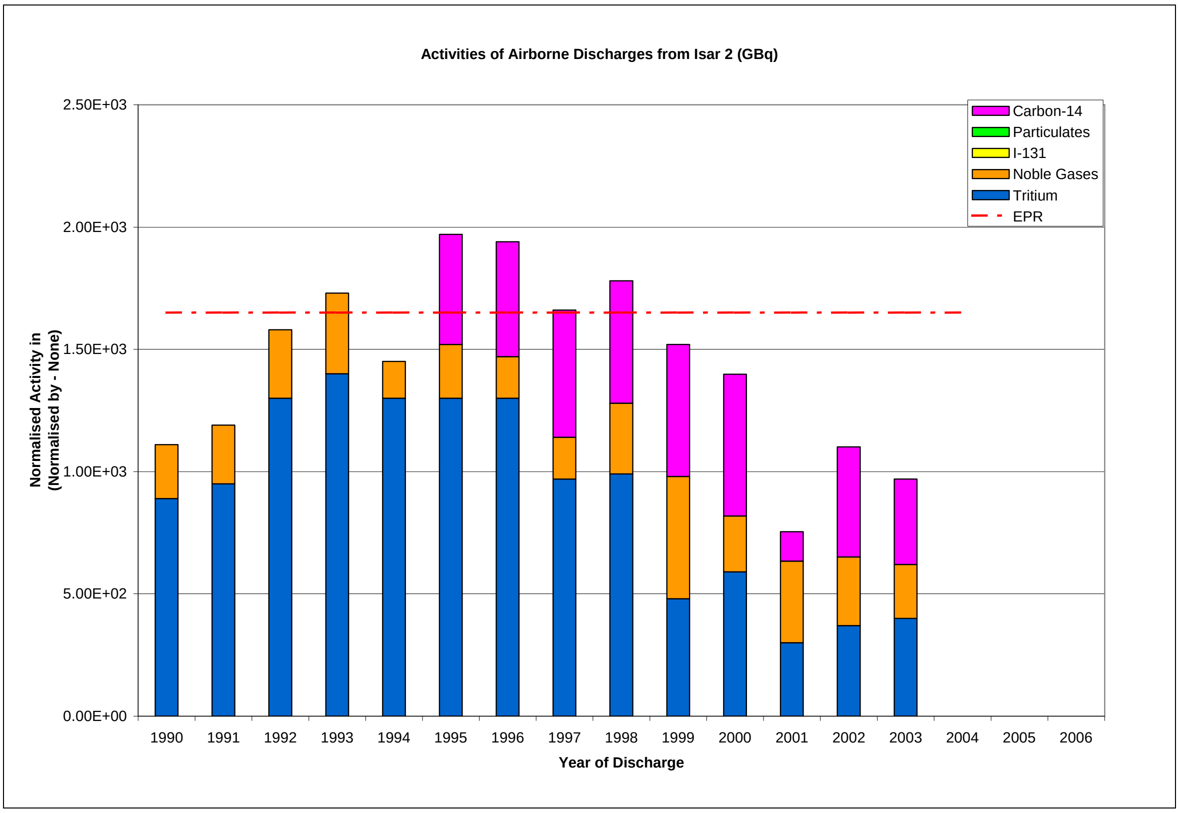

Figure 2.51 Activities of airborne discharges from Isar-2 (GBq).

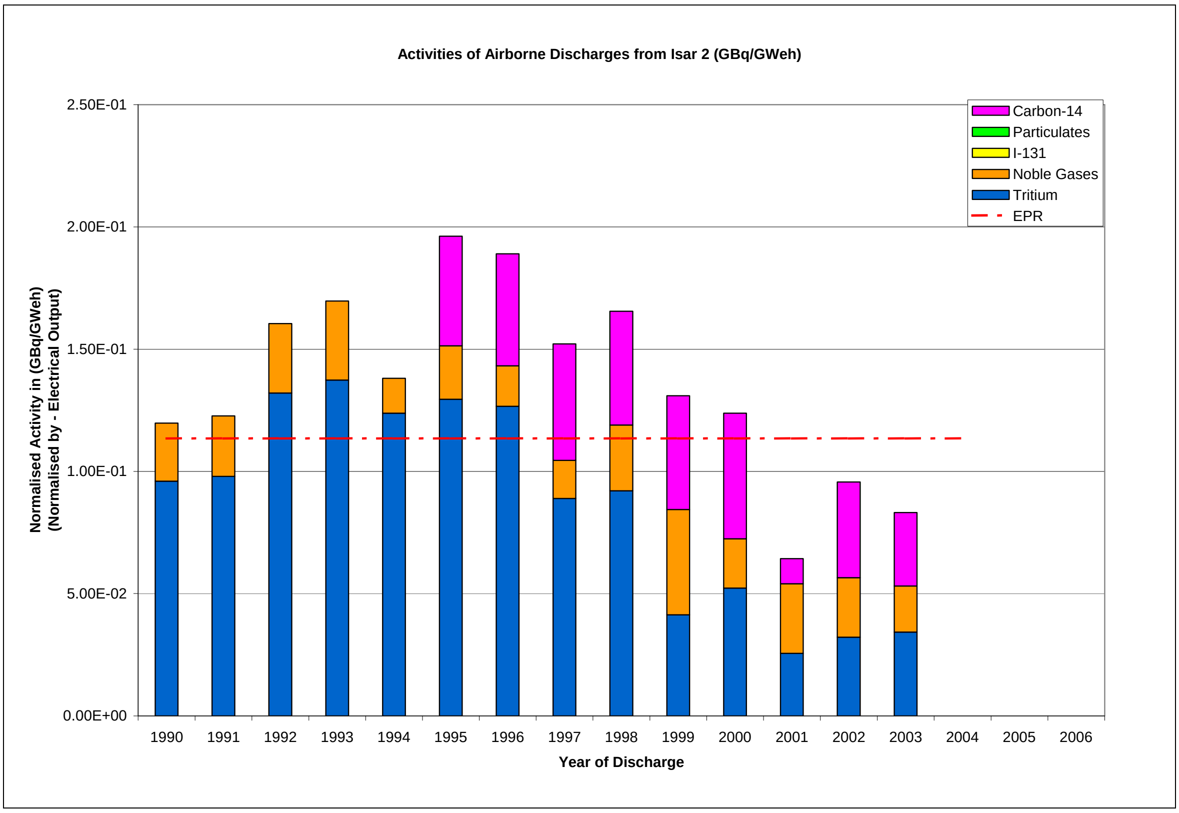

Figure 2.52 Activities of airborne discharges from Isar-2 (GBq/GWeh).

The caveats are that:

- discharge data from the UNSCEAR Report 2000 (Annex C) is reported for 1990–1997;
- recent operating experience feedback (OEF) regarding releases from 1300 MWe units is used as the reference to define the forecast radioactive release values for the new EPR unit.

It should be noted that the above charts lack the following data (due to current information gaps):

- no carbon-14 airborne discharges could be extracted for 1990–1994;
- no airborne particulates discharges could be extracted for 2000–2003;
- no noble gas discharges could be extracted for 2000–2003;
- no halogen discharges could be extracted for 2000–2003;
- no liquid discharges could be extracted for 2004–2006;
- no other liquid discharges could be extracted for 2003;
- no airborne discharges could be extracted for 2004–2006.

2.3 GE-Hitachi ESBWR predecessors

The following stations have been used in this study as predecessors to the proposed new GE-Hitachi ESBWR reactor design:

- Kashiwazaki-Kariwa;
- Shimane;
- Hamaoka;
- Shika;
- Clinton-1;
- Nine Mile Point.

The results for each of these are presented in the following subsections.

2.3.1 ESBWR Predecessor – Kashiwazaki-Kariwa

Charts – liquid discharges (Kashiwazaki-Kariwa, ESBWR)

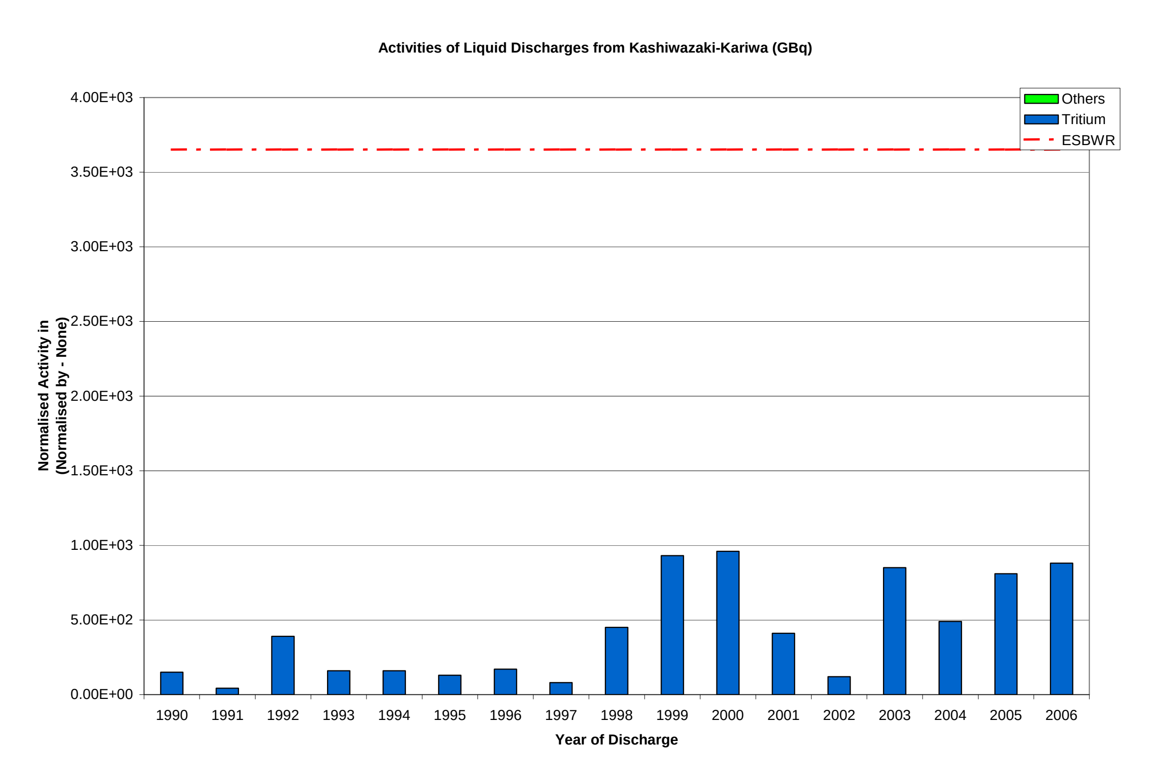

Figure 2.53 Activities of liquid discharges from Kashiwazaki-Kariwa (GBq).

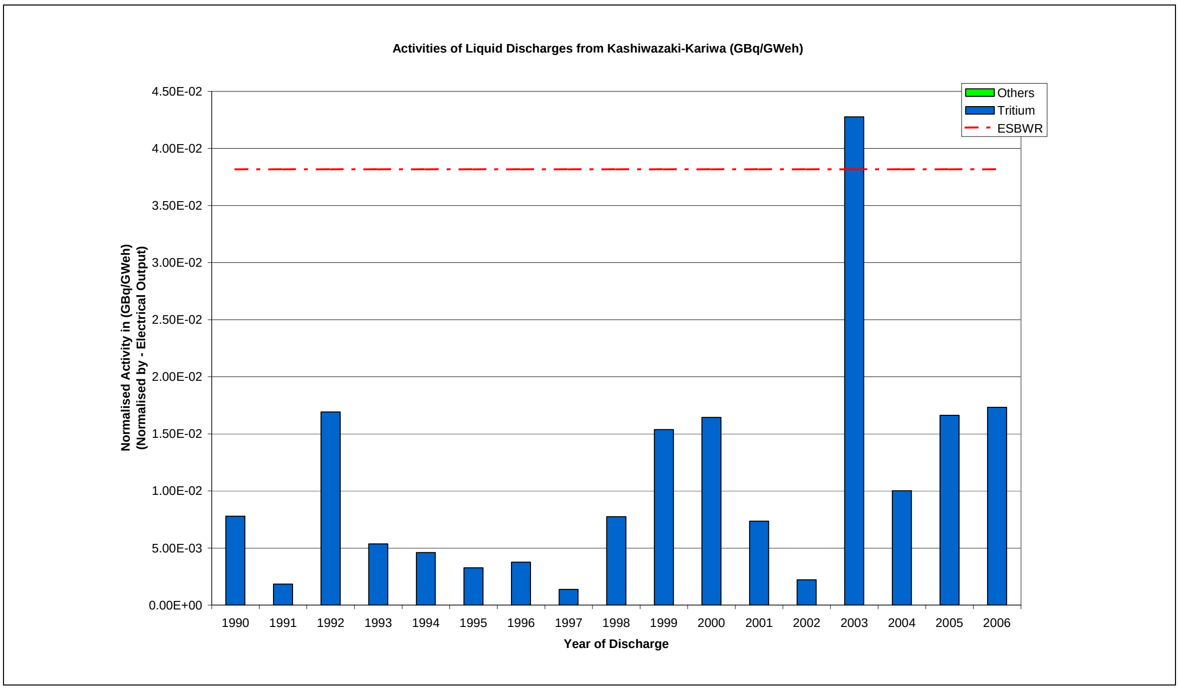

Figure 2.54 Activities of liquid discharges from Kashiwazaki-Kariwa (GBq/GWeh).

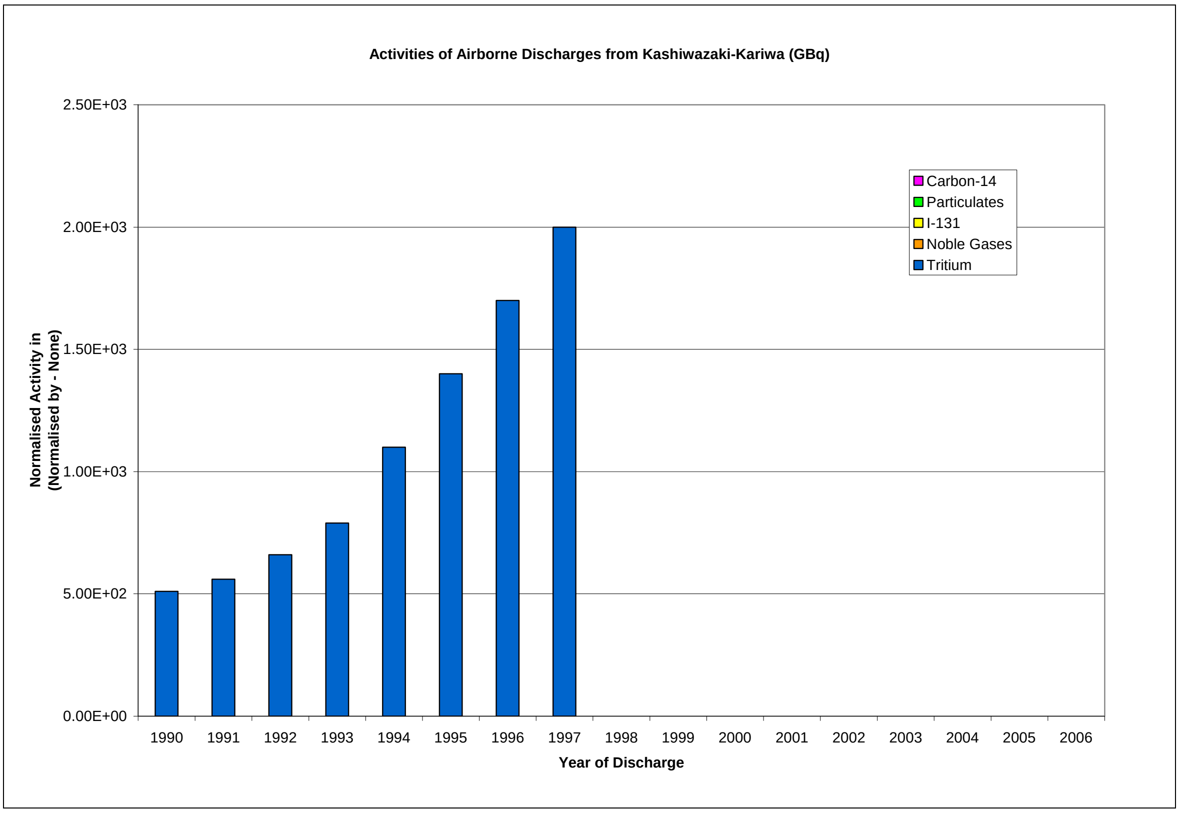

Figure 2.55 Activities of airborne discharges from Kashiwazaki-Kariwa (GBq).

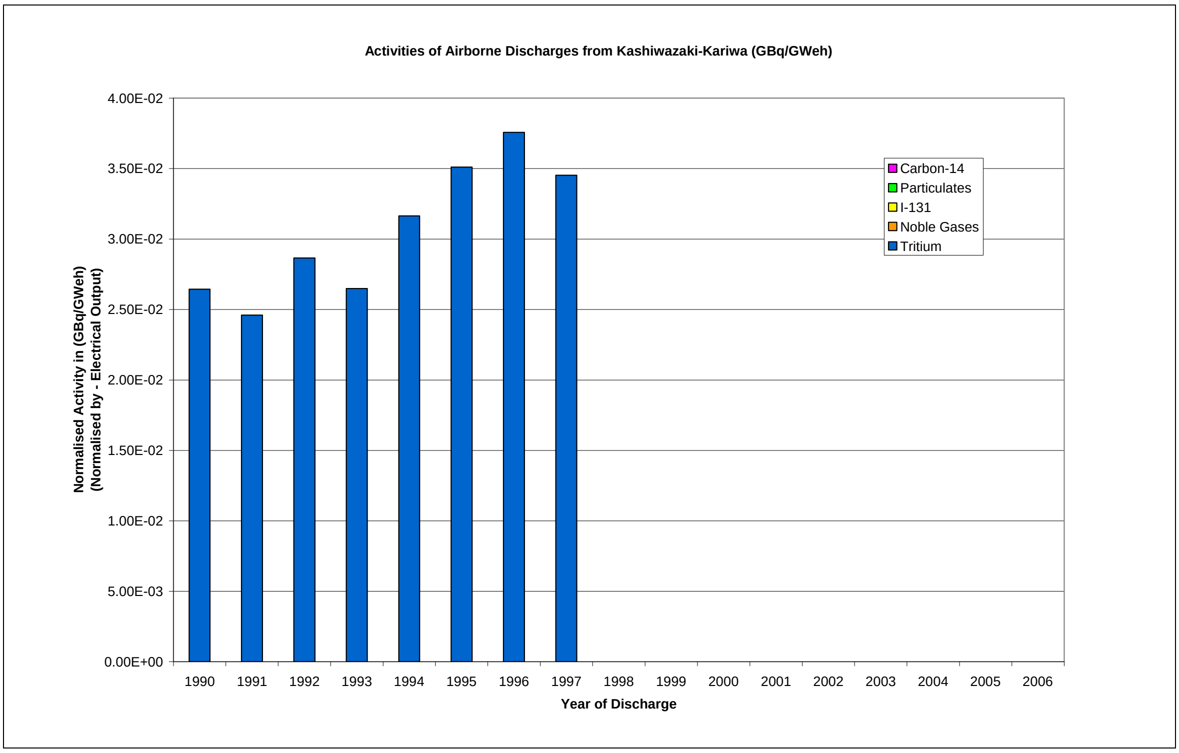

Figure 2.56 Activities of airborne discharges from Kashiwazaki-Kariwa (GBq/GWeh).

The caveats are that:

- the predicted value for airborne discharges from the ESBWR is 1.09E+06 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of actual discharges reported for Kashiwazaki-Kariwa;
- the predicted value for liquid discharges from the ESBWR is 3.65E+03 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of actual discharges reported for Kashiwazaki-Kariwa;
- the predicted electrically normalised value for airborne discharges from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of actual discharges reported for Kashiwazaki-Kariwa.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium data for 1998–2006;
- airborne particulates data for 1998–2006.

2.4 ESBWR predecessor – Shimane

Charts – liquid discharges (Shimane, ESBWR)

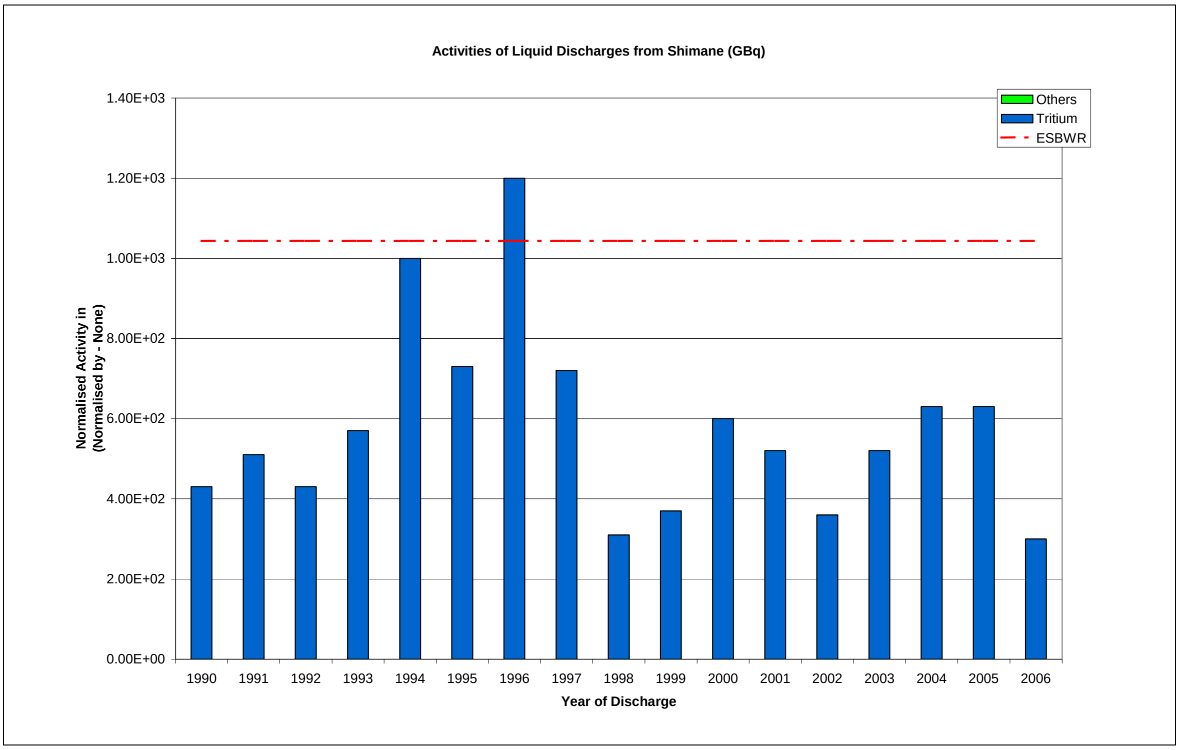

Figure 2.57 Activities of liquid discharges from Shimane (GBq).

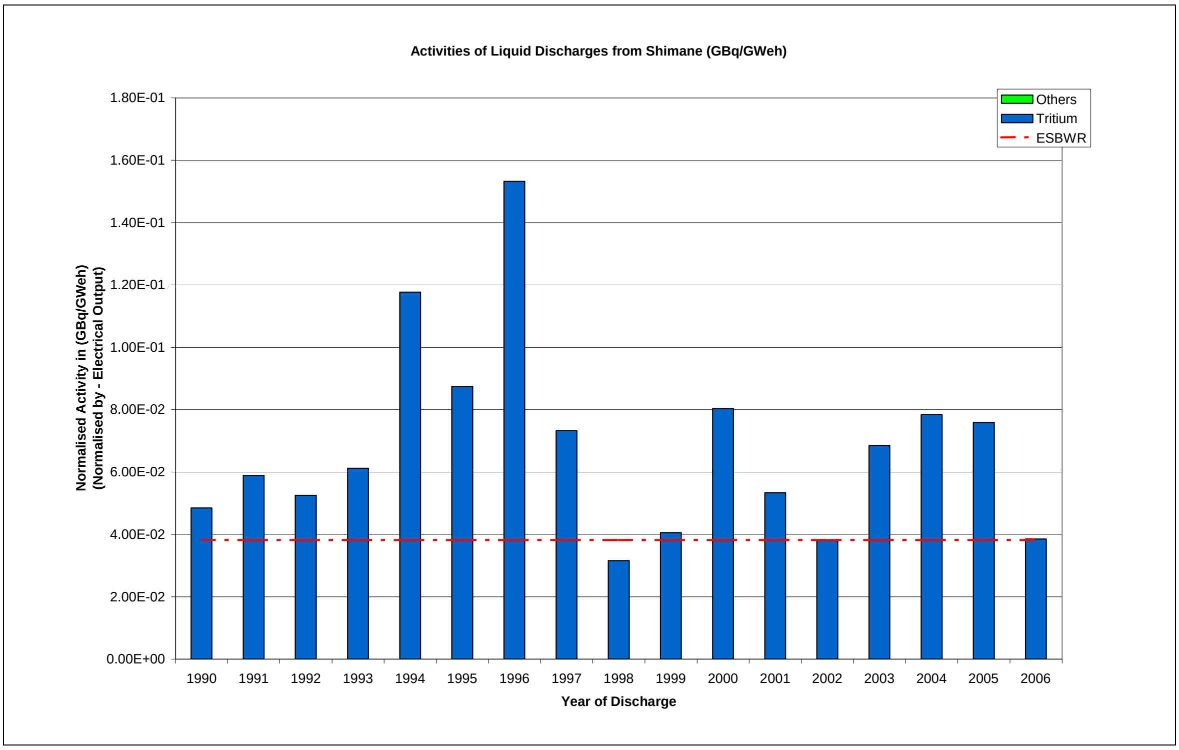

Figure 2.58 Activities of liquid discharges from Shimane (GBq/GWeh).

Charts – airborne discharges (Shimane, ESBWR)

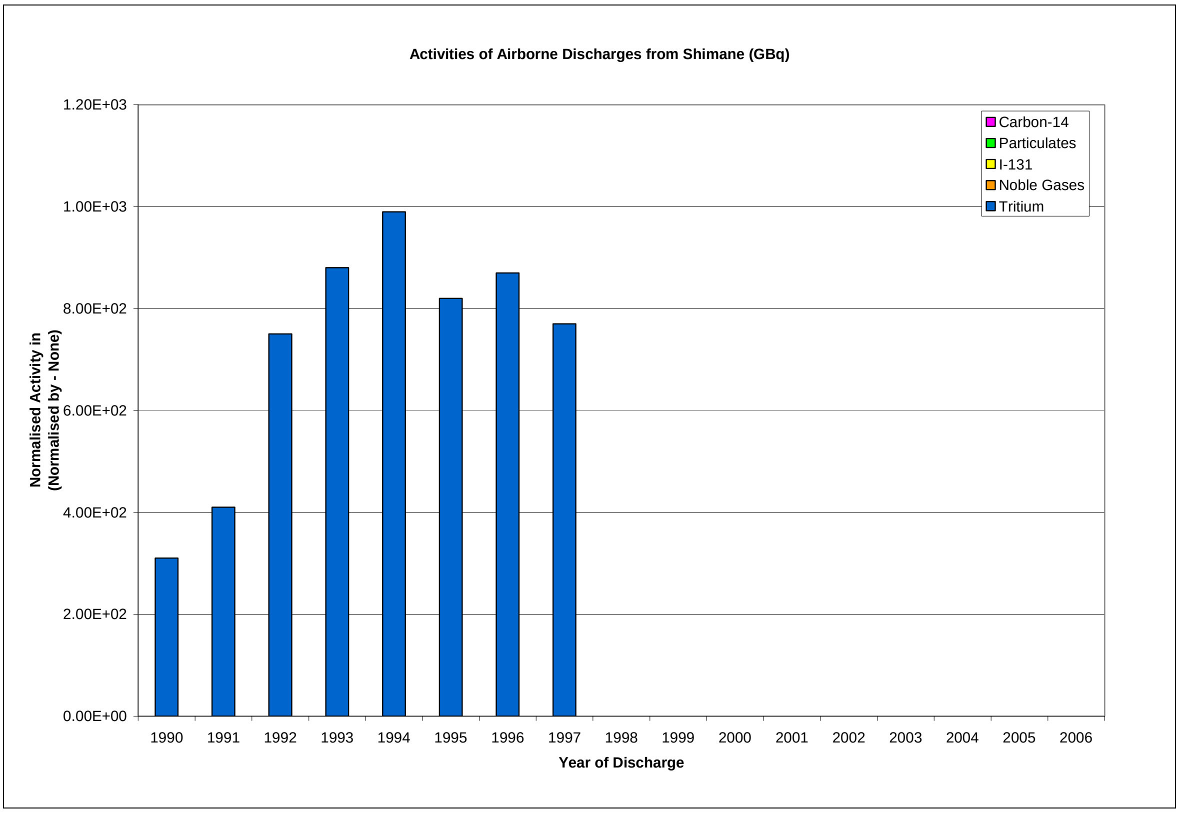

Figure 2.59 Activities of airborne discharges from Shimane (GBq).

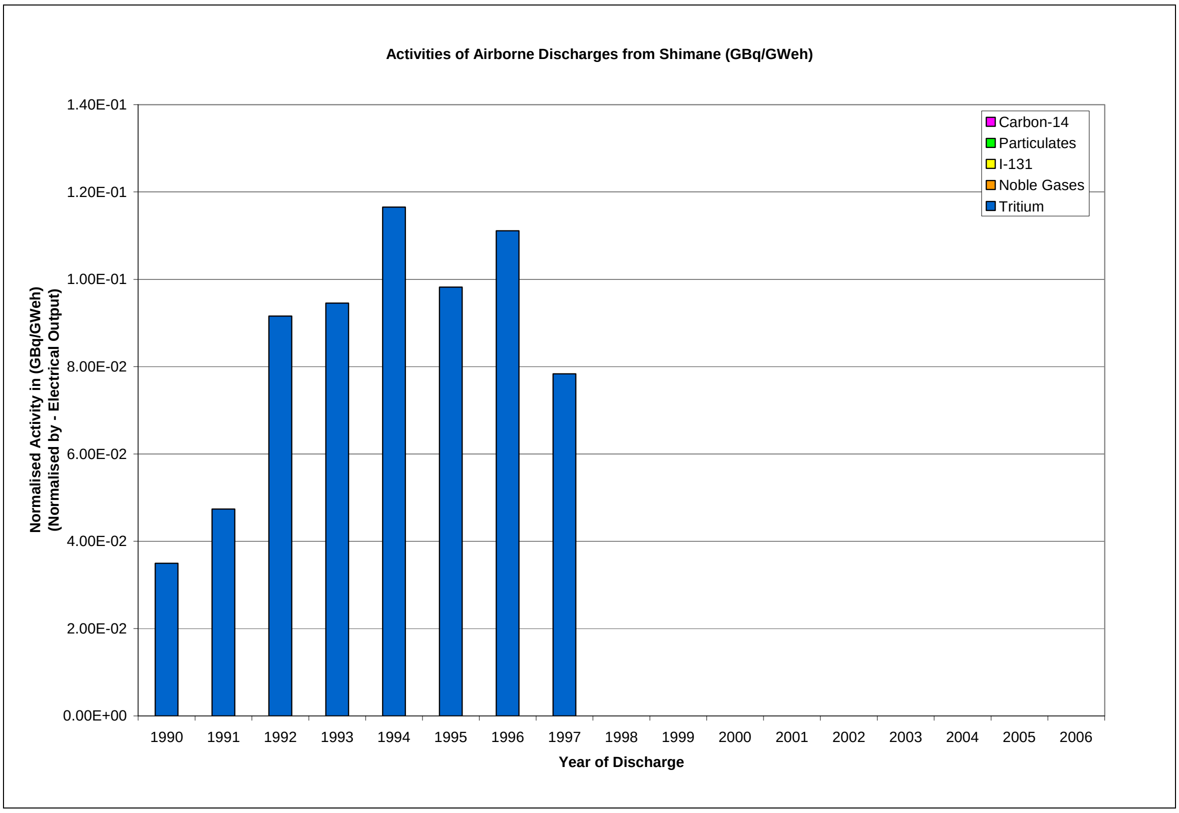

Figure 2.60 Activities of airborne discharges from Shimane (GBq/GWeh).

The caveats are that:

- The predicted value for airborne discharges from the ESBWR is 3.12E+05 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Shimane;
- The predicted electrically normalised value for airborne discharges from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Shimane.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium data for 1998–2006;
- airborne particulates data for 1998–2006.

2.4.1 ESBWR predecessor – Hamaoka

Charts – liquid discharges (Hamaoka, ESBWR)

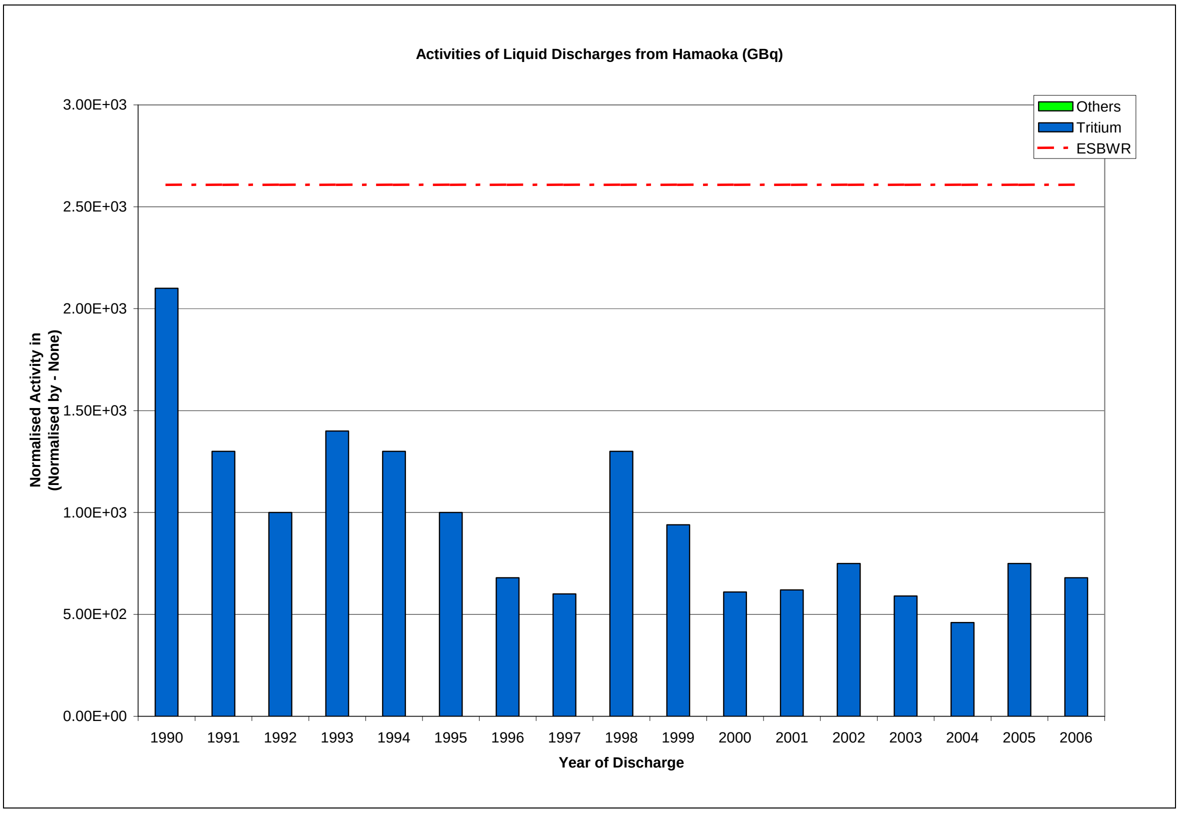

Figure 2.61 Activities of liquid discharges from Hamaoka (GBq).

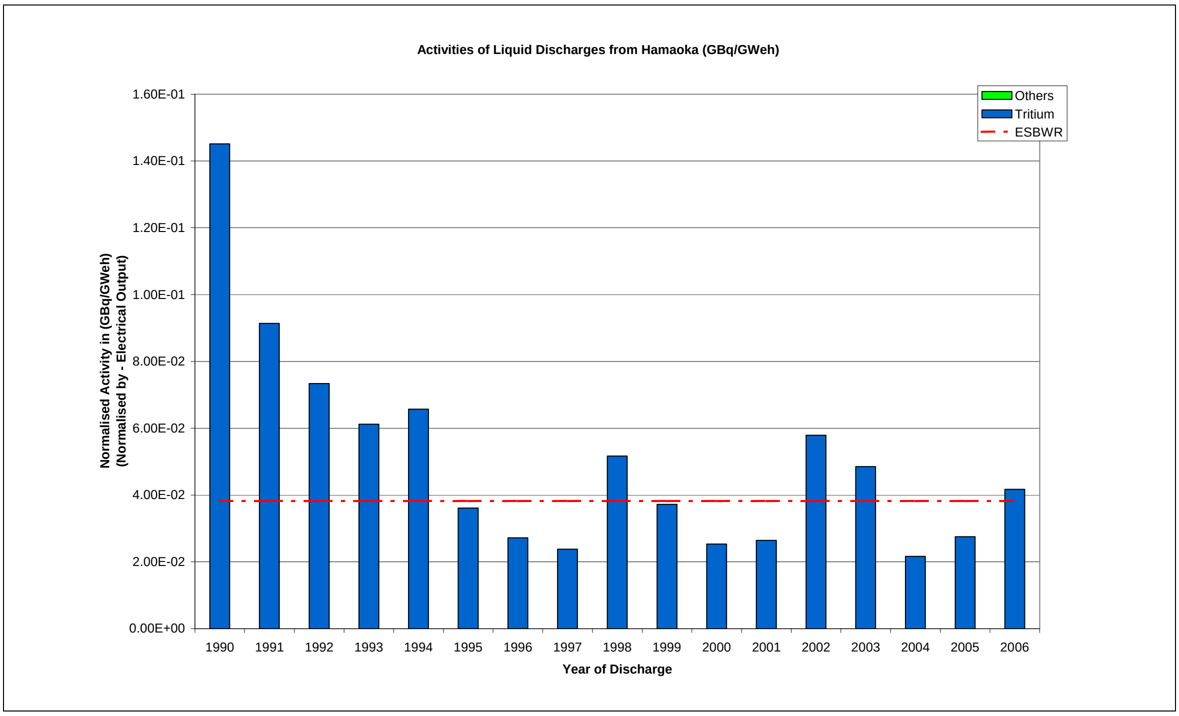

Figure 2.62 Activities of liquid discharges from Hamaoka (GBq/GWeh).

Charts – airborne discharges (Hamaoka, ESBWR)

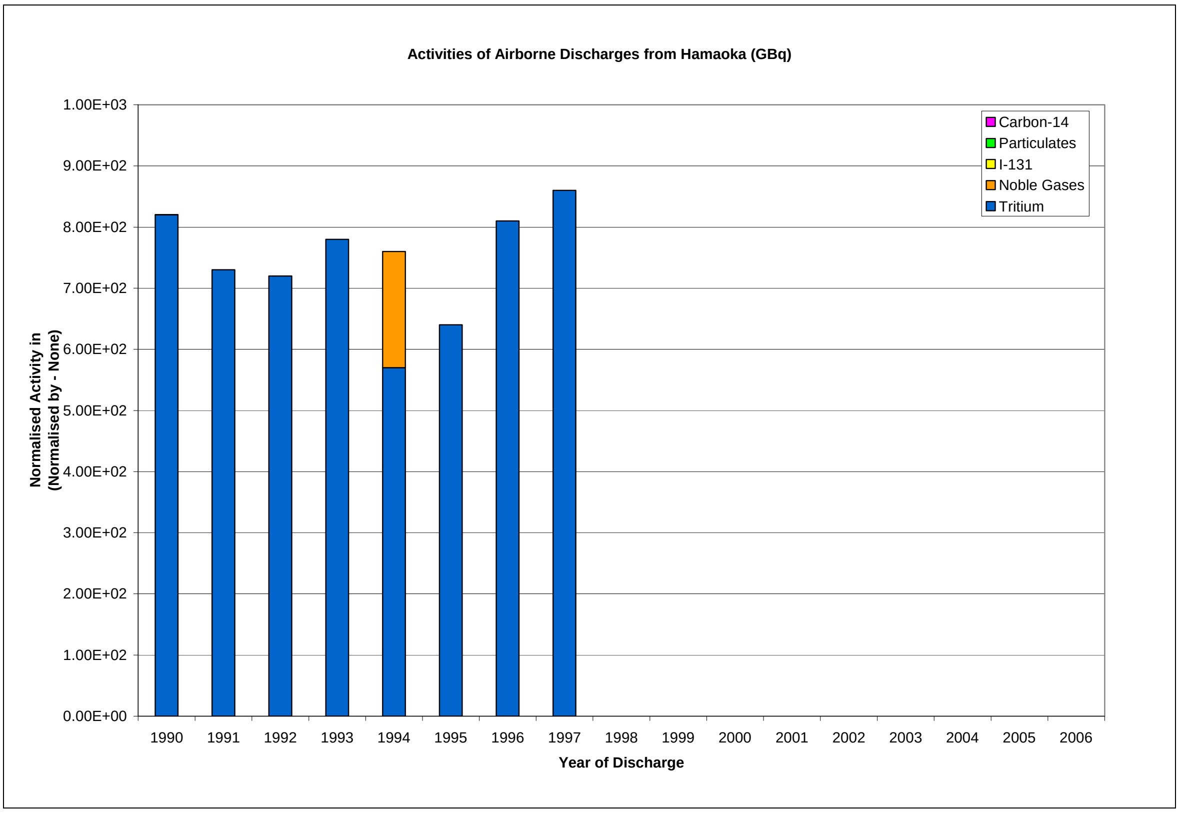

Figure 2.63 Activities of airborne discharges from Hamaoka (GBq).

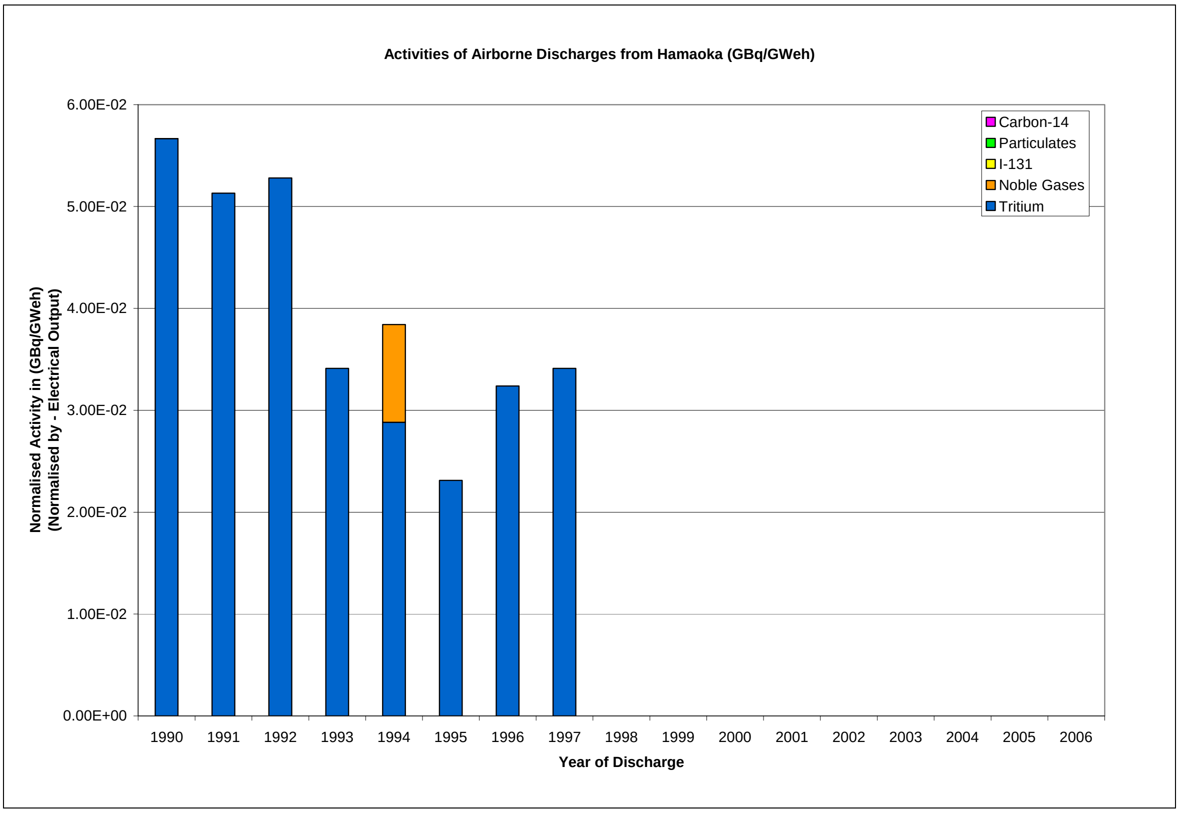

Figure 2.64 Activities of airborne discharges from Hamaoka (GBq/GWeh).

The caveats are that:

- The predicted value for airborne discharges from the ESBWR is 7.81E+05 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Hamaoka;
- The predicted electrically normalised value for airborne discharges from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Hamaoka.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium data for 1998–2006;
- airborne particulates data for 1998–2006.

2.4.2 ESBWR predecessor – Shika

Charts – liquid discharges (Shika, ESBWR)

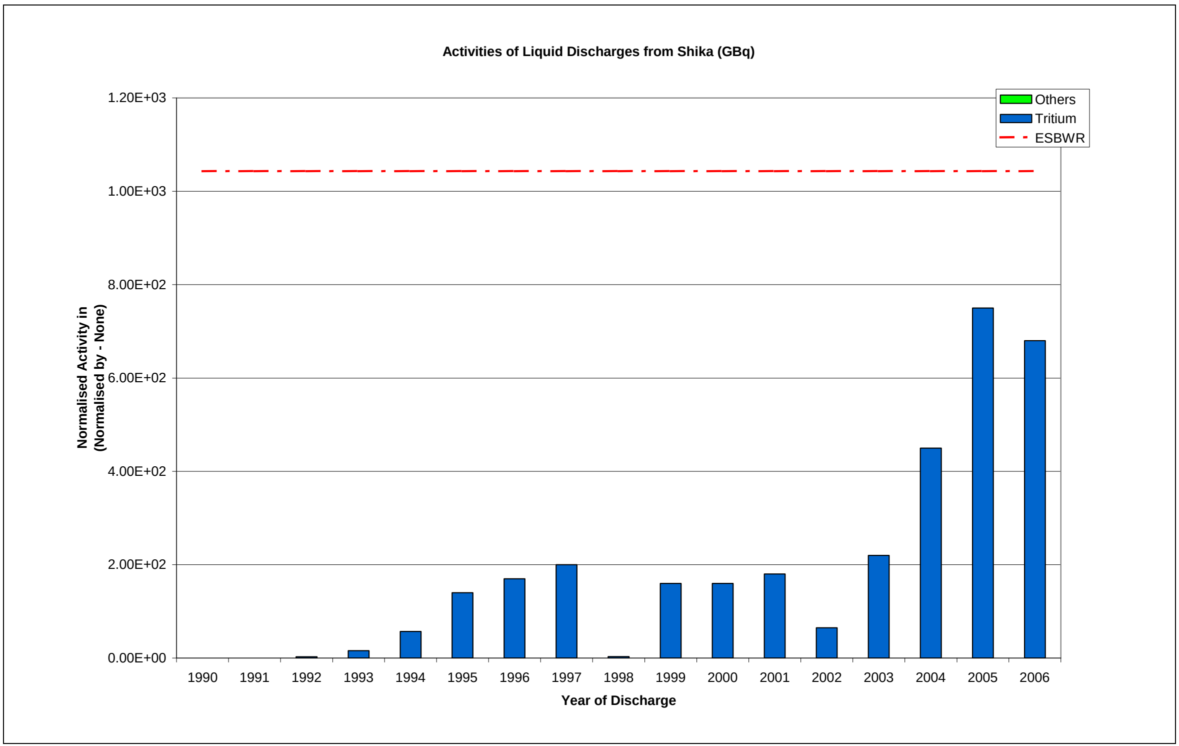

Figure 2.65 Activities of liquid discharges from Shika (GBq).

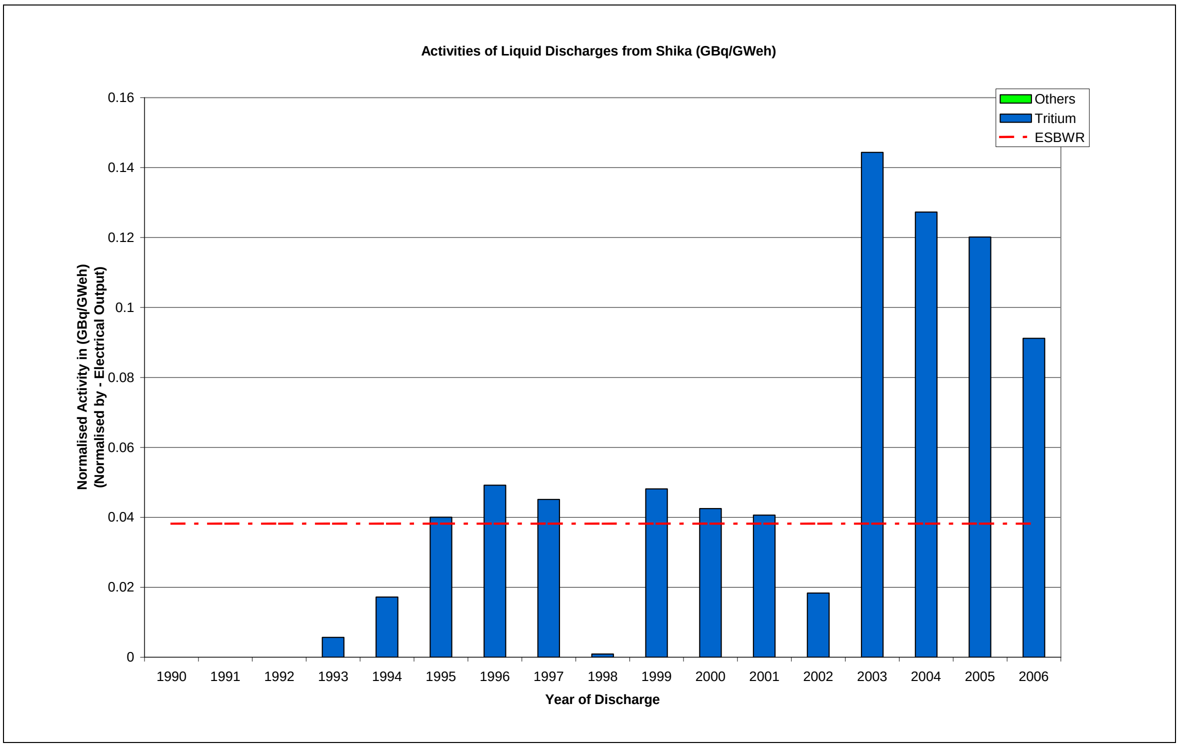

Figure 2.66 Activities of liquid discharges from Shika (GBq/GWeh).

Charts – airborne discharges (Shika, ESBWR)

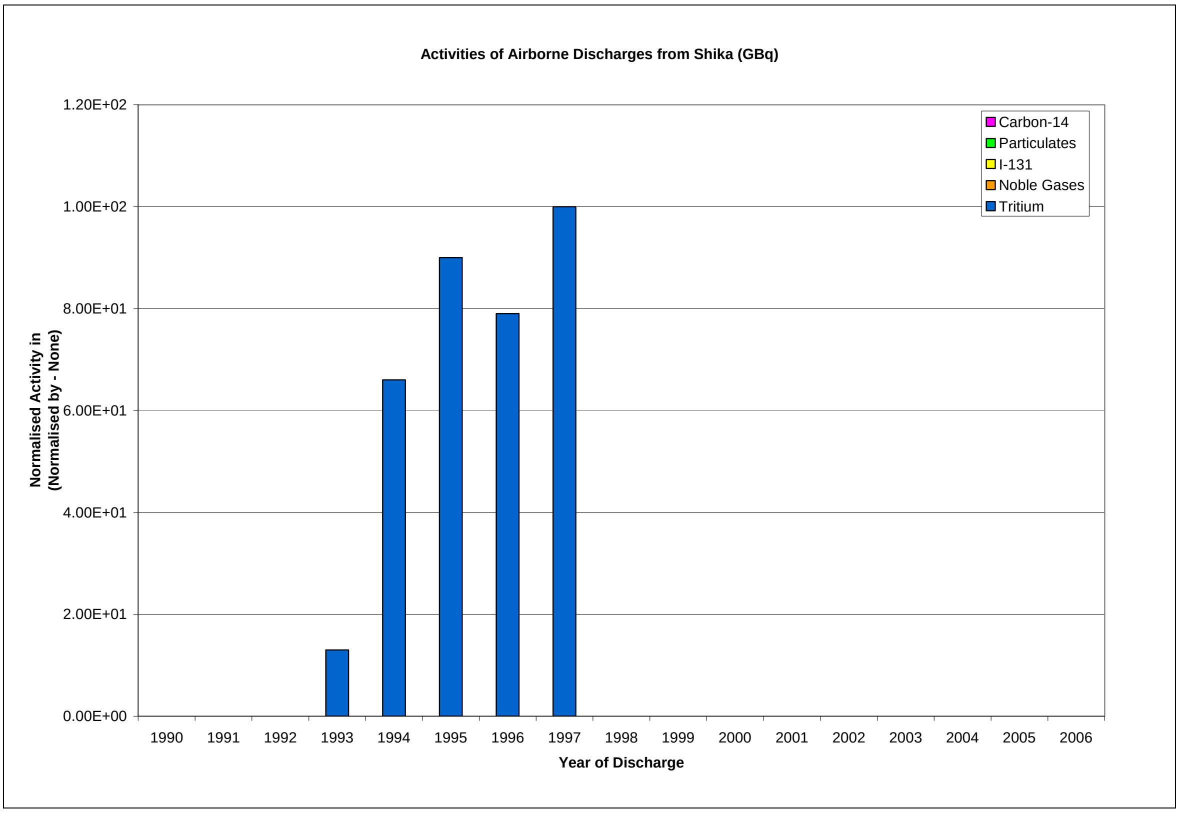

Figure 2.67 Activities of airborne discharges from Shika (GBq).

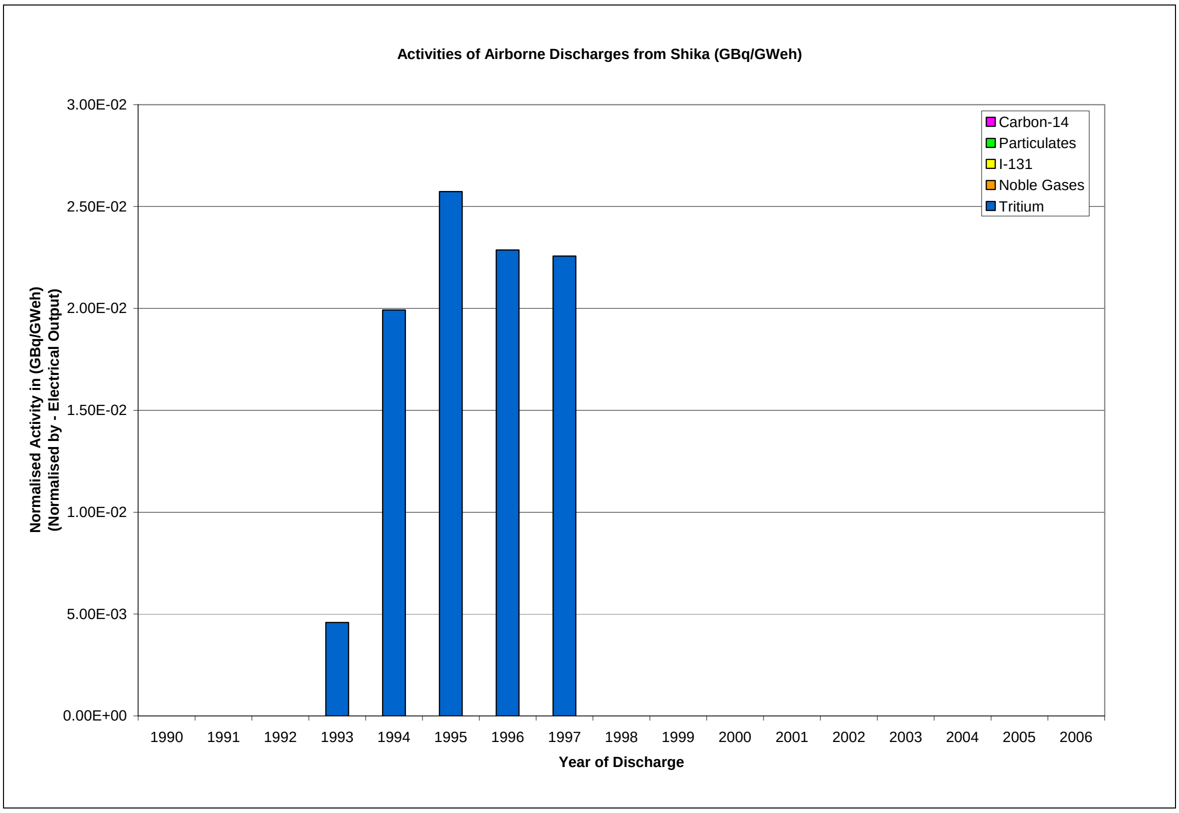

Figure 2.68 Activities of airborne discharges from Shika (GBq/GWeh).

The caveats are that:

- the predicted value for airborne discharges from the ESBWR is 3.12E+05 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Shika;
- the predicted electrically normalised value for airborne discharges from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Shika.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium data for 1998–2006;
- airborne particulates data for 1998–2006.

2.4.3 ESBWR predecessor – Clinton-1

Charts – liquid discharges (Clinton-1, ESBWR)

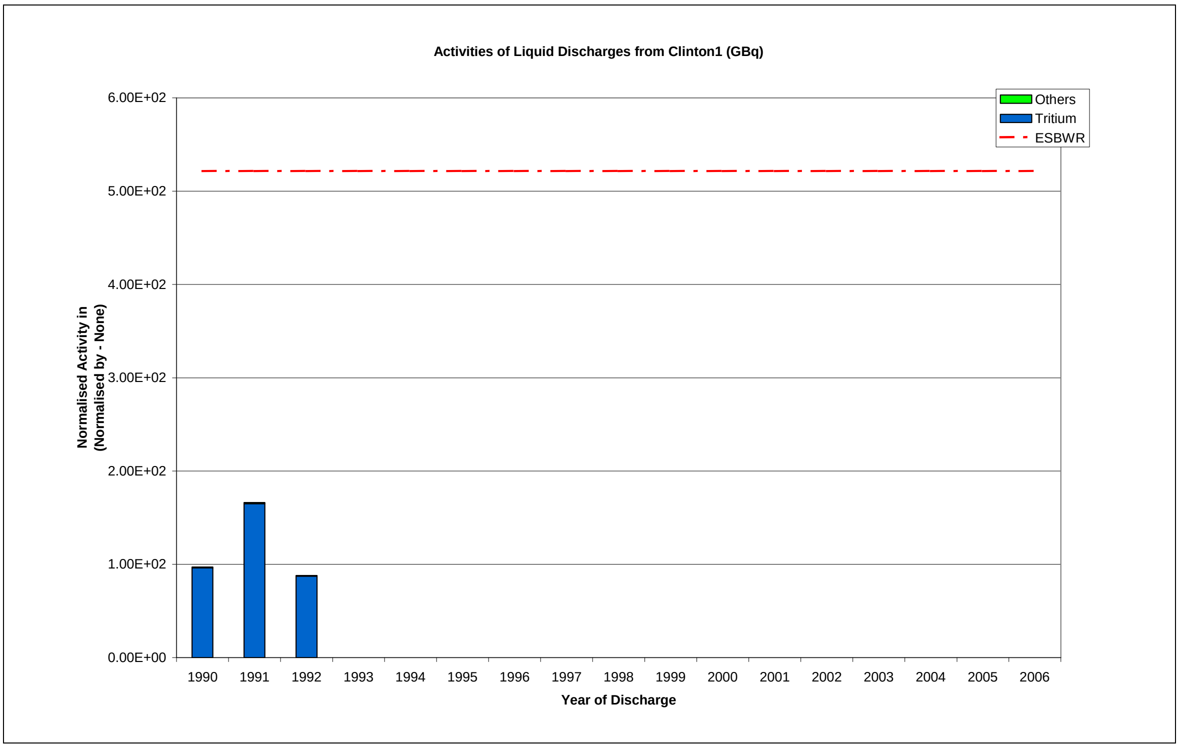

Figure 2.69 Activities of liquid discharges from Clinton-1 (GBq).

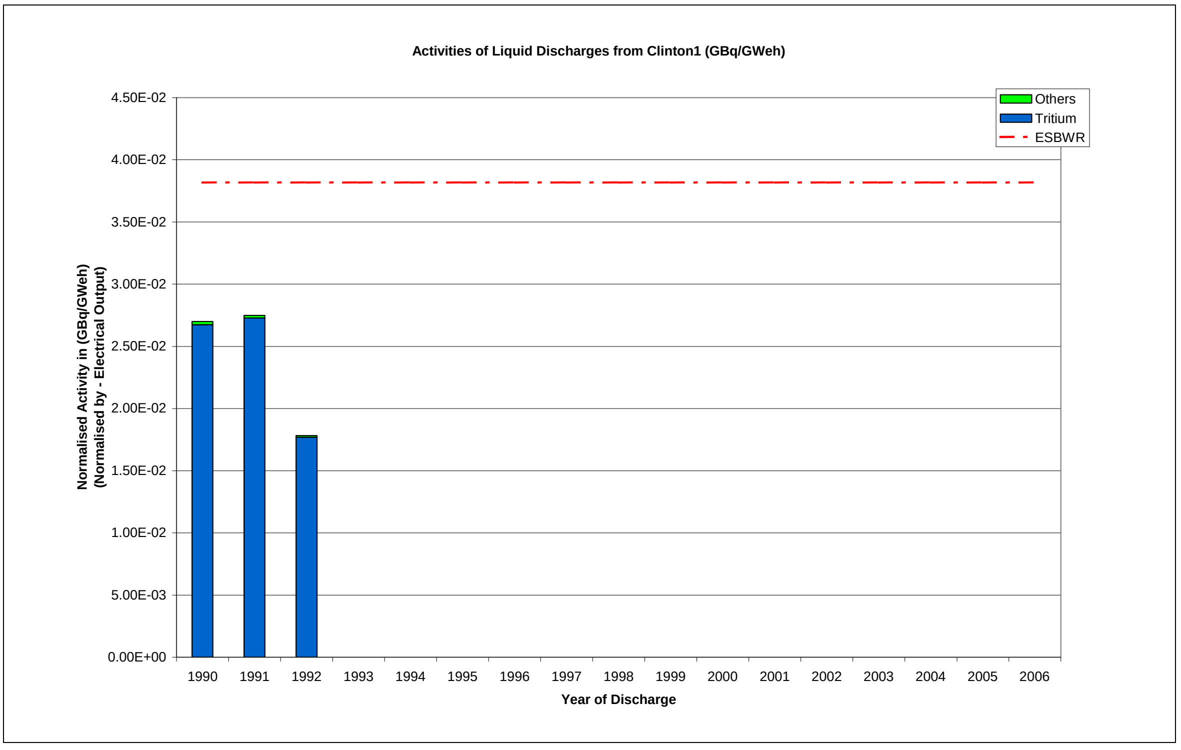

Figure 2.70 Activities of liquid discharges from Clinton-1 (GBq/GWeh).

Charts – airborne discharges (Clinton-1, ESBWR)

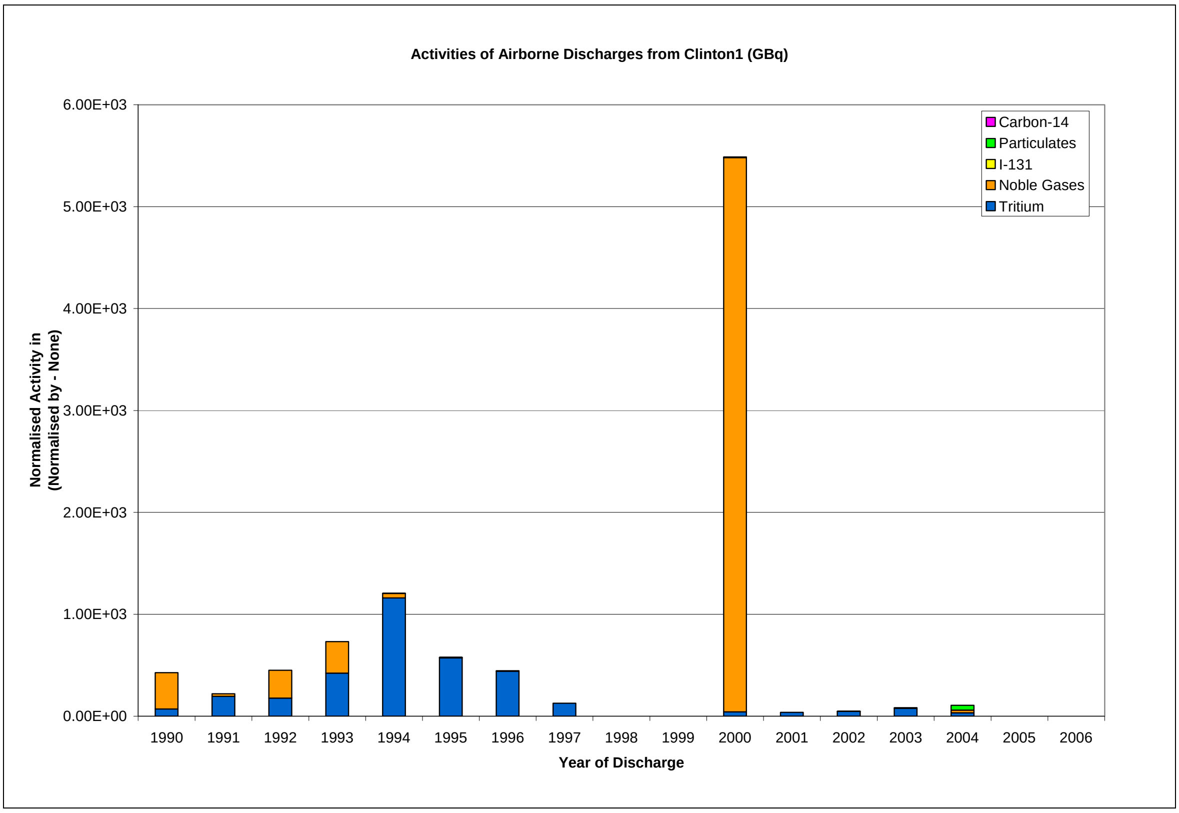

Figure 2.71 Activities of airborne discharges from Clinton-1 (GBq).

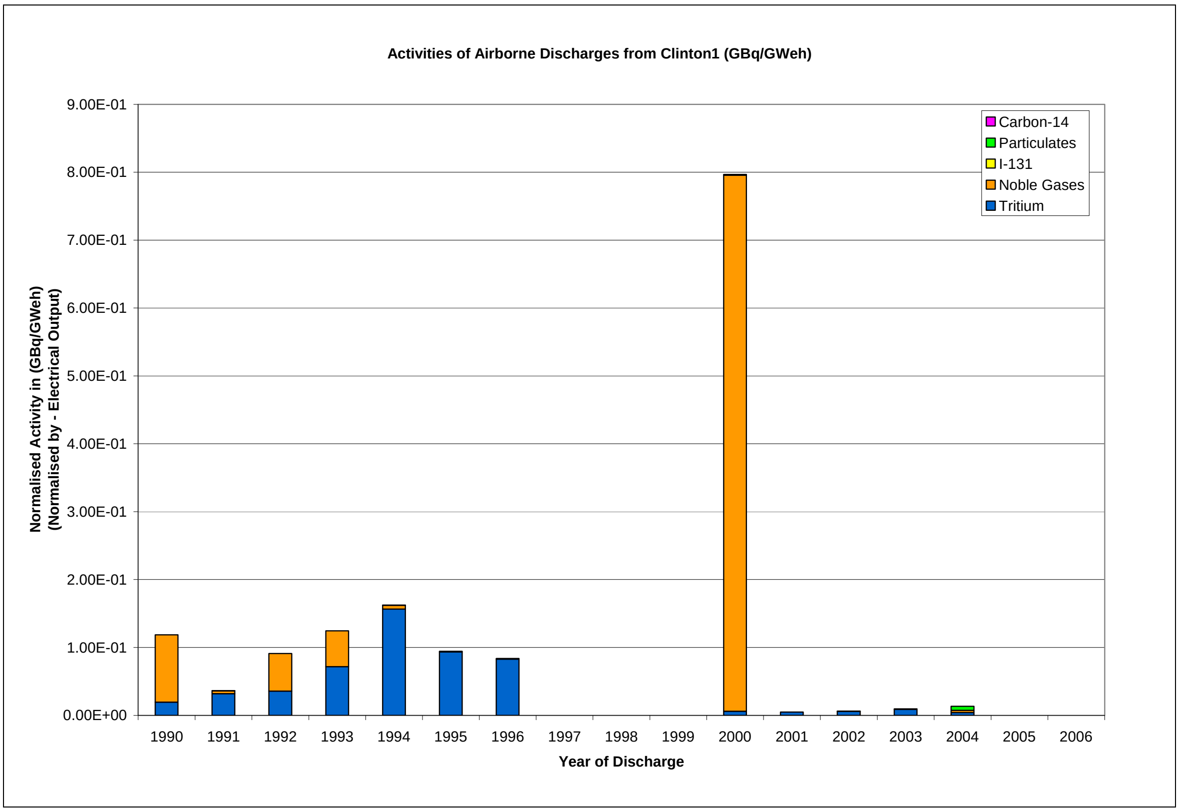

Figure 2.72 Activities of airborne discharges from Clinton-1 (GBq/GWeh).

The caveats are that:

- the predicted value for airborne discharges from the ESBWR is 156 TBq/a, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Clinton-1;
- the predicted normalised value for airborne discharges with respect to electrical outputs from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Clinton-1.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium, noble gases, halogens, halogens (other), particulates and tritium (elemental) data for the years 1998–1999 and 2005–2006;
- liquid tritium and other for the periods 1998–2000, 2003, and 2005–2006.

2.4.4 ESBWR predecessor – Nine Mile Point-1 and -2

Charts – liquid discharges (Nine Mile Point-1 and -2, ESBWR)

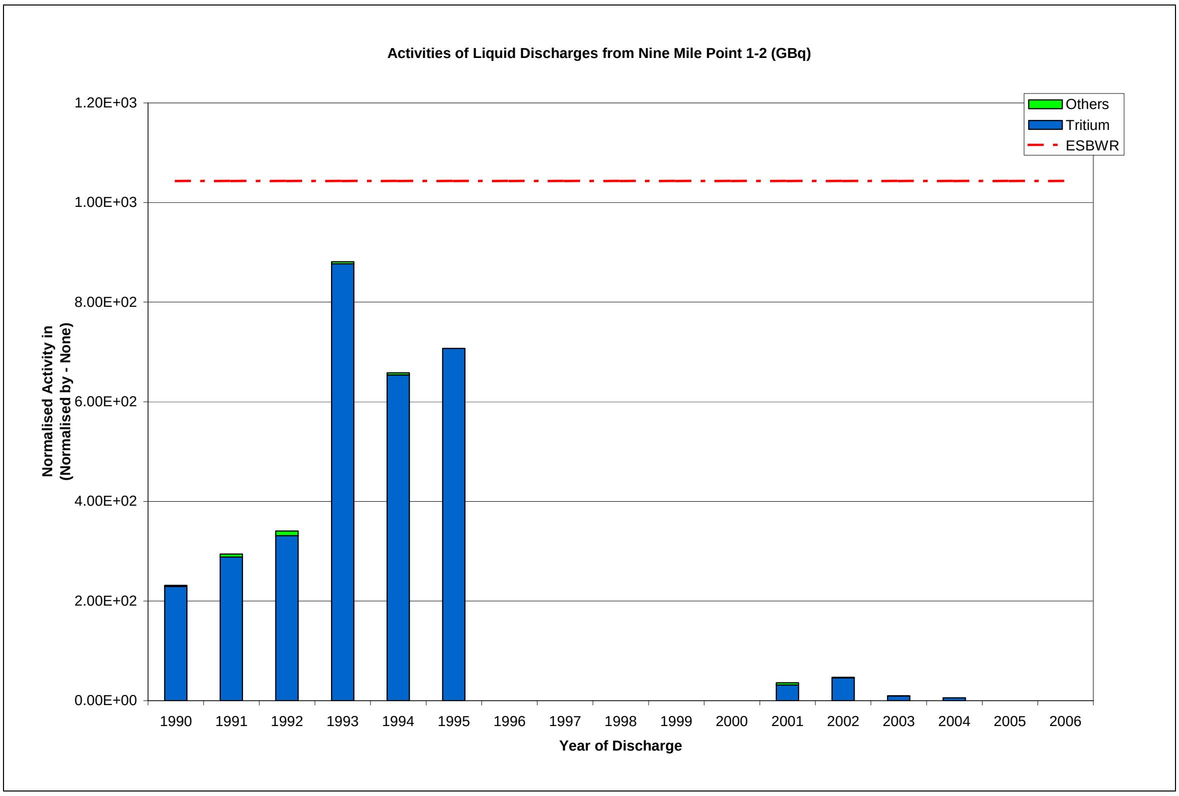

Figure 2.73 Activities of liquid discharges from Nine Mile Point (GBq).

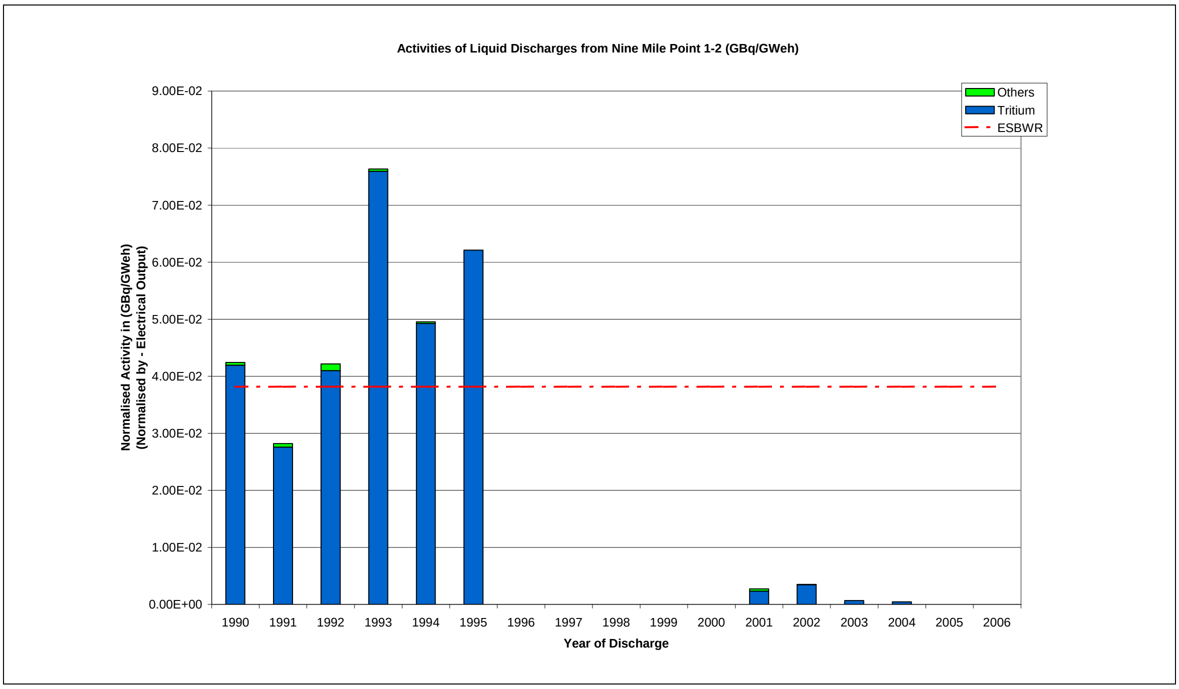

Figure 2.74 Activities of liquid discharges from Nine Mile Point (GBq/GWeh).

Charts – airborne discharges (Nine Mile Point-1 and -2, ESBWR)

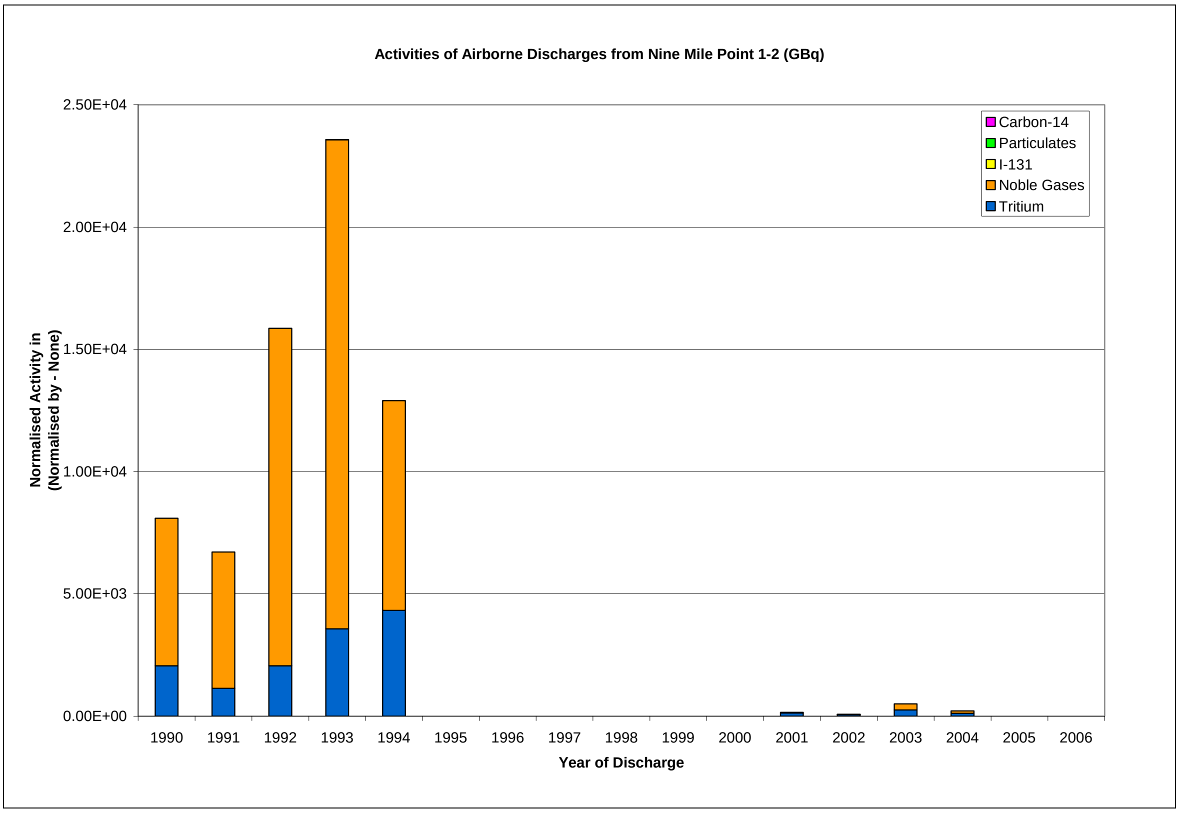

Figure 2.75 Activities of airborne discharges from Nine Mile Point (GBq).

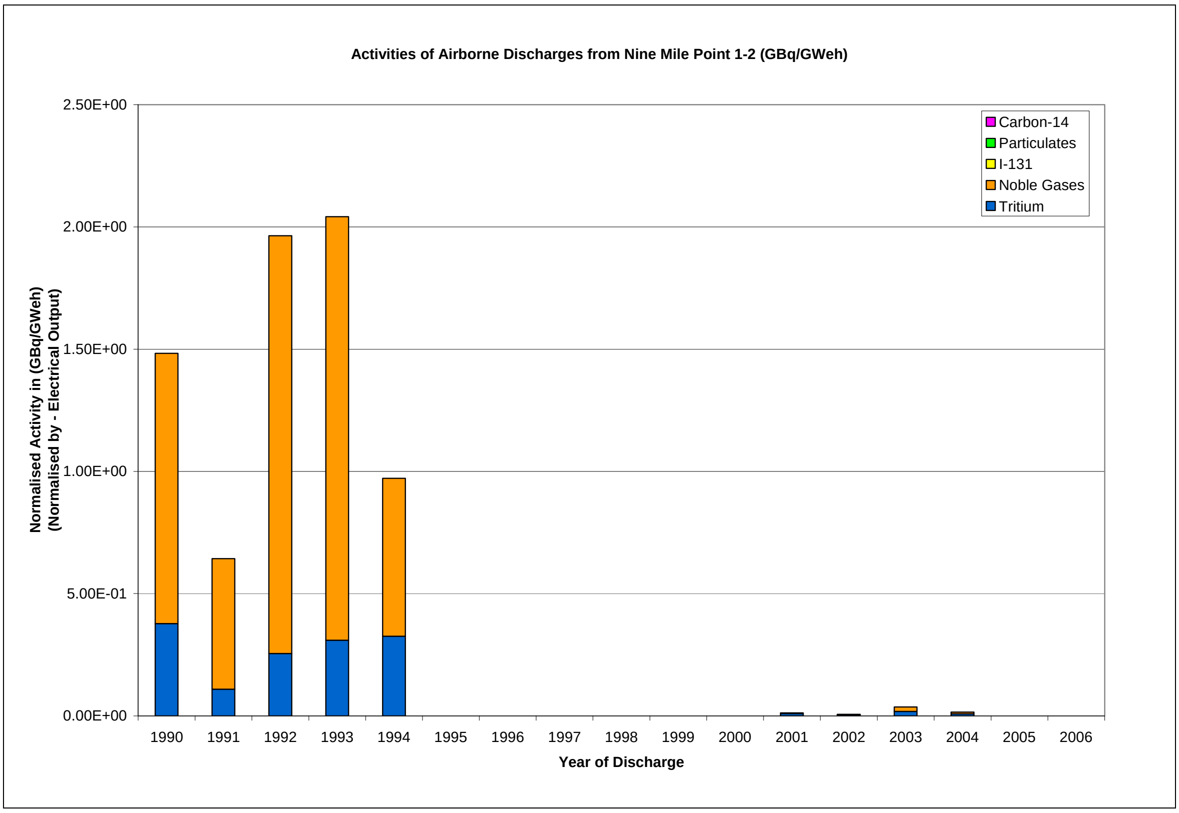

Figure 2.76 Activities of airborne discharges from Nine Mile Point (GBq/GWeh).

The caveats are that:

- the predicted value for airborne discharges from the ESBWR is 3.12E+05 GBq/a, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Nine Mile Point;
- the predicted normalised discharge for airborne discharges with respect to the electrical outputs from the ESBWR is 11.4 GBq/GWeh, but it is not indicated on the chart above due to the comparatively small activities of the actual discharges reported for Nine Mile Point.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data;
- airborne tritium, noble gases, halogens, halogens (other), particulates and tritium (elemental) data for the years 1998–1999 and 2005–2006;
- liquid tritium and other for the years 1998–2000 and 2005–2006.

2.5 AECL ACR-1000 predecessors

The following stations have been used in this study as predecessors to the proposed new AECL ACR-1000 reactor design:

- Bruce A;
- Bruce B;
- Gentilly-2;
- Pickering A;
- Pickering B;
- Point Lepreau;
- Darlington.

The results for each of these are presented in the following subsections.

Although the Cernavoda station in Romania was considered as a candidate reactor station in the main report, no discharge data was collated, as the information was not available.

2.5.1 ACR-1000 predecessor – Bruce A

Charts – liquid discharges (Bruce A, ACR-1000)

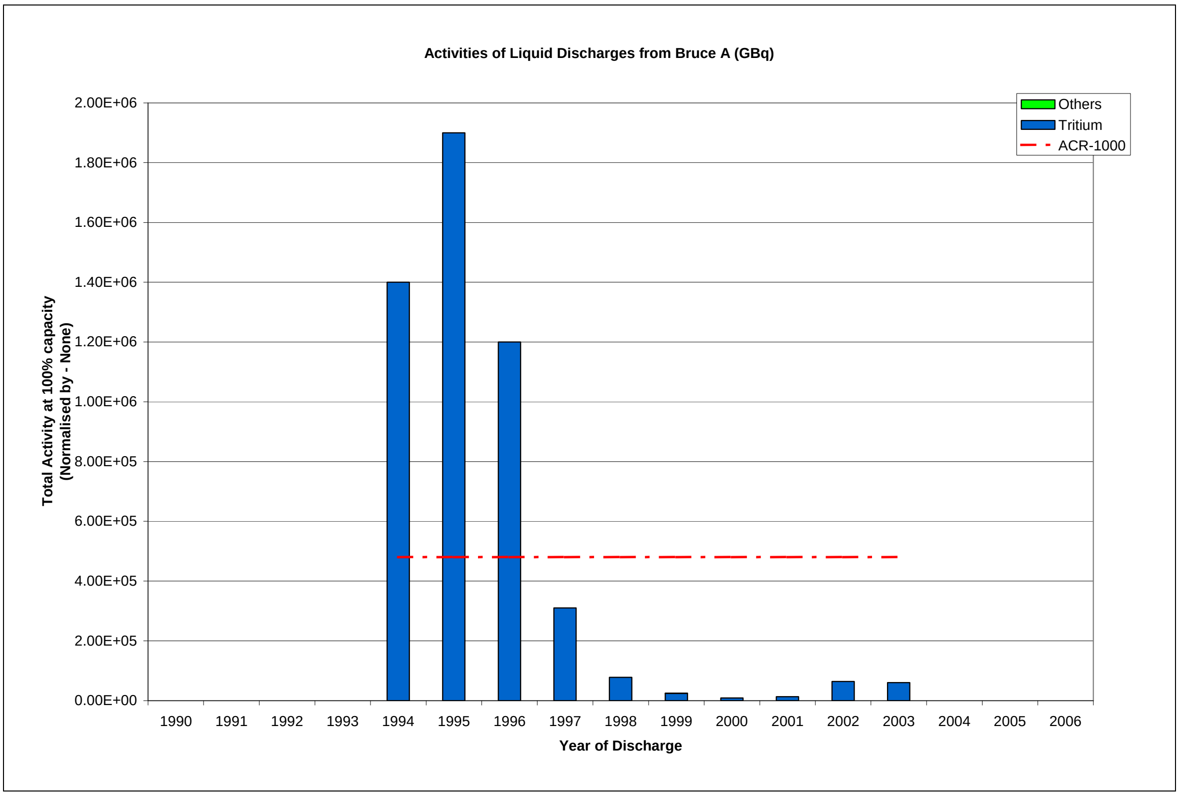

Figure 2.77 Activities of liquid discharges from Bruce A (GBq).

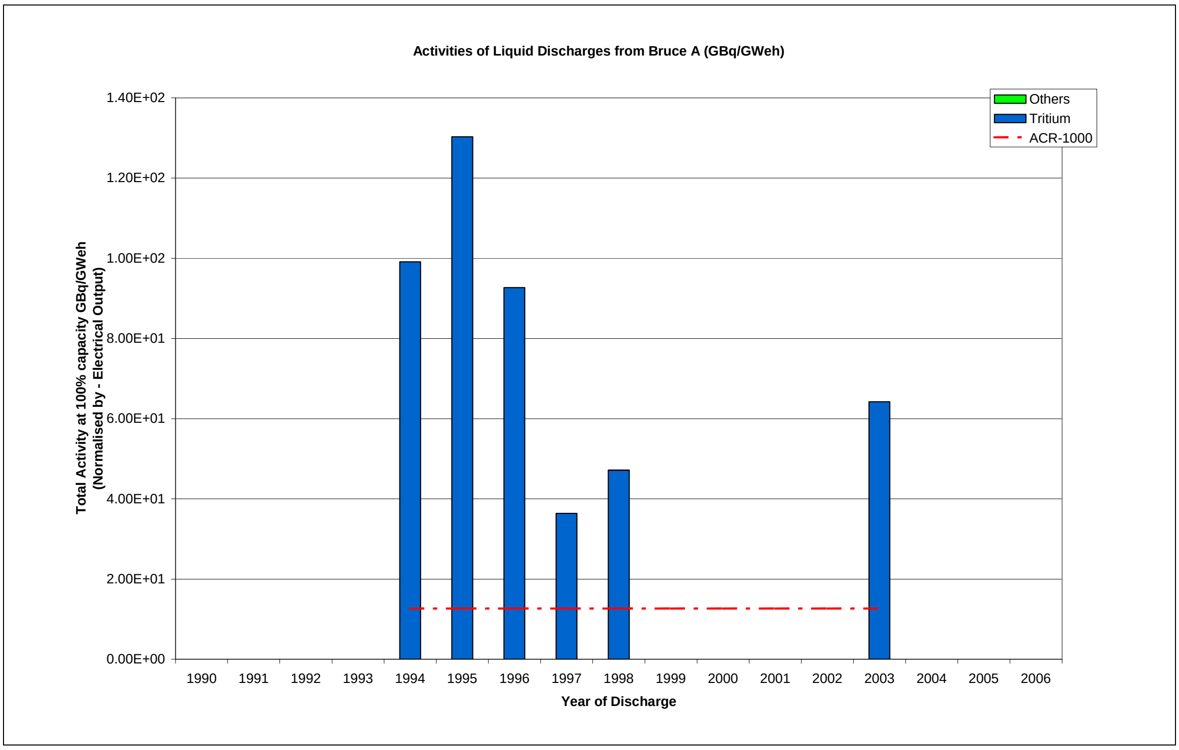

Figure 2.78 Activities of liquid discharges from Bruce A (GBq/GWeh).

Charts – airborne discharges (Bruce A, ACR-1000)

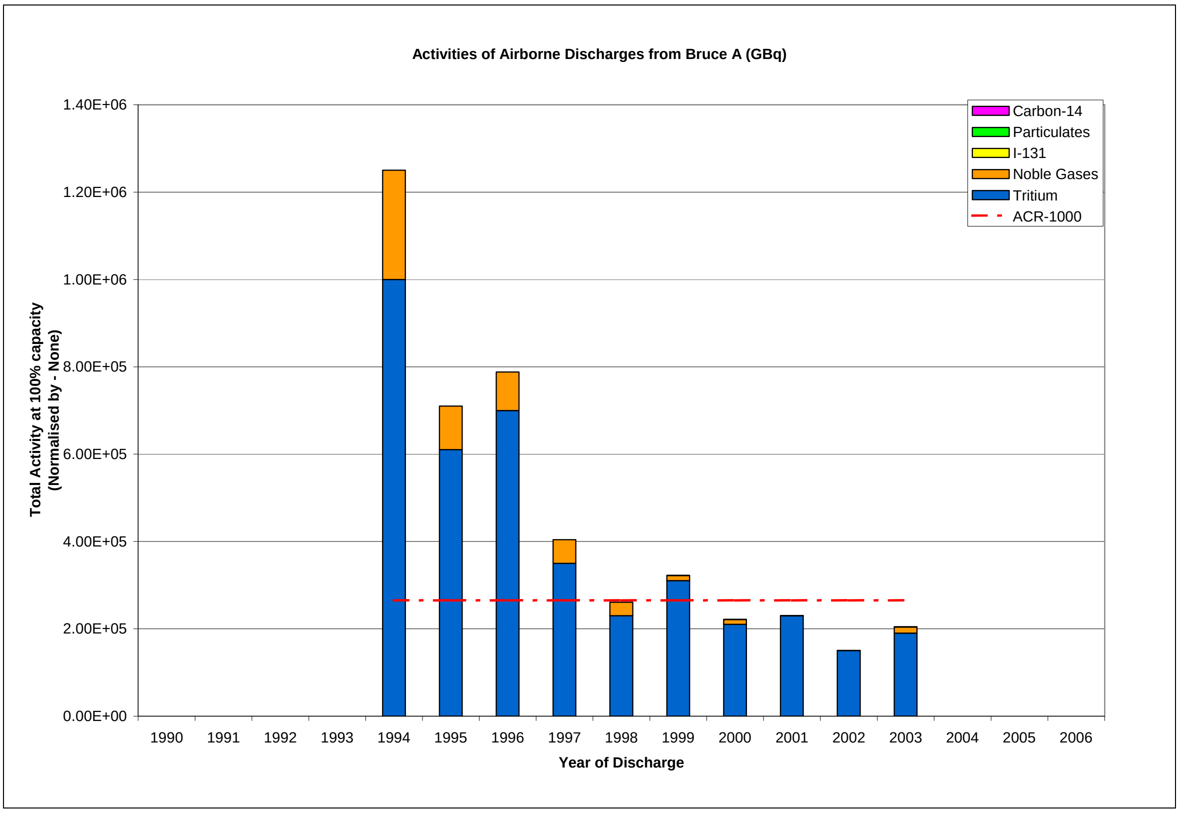

Figure 2.79 Activities of airborne discharges from Bruce A (GBq).

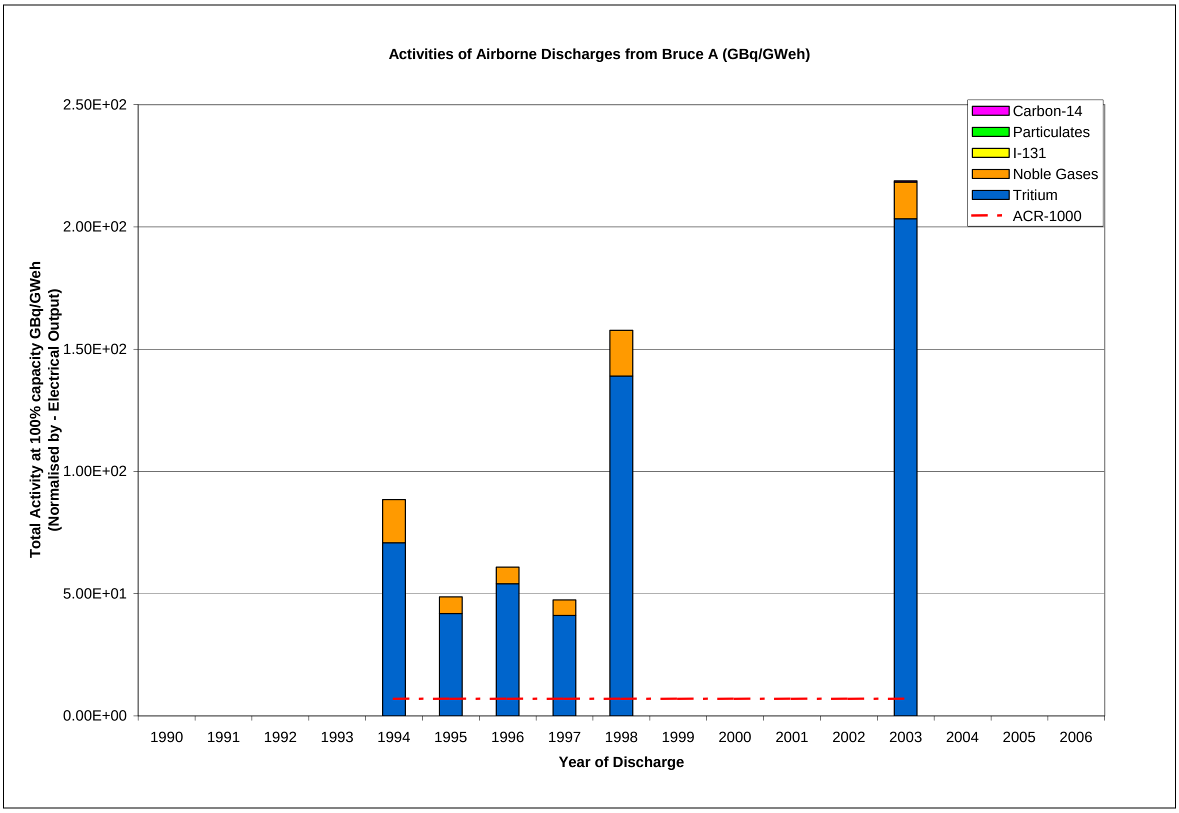

Figure 2.80 Activities of airborne discharges from Bruce A (GBq/GWeh).

The caveats to be taken into account are:

- carbon-14 data are only reported for some years;
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the charts above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the above charts lack the following data (due to current information gaps):

- liquid carbon-14 data for 1994–1998;
- airborne carbon-14 data for 1994–1998;
- predicted airborne particulates data for the ACR-1000.

2.5.2 ACR-1000 predecessor – Bruce B

Charts – liquid discharges (Bruce B, ACR-1000)

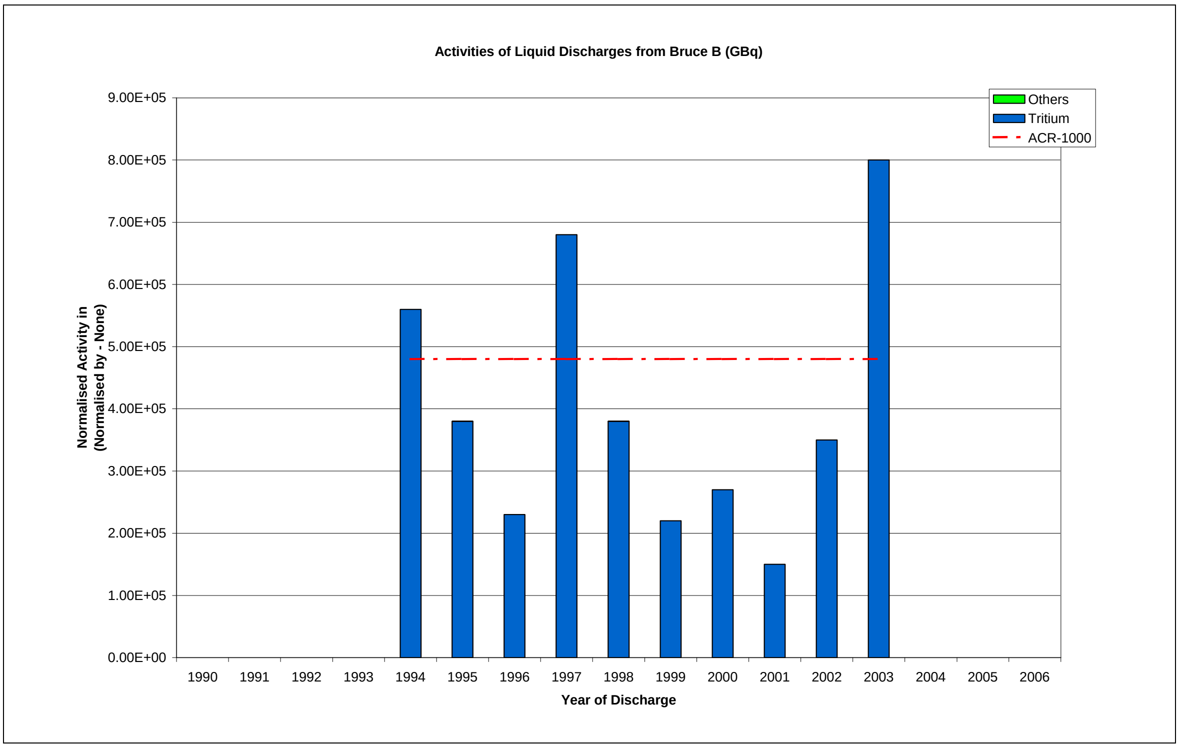

Figure 2.81 Activities of liquid discharges from Bruce B (GBq).

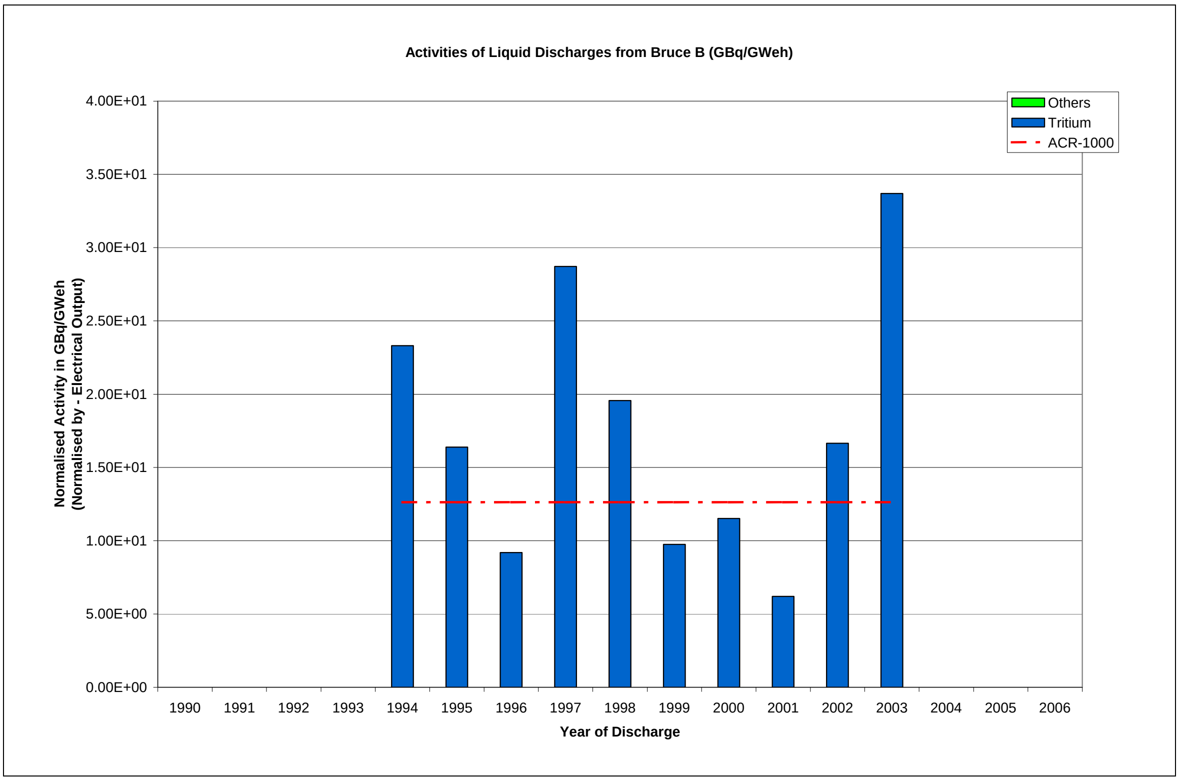

Figure 2.82 Activities of liquid discharges from Bruce B (GBq/GWeh).

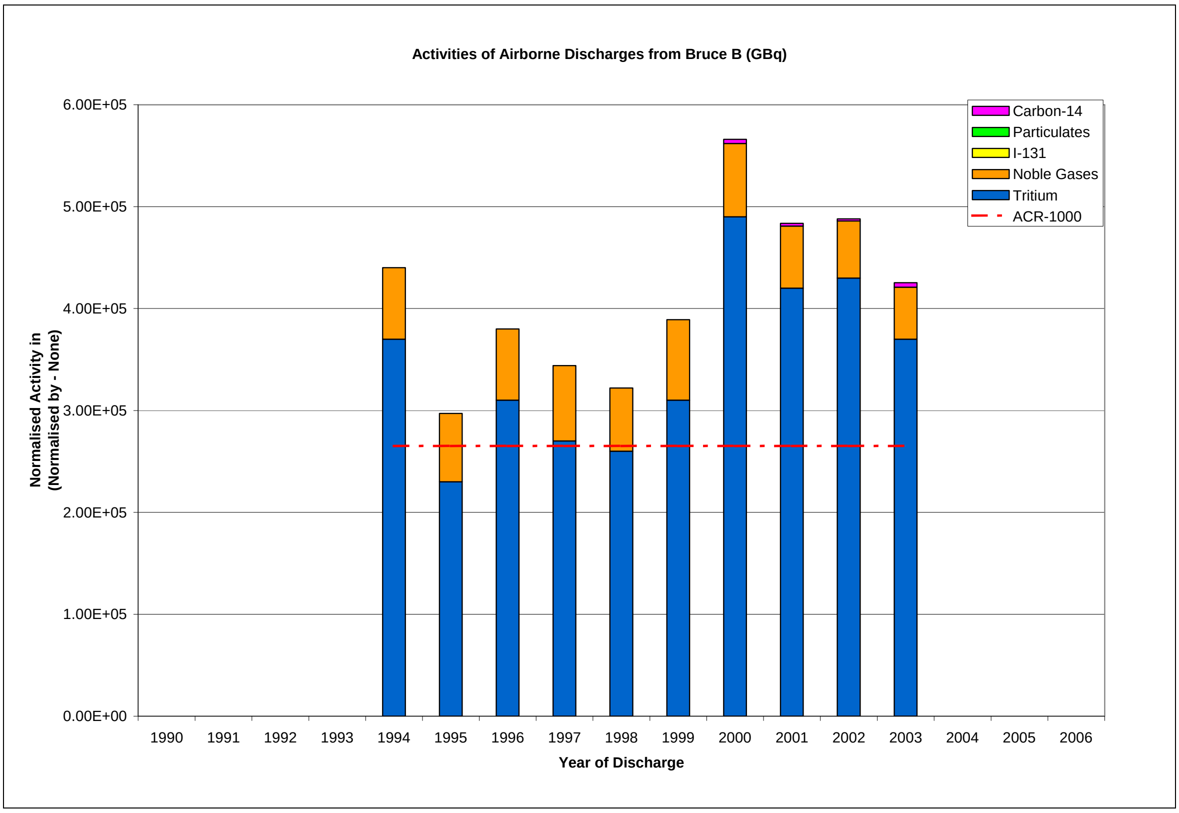

Figure 2.83 Activities of airborne discharges from Bruce B (GBq).

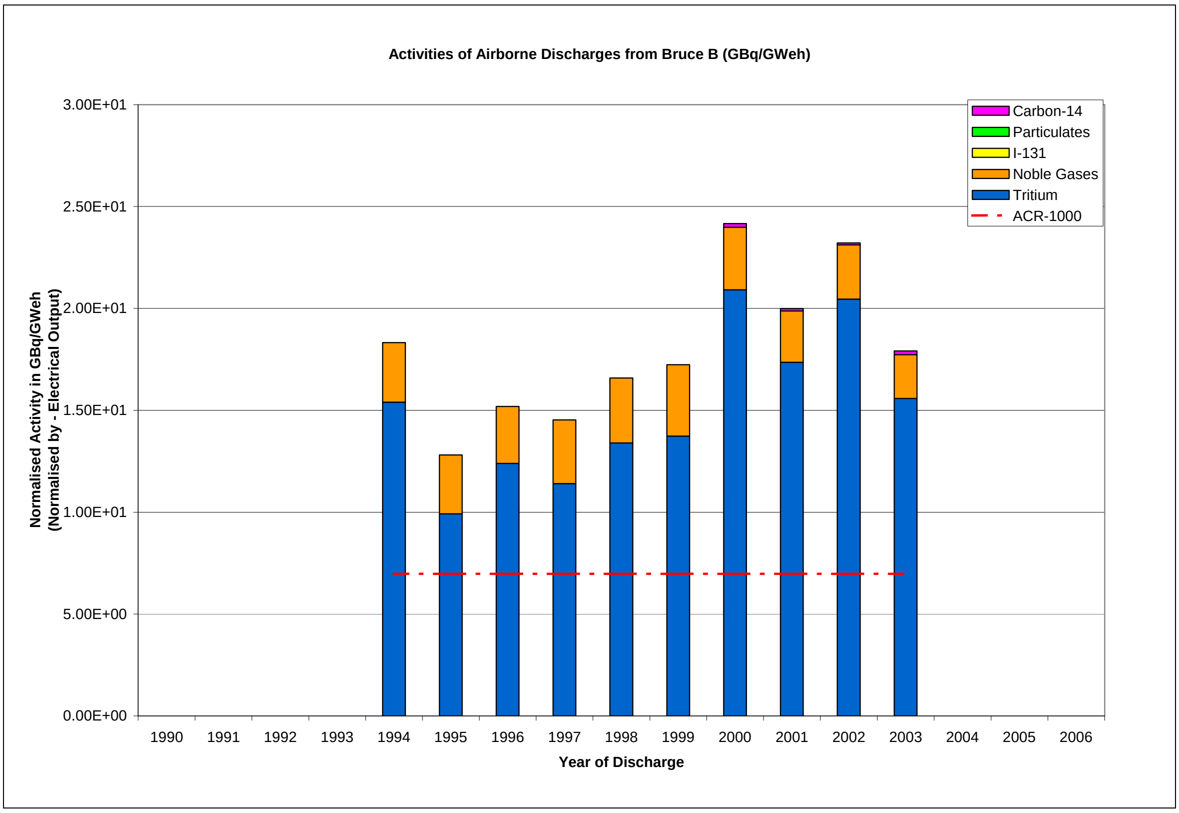

Figure 2.84 Activities of airborne discharges from Bruce B (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- the predicted liquid discharges from the ACR-1000 do not include a prediction for carbon-14;
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

2.5.3 ACR-1000 predecessor – Gentilly-2

Charts – liquid discharges (Gentilly, ACR-1000)

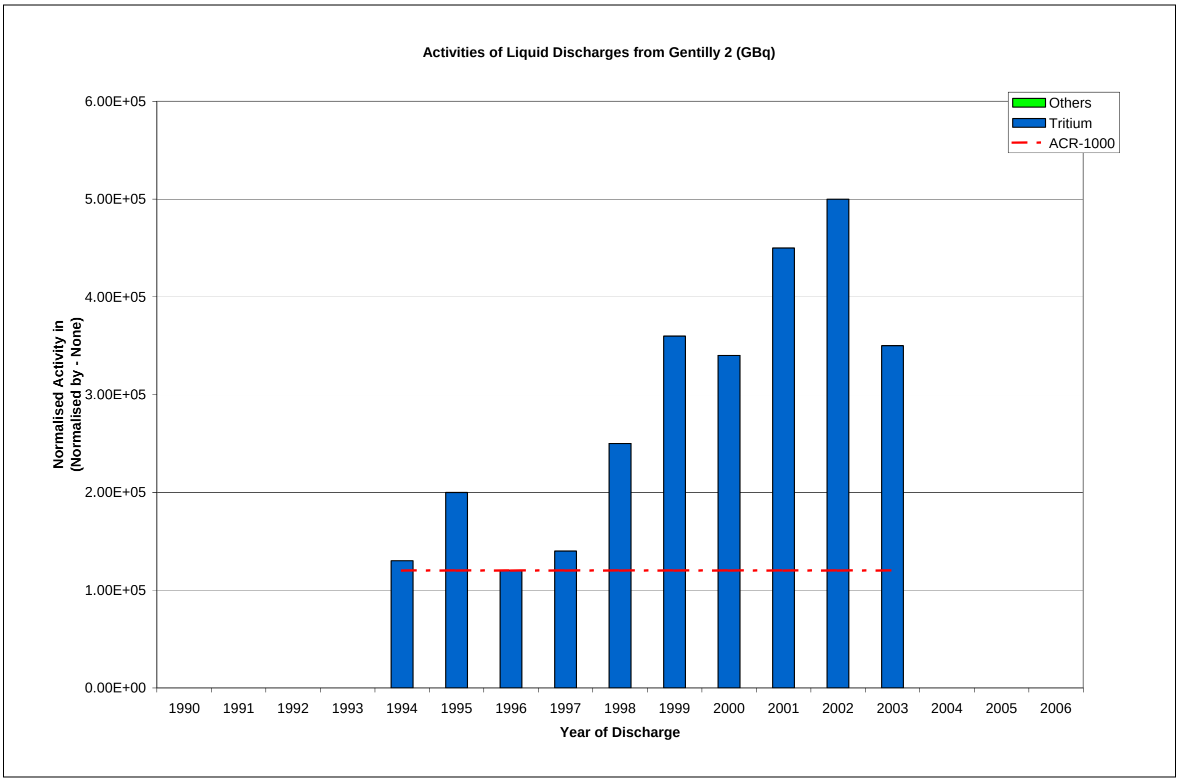

Figure 2.85 Activities of liquid discharges from Gentilly-2 (GBq).

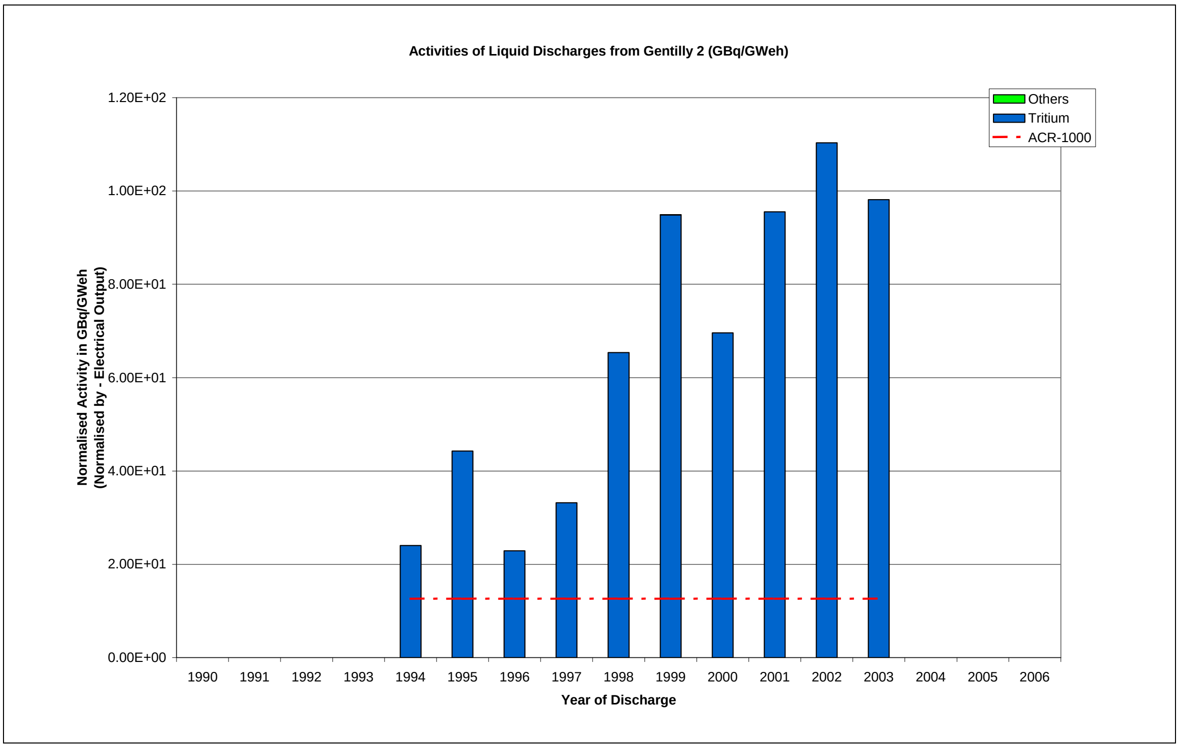

Figure 2.86 Activities of liquid discharges from Gentilly-2 (GBq/GWeh).

Charts – airborne discharges (Gentilly, ACR-1000)

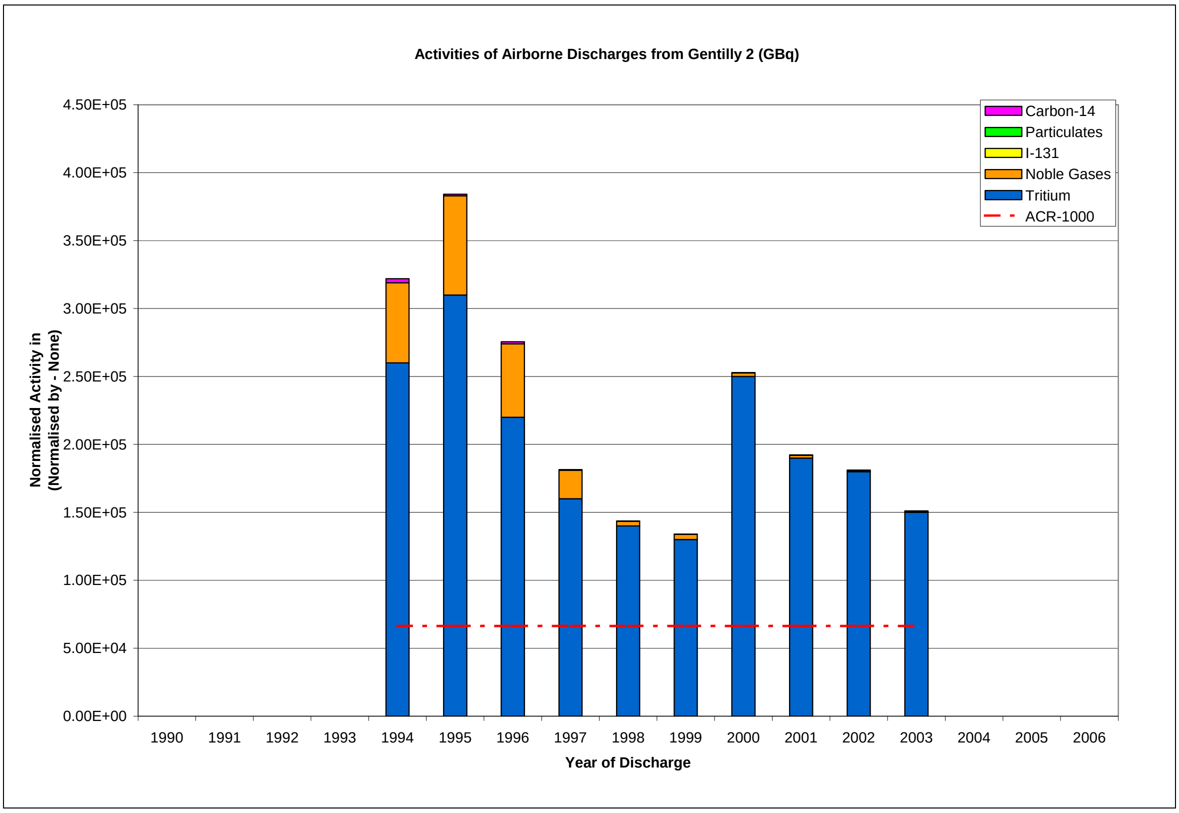

Figure 2.87 Activities of airborne discharges from Gentilly-2 (GBq).

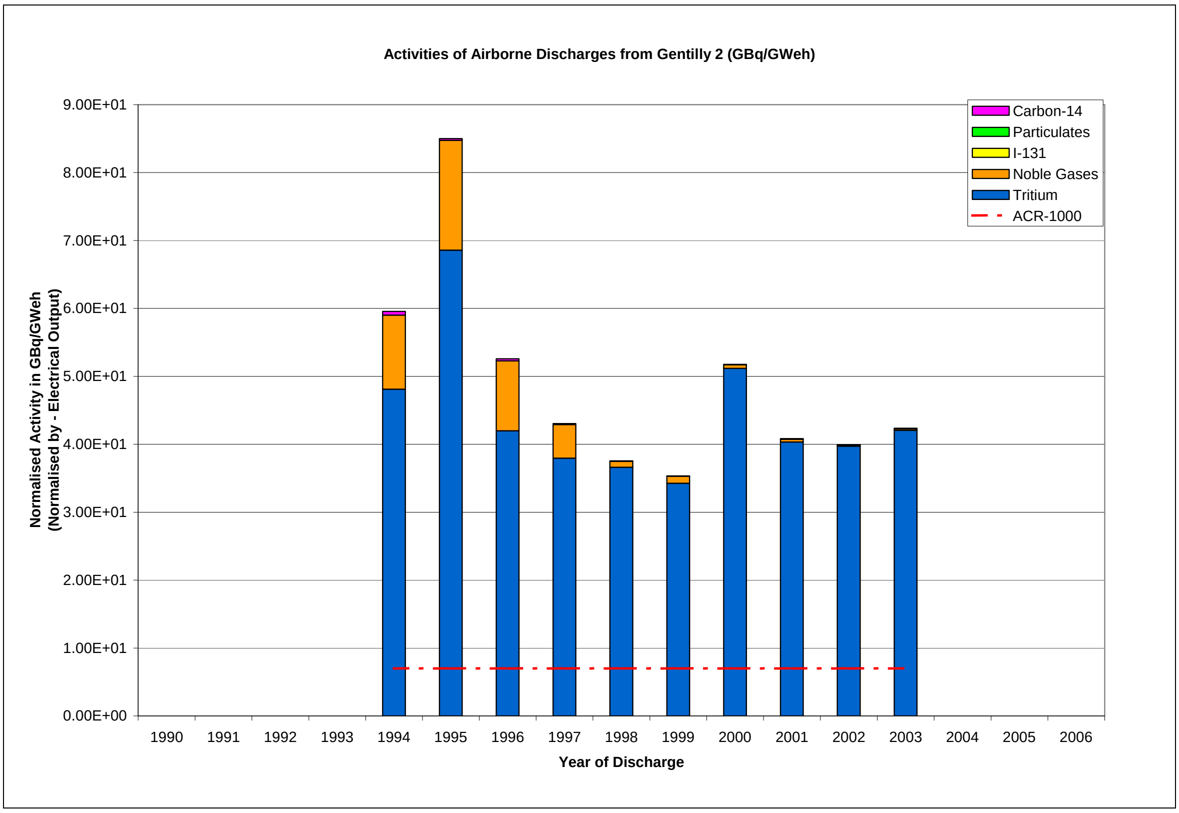

Figure 2.88 Activities of airborne discharges from Gentilly-2 (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- the predicted liquid discharges from the ACR-1000 do not include a prediction for carbon-14;
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the above charts lack the following data (due to current information gaps):

- predicted airborne particulates data for the ACR-1000.

2.5.4 ACR-1000 predecessor – Pickering A

Charts – liquid discharges (Pickering A, ACR-1000)

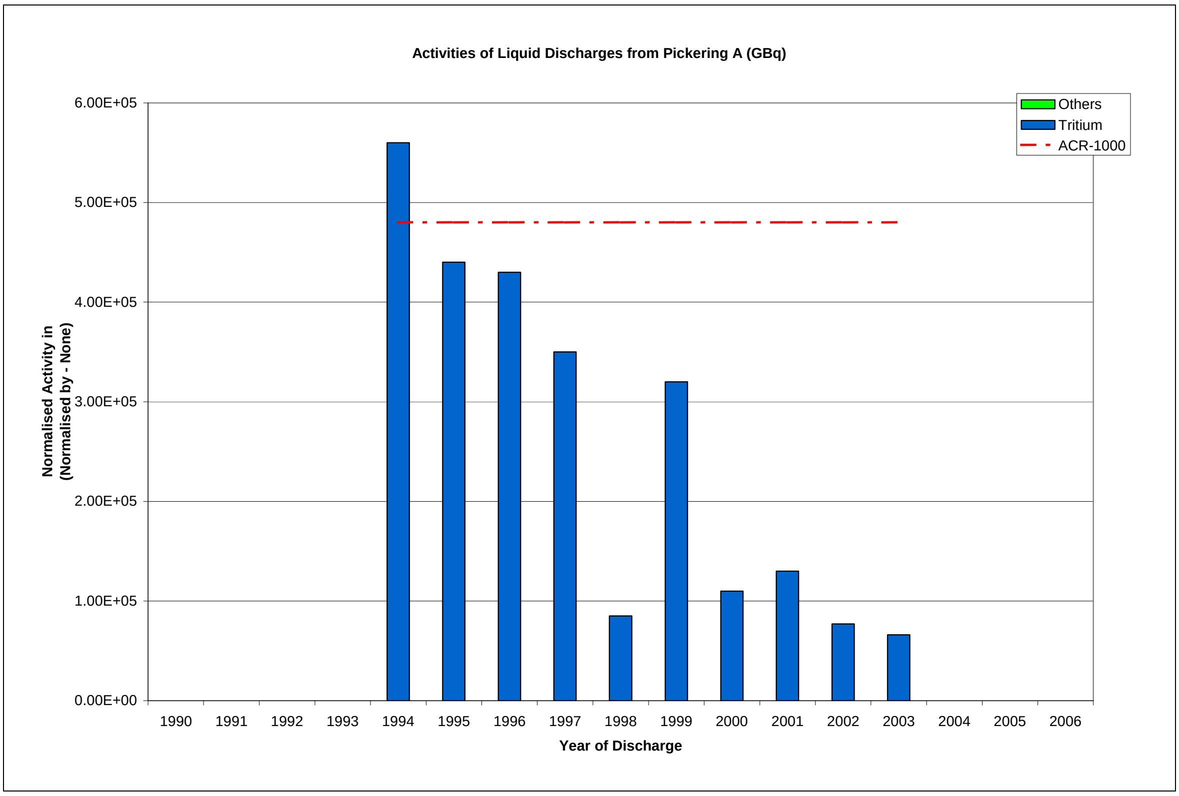

Figure 2.89 Activities of liquid discharges from Pickering A (GBq).

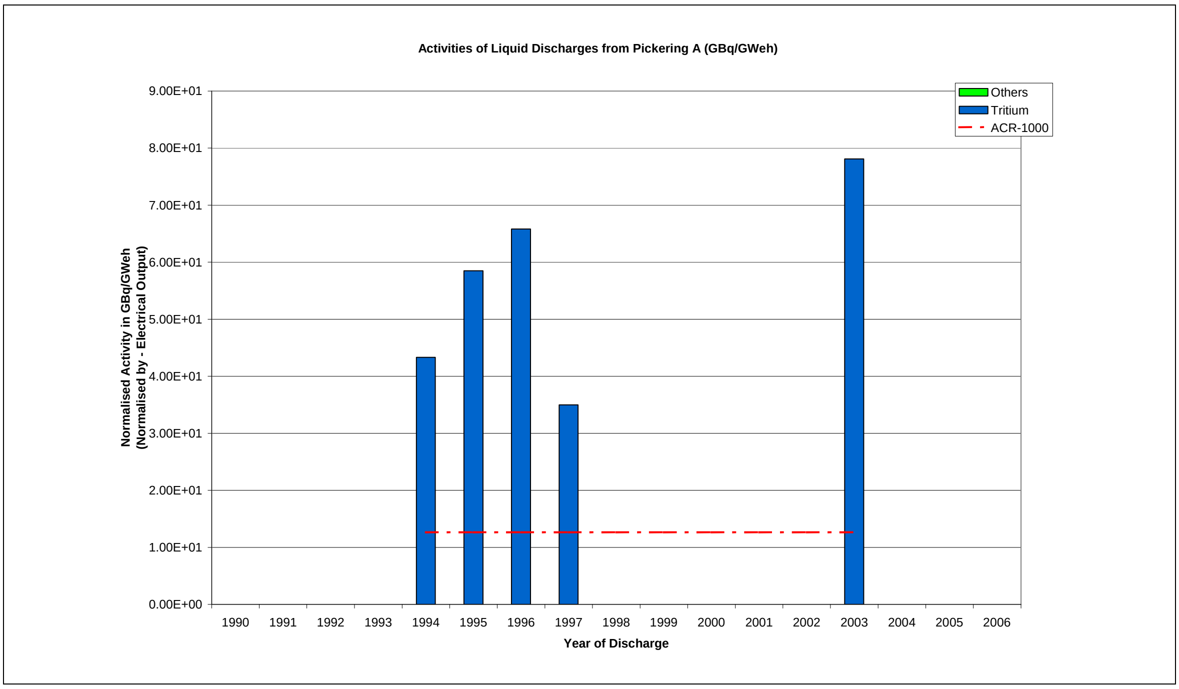

Figure 2.90 Activities of liquid discharges from Pickering A (GBq/GWeh).

Charts – airborne discharges (Pickering A, ACR-1000)

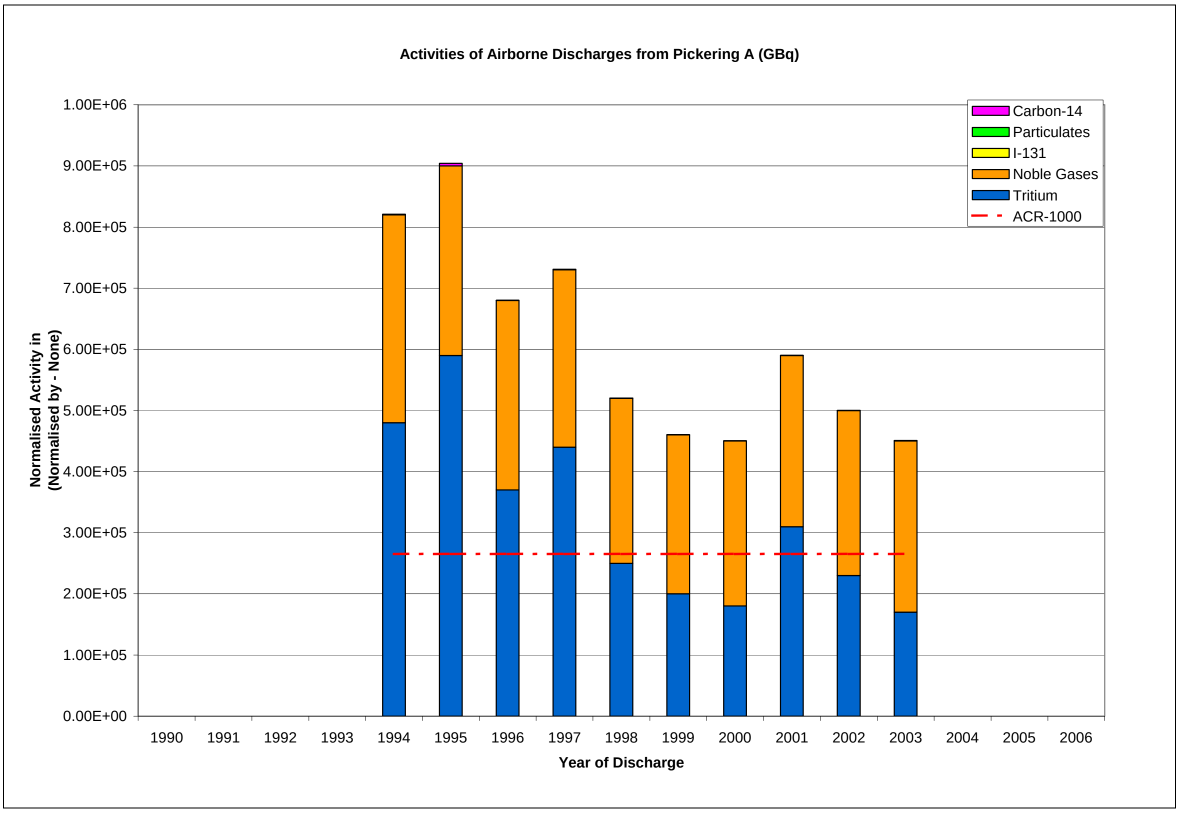

Figure 2.91 Activities of airborne discharges from Pickering A (GBq).

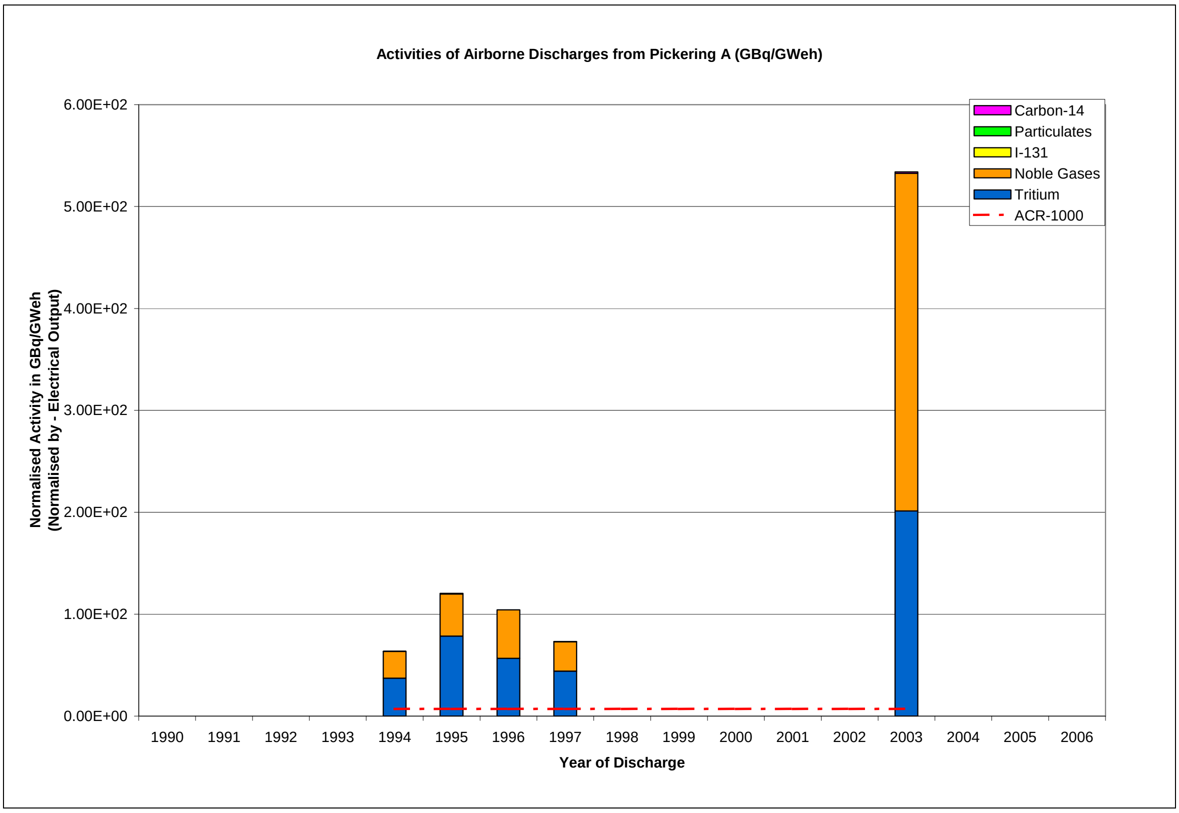

Figure 2.92 Activities of airborne discharges from Pickering A (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- liquid carbon-14 discharge data are not available for Pickering A because since 1999, carbon-14 releases in liquid effluent from Pickering A were reported but as an inclusion in the data for Pickering B (CNSC, 2005);
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the above charts lack the following data (due to current information gaps):

- liquid carbon-14 data (reported along with Pickering B discharges as from 1999);
- predicted airborne particulates data for the ACR-1000.

2.5.5 ACR-1000 predecessor – Pickering B

Charts – liquid discharges (Pickering B, ACR-1000)

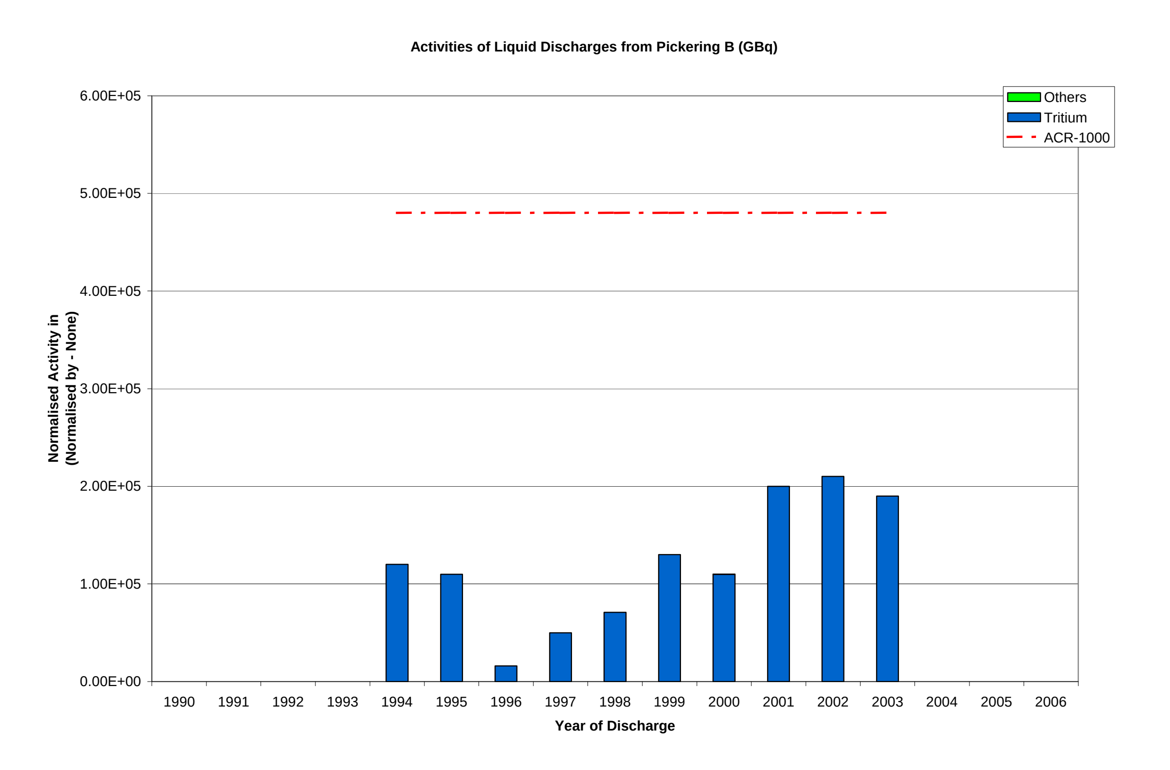

Figure 2.93 Activities of liquid discharges from Pickering B (GBq).

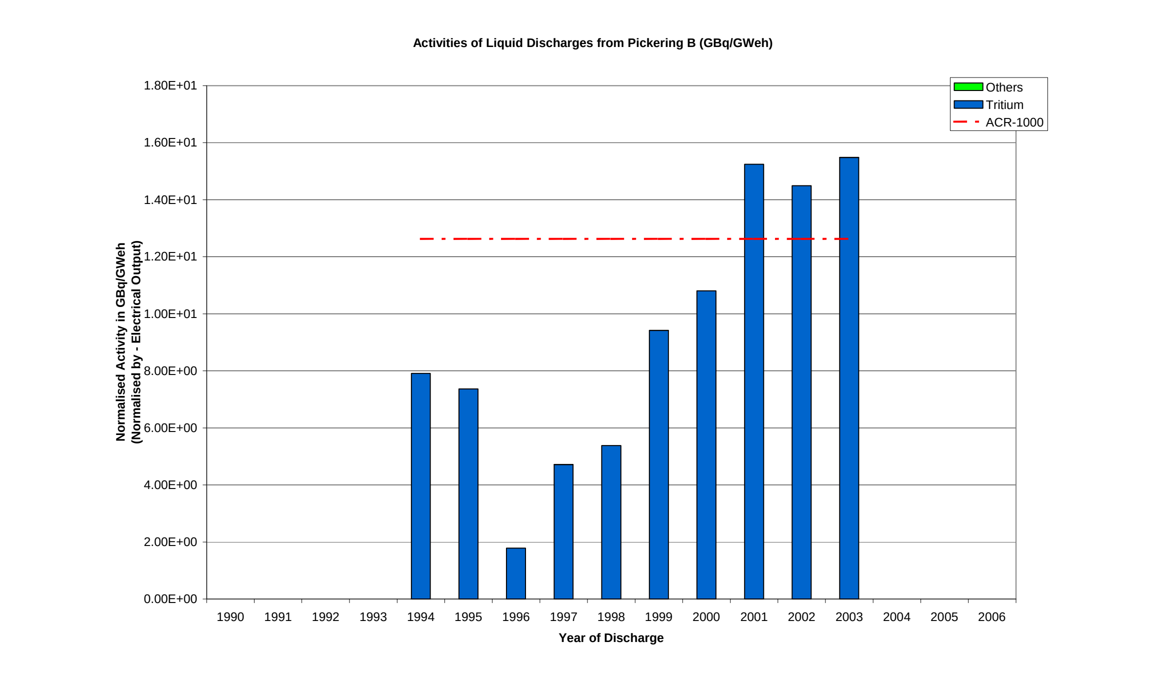

Figure 2.94 Activities of liquid discharges from Pickering B (GBq/GWeh).

Charts – airborne discharges (Pickering B, ACR-1000)

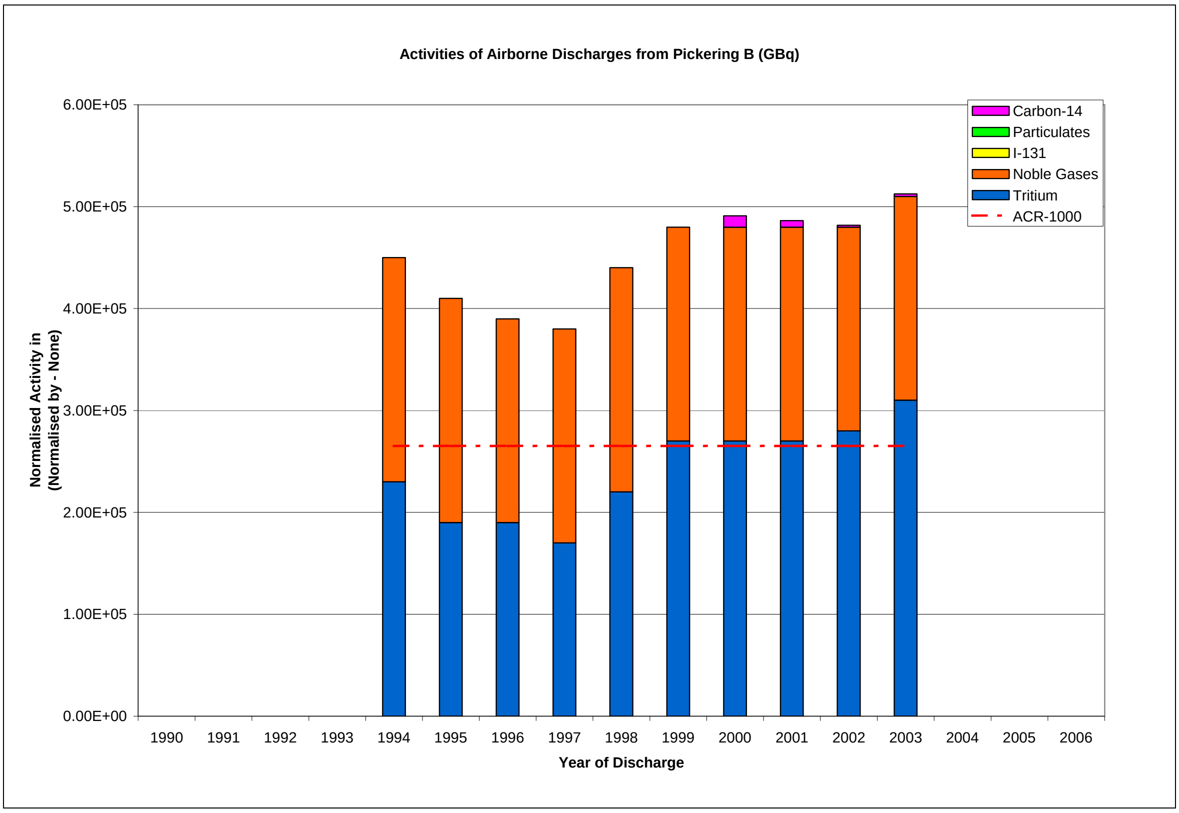

Figure 2.95 Activities of airborne discharges from Pickering B (GBq).

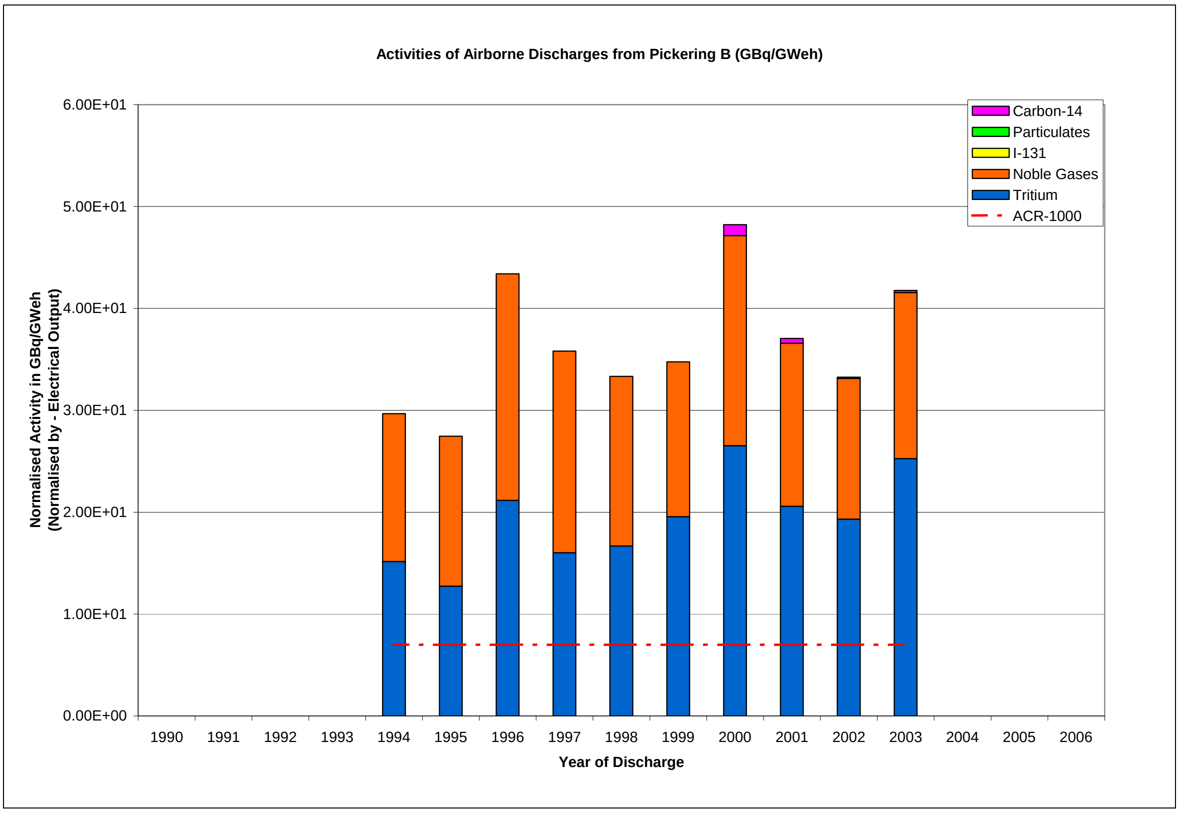

Figure 2.96 Activities of airborne discharges from Pickering B (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- liquid carbon-14 discharges for Pickering B include carbon-14 effluent from Pickering A (CNSC, 2005);
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data for 1994–1999;
- liquid carbon-14 data for Pickering B only (current data include carbon-14 discharges from Pickering A);
- predicted airborne particulates data for the ACR-1000.

2.5.6 ACR-1000 predecessor – Point Lepreau

Charts – liquid discharges (Point Lepreau, ACR-1000)

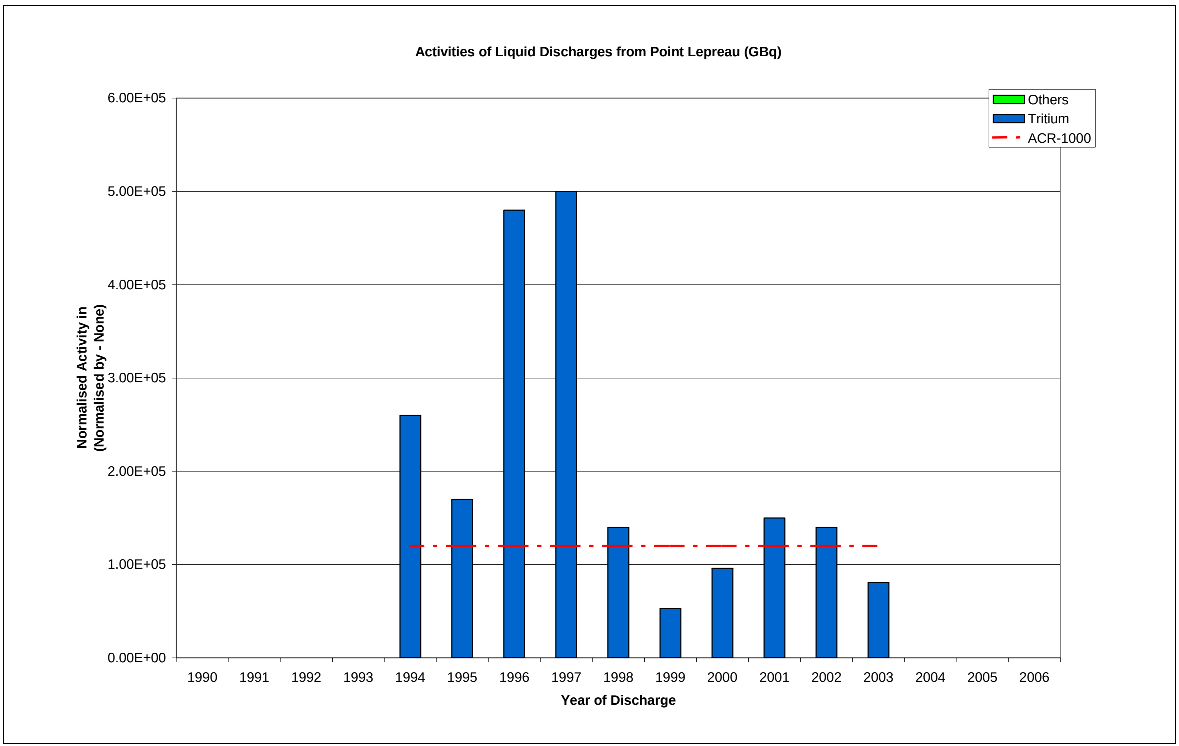

Figure 2.97 Activities of liquid discharges from Point Lepreau (GBq).

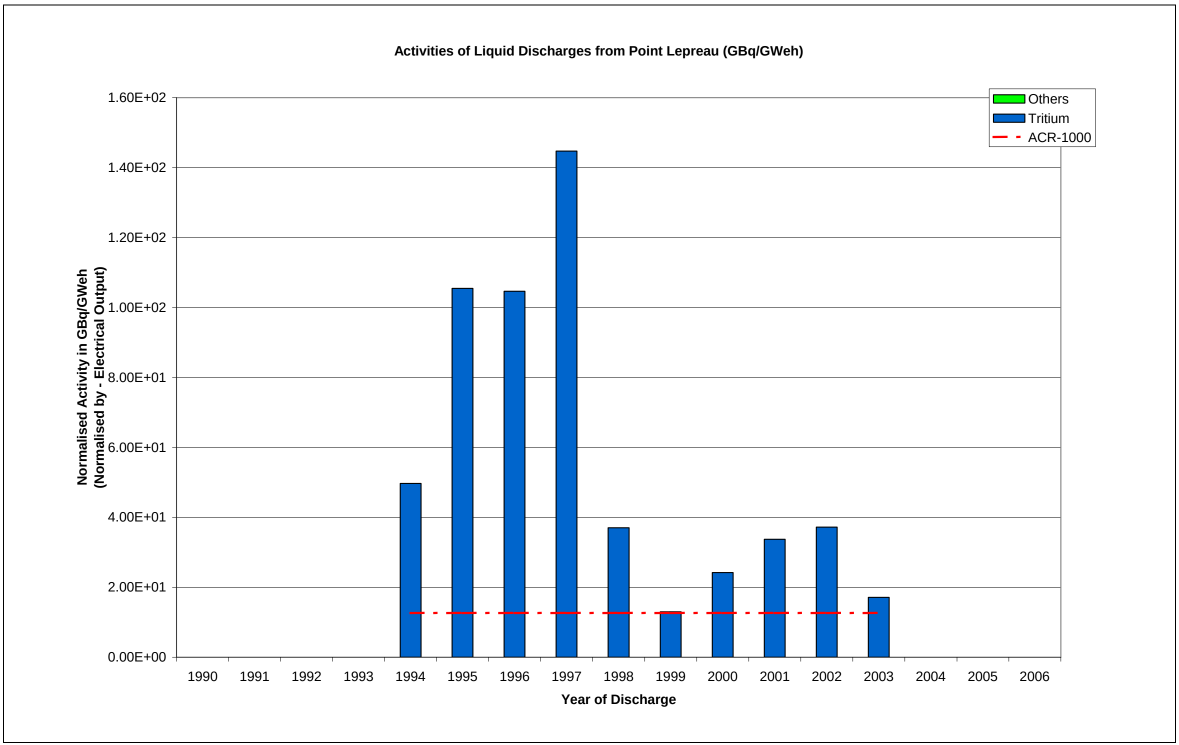

Figure 2.98 Activities of liquid discharges from Point Lepreau (GBq/GWeh).

Charts – airborne discharges (Point Lepreau, ACR-1000)

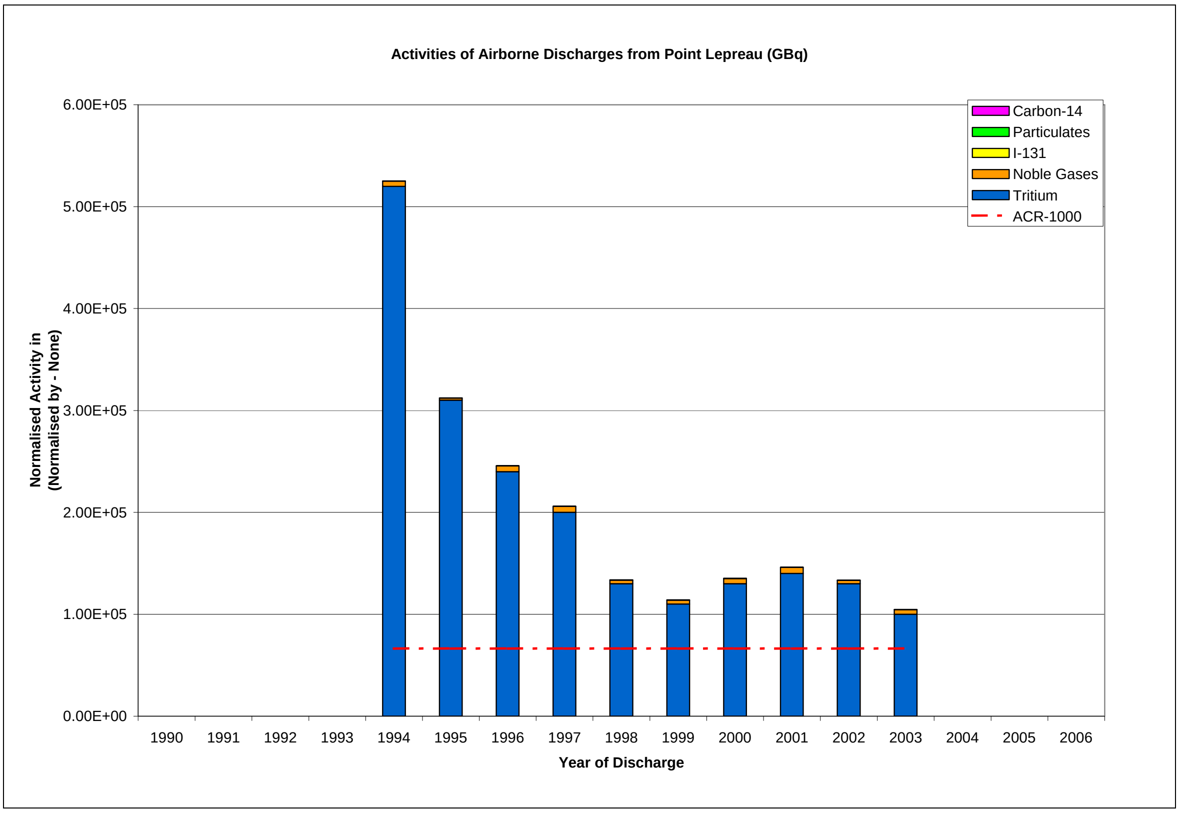

Figure 2.99 Activities of airborne discharges from Point Lepreau (GBq).

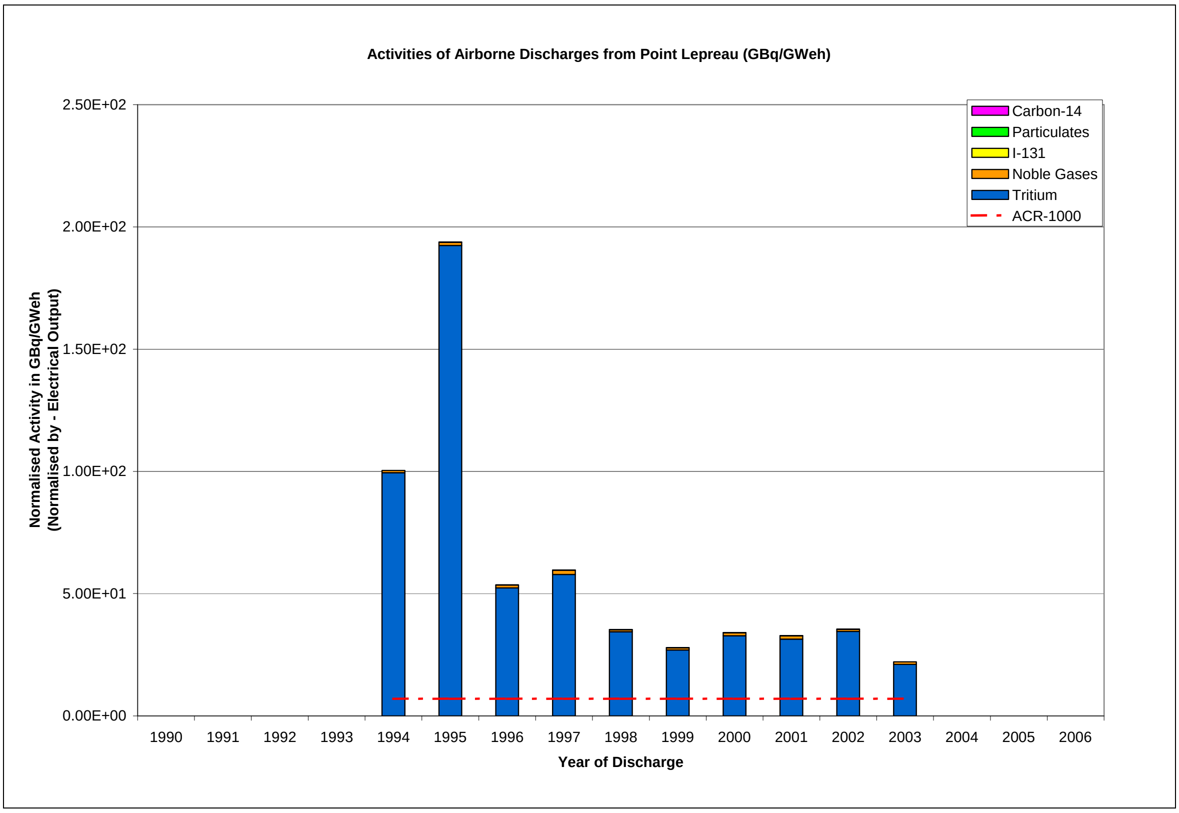

Figure 2.100 Activities of airborne discharges from Point Lepreau (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- the predicted liquid discharges from the ACR-1000 do not include a prediction for carbon-14;
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the above charts lack the following data (due to current information gaps):

- liquid carbon-14 data for 1994–1997;
- predicted airborne particulates data for the ACR-1000.

2.5.7 ACR-1000 predecessor – Darlington

Charts – liquid discharges (Darlington, ACR-1000)

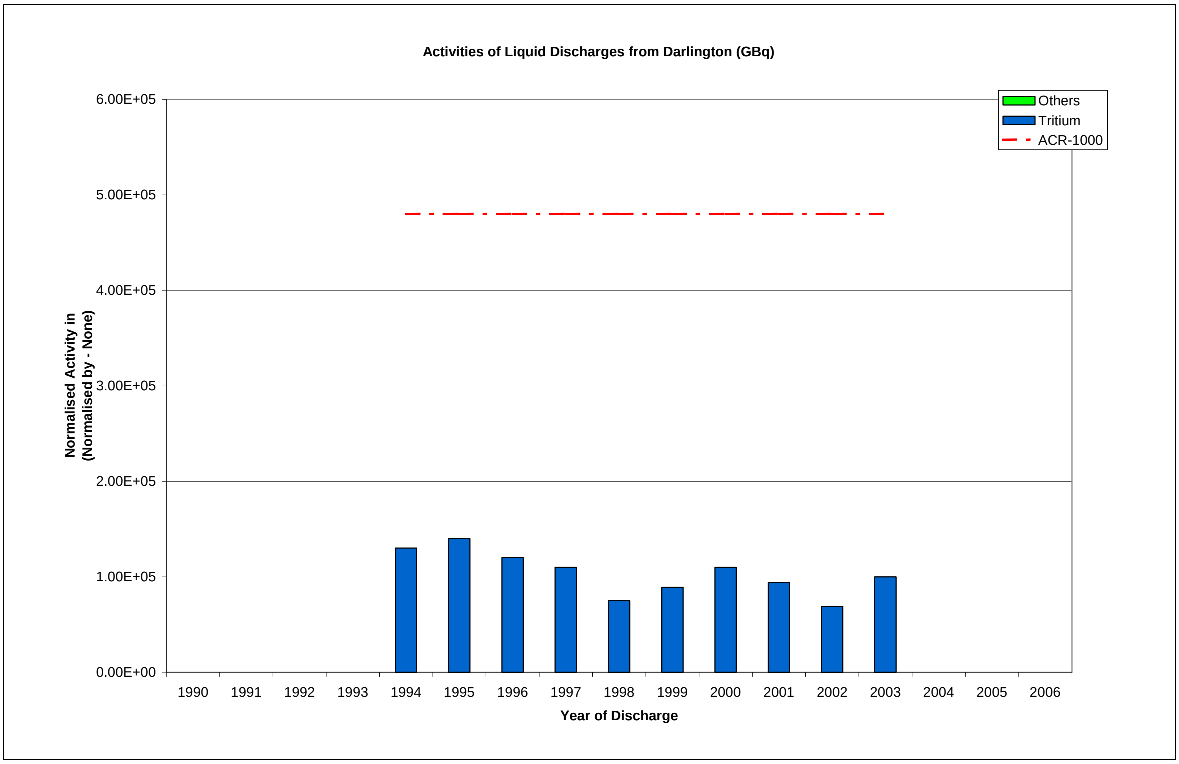

Figure 2.101 Activities of liquid discharges from Darlington (GBq).

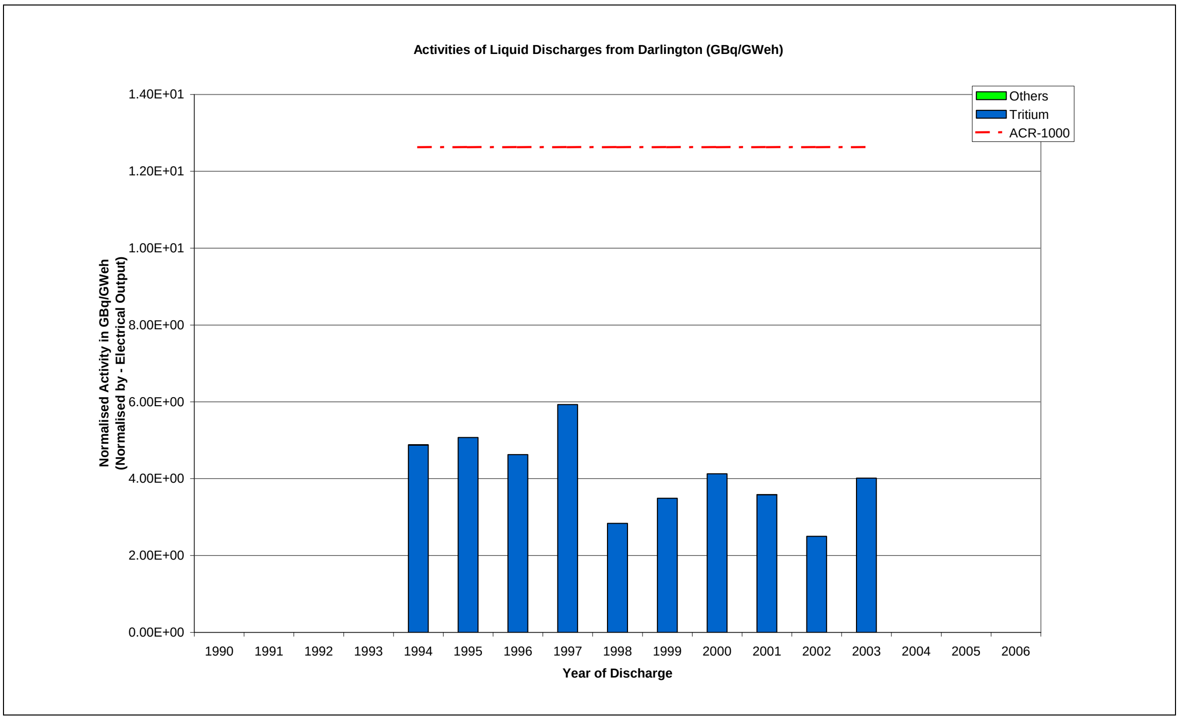

Figure 2.102 Activities of liquid discharges from Darlington (GBq/GWeh).

Charts – airborne discharges (Darlington, ACR-1000)

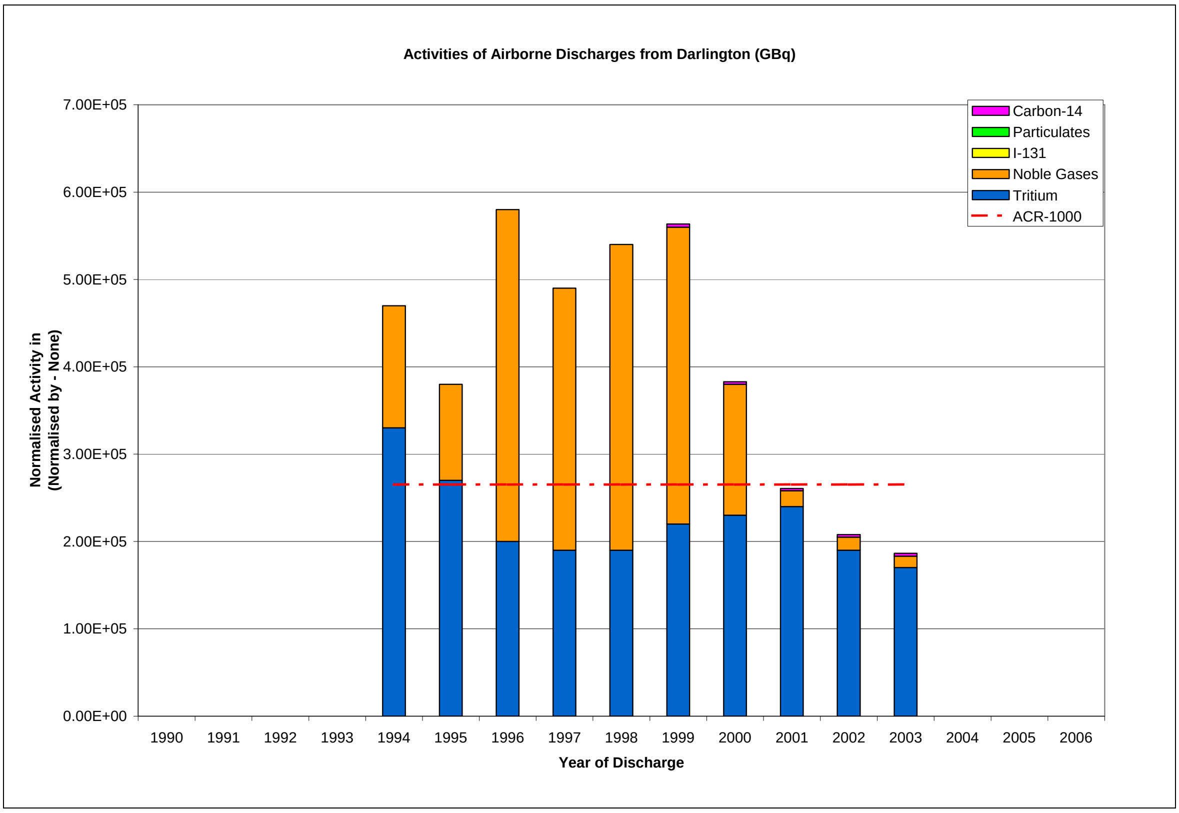

Figure 2.103 Activities of airborne discharges from Darlington (GBq).

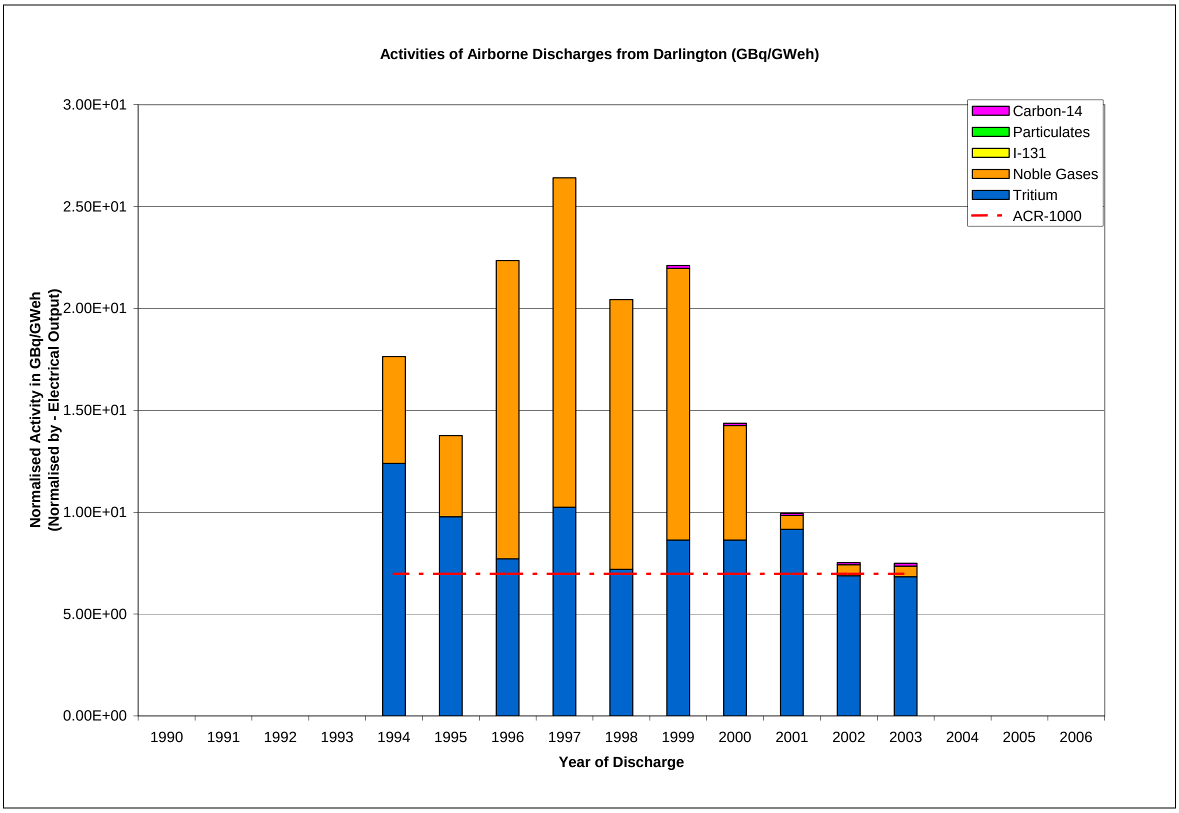

Figure 2.104 Activities of airborne discharges from Darlington (GBq/GWeh).

The caveats are that:

- carbon-14 data are only reported for some years;
- the predicted liquid discharges from the ACR-1000 do not include a prediction for carbon-14;
- the predicted airborne discharges from the ACR-1000 do not include a prediction for particulates;
- the predicted discharges for the ACR-1000 assume that a tritium removal facility will be operating (on-site or off-site) within three years of the reactor in-service date to reduce tritium activity in moderator water (<0.5 TBq/kg) (AECL, 2008);
- the noble gases fraction of the predicted activity indicated in the above were only available in GBq-MeV units. This value is obtained by multiplying the activity by the photon yield (a percentage) and the photon energy (in MeV) and then summing the result over all emissions. This combined measure of activity and energy is particular to CANDU reports and can be considered to be representative of the impact of radioactivity rather than activity itself.

It should be noted that the Darlington station also operates the Darlington Tritium Removal Facility (TRF) which discharges elemental tritium. Discharges from the TRF are not included in the charts above, but the data is provided in the relevant appendix of the main report. The Darlington TRF processes wastes from the Darlington reactors and also services other stations in Canada.

It should be noted that the above charts lack the following data (due to current information gaps):

- airborne carbon-14 data for 1994–1998;
- liquid carbon-14 data for 1994–1998;
- predicted airborne particulates data for the ACR-1000.

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3 Indicative operational range analysis

3.1 AP1000 predecessors

3.1.1 Liquid tritium discharges (AP1000 predecessors)

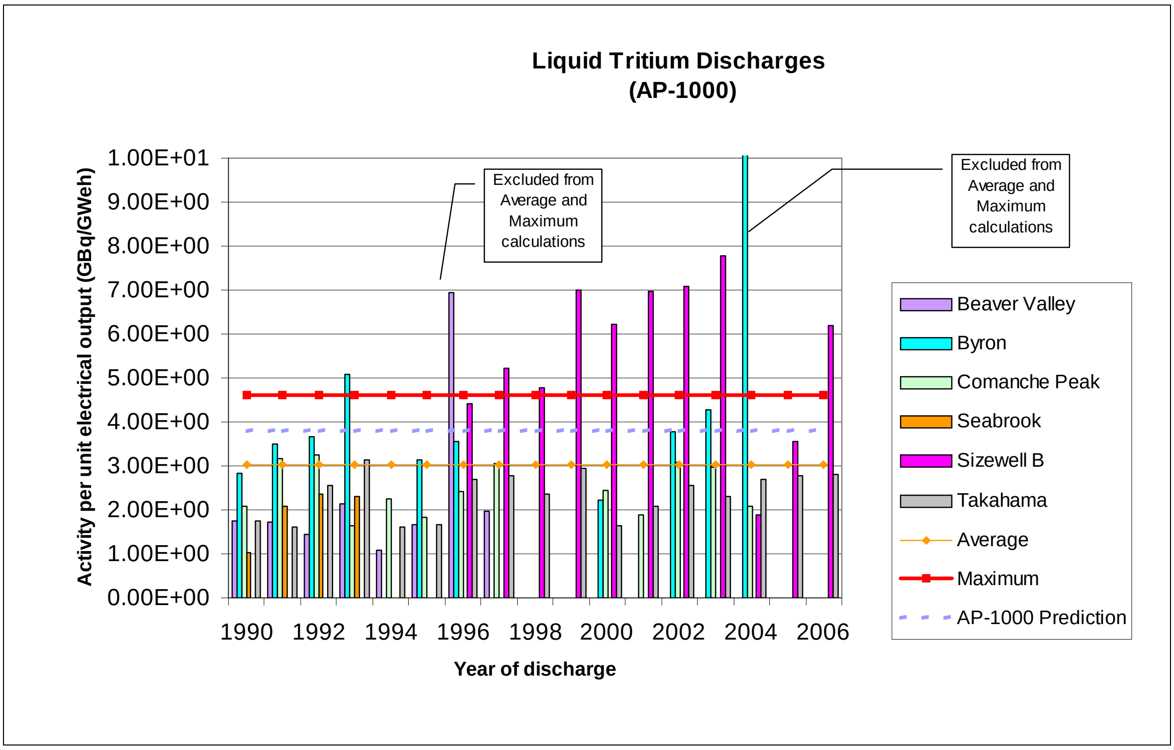

Figure 3.1 Liquid tritium discharges (AP1000 predecessors).

3.1.2 Other liquid discharges (AP1000 predecessors)

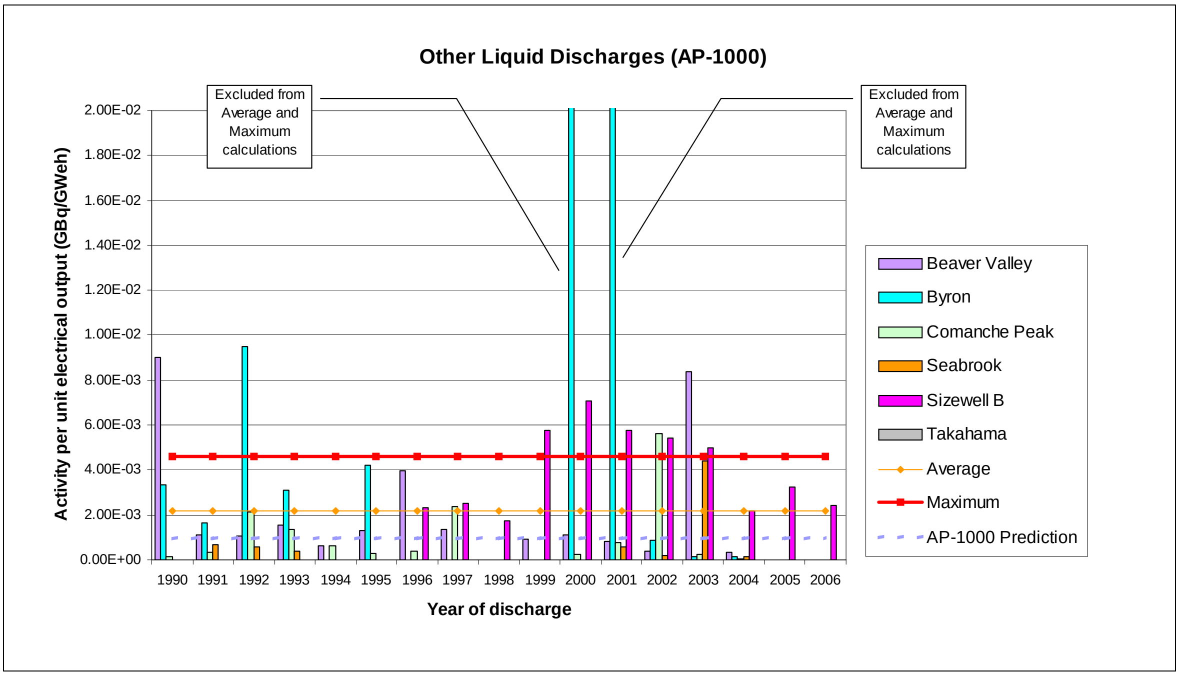

Figure 3.2 Other liquid discharges (AP1000 predecessors).

3.1.3 Airborne tritium discharges (AP1000 predecessors)

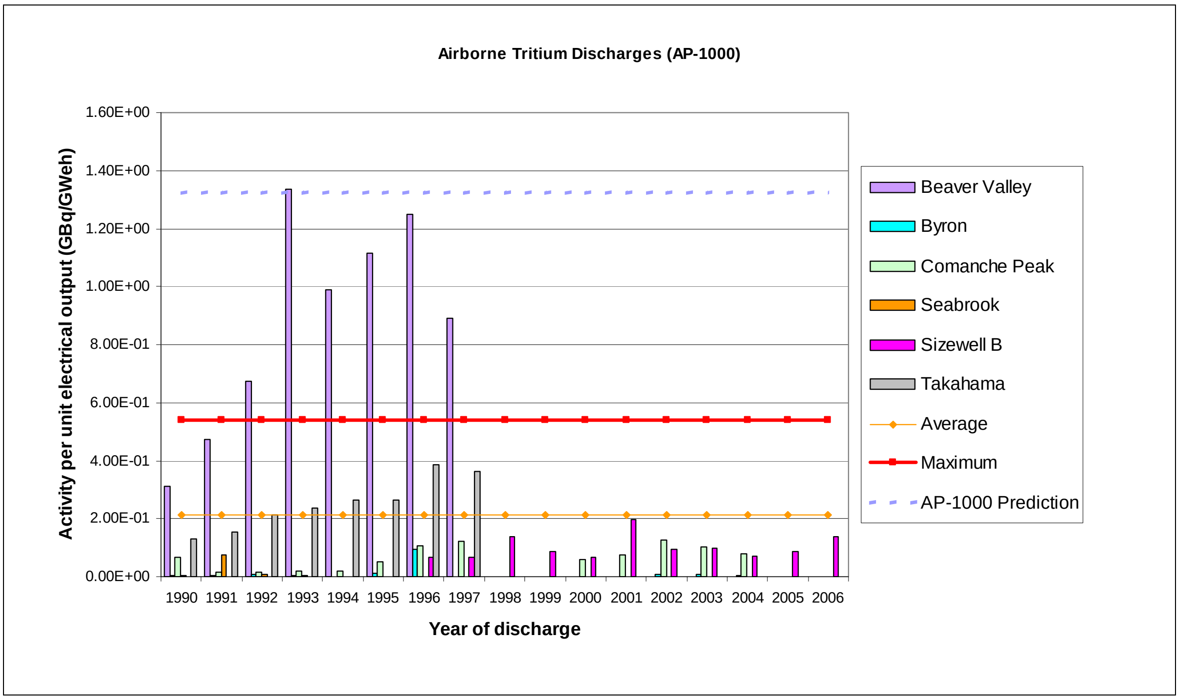

Figure 3.3 Airborne tritium discharges (AP1000 predecessors).

3.1.4 Airborne noble gas discharges (AP1000 predecessors)

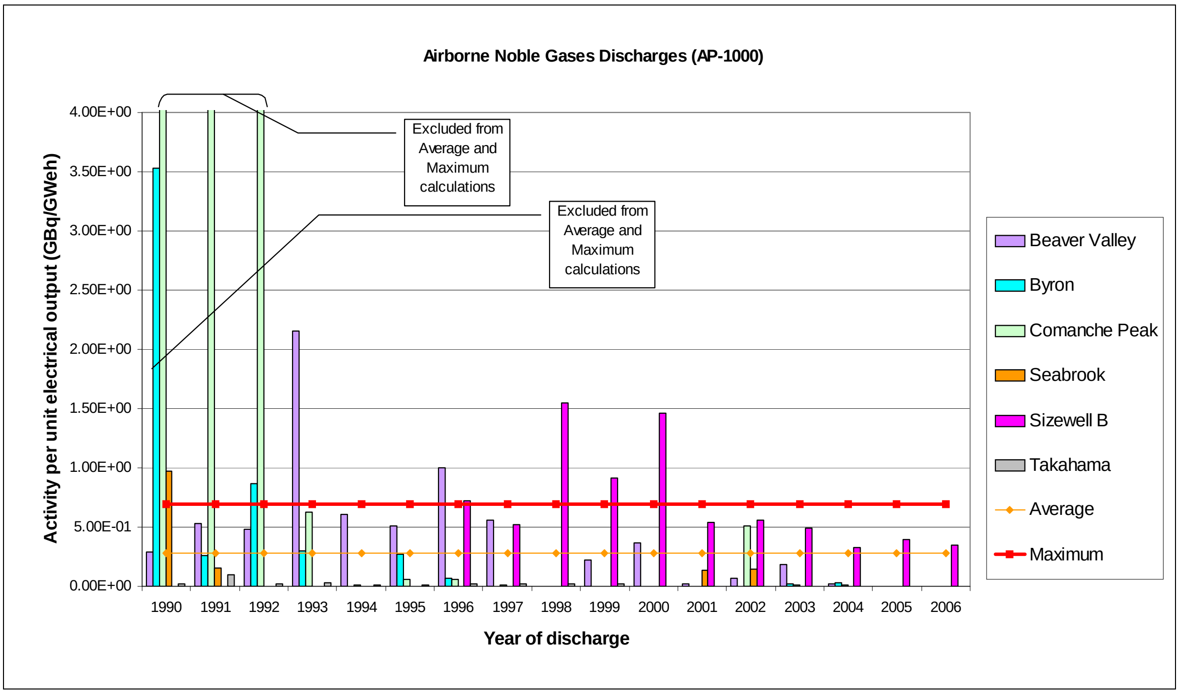

Figure 3.4 Airborne noble gas discharges (AP1000 predecessors).

3.1.5 Airborne iodine-131 discharges (AP1000 predecessors)

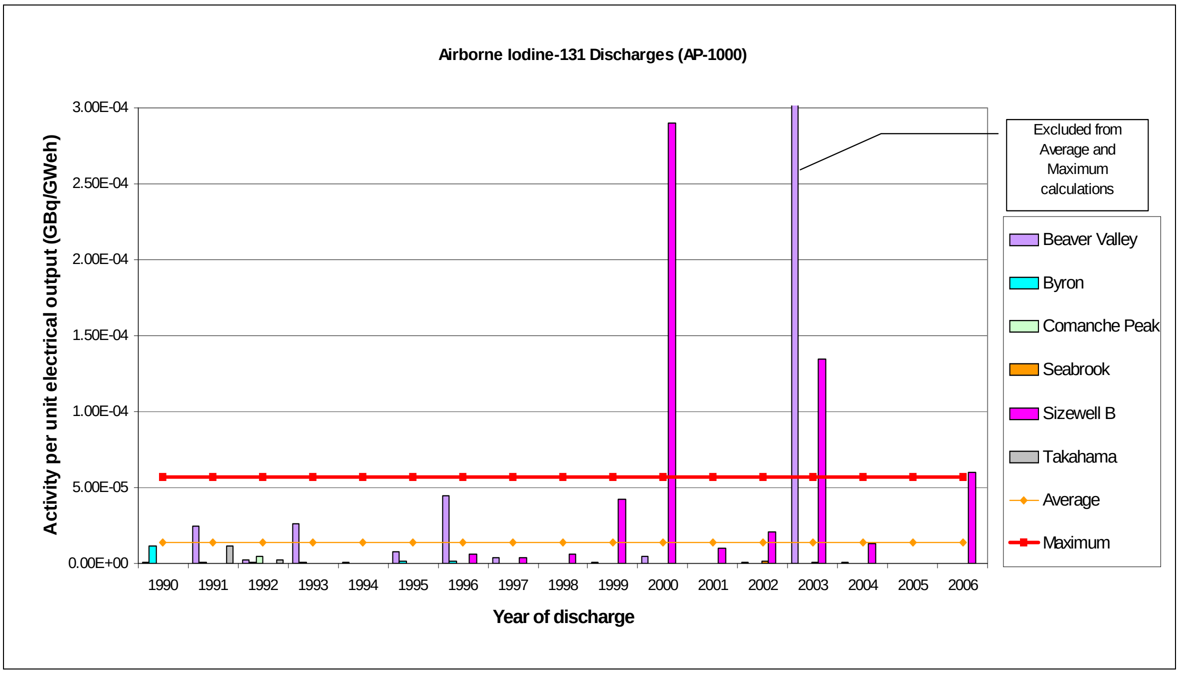

Figure 3.5 Airborne iodine-131 discharges (AP1000 predecessors).

3.1.6 Airborne particulates discharges (AP1000 predecessors)

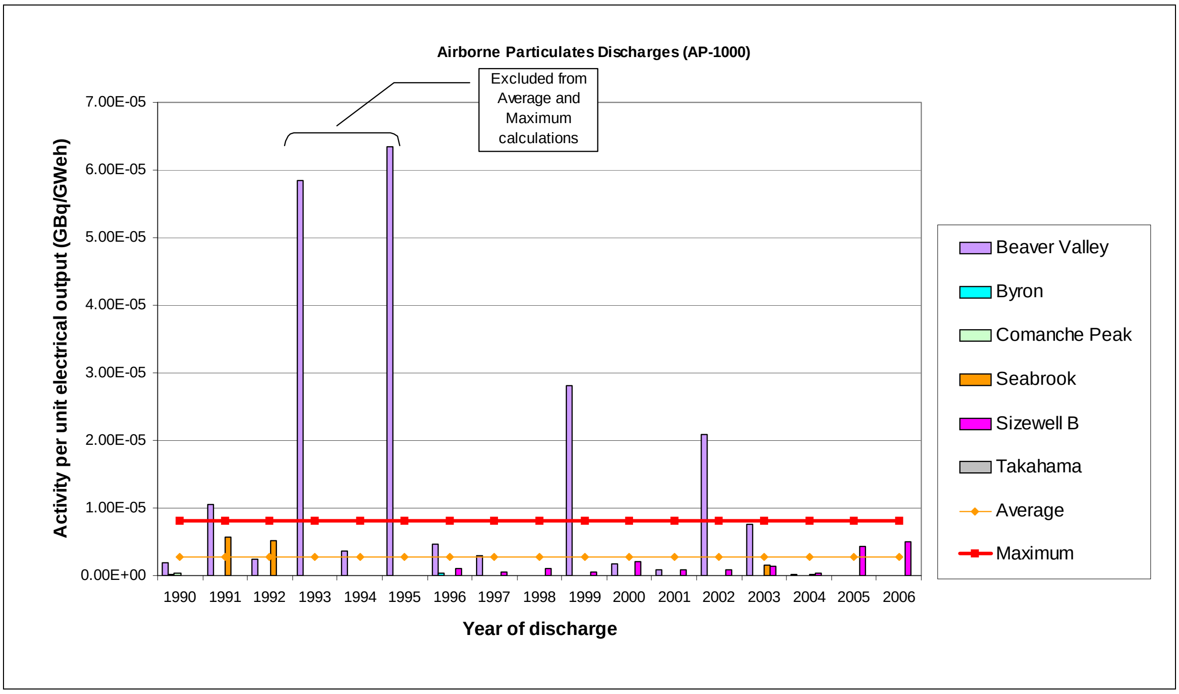

Figure 3.6 Airborne particulates discharges (AP1000 predecessors).

3.1.7 Airborne carbon-14 discharges (AP1000 predecessors)

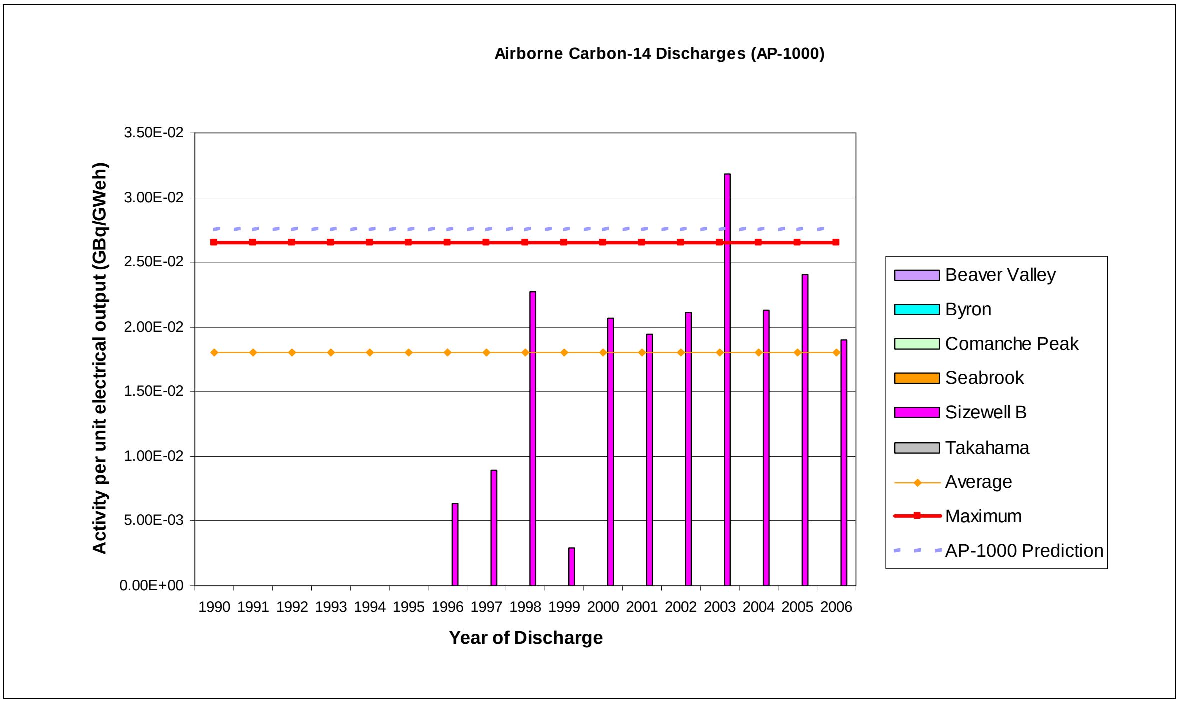

Figure 3.7 Airborne carbon-14 discharges (AP1000 predecessors).

3.2 EPR predecessors

3.2.1 Liquid tritium discharges (EPR predecessors)

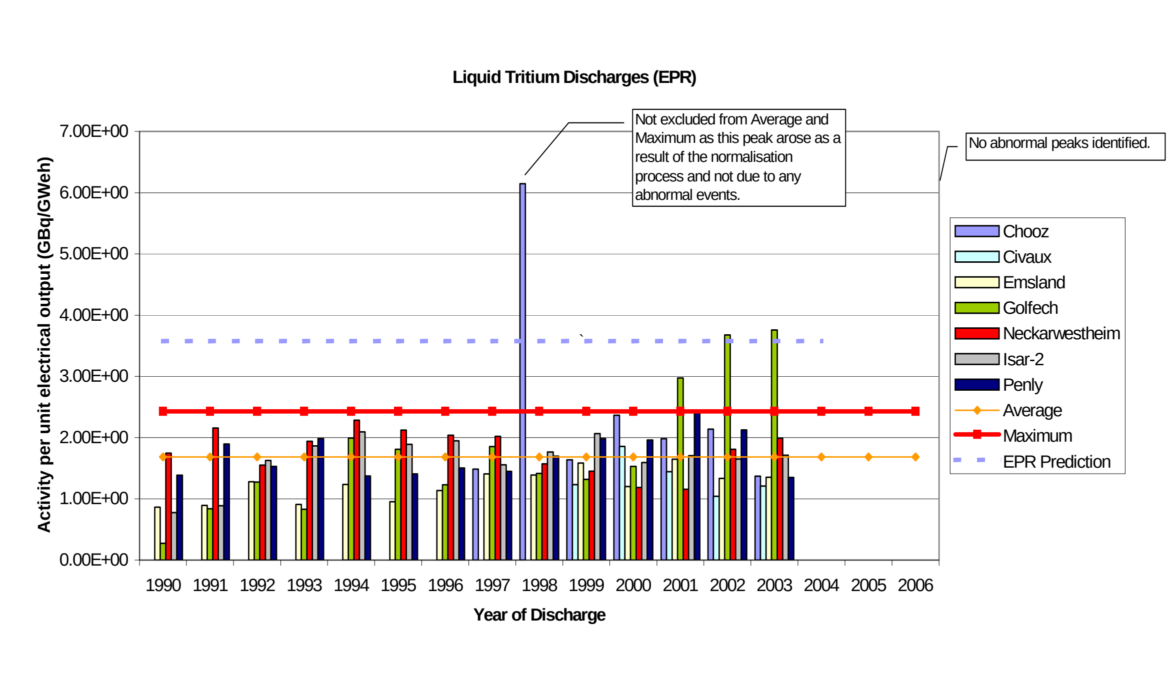

Figure 3.8 Liquid tritium discharges (EPR predecessors).

3.2.2 Other liquid discharges (EPR predecessors)

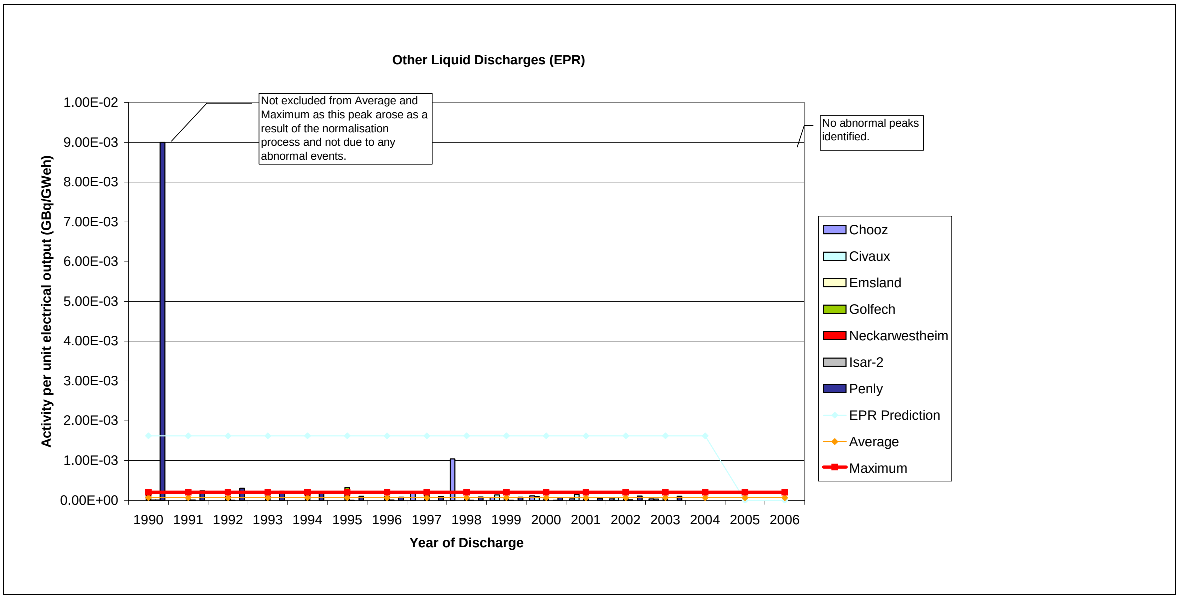

Figure 3.9 Other liquid discharges (EPR predecessors).

3.2.3 Airborne tritium discharges (EPR predecessors)

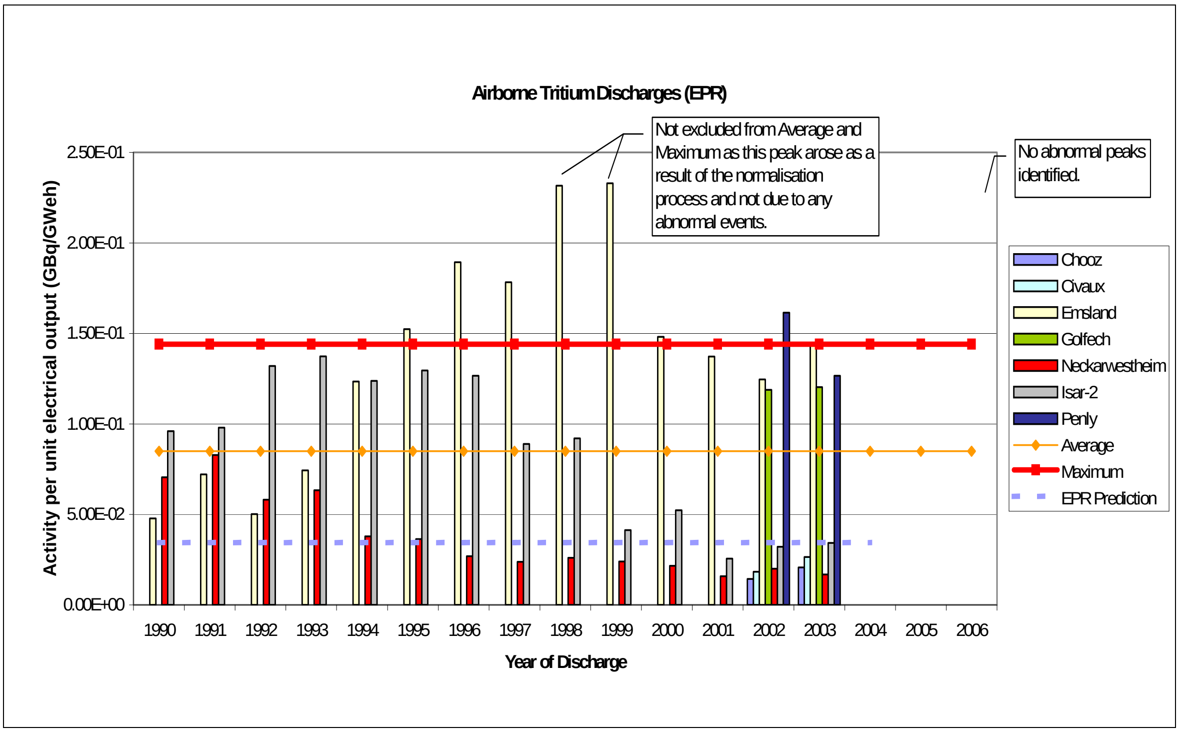

Figure 3.10 Airborne tritium discharges (EPR predecessors).

3.2.4 Airborne noble gas discharges (EPR predecessors)

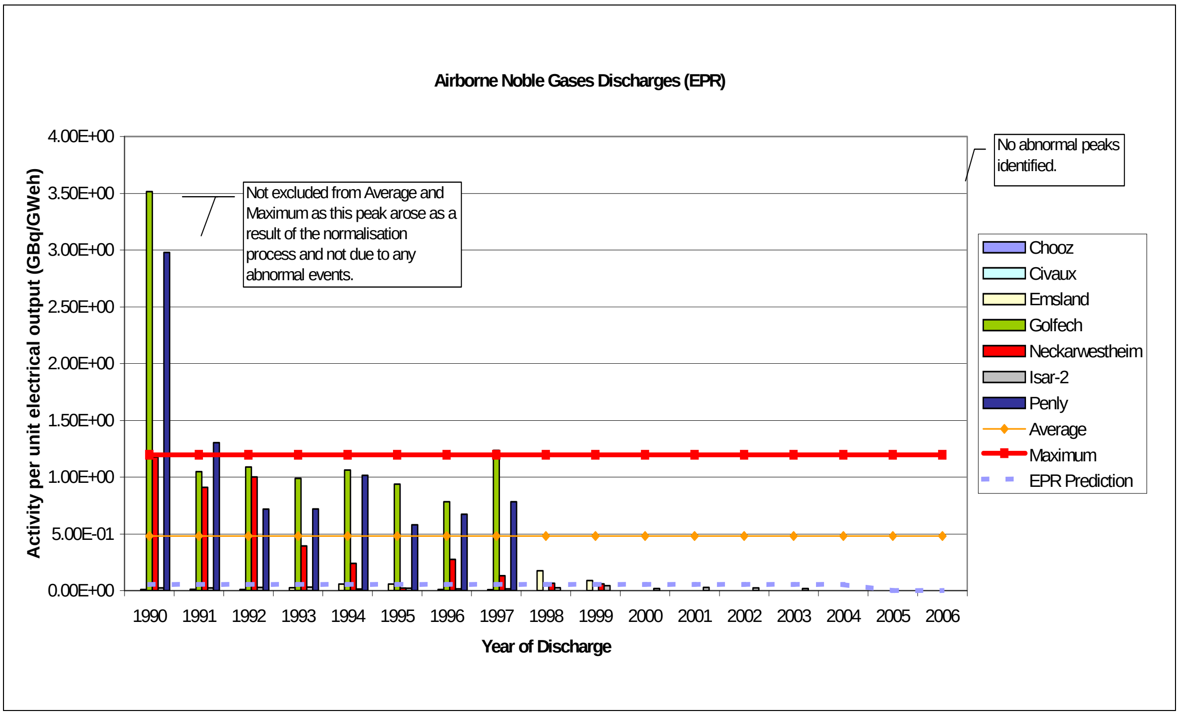

Figure 3.11 Airborne noble gas discharges (EPR predecessors).

3.2.5 Airborne iodine-131 discharges (EPR predecessors)

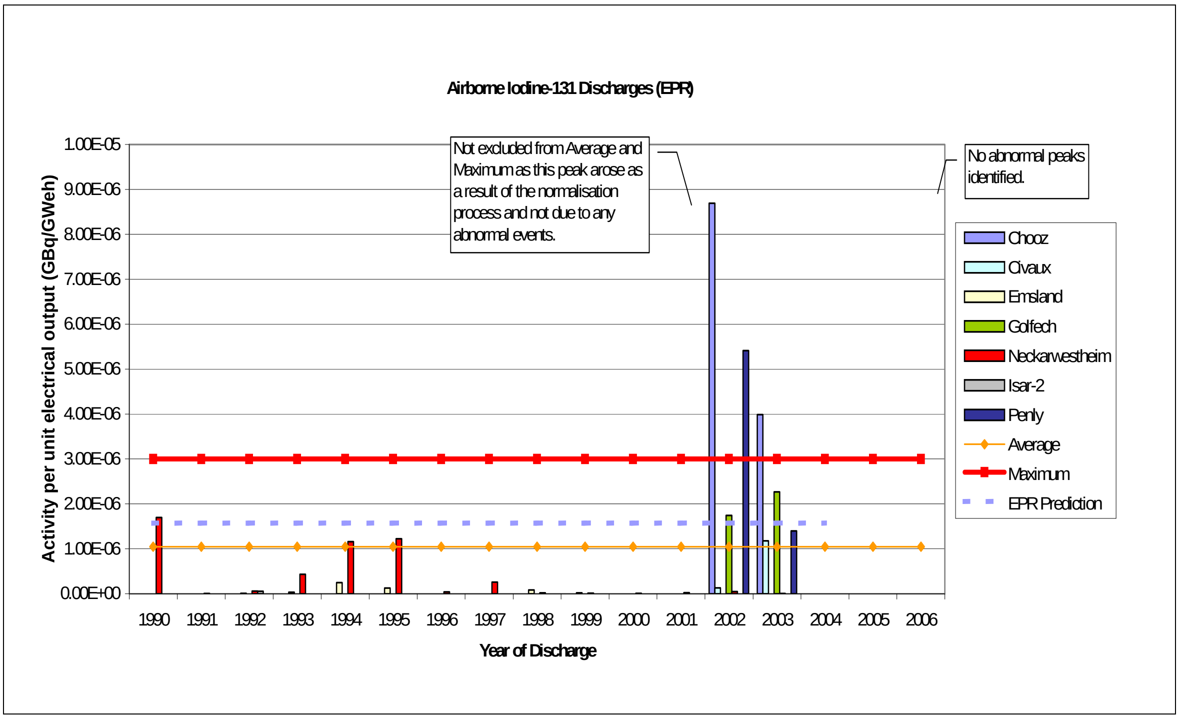

Figure 3.12 Airborne iodine-131 discharges (EPR predecessors).

3.2.6 Airborne particulates discharges (EPR predecessors)

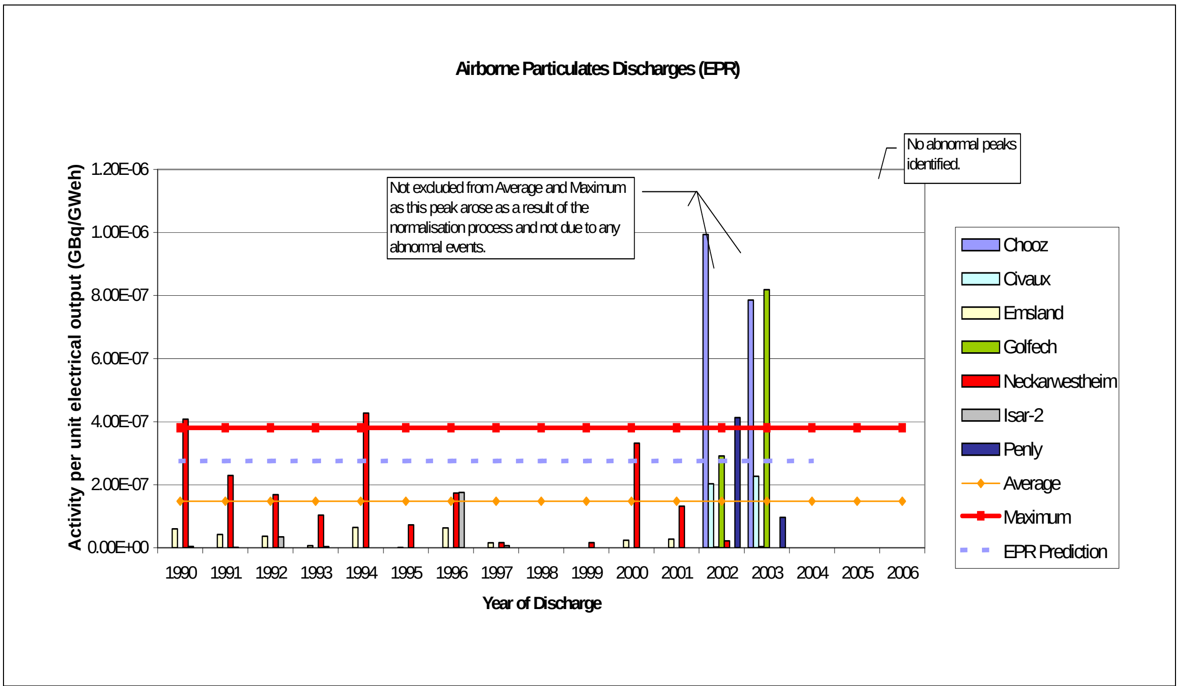

Figure 3.13 Airborne particulates discharges (EPR predecessors).

3.2.7 Airborne carbon-14 discharges (EPR predecessors)

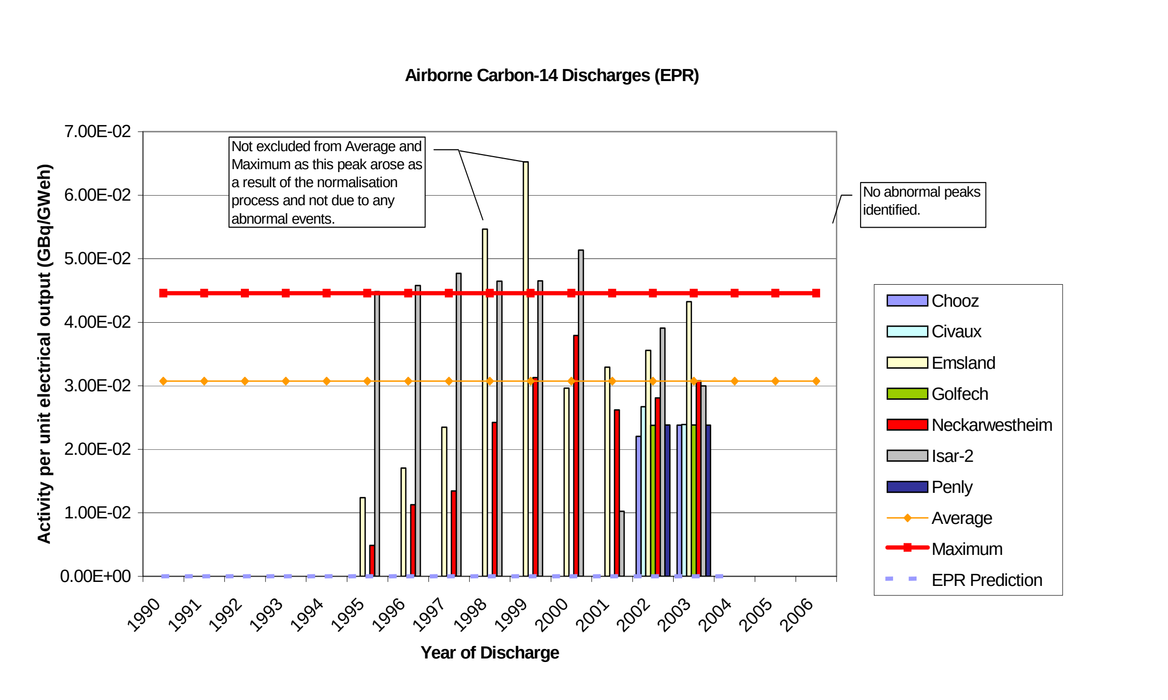

Figure 3.14 Airborne carbon-14 discharges (EPR predecessors).

3.3 ESBWR predecessors

3.3.1 Liquid tritium discharges (ESBWR predecessors)

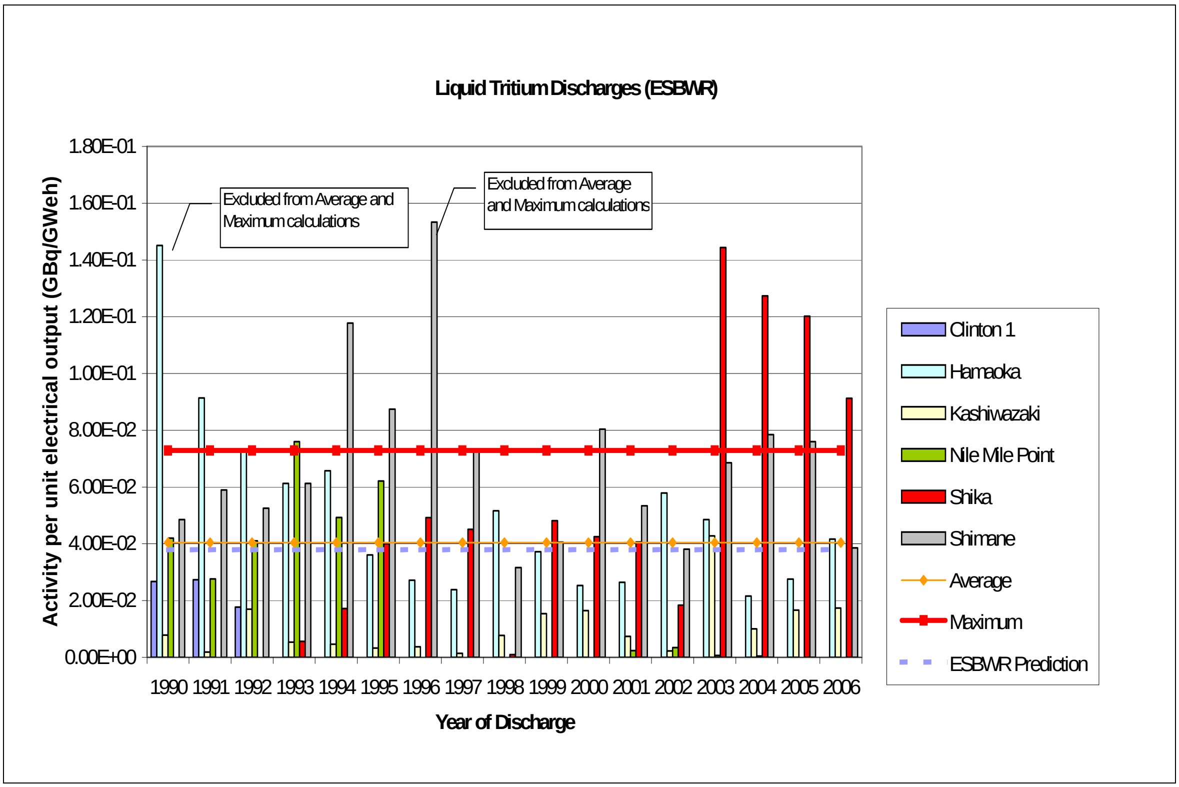

Figure 3.15 Liquid tritium discharges (ESBWR predecessors).

3.3.2 Other liquid discharges (ESBWR predecessors)

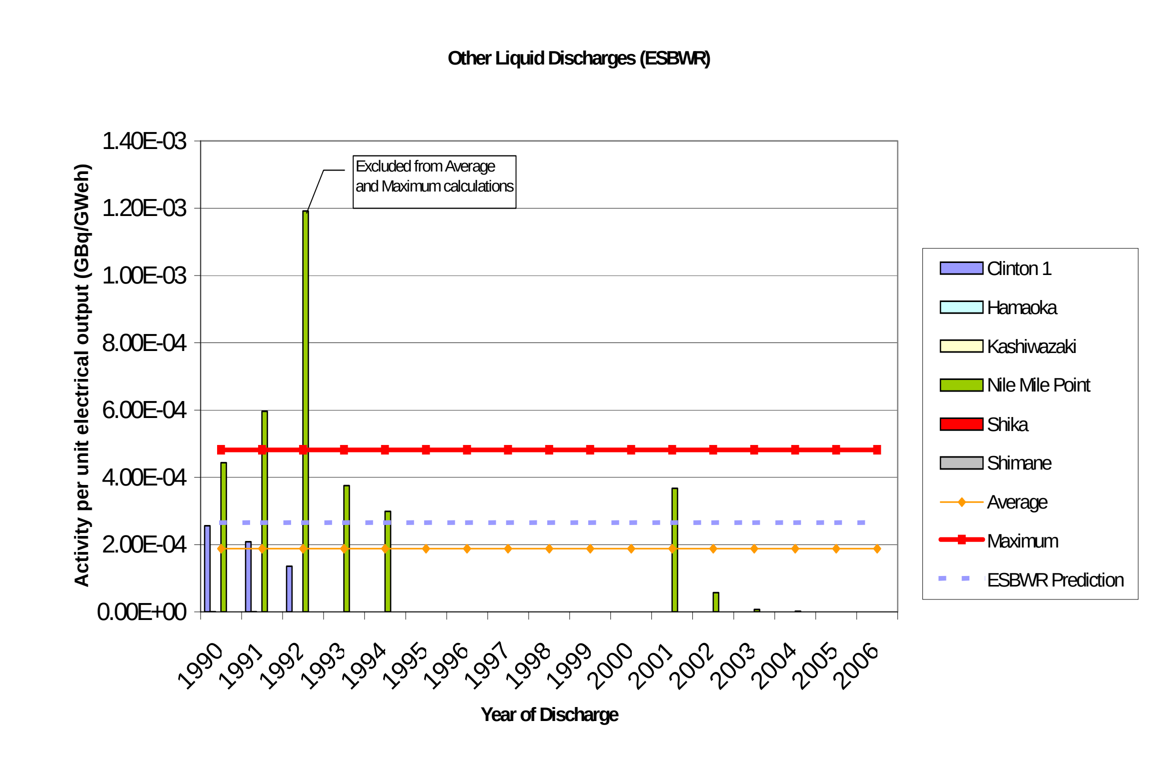

Figure 3.16 Other liquid discharges (ESBWR predecessors).

3.3.3 Airborne tritium discharges (ESBWR predecessors)

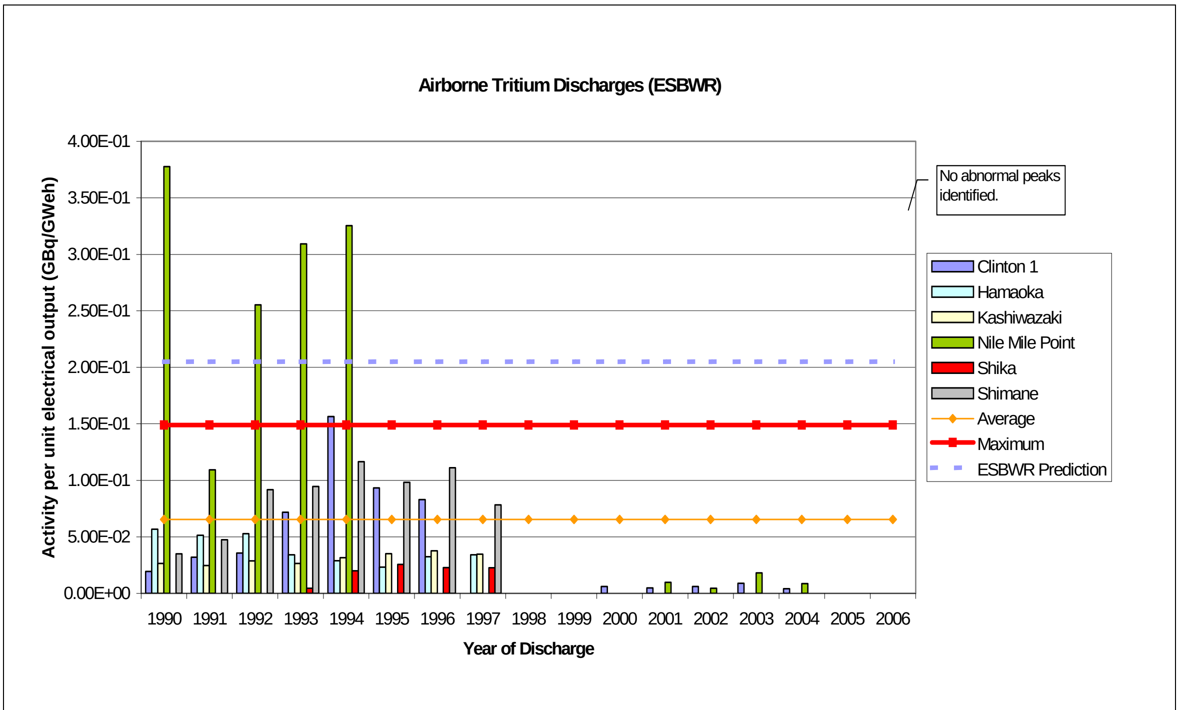

Figure 3.17 Airborne tritium discharges (ESBWR predecessors).

3.3.4 Airborne noble gas discharges (ESBWR predecessors)

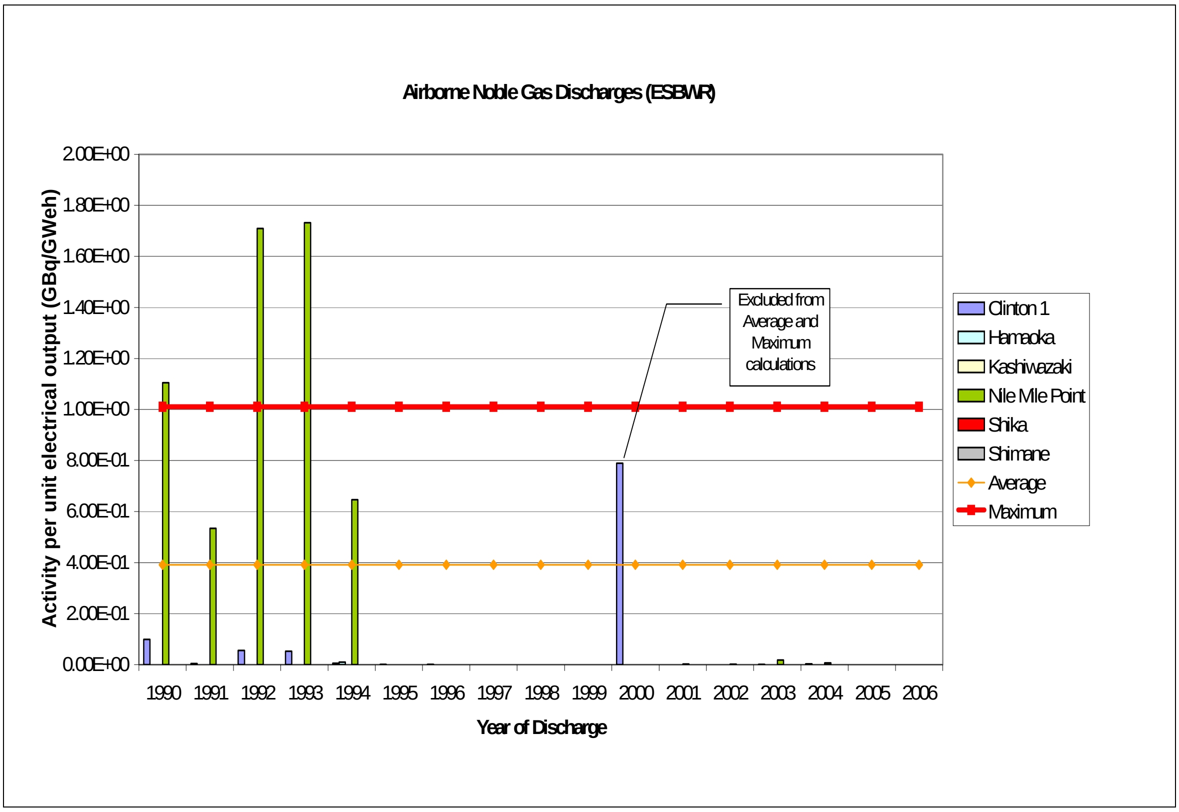

Figure 3.18 Airborne noble gas discharges (ESBWR predecessors).

3.3.5 Airborne iodine-131 discharges (ESBWR predecessors)

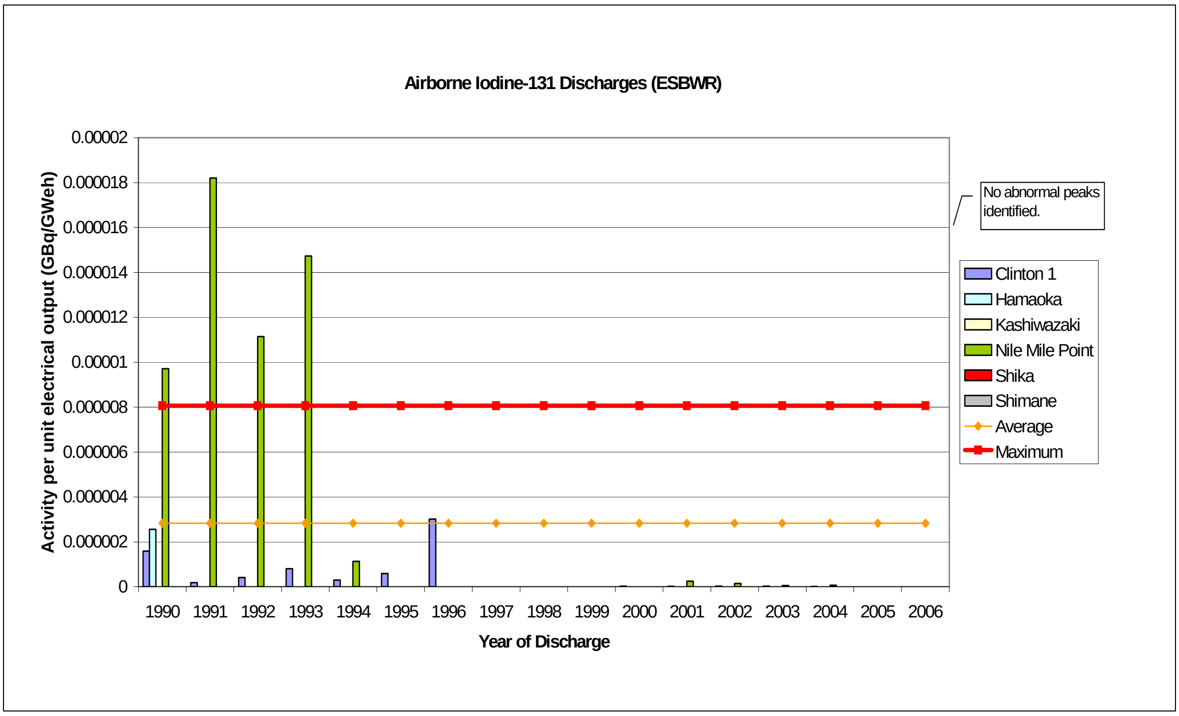

Figure 3.19 Airborne iodine-131 discharges (ESBWR predecessors).

3.3.6 Airborne particulates discharges (ESBWR predecessors)

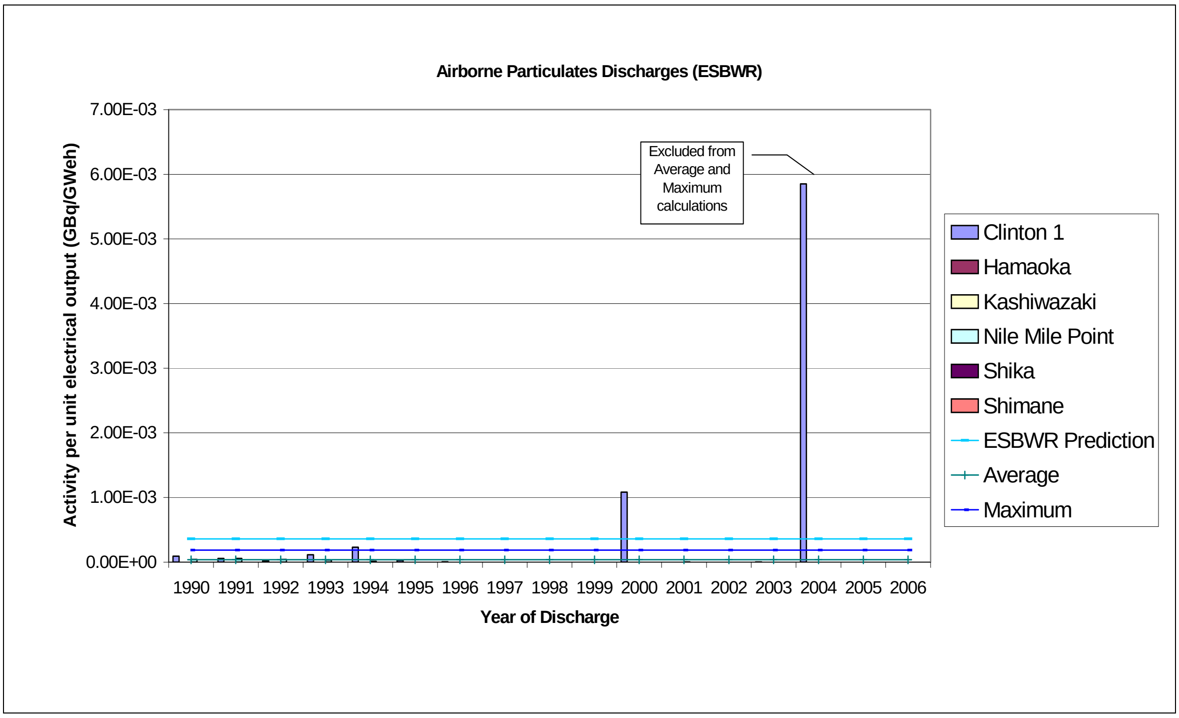

Figure 3.20 Airborne particulates discharges (ESBWR predecessors).

3.4 ACR-1000 predecessors

3.4.1 Liquid tritium discharges (ACR-1000 predecessors)

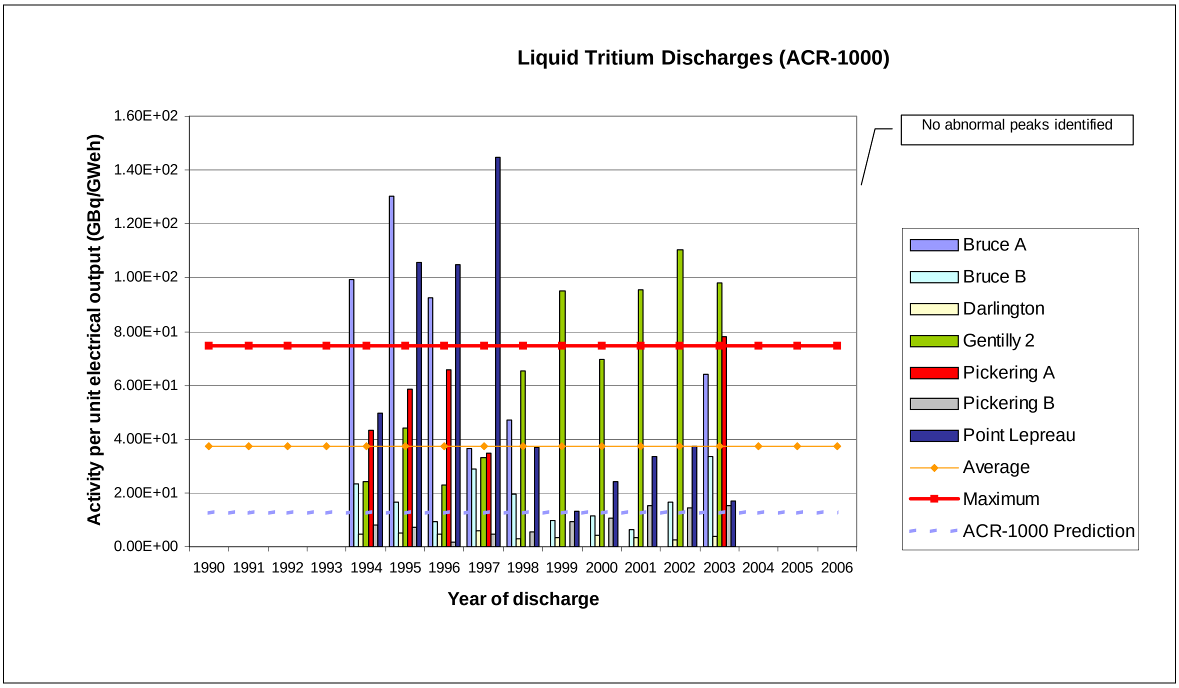

Figure 3.21 Liquid tritium discharges (ACR-1000 predecessors).

3.4.2 Other liquid discharges (ACR-1000 predecessors)

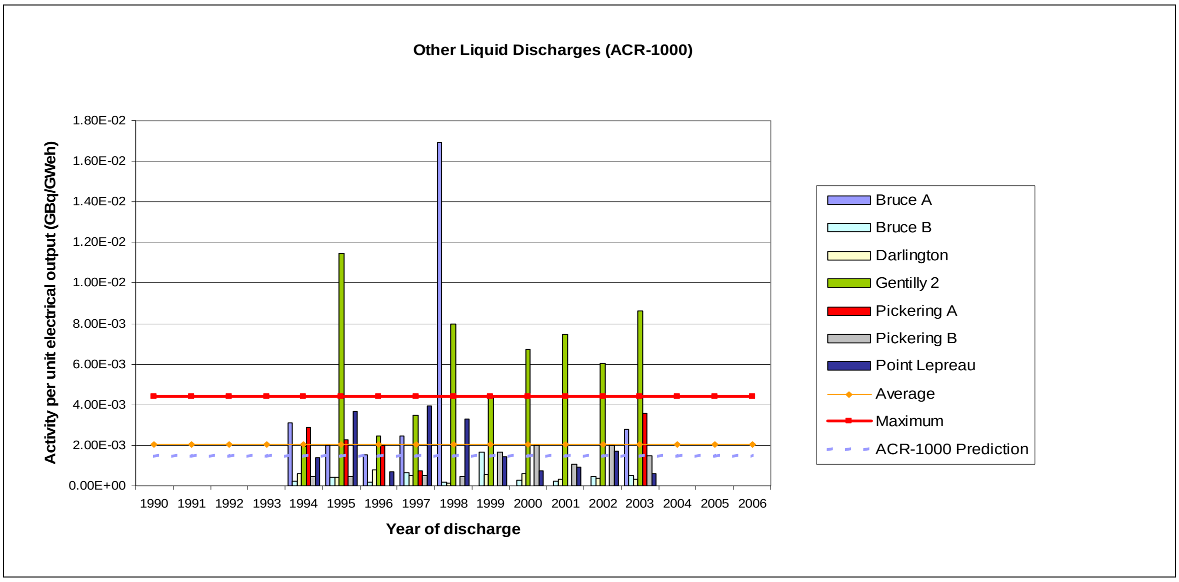

Figure 3.22 Other liquid discharges (ACR-1000 predecessors).

3.4.3 Airborne tritium discharges (ACR-1000 predecessors)

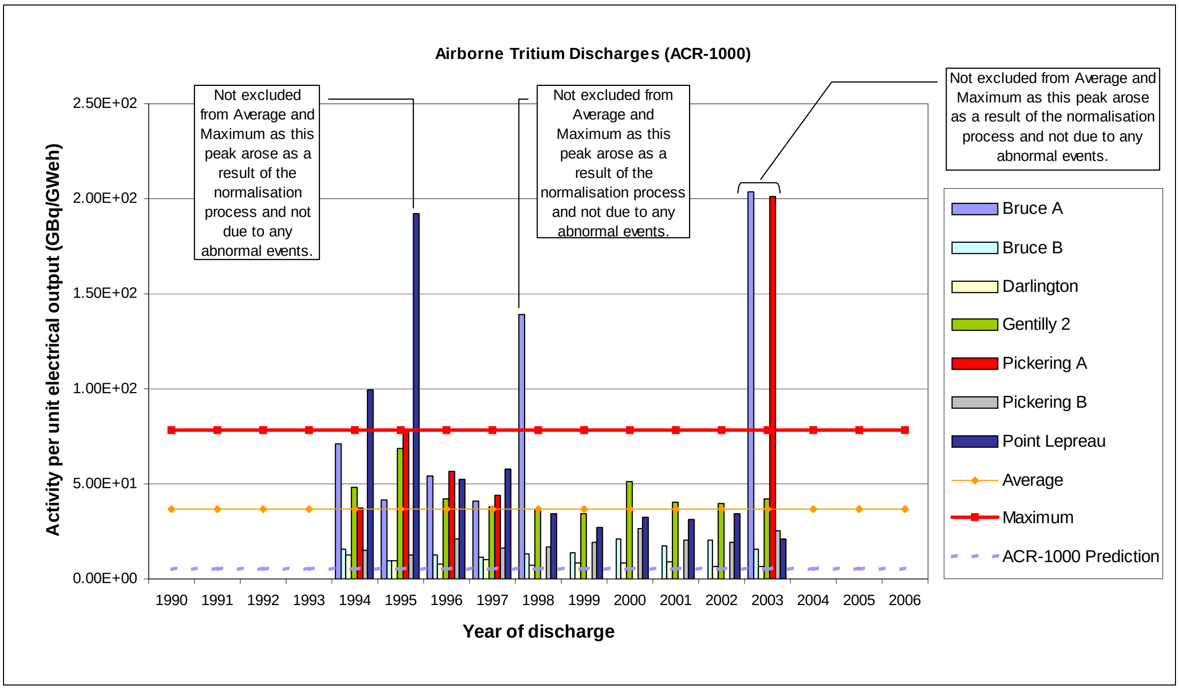

Figure 3.23 Airborne tritium discharges (ACR-1000 predecessors).

3.4.4 Airborne noble gas discharges (ACR-1000 predecessors)

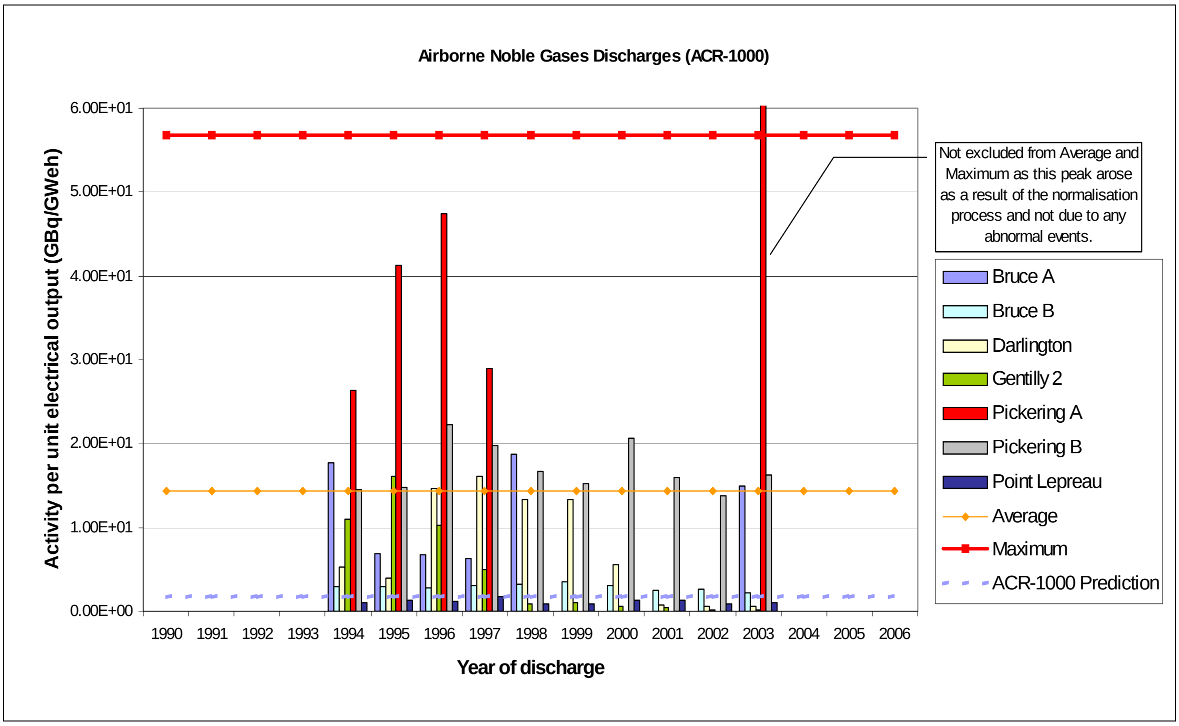

Figure 3.24 Airborne noble gas discharges (ACR-1000 predecessors).

3.4.5 Airborne iodine-131 discharges (ACR-1000 predecessors)

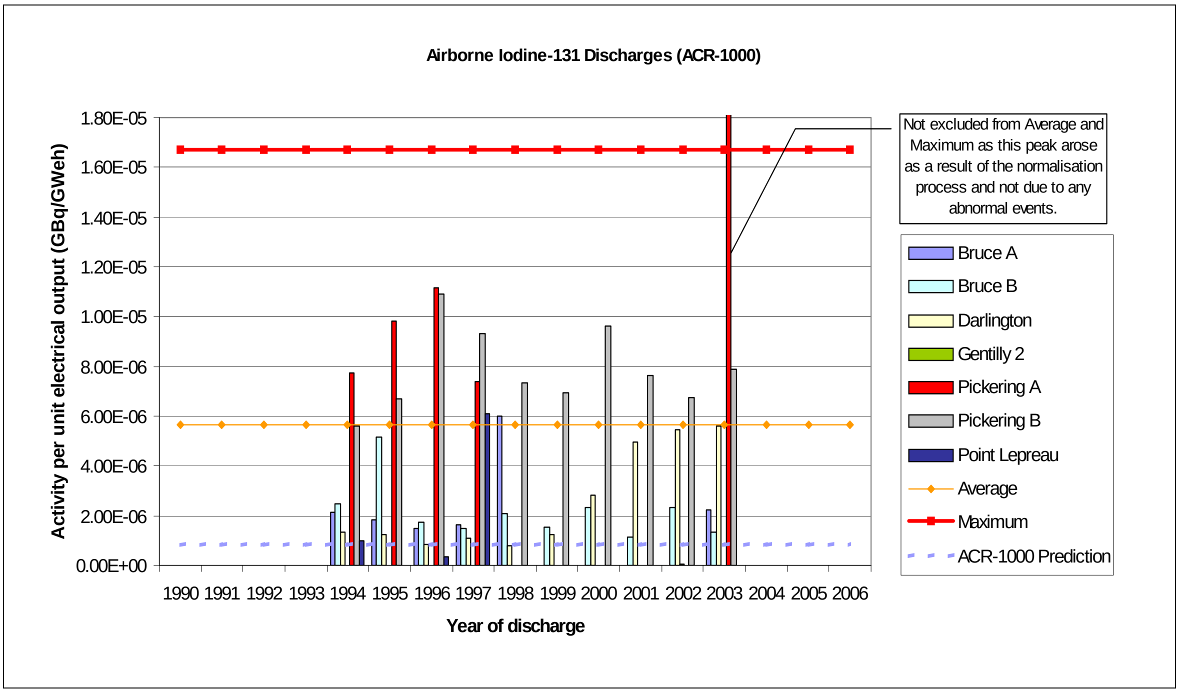

Figure 3.25 Airborne iodine-131 discharges (ACR-1000 predecessors).

3.4.6 Airborne particulates discharges (ACR-1000 predecessors)

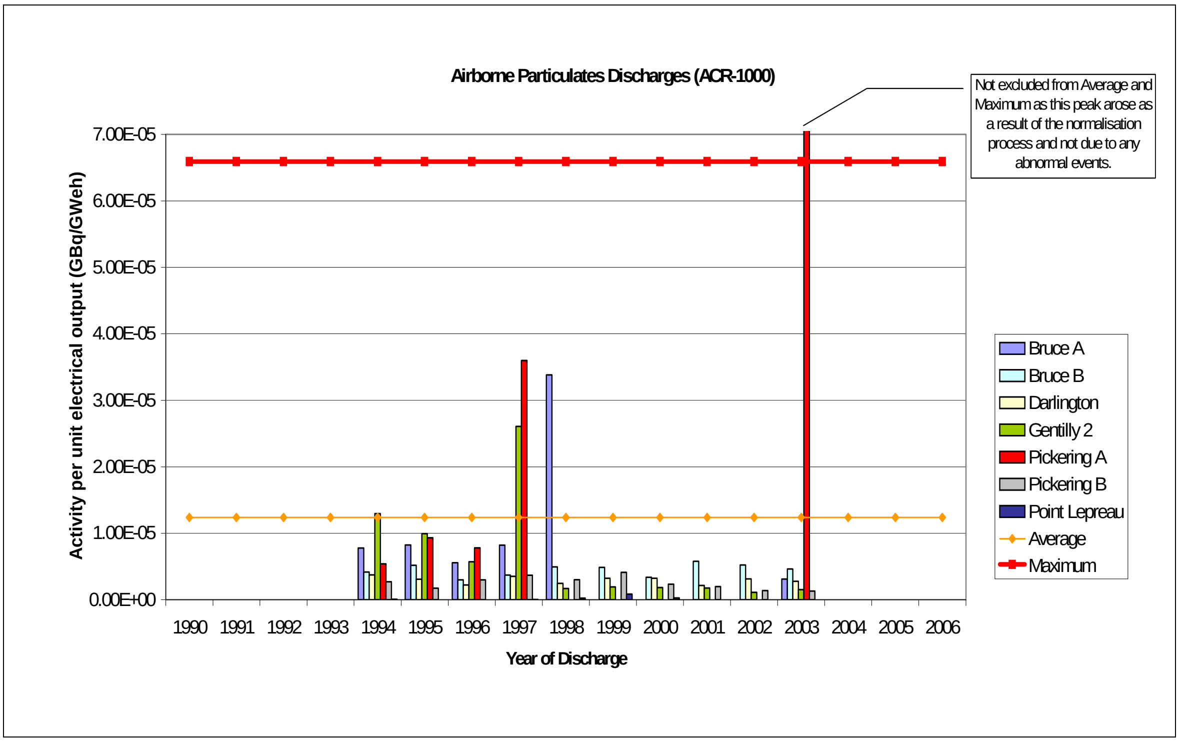

Figure 3.26 Airborne particulates discharges (ACR-1000 predecessors).

3.4.7 Airborne carbon-14 discharges (ACR-1000 predecessors)

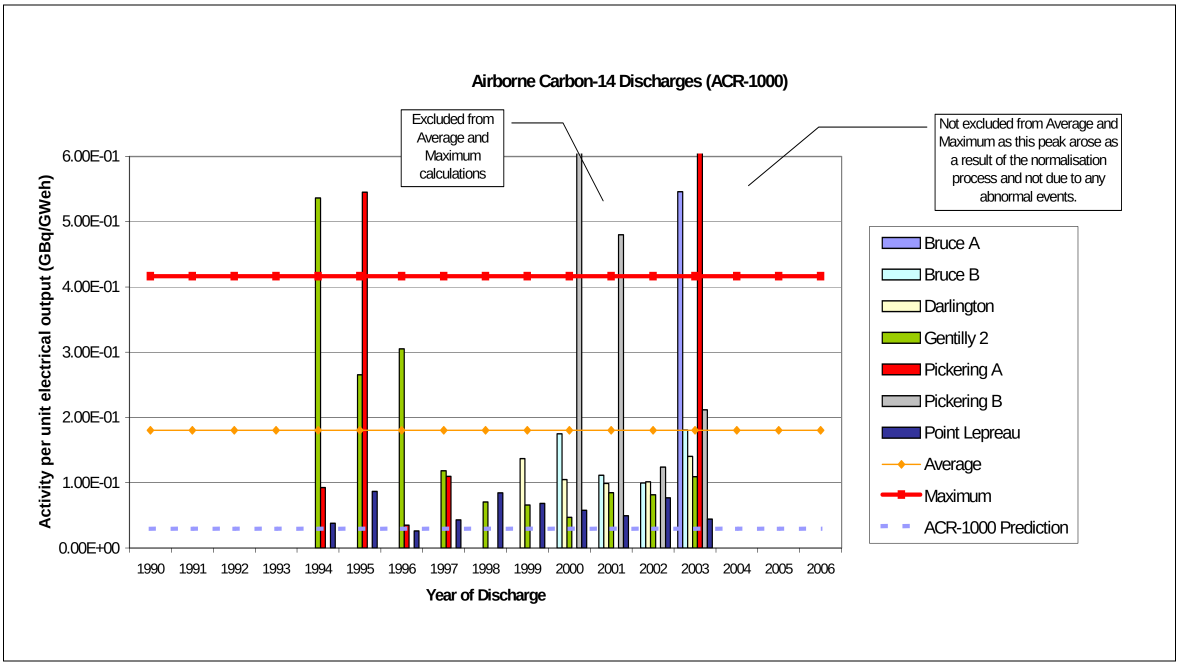

Figure 3.27 Airborne carbon-14 discharges (ACR-1000 predecessors).

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