Sellafield Ltd

Annual Discharges Review, 2015 - 2017

Purpose: Demonstration of the progressive reduction in discharges and hazard at Sellafield (NDA EPI Objective 5).

This paper was presented to the Sellafield Ltd Nuclear Safety Committee on 25 July 2018 for noting.

CONTENTS

Executive Summary

In general, permitted aerial and liquid discharges were lower in 2017 than in 2016. Significant reductions (>50%) of aerial discharges were reported for Kr-85, Sb-125, I-129 and Cs-137 and of liquid discharges for I-129. A significant increase (>50%) of aerial discharges was reported for Pu-Alpha and Pu-241. No significant increases of marine pipeline liquid discharges were reported between 2016 and 2017.

Discharges of Pu-Alpha from SIXEP increased between 2011 and 2016, steadying off in 2017. These were a reflection of the ramp-up of retrieval operations in FGMSP/SPP1 against a period of relatively low Pu-Alpha challenge. There are early indications that 2018 discharges will reflect those of 2013/14.

The end of oxide fuel reprocessing at Thorp in 2018 will result in significant reductions in site aerial discharges of Kr-85 (75%), I-129 (60%), Sr-90 (50%) and C-14 (50%) and liquid discharges of I-129 (80%).

Calculated doses to reference groups are similar to recent previous years. Dose to the marine reference group is greater than the terrestrial reference group. The marine dose (10% of the UK public dose limit) is dominated by historical discharges.

Permitted discharges are well below current permit limits suggesting there is generous headroom for future discharges. However, EA expect SL to offer significant reductions in site limits as part of the upcoming Major Permit Review application.

1 Discharge summary for 2017

There were no exceedances of radiological discharge limits in 2017. Discharges were generally low as a proportion of site limits, the highest for aerial discharges being Pu-Alpha at 18% of the limit and for marine pipeline liquid discharges Pu-Alpha at 21% of the limit. Further details of aerial and liquid discharges are given in Appendix A and B.

Radionuclides with significant differences in aerial and marine pipeline liquid discharges (>±50%) between 2016 and 2017 were as follows:

2017 discharges lower than 2016		Source of difference	2017 discharges higher than 2016		Source of difference
Aerial					
Kr-85	-51%	Thorp, -44% Magnox -7%	Pu-Alpha	+126%	R&T Facilities 126%
Sb-125	-83%	FHP, -83%	Pu-241	+126%	R&T Facilities 126%
I-129	-50%	Thorp, -47% Magnox -3%			
Cs-137	-59%	MWSF 1&2 -33% MWSF 3 -24%			
Liquid					
I-129	-50%	Thorp, -47% Magnox -3%			

Aerial discharge decrease

Kr-85 - the decrease in aerial discharges of Kr-85 can be explained by the reduction in tonnage throughput in Thorp and Magnox as given in Figure 1. Kr-85 discharge activities are especially influenced by the reprocessed fuel throughput in Thorp.

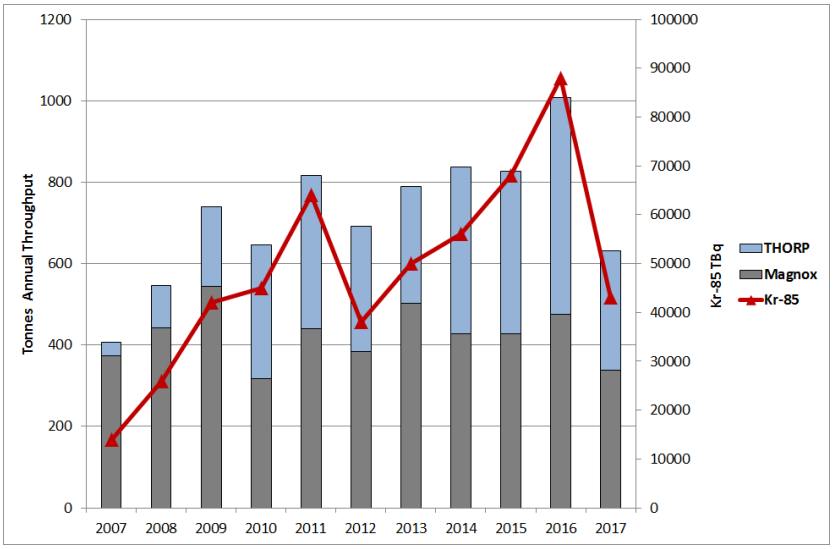

Figure 1: Kr-85 discharge trend against Thorp and Magnox reprocessing throughput

I-129 - as with Kr-85, I-129 aerial discharges are influenced by fuel throughput in Thorp (Figure 2). Since fuel throughput in Thorp was much lower in 2017 compared to 2016 (292 tonnes against 531 tonnes), discharges were subsequently lower.

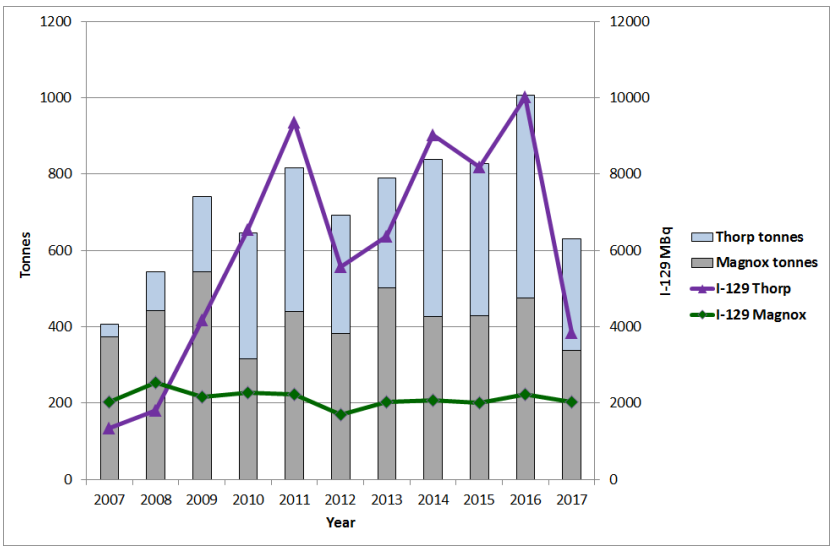

Figure 2: Aerial I-129 discharge trends against Thorp and Magnox reprocessing throughput

Cs-137 - aerial discharges are most influenced by releases from the MWSF. Removal of waste from this facility has resulted in lower Cs-137 discharges.

Sb-125 - the release of Sb-125 is influenced by the quantities and nature of aged corroded fuel processed in FHP. The management of the availability and scheduling of fuel in 2017 resulted in a significant drop, 83%, of Sb-125 aerial discharges.

Aerial discharge increase

Pu-Alpha and Pu-241 - aerial activities are influenced by discharges from the Research & Technical Facilities. Towards the end of 2017, major extractor fan maintenance was performed in this ageing facility resulting in an increase of Pu-Alpha and Pu-241 aerial discharges from this release point. Although there has been an increase compared to 2016 discharges, the 2017 annual discharges were only 11 – 18% of discharge limits. Discharges in 2018 have so far been typical of 2016 levels.

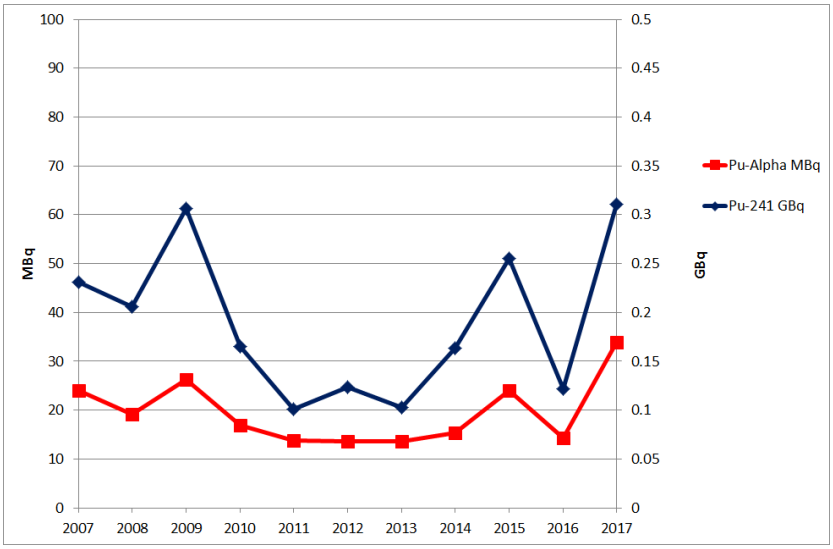

Figure 3: Aerial Pu-Alpha and Pu-241 discharge trends between 2007 and 2017

Liquid discharge decrease

I-129 - as with aerial discharges of Kr-85 and I-129, the liquid discharges of I-129 are also influenced by the tonnage throughput in Thorp. Due to the reduced throughput between 2016 and 2017, significant reductions in I-129 liquid discharges were observed in 2017.

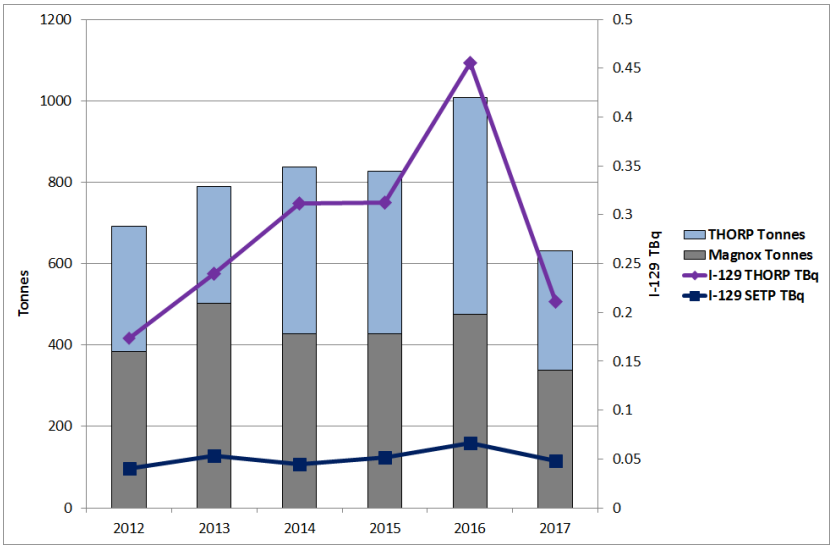

Figure 4: Liquid I-129 discharge trends against Thorp and Magnox reprocessing throughput

Based on 2017 discharge figures, the cessation of reprocessing at Thorp at the end of 2018 will result in the following significant site discharge reductions:

Aerial discharges:

C-14 50%

Kr-85 75%

Sr-90 50%

I-129 60%

Liquid discharges

I-129 80%

Although I-129 was the only radionuclide in marine pipeline liquid discharges with a significant difference (>50%) from 2016 discharges, several radionuclides had a reduction of 20 to 50% between 2016 and 2017. These reductions are a direct result of the quantities and types of materials processed in SETP and SIXEP during 2017.

Radionuclide	Change relative to 2016	Contributing plants % of 2017 discharge
H-3	-37%	SETP 97%
C-14	-26%	SETP 91%
Co-60	-40%	SETP 40%, SIXEP 34%
Zr/Nb-95	-33%	SETP 57%, SIXEP 43%
Cs-134	-35%	SETP 69%
Ce-144	-42%	SETP 43%, SIXEP 57%
Pu-241	-30%	SIXEP 68%
Am-241	-22%	SETP 64%
Cm-Alpha	-35%	SETP 98%
Alpha	-27%	SIXEP 65%

2 Dose summary for 2017

Table A3 provides 'Measured dose' and 'Interim measured dose' values for 2016 and 2017 aerial discharges. The 'Interim measured dose' is calculated using Sellafield Ltd data available on terrestrial foodstuffs monitored. The 'Measured dose' is calculated using the Sellafield Ltd data and the Food Standards Agency (FSA) monitoring data. The FSA data relate to a wider selection of terrestrial foodstuffs and become available in the summer (July/August) following the year end of discharges. Because of the delay in availability of such data, noticeable differences are present between aerial 'Interim measured dose' and 'Measured dose'.

The interim measured dose to the aerial reference group (Adult) for 2017 remains low at 9.8 μSv against the public dose limit of 1000 μSv.

The dose to the marine reference group (Adult) has decreased slightly to 100 μSv in 2017 from 105 μSv in 2016. Interim measured doses to the reference group from historic discharges of Pu-Alpha and ^{241}Am remain dominant, contributing 70% for the marine food consumption pathway in 2017.

Dose to the reference group from aerial discharges have been less than 20 μSv (2% of public dose constraint) since 2009. Dose to the reference group from marine discharges have been less than 200 μSv (20% of public dose constraint) since 2007 and around

100 μSv (10% of public dose constraint) since 2013. Further details of Sellafield reference group doses are given in Appendix A and B.

Updates of shellfish and fish consumption, and intertidal occupancy for the Sellafield area have been published annually, on behalf of the Regulators, since 1994. Consumption rates of total fish and total crustaceans are presently at their highest recorded rates since 1994 whereas the current consumption rate of total molluscs is towards the lowest recorded value. To reduce the sensitivity of marine dose calculations to inter-annual habit fluctuations, a 5 year rolling average of habits (fish, crustacean, mollusc consumption, beach occupancy) has been used. The overall doses from liquid discharges are still dominated by the presence of transuranic radionuclides in molluscs, which are largely due to historical discharges from the site.

3 Significant events and investigations

No significant off-site environmental events have occurred and therefore no investigations have been performed relating to 2017 aerial and liquid radiological discharges.

4 Forward look at key issues, predicted discharges and dose trends

Key issue

An application to vary the Radioactive Substances Activity (RSA) permit will be submitted in 2018 as part of the Major Permit Review (MPR) of the Site environmental permits. EA will consider the application (involving public consultation) which will make proposals for permit variation in 2 phases, firstly following the end of Thorp reprocessing shearing and secondly following the end of Magnox reprocessing de-canning. EA want to make significant reductions in site limits in order to demonstrate 'progressive and substantial' reductions in discharges, consistent with OSPAR goals. The MPR provides an important opportunity to simplify the numerous discharge limits and conditions, reviewing long standing historic requirements and those impacts which have now been reduced to negligible levels. A key aim of the review is to establish a more flexible and proportionate process which will better facilitate timely responses to changing SL strategies and uncertain discharges profiles.

Predicted discharges

The UK Strategy for Radioactive Discharges (UKSRD) was produced by the UK Government to show how it intends to implement the OSPAR Radioactive Substances Strategy (RSS). A key feature of OSPAR RSS and UKSRD is the requirement to apply the Best Available Techniques (BAT) approach to minimise liquid effluent discharges and their impacts into the future. The UKSRD also addresses aerial discharges (not required for OSPAR RSS). Sellafield Ltd supports the UK Government in these matters by:

- Providing forecasts of future discharges, including a breakdown of 'Operational' and 'Decommissioning' discharges;
- Assisting in the production of national BAT reports; and,
- Contributing to the definition of the term 'Close to Zero'. Once defined in the near future there may be pressure to take additional measures to reduce liquid effluent discharges from Sellafield.

It is important to note that neither strategy sets legally binding requirements on Sellafield Ltd: these are set by the EA via the environmental permit.

As reprocessing nears completion, the emphasis at Sellafield is shifting to environmental remediation, decommissioning and clean-up of the historical legacy with an increasing degree of uncertainty. The Overall Effluent Strategy model (OES) at Sellafield has been developed to predict current and future discharges from the Sellafield site. This model deals with a complex and varying set of interacting source terms, and is of increasing importance in forward predictions and identifying associated BAT arrangements. There has been significant and continual improvement in source data and forward predictions, whilst acknowledging the need for flexibility during periods of future uncertainty. Better understanding of these uncertainties relating to future discharges is an ongoing aspect of preparation for the retrieval and associated treatment plant capabilities. This is reflected in the OES Model predicting to within 20% for well understood flowsheets with predictable performance parameters. Greater uncertainty is associated where unique and shifting challenges exist.

Future effluent predictions are managed by the Sellafield Effluent Management Strategy team (SEMS) and effectively governed by the Sellafield Flowsheet Working Party.

The UKSRD liquid discharge expected outcomes for the site for 2020 to 2030 for annual Total Alpha discharges is 0.1 TBq. For annual Total Beta discharges, the expected outcome is 18 TBq for the same period (Figures 5 and 6).

Discharge and Dose trends

Current understanding and assumptions used in Sellafield Ltd's OES model show that predicted Total Alpha and Total Beta liquid discharges are not expected to compromise the UKSRD expected outcomes.

The recently published UKSRD 2018 review of the 2009 strategy recognises that forecasts are based on 'expected operational outcomes' and is not expected to impact adversely on Sellafield Ltd's plans, so long as Sellafield Ltd continues to demonstrate the application of BAT. It has been acknowledged that it is important to ensure that discharge reductions at Sellafield are not achieved at the expense of unacceptable increased accident risk. The review recognises that flexibility is required, due to uncertainties in future operations, thus ensuring that hazard and risk reduction activities are not compromised. The 2009 version of the UKSRD (UKSRD09) remains as extant Government Policy, with this 2018 review providing an update on progress against the UKSRD09.

Reference group doses from predicted future within-year[1] liquid and aerial discharges vary from 30 μSv (2018) to 10 μSv (2030) and from 7 μSv (2018) to 0.4 μSv (2030) respectively. These annual doses are much lower than the UK public dose limit of 1000 μSv. The reduction of terrestrial reference group doses will be evident when the volatile radionuclides within aerial discharges (^{85}Kr, ^{125}Sb, ^{129}I, ^{131}I) reduce when reprocessing stops; Thorp in 2018 and Magnox in 2020.

[1] Doses based on within-year discharges relate only to that year of discharge and do not consider historical contributions to dose.

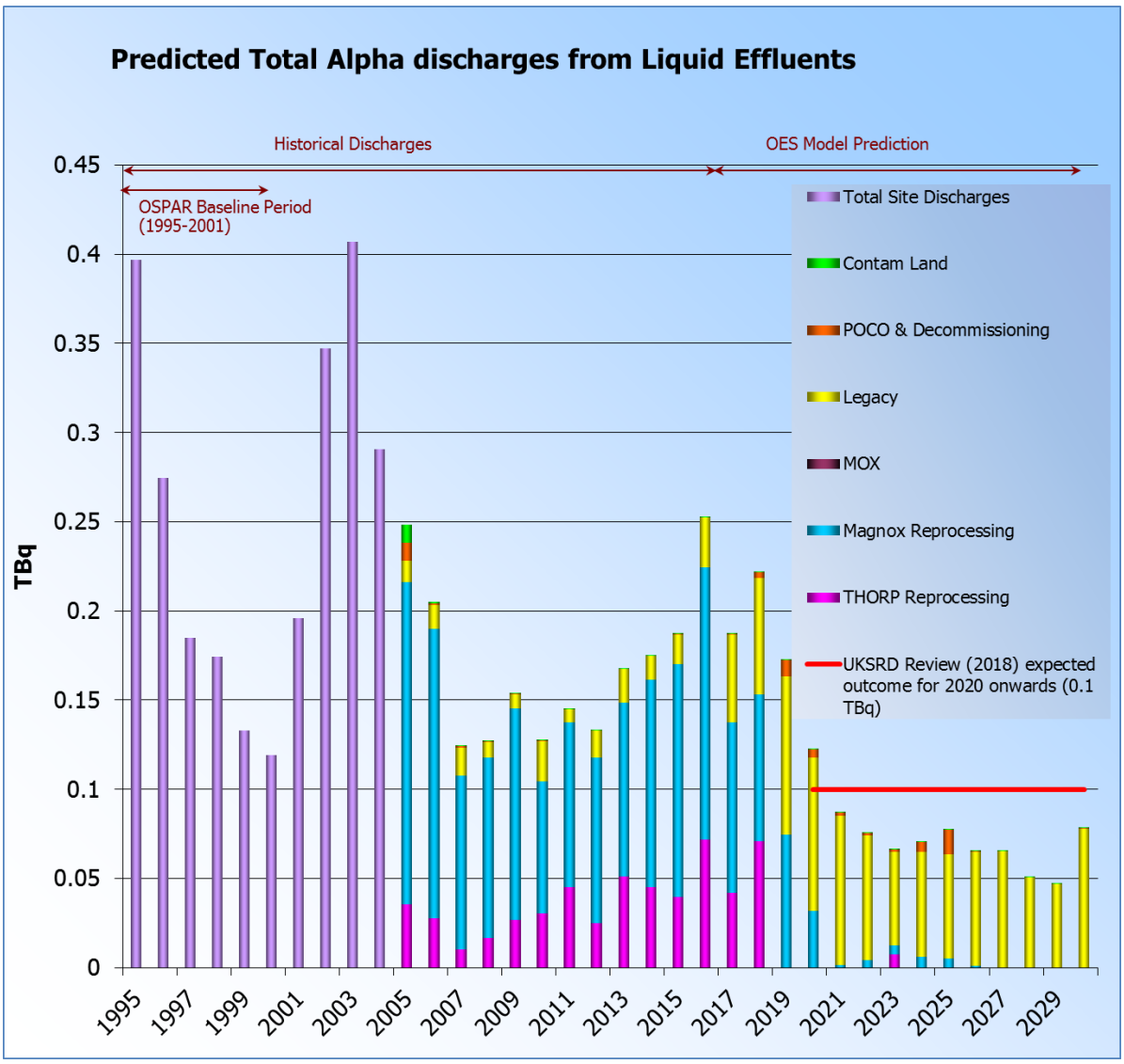

Figure 5: Past, current and predicted Total Alpha discharges from liquid effluents, 1995 – 2030.

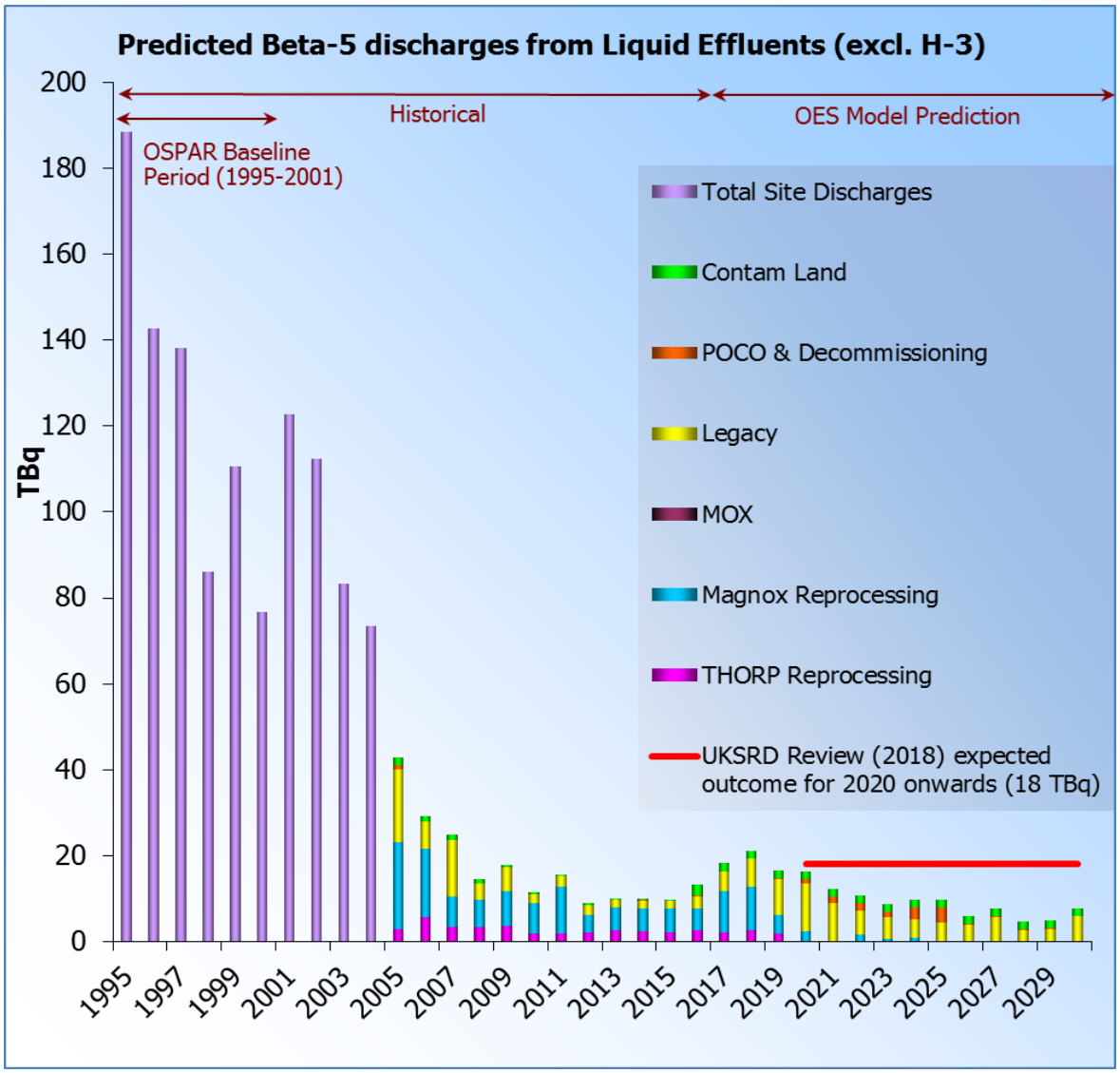

Figure 6: Past, current and predicted Total Beta-5 discharges from liquid effluents, 1995 – 2030 (excluding H-3).

5 Threats, risks and mitigation

Reducing the headroom between site RSA permit discharge limits and actual discharge quantities continues to be a major consideration during the 2018 MPR. The SL variation application will include proposals to reduce site limits (as well as to remove others and introduce a tiered limit structure to provide more flexibility to cover future discharge uncertainty). All areas of the site have needed to be fully engaged in the MPR process to ensure that future permits are conducive to the efficient delivery of future decommissioning and remediation programmes on site.

SIXEP Pu-Alpha annual discharge trends and BAT

In Section 1, it was described that the highest proportion discharged against the site limit for liquid discharges was Pu-Alpha at 21%. Liquid discharges of total alpha from site are dominated by Pu-Alpha discharges. The plant which contributes most activity to the

Pu-Alpha liquid discharges is SIXEP. SIXEP reduces the concentration of ^{137}Cs and ^{90}Sr in waste effluent. It was not designed to abate alpha-activity entering the plant.

Discharges of Pu-Alpha and Total Alpha from SIXEP between 1999 and 2017 are given in Figure 7.

Following the 6th Joint Convention on Safety of Spent Fuel and Radwaste Management 2018, Canada submitted a comment to ONR asking if the increase in liquid total alpha discharges (between 2011 and 2015) were still justified according to BAT assessment. Sellafield Ltd responded that 'period-to-period variability in discharges reflects plant operational variability' and that BAT is a regular topic of discussion between the EA and Sellafield Ltd.

Investigations into the elevated alpha discharges from SIXEP were made by Sellafield (MRTC/2016/41 (Issue 1.1)) in 2016. It was found that increased discharges coincided with the increase in operations within FGMSP in preparation for Bulk Retrieval Operations although there was 'no clear evidence to establish the cause of the increase in alpha discharges'.

There is an ongoing combined R&D task across the SIXEP effluent stream to improve understanding of the alpha challenge and SIXEP abatement performance and how it varies with changes in donor plant operations. This includes investigation into mitigation measures which could be deployed if the situation deteriorates in future (e.g. assessment of settling aids to reduce the particulate and associated alpha challenge). Management arrangements are in place to monitor and control donor plant operations and assess the impact on discharges. These arrangements have the ability to respond to discharge trends of interest.

Pu-Alpha discharges are only elevated in comparison to a period in recent years in which operations have provided a relatively low challenge i.e. FGMSP was in care and surveillance ahead of the start of retrieval operations and the rate of corroded fuel processing in FHP was low compared to the early 2000s.

Annual discharges have levelled since 2016 thus interrupting the increasing trend since 2011 despite the continuing ramp-up of retrieval operations in FGMSP/SPP1 over this time period. In considering recent monthly discharge trends, there has been a decrease over the last 12 months (peaked in April 2017 at 30.3% of Rolling Annual Plant Limit, cf. 25.1% in Apr 2018). The discharges recorded so far in 2018 (Jan – April) are more consistent with 2013 and 2014 discharges and lower than the respective periods of 2015 – 2017 discharges.

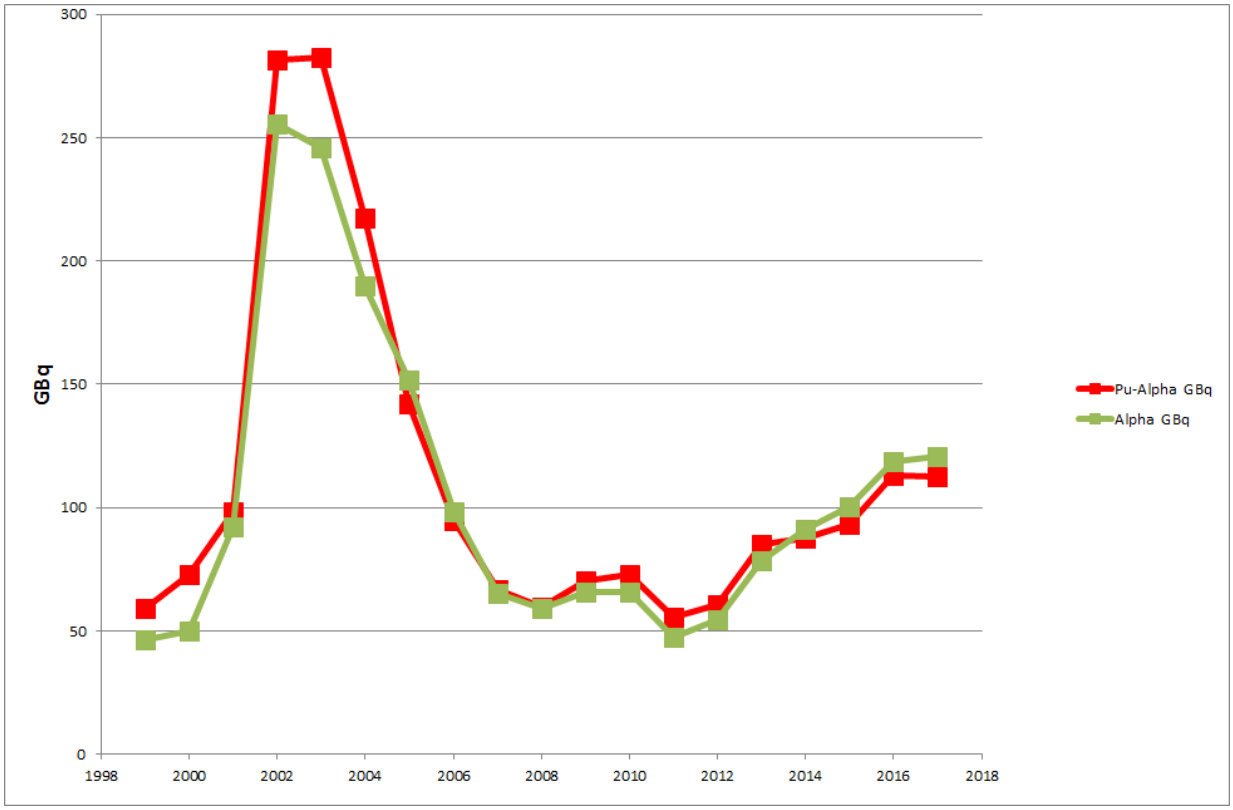

Figure 7: Liquid Pu-Alpha and Total Alpha discharge trends from SIXEP between 1999 and 2017

6 Sellafield Ltd Environmental Monitoring Programme

The statutory environmental monitoring programme (EMP) is continually adapting to changing environmental impacts from the permitted discharges to air and sea. Through the application of BAT, annual radiological impacts are used to re-assess the programme to identify where attention and resources should be given and where they should be removed (in discussion with the EA). The latest EMP BAT review was performed during 2017. This was well received by the EA resulting in all but one Sellafield Ltd recommendation being accepted for the improvement of the monitoring programme for 2018.

Terrestrial exposure pathways covered by the EMP are terrestrial food consumption (potatoes, milk and drinking water), inhalation, external radiation, immersion and direct radiation. Marine exposure pathways include seafood consumption (fish, crustaceans, molluscs) and external radiation from beach occupancy. The coverage of these pathways is sufficient for Sellafield Ltd to perform the appropriate dose assessments. Minor terrestrial pathway contributions are covered by the Food Standards Agency (FSA) monitoring programme. Other key indicator environmental media are also monitored – grass, river water, soil, total deposition, seawater, seaweed, sand and silt.

In addition, beaches along the Cumbrian coast are monitored for contaminated particles and stones. In excess of 150 hectares were monitored in 2017 with 191 particles and 35 larger objects being recovered. Oversight of the particles programme is carried out by the Sellafield Particles Working Group convened by the EA with FSA, PHE, NDA and

Sellafield Limited in attendance. The results of the programme and their public health implications are reviewed by the Department of Health Committee on Medical Aspects of Radiation in the Environment (COMARE). Public Health England has stated that:

"The conclusion, based on the currently available information, is that the overall health risks to beach users are very low and significantly lower than other risks that people accept when using the beaches."

Full details of the Particles in the Environment programme can be found on the Sellafield website[2] .

7 Conclusions

In general, 2017 aerial and liquid discharges and doses to reference groups are similar to recent previous years.

Rising Pu-Alpha discharges from SIXEP between 2011 and 2016 were a reflection of the ramp-up of retrieval operations in FGMSP/SPP1 against a period of relatively low Pu-Alpha challenge. There are early indications that 2018 discharges will reflect those of 2013/14.

Dose to the marine reference group is greater than the terrestrial reference group. The marine dose (10% of the UK public dose limit) is dominated by the contributions from historical discharges.

Permitted discharges are well below current permit limits. EA expect SL to offer significant reductions in site limits as part of the upcoming MPR application.

Predicted future liquid discharges are not expected to be compromised by the UKSRD review expected outcomes of 0.1 TBq per year for Total Alpha and 18 TBq for Total Beta discharges.

[2] https://www.gov.uk/government/collections/sellafield-ltd-environmental-and-safety-reports

Appendix A 2017 Aerial Discharge Tables

Table A1 Sellafield aerial effluent discharges from stacks

Radionuclide	Limit MBq	2015 Discharge MBq	2016 Discharge MBq	2017 Discharge MBq	2017 Discharge as % of limit
H-3	1.10E+09	8.42E+07	1.23E+08	9.94E+07	9%
C-14	3.30E+06	4.18E+05	4.42E+05	4.16E+05	13%
Kr-85	4.40E+11	6.82E+10	8.75E+10	4.33E+10	10%
Sr-90	7.10E+02	2.88E+01	2.95E+01	3.10E+01	4%
Ru-106	2.30E+04	7.32E+02	7.02E+02	6.51E+02	3%
Sb-125	3.00E+04	1.24E+04	1.01E+04	1.71E+03	6%
I-129	7.00E+04	1.12E+04	1.30E+04	6.52E+03	9%
I-131	3.70E+04	4.35E+02	4.23E+02	3.74E+02	1%
Cs-137	5.80E+03	8.95E+01	1.02E+02	4.16E+01	1%
Rn-222	5.00E+05	4.26E+04	4.26E+04	3.91E+04	8%
Pu-Alpha	1.90E+02	2.57E+01	1.54E+01	3.47E+01	18%
Pu-241	3.00E+03	2.93E+02	1.47E+02	3.32E+02	11%
Am-241/Cm-242	1.20E+02	1.55E+01	1.36E+01	1.70E+01	14%
Alpha(1)	8.80E+02	8.17E+01	1.08E+02	1.11E+02	13%
Beta(1)	4.20E+04	6.20E+02	1.24E+03	7.85E+02	2%

(1) Alpha and Beta values include Open Fuel Storage Ponds & Other Approved Outlets (OFSP&OO) contributions described in Table A2.

Table A2 Sellafield aerial effluent discharges from OFSP&OO

Radionuclide	Limit MBq	2015 Discharge MBq	2016 Discharge MBq	2017 Discharge MBq	2017 Discharge as % of limit
Alpha	5.00E+02	3.39E+01	7.48E+01	5.57E+01	11.1%
Beta	1.30E+04	3.91E+02	9.92E+02	6.00E+02	4.6%

Table A3 Sellafield reference group doses based on measured environmental activity concentrations (Adult). Doses include contributions from historical discharges.

Radionuclide	Interim measured dose in 2016, μSv (1)	Measured dose in 2016, μSv (2)	Interim measured dose in 2017, μSv (3)
H-3	0.03	0.14	0.01
C-14	0.13	0.59	0.08
Kr-85 (4)	0.40	0.40	0.17
Sr-90	0.23	0.84	0.20
Ru-106 (5)	0.003	0.03	0.002
Sb-125	0.03	0.07	0.01
I-129	0.27	1.10	0.11
I-131	0.004	0.001	0.005
Cs-134	0.0003	0.37	0.0003
Cs-137	0.40	0.96	0.20
Pu-Alpha	0.43	0.53	0.29
Pu-241	0.23	0.58	0.23
Am-241+Cm-242	0.34	0.58	0.24
Total (6)	2.5	6.3	1.6
Direct Shine	5.4	5.4	4.4
Beach External	1.3	2.8	2.8
Marine Foods	1.2	1.1	1.1
Overall Total	**10.4**	**15.6**	**9.8**

(1) Taken from Quarter 4 2016 Statutory Environmental Monitoring report.
(2) Taken from Sellafield Ltd Annual report on 2016 data
(3) Taken from Quarter 4 2017 Statutory Environmental Monitoring report.
(4) Calculated from 2016 and 2017 monitoring data.
(5) Based on modelled doses using Environmental Assessment Software (EAS) 4.0.3 with individual stack to reference group distances.
(6) Total dose for 2017 is based on Sellafield Ltd monitoring data only. FSA terrestrial data for 2017 will be used to complete the measured dose calculations. The completed data, which will include minor radionuclides and exposure pathways <1 μSv, will be available in October 2018.

Table A4 Sellafield reference group doses based on modelled predictions and calculations from aerial discharges (Adult). Doses are from a single year's discharge.

Radionuclide	Modelled Dose in 2016, μSv	Modelled Dose in 2017, μSv
H-3	0.19	0.10
C-14	0.10	0.11
Kr-85	0.61	0.26
Sr-90	0.0005	0.0005
Ru-106	0.003	0.002
Sb-125	0.07	0.01
I-129	2.2	1.0
I-131	0.004	0.005
Cs-137	1.1	0.7
Rn-222	0.05	0.05
Pu-Alpha	0.36	0.31
Pu-241	0.004	0.010
Am-241+Cm-242	0.02	0.02
Total	**4.7**	**2.5**

Table A5 Sellafield reported reference group doses 1997 – 2017 from aerial discharges

Year	Reference Group Dose	Comment
1997	124	Reduced limit of detection for ^{106}Ru
1998	118	No significant changes
1999	215	Direct radiation = 150 μSv
2000	210	Direct radiation = 150 μSv
2001	168	Direct radiation = 110 μSv
2002	44	Lower direct radiation and ^{41}Ar due to Calder shut down
2003	38	Lower direct radiation and ^{41}Ar due to Calder shut down
2004	18	Lower direct radiation and ^{41}Ar due to Calder shut down
2005	16	No significant changes
2006	28	Change in methodology for calculating doses
2007	26	No significant changes
2008	22	Reduction in external radiation from Radioactivity in Food and the Environment (RIFE) data
2009	13	Relocation of milk supply
2010	14	No significant changes
2011	13	No significant changes
2012	12	No significant changes
2013	11	No significant changes
2014	17	Direct shine dose calculation amended
2015	14	No significant changes, includes beach external, marine
2016	16	No significant changes, includes beach external, marine foods and direct shine.
2017	10	Reduction in aerial discharges in ^{85}Kr, ^{125}Sb, ^{129}I, ^{137}Cs

Appendix B 2017 Liquid Discharge Tables

Table B6 Sellafield marine pipeline liquid effluent discharges

Radionuclide	Limit GBq	2015 Discharge GBq	2016 Discharge GBq	2017 Discharge GBq	2017 Discharge As % of limit
H-3	1.80E+07	1.54E+06	2.05E+06	1.30E+06	7%
C-14	2.10E+04	4.92E+03	4.83E+03	3.60E+03	17%
Co-60	3.60E+03	5.13E+01	3.53E+01	2.12E+01	1%
Sr-90	4.50E+04	1.59E+03	2.01E+03	2.12E+03	5%
Zr/Nb-95	2.80E+03	9.64E+01	9.43E+01	6.36E+01	2%
Tc-99	1.00E+04	1.66E+03	1.90E+03	1.57E+03	16%
Ru-106	5.10E+04	7.03E+02	1.09E+03	1.03E+03	2%
I-129	2.00E+03	3.65E+02	5.22E+02	2.59E+02	13%
Cs-134	1.60E+03	6.67E+01	6.56E+01	4.24E+01	3%
Cs-137	3.40E+04	3.08E+03	3.72E+03	3.31E+03	10%
Ce-144	4.00E+03	1.94E+02	2.13E+02	1.24E+02	3%
Np-237	7.30E+02	3.65E+01	3.14E+01	3.63E+01	5%
Pu-Alpha	7.00E+02	1.39E+02	1.79E+02	1.50E+02	21%
Pu-241	2.50E+04	2.36E+03	2.99E+03	2.09E+03	8%
Am-241	3.00E+02	2.87E+01	2.58E+01	2.02E+01	7%
Cm-Alpha	5.00E+01	1.19E+00	2.96E+00	1.92E+00	4%
Alpha	9.00E+02	1.87E+02	2.53E+02	1.84E+02	20%
Beta	1.80E+05	9.52E+03	1.31E+04	1.21E+04	7%
Uranium (kg)	2000	328	342	348	17%

Table B7 Sellafield Factory Sewer liquid effluent discharges

Radionuclide	Limit GBq	2015 Discharge GBq	2016 Discharge GBq	2017 Discharge GBq	2017 Discharge as % of limit
H-3	6.80E+01	7.40E+00	7.89E+00	6.38E+00	9%
Alpha	3.00E-01	9.31E-02	8.14E-02	1.23E-01	41%
Beta	6.00E+01	2.65E+00	5.18E+00	3.49E+00	6%

Table B8 Sellafield reference group doses based on measured environmental activity concentrations (Adult). Doses include contributions from historical discharges.

Radionuclide	Interim Measured Dose in 2016, μSv (1)	Measured Dose in 2016, μSv (2)	Interim Measured Dose in 2017, μSv (3)
C-14	5.3	4.0	6.2
Co-60	0.04	0.04	0.03
Sr-90	0.57	0.58	0.27
Tc-99	1.8	1.8	2.0
Ru-106	0.54	0.54	0.63
Sb-125	0.007	0.007	0.006
I-129	0.96	0.96	1.89
Cs-137	2.9	2.9	3.9
Np-237	0.02	0.01	0.01
Pu-Alpha	15	15	13
Pu-241	1.1	1.1	0.8
Am-241	30	29	24
Cm-Alpha	0.15	0.15	0.06
External	49	49	48
Total dose	**107**	**105**	**100**

(1) Calculated from 2012 - 2016 5 year average habit data and SL monitoring data (excludes aerial pathways).
(2) Taken from Sellafield Ltd Annual report on 2016 data (excludes aerial pathways).
(3) Calculated from 2013 - 2017 5 year average habit data and SL monitoring data (excludes aerial pathways).

Table B9 Sellafield reference group doses based on modelled predictions and calculations from liquid discharges (Adult). Doses are from a single year's discharge.

Radionuclide	Modelled Dose in 2016, μSv	Modelled Dose in 2017, μSv
H-3	0.03	0.02
C-14	4.3	3.2
Co-60	0.04	0.03
Sr-90	0.57	0.60
Zr/Nb-95	0.004	0.003
Tc-99	0.82	0.67
Ru-106	1.4	1.35
I-129	0.48	0.24
Cs-134	0.02	0.01
Cs-137	1.2	1.06
Ce-144	0.10	0.06
Np-237	0.17	0.20
Pu-Alpha	7.6	6.4
Pu-241	2.7	1.9
Am-241	1.1	0.86
Cm-Alpha	0.04	0.03
External	1.1	1.0
Total	**22**	**18**

Table B10 Sellafield reported reference group doses 1997 – 2017 from liquid discharges

Year	Reference Group Dose μSv	Comment
1997	132	No significant changes.
1998	102	Reduced ^{99}Tc concentrations in winkles and lobsters.
1999	136	Inclusion of external dose (23 μSv) during winkle
2000	155	Increased consumption of winkles and lobster.
2001	148	Reduced actinide concentrations in molluscs.
2002	197	Increased environmental concentrations of ^{241}Am, Pu-
2003	220	Increase in consumption rates.
2004	240	Increase in consumption of winkles and mussels.
2005	230	Reduced ^{99}Tc concentrations.
2006	212	Reduced ^{99}Tc concentrations.
2007	187	Reduction in discharge levels.
2008	193	No significant changes.
2009	161	Reduced consumption rates and lower concentrations.
2010	161	No significant changes.
2011	135	Reduced consumption rates.
2012	129	Increase in ^{241}Am concentrations in molluscs.
2013	105	Decrease in Pu-Alpha concentrations in molluscs.
2014	101	Decrease in Pu-Alpha and ^{241}Am concentrations in molluscs.
2015	99	No significant changes
2016	105	Increase in Pu-Alpha and ^{241}Am concentrations in molluscs.
2017	100	Decrease in Pu-Alpha and ^{241}Am concentrations in molluscs.