National Aeronautics and
Space Administration

John H. Glenn Research Center
Lewis Field
Plum Brook Station
Sandusky, OH 44870

October 6, 2009

Reply to Attn of: QD

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Plum Brook Reactor Facility, Licenses Nos. TR-3, Docket No. 50-30 and R-93, Docket No. 50-185, Request for Additional Information Related to NASA's Request to Amend Licenses

The following response is affirmed under 28 USC Section 1746.

Enclosed is the response to your letter dated June 11, 2009, requesting additional information relating to approval of the National Aeronautics and Space Administration's Request for Amendment to Licenses TR-3 and R-93. Several of the responses in Enclosure 1 include attachments consisting of drawings, photographs, maps and computer print-outs. These are included in electronic form on the attached CDROM. A detailed listing of the Attachments is provided with each detailed response in Enclosure 1.

The responses are true and correct to the best of my knowledge and belief. I declare under penalty of perjury that the foregoing is true and correct. Executed this 6th day of October 2009.

Should you have any questions or need additional information, please contact me at NASA Plum Brook Station, 6100 Columbus Avenue, Sandusky, Ohio 44870, or by telephone at (419) 621-3277.

Sincerely,

for Keith M. Peecook
NASA Decommissioning Program Manager

Enclosure: (1) Responses to Comments, 63 pages
Attachments: (31) Attachments on 1-CDROM

cc:
USNR/C. J. Glenn (FSME)
USNRC/J. Webb (FSME)
USNRC/K. Pinkston (FSME)
USNRC/W. G. Snell (R.III/DNMS/DB).
ODH/M. J. Rubadue

National Aeronautics and Space Administration
Response to Request for Additional Information
Regarding
U.S. Nuclear Regulatory Commission
Review of NASA Request for License Amendment

TABLE OF CONTENTS

Section	Section Title	Page
1	Response to Comment Number 1	1
2	Response to Comment Number 2	8
3	Response to Comment Number 3	14
4	Response to Comment Number 4	17
5	Response to Comment Number 5	22
6	Response to Comment Number 6	26
7	Response to Comment Number 7	27
8	Response to Comment Number 8	29
9	Response to Comment Number 9	33
10	Response to Comment Number 10	35
11	Response to Comment Number 11	38
12	Response to Comment Number 12	39
13	Response to Comment Number 13	42
14	Response to Comment Number 14	44
15	Response to Comment Number 15	46
16	Response to Comment Number 16	47
17	Response to Comment Number 17	52

List of Tables

Table	Description	Page
Table 1	Comparison of Surface Soil Screening Level Concentrations with Measured Values in Plum Brook Sediments	2
Table 2	Summary of Plum Brook Dose Assessment Results	3
Table 3	Mass of Potentially Impacted Soil and Sediment in Plum Brook Watershed	6
Table 4	Parameter Values for ALARA Cost Benefit Calculation	7
Table 5	2005 Pentolite Ditch and Plum Brook Sediment Sample Vendor Analysis Results	10
Table 6	Additional Samples Selected for Vendor Laboratory Analysis	12
Table 7	Elevated Activity Estimates for Flood Plain and Estuary	16
Table 8	Summary of Key Parameters for Alternative Brookside Resident Scenario Dose Calculation	20
Table 9	Comparison of Brookside Resident Alternative Scenario with TBD-08-006 Results	21
Table 10	Summary of RESRAD Parameter Values for Revised Suburban Gardener Scenario	23
Table 11	Suburban Gardener Revised Dose Calculation Results and Comparison with Initial Results	24
Table 12	Check Calculation Summary for Cs-137 Fish Ingestion Pathway Dose	30
Table 13	Comparison of Recreationist Scenario Revised Dose Calculations with TBD-08-006 Results	31
Table 14	Comparison of Cs-137 Measurements Upstream and Downstream of Section 2	40
Table 15	Estimated Mass of Fine Sediment Delivered to East Sandusky Bay	49
Table 16	Estimated Fallout Cs-137 Deposition in East Sandusky Bay	50
Table 17	Soil Radionuclide Mixture for PBRF Resident Farmer Dose Assessment	56
Table 18	Water-dependent Pathway Doses for PBRF Resident Farmer	56

List of Figures

Figure	Description	Page
Figure 1	Size Distribution of Localized Areas of Elevated Activity in Stream Meander Section	15
Figure 2	Cs-137 Concentration Trend – Plum Brook Sections 1 -3	40
Figure 3	Upstream and Downstream Frequency Distributions of Cs-137 Concentration	41
Figure 4	Cs-137 Dose from Drinking Water – Unsaturated Zone Removed	53
Figure 5	Co-60 Dose from Drinking Water – Unsaturated Zone Removed	54
Figure 6	Drinking Water Bounding Dose	55

List of Attachments

Attachment	Description	No. of Pages	Location
Att. 4-1	RESRAD Case Run Reports for Alternative Brookside Resident Scenario, with Index	214 pages	CDROM
Att. 4-2	EXCEL file print-out showing dose calculation details	1 page	CDROM
Att. 5-1	RESRAD Case Run Reports for Revised Suburban Gardner Scenario, with Index	97 pages	CDROM
Att. 5-2	EXCEL file print-out showing dose calculation details	1 page	CDROM
Att. 7-1	RESRAD Case Run Reports for Revised Country Club Worker Scenario, with Index	70 pages	CDROM
Att. 7-2	EXCEL file print-out showing dose calculation details	1 page	CDROM
Att. 8-1	Graphic - Conceptual Model for Fish Ingestion Pathway – Plum Brook Estuary	1 page	CDROM
Att. 8-2	RESRAD Case Run Reports for Revised Recreationist Scenario, with Index	40 pages	CDROM

Att. 8-3	EXCEL file printout showing dose calculation details ----------	1 page	CDROM
Att. 13-1A	Map Number 39043C0095D, NFIP Flood Insurance Rate Map, Erie Co. Ohio. Shows area inundated by 100 year flood on Plum Brook from Clark Rd to just north of US Route 2 overpass. -------	1 page	CDROM
Att. 13-1B	Map Number 39043C0092D, NFIP Flood Insurance Rate Map, Erie Co. Ohio. Shows area inundated by 100 year flood on Plum Brook from 1375 ft. north of Hull Rd. to Sandusky Bay. ----------	1 page	CDROM
Att. 13-2A	Sheet 138, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from north boundary of NASA Plum Brook site to 1300 ft. north of Clark Rd	1 page	CDROM
Att. 13-2B	Sheet 137, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from 800 ft. south of Botay-Taylor Rd intersection to St. Rt. 2 ----------	1 page	CDROM
Att. 13-2C	Sheet 136, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from St. Rt. 2 to Galloway Rd ----------	1 page	CDROM
Att. 13-2D	Sheet 152, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from NE of Galloway Rd. to 800 ft. north of Hull Rd ----------	1 page	CDROM
Att. 13-2E	Sheet 151, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from 800 ft. north of Hull Rd. to US Rt. 6 overpass ----------	1 page	CDROM
Att. 13-2F	Sheet 180, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from US Rt. 6 overpass to confluence with Sandusky Bay ----------	1 page	CDROM
Att. 14-1	SR39 Posting Plot, Aerial photo of Plum Brook Estuary showing survey-sampling transects ----------	1 page	CDROM
Att. 14-2	SR44 Investigative Samples Around Samples from SR39, Aerial photo of Lower Plum Brook Estuary showing survey-sampling transects with investigative samples ----------	1 page	CDROM
Att. 14-3	SR41 Posting Plot, Aerial photo of Plum Brook Lower Flood Plain showing survey-sampling transects ----------	1 page	CDROM
Att. 14-4	1969 Flood Record in Stream Mouth Wetland, Graphic of Plum Brook Estuary showing survey-sampling transects with color-coded sample results ----------	1 page	CDROM

Att. 14-5	1969 Flood Record in Stream Mouth Wetland, Graphic of Plum Brook Estuary showing survey-sampling transects with color-coded sample results – with commentary ----------	1 page	CDROM
Att. 14-6	Cs-137 Details in Flood Plain Area, Graphic of Plum Brook Flood Plain showing survey-sampling transects with color coded sample results ----------	1 page	CDROM
Att. 16-1A	Photograph File# PW-2V-137, 1958 aerial photo showing the Plum Brook stream Mouth and East Sandusky Bay to the north --	1 page	CDROM
Att. 16-1B	Photograph File# PW-2V-126, 1958 aerial photo showing eastern end of Sandusky Bay ----------	1 page	CDROM
Att. 16-2A	Photograph File# 317, 1971 aerial photo showing Plum Brook from Hull to Cleveland Rd. (US Route 6) and the lower half of the estuary ----------	1 page	CDROM
Att. 16-2B	Photograph File#, 353, 1971 aerial photo showing the Plum Brook estuary opening into East Sandusky Bay ----------	1 page	CDROM
Att. 16-3	Photograph File# Sheet 150, 1986 aerial photo showing the Plum Brook Estuary and East Sandusky Bay to the north ----------	1 page	CDROM
Att. 16-4	Photograph File#, 2009 Aerial, 2009 aerial photo of East Sandusky Bay showing the Plum Brook Estuary ----------	1 page	CDROM
Att. 17-1	RESRAD case run reports with index ----------	89 pages	CDROM
Att. 17-2	Sensitivity Analysis for Plum Brook Drinking Water Pathway Dose Assessment, Figures ----------	4 pages	CDROM

1. **Comment:** It is not clear how ALARA is going to be addressed for the residual radioactivity in the Plum Brook.

Basis: The radiological criteria for unrestricted use in 10 CFR 20.1402 includes a requirement that the residual radioactivity has been reduced to levels that are as low as is reasonably achievable (ALARA).

Path Forward: Describe how the ALARA requirement will be satisfied.

NASA Response: Justification that residual contamination levels of PBRF radionuclides in the Plum Brook watershed are ALARA comprises the following: [1]

- Current sediment activity concentration levels are below generic screening levels for surface soil published by the NRC.
- The estimated dose to the average member of the critical group is less than one mrem/y. This is well below the 25 mrem per year dose criterion and is indistinguishable from the "background" dose from man-made radionuclides in the Plum Brook watershed.
- Incremental reduction in the calculated dose is possible in theory through removal of contaminated sediment. A simplified cost-benefit model is used to show that existing levels are ALARA.

Comparison to Screening Level Values

The NRC guidance on determining that residual contamination levels are ALARA includes the following:

> "In light of the conservatism in the building surface and surface soil generic screening levels developed by the NRC, NRC staff presumes, absent information to the contrary, that licensees who remediate building surfaces or soil to the generic screening levels do not need to provide analyses to demonstrate that these screening levels are ALARA. In addition, if residual radioactivity cannot be detected, it may be presumed that it had been reduced to levels that are ALARA. Therefore the licensee may not need to conduct an explicit analysis to meet the ALARA requirement."

The inventory of radionuclides of dose-significance at PBRF that could have been released in liquid effluents to the Plum Brook comprises eight radionuclides. As discussed in the response to RAI Comment No. 2, the PBRF Final Status Survey Plan identifies tritium, Co-60, Sr-90, I-129, Cs-137, Eu-154, U-233/234 and U-235/236 as the "radionuclides of concern" in residual radioactivity at the PBRF. The combined dose from other radionuclides detected during PBRF characterization is shown to be less than 10% of the calculated dose from all the radionuclides identified. The other radionuclides are not required to be explicitly accounted for in the FSS of

[1] The NRC Staff Regulatory Position providing guidance on demonstrating that residual activity is ALARA was issued in SECY-98-051, "Guidance in Support of Final Rule on Radiological Criteria for License Termination', March 16, 1998. This guidance was initially published in Draft Regulatory Guide DG-4006, but has been reissued in NUREG-1757 Volume 2, Appendix N.

the PBRF.[2] The eight radionuclides thus comprise the list of potential radionuclides of concern in Plum Brook sediments. Their concentrations are compared to screening level values. Table 1 lists NRC screening levels for the eight radionuclides and compares them to concentrations measured in Plum Brook sediments.

It is seen from Table 1 that all the radionuclides are well below the respective screening level values. Only Co-60 and Cs-137 are measured at concentrations above background in the sediments. The average concentrations shown in the table are averages of measured concentrations in samples of sediment from Stream Section 1, the section that runs from the confluence of Plum Brook with the Pentolite Ditch to US Rt. 2, a distance of 1.6 miles. This portion of the Plum Brook contains the highest levels of Cs-137 and Co-60 measured in the entire Plum Brook watershed.

Table 1, Comparison of Surface Soil Screening Level Concentrations with Measured Values in Plum Brook Sediments

Radionuclide	Screening Level (pCi/g) (1)	Plum Brook Sediment (pCi/g)	Comment - Source
H-3	110	< MDA	Reported by vendor lab.
Co-60	3.8	0.13 ± 0.07 (2)	Average in Stream Section 1, see Table 4, TBD-08-005
Sr-90	1.7	<MDA	Reported by vendor lab.
I-129	0.5	<MDA	Reported by vendor lab.
Cs-137	11	1.2 ± 2.8 (2)	Average in Stream Section 1, see Table 5, TBD-08-005
Eu-154	8	<MDA	No detects in samples analyzed by on-site lab or in samples sent to vendor lab.
U-234	13	1.1 to 5.8	Reported by vendor lab. (3)
U-235	8	Background equivalent	Reported by vendor lab. (3)

Table 1 Notes.

1. In this comparison, the screening levels are assumed to be average concentrations in surface soil. They are obtained from doses calculated under the assumption that the contaminated soil volume is uniformly contaminated at a constant initial concentration. See NUREG/CR-5512, Vol. 1, "Residual Contamination from Decommissioning", PNL-7794, October 1992.
2. Sediment concentrations of Co-60 and Cs-137 are reported as the mean ± one standard deviation. The 99% upper confidence limits of the means, estimated as the mean + three standard deviations, are below the respective screening level values for Co-60 and Cs-137.
3. As discussed in the response to Comment No. 2, natural uranium concentrations in the Plum brook watershed are elevated, well above the average concentration in US soil.

[2] NASA Safety and Mission Assurance Directorate, *Final Status Survey Plan for the Plum Brook Reactor Facility*, Revision 1, February 2007.

Indistinguishable from the Dose from Man-made Radionuclides in the Plum Brook Watershed

Calculated doses to members of the public from radionuclides of PBRF origin in Plum Brook sediments are compared to doses from Cs-137 in the environment due to world-wide fallout. The results of the Plum Brook dose assessment are summarized in Table 2 below. The table shows the highest calculated dose for the four scenarios to be 0.92 ± 0.44 mrem/y. This is considered to represent an upper bound dose to the average member of the critical group.

Table 2, Summary of Plum Brook Dose Assessment Results

Scenario	Total Scenario Dose (mrem/y)	Cs-137 Dose (mrem/y)	Cs-137 Fraction of Total Dose (%)	Co-60 Dose (mrem/y)	Co-60 Fraction of Total Dose (%)
Suburban Gardner (1)	2.42 ± 1.28 E-01	2.22 ± 1.28 E-01	92	1.99 ± 1.0 E-02	8
Brookside Resident (2)	9.24 ± 4.41 E-01	7.38 ±4.33 E-01	80	1.86 ± 0.83 E-01	20
CC Maintenance Worker (3)	3.61 ± 2.23 E-01	2.64 ± 2.12 E-01	73	9.73 ± 6.95 E-02	27
Recreationist (4)	6.85 ± 3.15 E-01	6.50 ± 3.14 E-01	95	3.52 ± 2.26 E-02	5

Table 2 Notes:

1. See the response to RAI Comment No. 5. The calculated dose for the Suburban Gardner was revised in response to the comment. The updated result is shown in the table.
2. See the response to RAI Comment No. 4. A dose assessment was performed for the Brookside Resident using an alternate scenario wherein the contaminated zone under the house was increased to 50% of the house footprint, the local area of elevated activity was placed under the house and the resident is assumed to consume vegetables grown in a garden containing contaminated sediment. The total calculated dose for the alternate scenario is 1.34 ± 0.68 E+00 mrem/y. As discussed in the response to Comment No.4, NASA believes that the alternative scenario does not represent credible exposure conditions for residents in the Stream Section 2 watershed.
3. See the response to RAI comment No. 7. The dose assessment for the Country Club Maintenance Worker was revised in response to the comment – the revised dose is shown in the table.
4. See the response to RAI comment No. 8. The dose assessment for the Recreationist was revised in response to the comment – the revised dose is shown in the table.

Estimates of the annual dose to individuals from man-made radionuclides in the environment have been published by expert committees. The National Council on Radiation Protection and Measurements (NCRP) estimated the annual average effective dose equivalent to individuals in the US from man-made radionuclides in the environment to be 1.4 mrem in 1987.[3] More recently (2000), the United Nations Scientific Committee on the Effects of Atomic Radiation

[3] NCRP Report No. 93, "Ionizing Radiation Exposure of the Population of the United States", September 1987.

(UNSCEAR), reported the average world-wide annual dose to individuals from man-made Cs-137 in the environment to be 0.7 mrem/y.[4]

These estimates are consistent, within the uncertainties and considering the decay of principal man-made radionuclides in the environment between the mid-1980's and the year 2000.[5] Uncertainties in these estimates were noted in the respective publications; the UNSCEAR report stated that doses to individuals from these sources could be expected to vary by "up to a factor of three."

Considering the uncertainties in the Plum Brook dose assessment results and in the NCRP and UNSCEAR estimates, it is concluded that the calculated doses (from radionuclides of PBRF origin in Plum Brook sediments) are indistinguishable from the dose received by individuals living in the Sandusky area from man-made radionuclides in the environment. It is also noted that individuals living in the vicinity of surface water bodies such as the Plum Brook and its estuary receive above average exposure from man-made radionuclides due to the accumulation of cesium-bearing fine sediments from surface runoff and erosion.[6] If the calculated doses are indistinguishable from existing "background" doses, it is not possible to demonstrate with any degree of confidence, reduction in dose attributable to remedial actions. Hence, the current residual activity levels of radionuclides of PBRF origin in the Plum Brook and the calculated doses from these radionuclides must be considered ALARA.

Calculation of ALARA Concentration using Simplified Cost-benefit Analysis

In a cost benefit decision framework, the concentration of residual contamination is considered to be ALARA when the present worth of the averted dose (the benefit) is greater than or equal to the cost to remediate. A simplified cost-benefit analysis method outlined in Appendix N of NUREG-1757 Vol.2 illustrates how this criterion is applied to demonstrate compliance with the ALARA requirement. In this method, the cost to remediate is set equal to the present worth of the collective dose averted. The "ALARA concentration" of a single radionuclide is calculated as the ratio of the concentration to its' $DCGL_W$. This is determined using the equation below.

[4] UNSCEAR 2000 Report, Vol. 1, "Sources and Effects of Ionizing Radiation", 2000.

[5] The principal sources of manmade radionuclides in the environment are fallout from atmospheric weapons tests, releases from nuclear fuel cycle facilities and reactors. There have been no significant releases since the Chernobyl accident in 1986 (UNSCEAR 2000).

[6] See for example, J. C. Ritchie and R. McHenry, "Application of Fallout Cesium-137 for Measuring Soil Erosion and Sediment Accumulation Rates and Patterns: A Review", Journal of Environmental Quality, Vol. 19, pp 215-233, 2000.

$$\frac{Conc}{DCGL_W} = \frac{Cost_T}{\$2000 \, x \, P_D \, x \, 0.025 \, x \, F \, x \, A} \, x \, \frac{r+\lambda}{1-e^{-(r+\lambda)N}} \qquad \text{(Equation 1)}$$ [7]

The estimated cost to remediate and values assigned to the other variables are input into the equation. Calculated values of the ratio, Conc./$DCGL_W$, greater than or equal to one are considered to be ALARA. For application to the present situation, the equation is modified slightly. The current estimated average concentration of Cs-137 in Plum Brook sediments is substituted for the $DCGL_W$ and 0.001 rem is substituted for 0.025 rem to obtain Equation 2.

$$\frac{Conc}{REF} = \frac{Cost_T}{\$2000 \, x \, P_D \, x \, 0.001 \, x \, F \, x \, A} \, x \, \frac{r+\lambda}{1-e^{-(r+\lambda)N}} \qquad \text{(Equation 2)}$$

In the modified equation the terms are:

Conc. = ALARA concentration of an individual radionuclide (pCi/g),
REF = concentration corresponding to one mrem/y, the current upper bound estimated dose from Plum Brook sediments contaminated with Cs-137 of PBRF origin,
$Cost_T$ = cost of remediation (current \$),
r = discount rate for present worth calculation, (y^{-1}),
λ = radioactive decay constant (y^{-1}),
\$2000 = dollar cost of unit collective dose averted (\$/person-rem),
P_D = population density for the scenario critical group (people/m^2),
0.001 = dose corresponding to the REF concentration (rem),
F = effectiveness of remediation action selected,
A = area of land affected by the remediation action, and
N = number of years over which collective dose averted benefit is calculated.

Calculation of the ALARA concentration of Cs-137 is performed using Equation 2 with parameter values shown in Table 4. The cost to remediate includes the costs of excavation, shipping and disposal at a licensed low level radioactive waste disposal facility. The costs of accidents during remediation and transportation, dose to remediation workers and other costs are not included. The cost to remediate is estimated as:

(amount of material to be removed) x (unit cost of excavation and disposal).

The amount of contaminated soil/sediment to be removed and disposed of is estimated to be 1840 metric tons (MT). This is obtained as follows. The total amount of potentially impacted soil and sediment in the Plum Brook stream meander, the flood plain and the estuary is estimated to be 184,000 MT. The calculations for developing this estimate are summarized in Table 3. The total mass of material is obtained as the sum of the estimated mass associated with each stream

[7] Simplified model presented as Equation N-8 in NUREG-1757, Appendix N.

section. The calculated mass in each stream section is based on the dimensions shown. It is assumed that the impacted zone cross section in the stream meander sections is 5 meters wide and 30 cm thick. The upper flood plain, Section 3, cross section is assumed to be 60 meters wide and 45 cm thick. The estuary, Section 4, cross section is assumed to be 150 meters wide and 60 cm thick. The average density of material is assumed to be 1.5.

Table 3, Mass of Potentially Impacted Soil and Sediment in Plum Brook Watershed

Stream Section	Length (mi)	Length (m)	width (m)	Thickness (cm)	Vol. (m^3)	Mass (MT)
1	1.6	2574.95	5	30	3.86E+03	5.79E+03
2	1	1609.34	5	30	2.41E+03	3.62E+03
3	0.85	1367.94	60	45	3.69E+04	5.54E+04
4	0.55	885.14	150	60	7.97E+04	1.19E+05
Total						1.84E+05

It is assumed that the remediation is targeted to focus on areas of elevated activity and that only one percent of the total mass, 1840 MT, is removed for disposal. The unit cost of excavation, shipping and disposal is estimated as follows:

1. sediment excavation at $ 27.54/MT, [8]
2. transportation and disposal at $218.00/MT, [9]
3. The total cost of excavation, shipping and disposal is $245.54/MT.

The estimated cost of remediation is then calculated to be $451,794 ($245.54/MT x 1840 MT).

[8] US Army Corps of Engineers, Pittsburgh District, "Draft Detailed Project Report and Integrated Environmental Assessment", Appendix 4, Cost Estimates, North Lake Park Allegheny County, PA Section 206 Aquatic Ecosystem Restoration Project, August 2006. The cost estimate is given as $31.59/yd^3 for excavation of aquatic sediments.
[9] Disposal cost, $106.28/ton, Transportation cost, $78.22/ton and shipping liner cost, $13.70/ton. Personal communication, Al Castagnacci, Clauss Construction, July 20, 2009. Cost per ton is multiplied x 1.1 to convert to cost per MT.

Table 4, Parameter Values for ALARA Cost Benefit Calculation

Parameter	Name/Description	Units	Reference Value	Data Source/Comment
Conc.	Concentration	pCi/g	NA	to be calculated
REF	Concentration guideline value corresponding to 1 mrem/y	pCi/g	1.2	Average concentration of Cs-137 in Stream Section 1
$Cost_T$	Total cost of remediation	$	$477,500	See explanation above
P_D	population density	m^{-2}	0.0004	NUREG-1757 App. N
A	area being evaluated	m^2	1.46E+06	Area of Plum Brook watershed zoned residential (1)
F	fraction of activity removed	Unit-less	0.5	Assumption
N	time of dose integration	y	1000	NUREG-1757 App. N
r	discount rate	y^{-1}	0.03	NUREG-1757 App. N
λ	decay constant (Cs-137)	y^{-1}	0.023	Kocher (2)

Table 4 Notes.

1. The total Plum Brook Watershed area zoned residential is calculated from the following data: Stream Section 1, Upper Meander, watershed area 0.7 mi^2 and 30% residential. Stream Section 2, Lower Meander, watershed area 0.59 mi^2 and 60% residential.
2. David C. Kocher, "Radioactive Decay Tables", Technical Information Center, US Department of Energy, DOE/TIC 11026, 1981.

The ALARA cost-benefit calculation described above yields a Conc./REF ratio of ~ 41 (40.98). This means that it is not cost effective to remediate and that the current concentration of Cs-137 of PBRF origin in Plum Brook sediments is ALARA. The calculated result for Cs-137 is limiting in determining the ALARA concentration considering that it is the major constituent in the sediments and delivers the largest portion of the calculated dose from the exposure scenarios. As a check, the calculation was performed using Co-60 parameters in Equation 2 and a Conc./REF ratio of over 600 was obtained.

2. **Comment:** More Information is needed to confirm that Cs-137 and Co-60 are the only radionuclides of Plum Brook reactor Facility (PBRF) origin present at levels above background in the Plum Brook.

Basis: The radiochemical analysis performed for two ditch samples and three Plum Brook sediment samples is described on pages 3 and 4 of the National Aeronautics and Space Administration (NASA) Technical Basis Document (TBD) titled, "Radiological Characterization of Plum Brook Sediments, PBRF-TBD-08-005, Revision 1. Because only Cs-137 and Co-60 were present at levels above background, it was concluded that these were the only radionuclides of PBRF origin present in Plum Brook. More information is needed about the representativeness of these samples and the basis for concluding that other radionuclides are not present in the Plum Brook based on the other radionuclides not being present in these samples.

Path Forward: Provide additional information about the ditch and Plum Brook sediment samples discussed above and provide justification for concluding that the fact that other radionuclides were not found in these samples indicates that other radionuclides of PBRF origin are not present anywhere in Plum Brook.

NASA Response: The following information is provided to support the conclusion that other radionuclides of PBRF origin are not present anywhere in the Plum Brook:

1. Additional information about samples of sediment from Pentolite Ditch and Plum Brook that were previously sent to vendor laboratories for analysis of other radionuclides.

2. Identification of "radionuclides of concern" in residual contamination listed in the Final Survey Plan that could have entered the Plum Brook – and discussion of how their absence in Plum Brook sediments is verified.

3. Results from six sediment samples recently sent to a vendor laboratory for analysis to provide additional evidence that radionuclides of Plum Brook origin other than Cs-137 and Co-60 are not present.

Samples Previously Sent to Vendor Laboratories

Selected samples from two characterization surveys were sent to vendor laboratories for comprehensive analysis. They included:

- Two sediment samples from the 2004 Pentolite Ditch characterization survey performed by Montgomery Watson were sent to Eberline Services, Oak Ridge, TN. The request for analysis included: gamma spectroscopy, tritium, C-14, Ni-63, Sr-90, isotopic uranium and isotopic thorium.

- Three sediment samples from the 2005 Plum Brook scoping characterization survey conducted by NASA were sent to Severn Trent Laboratories, Earth City, MO. The

request for analysis included: gamma spectroscopy, tritium, Sr-90, I-129 and isotopic uranium.

These five samples are identified in Table 5. The table also summarizes the analytical results. Measured concentrations of Cs-137 and Co-60 were reported as > MDA for all samples except one sample where Co-60 was reported as < MDA. Reported concentrations of Cs-137 ranged from 2.5 to 39.4 pCi/g. The radionuclides: tritium, C-14, Ni-63, and Sr-90 were reported as "non-detects" by the vendor laboratories. Uranium-235, the most likely indicator of uranium of PBRF origin, was reported as "background equivalent".

The Pentolite Ditch sediments contain the major fraction of the Cs-137 and Co-60 inventory of PBRF origin that still remains in the Plum Brook watershed.[10] If any other sediment-bound radionuclides of PBRF origin are present in the Plum Brook watershed, their probability of detection is greatest in samples of Pentolite Ditch sediments. If not measured in Pentolite Ditch sediments, they will not likely be measured downstream in Plum Brook sediments.

Identification of Radionuclides of Concern

The PBRF Final Status Survey Plan reports that soil and structural surfaces at the PBRF may contain one or more of the following radionuclides: tritium, Co-60, Sr-90, I-129, Cs-137, Eu-154, U-233/234 and U-235/236. The dose from all radionuclides other than Co-60, Sr-90 and Cs-137 in PBRF soil totaled 2% of the 25 mrem/y release criterion dose. This is much less than 10% of 25 mrem/y, the fraction below which "other" radionuclides are not required to be explicitly accounted for in the FSS. However, for purposes of assessment of doses from Plum Brook sediments, the presence of all eight of the listed radionuclides has been evaluated. All of these radionuclides, except Co-60 and Eu-154, are also present in the Plum Brook watershed as naturally occurring or of anthropogenic origin, albeit at low (and variable) concentrations.

Conclusively demonstrating that no radionuclides of concern other than Cs-137 and Co-60 are present in Plum Brook sediments requires determining their background concentrations and variability. For example, the Severn Trent Laboratory reported U-233/234 concentrations ranging from 1.12 to 5.8 pCi/g in the samples from the 2005 scoping survey. The average concentration in these samples is 2.8 ± 2.6 pCi/g (one standard deviation). It is noted that relatively high concentrations of uranium are common in surface soils in the Sandusky Ohio region. This results from near-surface layers of the uranium-bearing Ohio Shale formation which contains uranium at concentrations ranging from 10 to 40 ppm (~ 3 to 13 pCi/g).[11] Also, uranium concentrations in soil in the western half of the state are on average above 3 ppm (~ 1

[10] An estimate of the remaining Cs-137 inventory in Pentolite Ditch sediments is developed as follows: Length 875 m. x 3 m. width x 15 cm depth x average Cs-137 concentration of 2 pCi/g yields an estimated inventory of 1.2 mCi. This is nearly ½ of the estimated 2.5 mCi remaining from the total estimated activity released from PBRF operations (1963 through 1973). Note that this estimate of the remaining Cs-137 inventory applies to conditions prior to remediation of Pentolite Ditch sediments in August, 2009.

[11] "Geology of Radon in Ohio", University of Toledo, Ohio Radon Information System Web Site: http://aprg.utoledo.edu/radon/Geology.

pCi/g); higher than the US average (0.6 to 0.95 pCi/g). The Plum Brook ravine intersects thin layers of Ohio Shale at several locations in the vicinity of the PBRF. [12]

Table 5, 2005 Pentolite Ditch and Plum Brook Sediment Sample Vendor Analysis Results

Sample ID	Location-Description	Cs-137 (pCi/g)	Co-60 (pCi/g)	Other
CS040826-037 (1)	Pentolite Ditch stream ravine 380 ft E. of WEMS outfall – surface sediment	3.94 ± 0.31 E+01	8.77 ± 1.99 E-01	H-3: non-detect C-14: non-detect Ni-63: non-detect Sr-90: non-detect Isotopic U: background equivalent for U-234, 235 & 238
CS040826-048 (1)	Pentolite Ditch stream ravine 790 ft E. of WEMS outfall – surface sediment	1.34 ± 0.14 E+01	3.21 ± 1.09 E-01	H-3: non-detect C-14: non-detect Ni-63: non-detect Sr-90: non-detect Isotopic U: background equivalent for U-234, 235 & 238
SVI-04-9 (2) (SVI-0-4-3 SP-1)	Pentolite Ditch at WEMS - 13 to 18 in.	8.3 ± 1.2 E+00	2.4 ± 1.1 E-01	H-3: non-detect I-129: non-detect Sr-90: non-detect U-233/234: 1.58 ± 0.27 E+00 U-235/236: background equivalent
SVI-04-31 (2) (SVI-04-5 SP-2)	Taylorbrook Rd. - 0 to 6 in (QC)	2.92 ± 0.21 E+01	4.3 ± 1.3 E-01	H-3: - non-detect Sr-90: non-detect I-129: non-detect U-233/234: 5.8 ± 1.6 E-01 U-235/236: background equivalent
SVI-04-73 (2) (SVI-04- SP-10)	US Rt. 6 - 13 to 18 in.	2.5 ± 0.35 E+00	Non-detect (MDC = 0.19)	H-3: non-detect Sr-90: non-detect I-129: non-detect U-233/234: 1.12 ± 0.22 E+00 U-235/236: background equivalent

Table 5 Notes.

1. Samples analyzed by Eberline Services, Final Report of Analysis, No. 05-06027, June 22, 2005. Typical MDA values are: H-3 (5 .0), C-14 (2.5) , Ni-63 (5.0), Co-60 (0.2), Sr-90 (0.55), Cs-137 (0.2), Eu-154 (1.0), U-234 (0.2), U-235 (0.18), U-238 (0.2), all in units of pCi/g.

2. Samples analyzed by Severn Trent Laboratories, Analytical Report for Project No. 530625776, November 17, 2005. Typical MDA values are: H-3 (1.0), Co-60 (0.2), Sr-90 (1.1), I-129 (1.0), Cs-137 (0.2), Eu-154 (1.0), U-234 (0.05), U-235 (0.05), all in units of pCi/g.

[12] C. B. Hatfield, "Middle Devonian Carbonate Rocks and Shales of North-Central Ohio", Ohio Journal of Science Vol. 88 No. 1 pp 18-22, 1988.

Additional Samples Sent to Vendor Laboratories

To provide additional confirmation that no radionuclides of concern of PBRF origin other than Cs-137 and Co-60 are present in Plum Brook sediments, NASA has selected samples from the PBRF sample archive and sent them to a qualified vendor laboratory for analysis. The samples were selected to be representative of sediment deposits in the entire stream course, from the northern boundary of the PBRF to the stream mouth. The selection was biased to select the sample from each section of the stream course with the highest Cs-137 concentration (measured by gamma spectroscopy at the time of sample collection). The premise of the sample selection is that samples containing elevated concentration of Cs-137 would be the most likely to also contain other radionuclides of PBRF origin.

The samples are identified and the results of the analysis are shown in Table 6. The sample analysis request included: gamma spectroscopy (including Eu-154), H-3, Sr-90, I-129 and isotopic uranium. As expected, Cs-137 was measured in all the samples at concentrations which closely agree with the original analysis results. Four of the six samples showed Co-60 concentrations > MDA; all were < 0.5 pCi/g. Of the other radionuclides, Sr-90, I-129, Eu-154 and U-235, were reported as "non-detects" (< MDA) by the Laboratory. Uranium-234 and 238 were reported in all six samples as >MDA. The U-234 and U-238 results, 0.5 to 0.9 pCi/g, are well within the expected range of background concentrations. Tritium results were reported as < MDA in five of the six samples. For the single sample whose result was reported as > MDA, the result was 1.99 ± 1.02 pCi/g. This was slightly above the average tritium MDA (1.67 ± 0.3 pCi/g). Given the high relative uncertainty in this result; and that it is within 3-sigma of the MDA, this result is below the "quantification limit", the concentration that can be reliably detected and reported as present in the sample.[13] Also, this result is within the range of measured tritium background concentrations in US soil.[14]

---

[13] See, American Laboratory, Vol. 39 November 2002, "Statistics in Analytical Chemistry."

[14] Reported background concentrations of tritium in soil in the US range from 0.05 to 2.3 pCi/g. For examples, see the references listed below:

1. "Pantex Plant Final Report on Tritium Releases to the Environment", July 2005. http://www.seco.cpa.state.tx.us/zzz_pantex/erproject/10TritiumReleasesReport/paip-tritiumreport7-05.pdf
2. Lawrence Berkeley Laboratory, "Environmental Monitoring Program Report for 1999". http://www.lbl.gov/ehs/esg/99ser/
3. Los Alamos National Laboratory, "Baseline Tritium Concentrations in Soils and Vegetation: The Tshirege Woodland Site at TA-54", LA-UR-98-1079, 1989
4. QST Environmental, "Results of Preliminary Soil Sampling at Runkle Valley Ranch in Simi Valley, California" February 5, 1999.

Table 6, Additional Samples Selected for Vendor Laboratory Analysis

Sample ID.	Location- Description	Cs-137 (pCi/g)	Co-60 (pCi/g)	Other (pCi/g)
SR-45-93	Stream Section 1 (Sub-Section A), 6 -12 in.	74.0 ± 0.57	0.49 ± 0.06	H-3: non-detect Sr-90: non-detect I-129: non-detect Eu-154: non-detect U-234: 0.93 ± 0.23 U-235: non-detect U:238: 0.89 ± 0.22
SR-49-42	Stream Section 1 (Sub-Section E), 0 -6 in. QC	20.4 ± 0.38	0.25 ± 0.07	H-3: non-detect Sr-90: non-detect I-129: non-detect Eu-154: non-detect U-234: 0.76 ± 0.27 U-235: non-detect U:238: 0.93 ± 0.31
SVI-04-55	Stream Section 2, Galloway Rd, 7 -12 in.	0.67 ± 0.10	< MDA (0.09)	H-3: non-detect Sr-90: non-detect I-129: non-detect Eu-154: non-detect U-234: 0.76 ± 0.27 U-235: non-detect U:238: 0.93 ± 0.31
SR-33-35	Stream Section 2/3, PBCC, 0 – 6 in.(pond dredge spoil pile)	9.44 ± 0.13	0.16 ± 0.04	H-3: 1.99 ± 1.02 Sr-90: non-detect I-129: non-detect Eu-154: non-detect U-234: 0.67 ± 0.25 U-235: non-detect U:238: 0.78 ± 0.27
SR-54-38	Stream Section 3, Perkins Ave to Rt 6, 0 – 6 in.	12.0 ± 0.30	< MDA (0.05)	H-3: non-detect Sr-90: non-detect I-129: non-detect Eu-154: non-detect U-234: 0.54 ± 0.21 U-235: non-detect U-238: 0.46 ± 0.19

Table 6, Additional Samples Selected for Vendor Laboratory Analysis

Sample ID.	Location- Description	Cs-137 (pCi/g)	Co-60 (pCi/g)	Other (pCi/g)
SR-53-24	Stream Section 4, Rt. 6 to Bay, 18 – 30 in.	17.4 ± 0.41	0.30 ± 0.07	H-3: non-detect Sr-90: non-detect 129: non-detect Eu-154: non-detect U-234: 0.29 ± 0.15 U-235: non-detect U:238: 0.50 ± 0.18

Table 6 Notes:

1. Samples analyzed by Teledyne-Brown Engineering, Report of Analysis L39109, 09/09/09.
2. Typical MDAs are: H-3 (1.5 to 2.0), Sr-90 (0.15), I-129 (0.5), U-234 (0.15), U-235 (0.02 to 0.08), U-238 (0.05 to 0.2), (U-isotopic by alpha spectroscopy), all MDAs in pCi/g.

3. **Comment:** The basis for the assumed areas for the localized areas of elevated activity is not provided.

Path Forward: Provide justification for the values used for the area of the contaminated zone parameter in the RESRAD calculations for the localized areas of elevated activity in the NASA TBD titled" Revised Dose Assessment for Plum Brook Sediments" PBRF-TBD-08-006, Revision 0.

NASA Response: The source models used for the Plum Brook dose assessment include localized areas of elevated activity. These are modeled as right circular cylinders where the area of the cylinder end surface corresponds to the ground surface. As stated in PBRF-TBD-08-005 (page 33 footnote):

> "The size of the elevated area source term is estimated from review of SR reports for investigational and bounding surveys. From this review it is estimated that the "typical" elevated area in stream Sections 1 and 2 can be modeled as a cylinder of one meter radius and the typical elevated area in Sections 3 and 4 modeled as a cylinder of 3 meter radius."

Details of the estimates are provided below.

Estimates were developed for elevated activity areas for the two distinct portions of the Plum Brook stream and watershed:

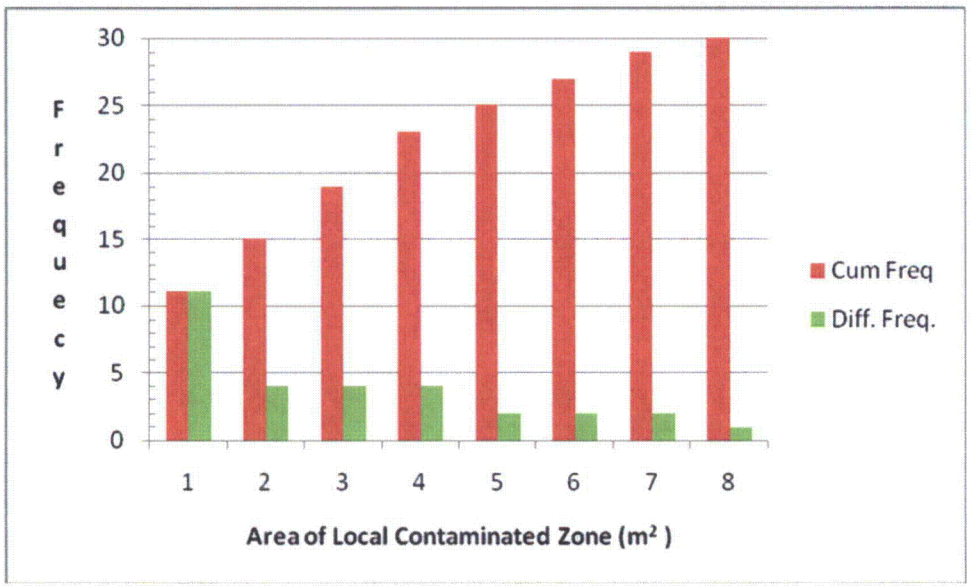
- Meander sections
- Flood plain and Estuary (Stream Mouth).

The setting for the Suburban Gardner and Brookside Resident scenarios is the Plum Brook Stream Meander section. The areas of elevated activity in the stream meander Section 1, Pentolite Ditch to US Rt. 2, were documented in Characterization Survey Packages: SR 45, 46, 47, 48 and 49. These packages were established to investigate the areas of elevated activity identified in earlier surveys of this stream section. A total of 30 localized areas of elevated activity were identified and investigated. The 30 elevated activity areas were located within the stream banks and occurred at an average frequency of one per 86 meters along the 1.6 mile course of Stream Section 1.

The area of each was delineated as the region where the scan survey NaI detector response exceeded an investigation action level set at 300 gross cpm. The detector was setup to count in the energy window corresponding to the Cs-137 (Ba-137) 662 keV principal gamma energy.[15] The average area of the 30 elevated activity areas identified and investigated is 2.84 ± 2.1 m^2 (one standard deviation). As a result, the elevated activity source term is modeled as a cylinder of one meter radius (3.14 m^2 area). The distribution of elevated activity areas is illustrated in Figure 1.

[15] The 300 gross cpm is based on an investigation-action level of 6 pCi/g Cs-137 (average concentration) in surface soil (0 to 15 cm). The average Cs-137 concentration in 382 samples collected during the investigation of the 30 elevated areas was 7.3 ± 9.9 pCi/g. See PBRF-TBD-08-005, "Radiological Characterization of Plum Brook Sediments", Revision No.1.

Figure 1, Size Distribution of Localized Areas of Elevated Activity in Stream Meander Section



The figure shows that the distribution of areas is right skewed. This is confirmed in that the median area (2.25 m^2) is less than the mean. The estimated average of the areas is biased high because most of the small areas, those less than one m^2, were assigned an area of one m^2 by the technicians who delineated the areas.

The area of the elevated activity source model used in dose calculations for the Country Club Maintenance Worker and Recreationist exposure scenarios is 28.27 m^2 (a circle with a radius of 3 m). The settings for these scenarios are assumed to be the Plum Brook Flood Plain and Estuary, respectively. The size of the elevated activity source used in these exposure scenarios is based on elevated activity area estimates reported in characterization packages that covered the Flood Plain and Estuary. Three estimates of elevated activity areas were found and the average radius of these is approximately 3 meters. A summary of the estimates is provided in Table 7.

Two elevated activity areas located in the flood plain between Perkins Ave and the US Rt. 6 overcrossing were investigated and delineated by scan surveys using the method described above. However, the use of scan surveys to identify and delineate areas of elevated activity in the floodplain and estuary is restricted by surface conditions. Sediments in the open stream are mostly underwater. In the flood plain, the terrain is very uneven with many surface obstacles – downed trees, brush, rocks and thick vegetation. In the estuary, the adjacent marshland is thickly vegetated.

The investigation of areas of elevated activity in the flood plain is reported in Characterization Survey Package SR-41. Estimation of areas of elevated activity in the stream mouth estuary is based on evaluation of Cs-137 "concentration patterns" from sample results and the professional judgment of a consulting hydrogeologist. The estimated area of the typical or "reference" area of elevated activity is reported as 248 ft^2 in characterization package SR-44.

Table 7, Elevated Activity Estimates for Flood Plain and Estuary

Characterization Pkg.	Elevated Area ID	Method to Delineate	Estimated Area (ft^2)	Radius (m)
SR-41, Flood Plain	IM-1	Gamma scan	200	2.43
SR-41 Flood Plain	IM-2	Gamma scan	490	3.81
SR-44 Stream Mouth	Generic	Survey design estimate	248	2.71
Average				2.98 ± 0.73

4. **Comment:** Additional justification is needed for some of the assumptions used in the Brook-Side Resident scenario.

Basis: The Brook-Side Resident scenario considers a receptor living in a house. This resident is modeled as spending 1/4 of their indoor time above the contaminated zone. A local area of elevated concentration is assumed to be located outside the residence. The Brook-Side Resident is assumed to be a different person than the Suburban Gardener. The U.S. Nuclear Regulatory Commission (NRC) staff needs additional justification for these assumptions.

The footprint of the house in the resident scenario is assumed to be partially located over the contaminated zone. This assumption is accounted for in the RESRAD modeling by dividing the indoor occupancy time by 4. However, it may not be appropriate to account for a reduced area of the contaminated zone by adjusting the occupancy time. For example, the direct radiation dose to a receptor which is located near the contaminated zone may not be much less than the dose to a receptor which is directly above the contaminated zone. In addition, a receptor may not spend the same amount of time in all portions of their house, so their dose may not be directly proportional to the fraction of the footprint that is located over the contaminated zone. NRC staff recognizes that mixing of contaminated sediments with clean soil would likely occur if sediments were moved from Plum Brook to the site of the house and that the dose assessment initially submitted by NASA does not take credit for this mixing. However, it is not clear that the selected scenario is conservative compared to a scenario in which the exposure times were longer and the concentrations were lower.

Additional justification is also needed to support the assumption that the local area of elevated contamination is not located directly under the residence. Because the receptor spends more time indoors than outdoors, the dose from a hot spot located under the residence would be higher than the dose from a hot spot located elsewhere on the property even though the residence would provide some shielding.

The basis for the Suburban Gardener and Brook-Side Resident being two different scenarios is also needed. It is likely that the Suburban Gardener would live in the vicinity of their garden, so the same receptor could receive a dose both while in their house and from consuming plant foods grown on contaminated soils. In addition, if a garden in which the higher concentration sediments were used as topsoil was located near the house, the resident of the house would likely receive an external radiation dose from the radionuclides in the garden while they are inside.

Path Forward: Provide additional justification for the following assumptions used in the dose assessment:

i. the resident only spends 1/4 of their time over the contaminated zone.
ii. the local area of elevated contamination is not located under the house.
iii. the resident does not also have a garden in which plants are grown for consumption.

Alternatively, a revised dose assessment that does not include these assumptions could be provided.

NASA Response: The Brookside Resident scenario is placed on the stream section indentified as Stream Section 2, the lower meander section. This section lies between US Rt. 2 and the interior of the Plum Brook Country Club (PBCC). This scenario was developed because:

a. Flood events have occurred during the period of PBRF operations which created backwaters along the Plum Brook in the stream section between Rt 2 and Hull Rd (S. Boundary of the PBCC).

b. Some of the homes on residential properties that border the Plum Brook in this section of the stream were constructed after 1969 (year of the major flood).

c. The directions from NASA were to develop an exposure scenario that represents conservative upper bounds of exposure conditions for each of the four stream sections.

It is concluded that homes were constructed after 1969 on land where flood backwater areas were created by the 1969 flood. The Brookside Resident exposure scenario was developed to represent a conservative upper-bound case for exposure to a member of the public in this stream section. This scenario is considered by NASA to be a conservative upper bound case for the following reasons:

a. Scan surveys have been conducted on former flood backwater areas along the Plum Brook upstream and downstream of Stream Section 2. The only locations with detectable Cs-137 were in two residential yards located in the upper stream meander section, upstream of Section 2, where it was learned that material from the Plum Brook stream banks had been used as fill for lawns. The likelihood is small that residences have been constructed on land containing radioactivity of Plum Brook origin. Further, even if this did occur, the surface and near-surface soil would have been removed from the house footprint during excavation for basements and footers. Any contaminated soil remaining under a completed house would consist of remnants or soil mixed with clean fill.

b. The source term model used in the scenario is a highly conservative construct. It is based on characterization of sediment deposits within the Plum Brook ravine – no contaminated sediments have been found in flood backwater areas.

c. A garden was not included in this scenario because no vegetable gardens have been observed on residential property bordering Stream Section 2 during the period from 2005 to the present.

d. The assumption that the resident spends ¼ of the indoor occupancy time over the contaminated zone is based on a "sample problem" described in NUREG-CR-5512, Appendix B, Sample Problems (B.3.2.1.1, RR1 Contamination Under a House).[16] It is

[16] NUREG-CR-5512, "Residual Contamination from Decommissioning, Volume 2, Users Manual DandD Version 2.1", April 2001.

noted that the sample problems in NUREG-CR-5512 do include cases where a higher fraction of the house lies on contaminated soil.

Even though NASA does not believe that the revised dose assessment suggested in the "Path Forward" for this RAI comment represents credible exposure conditions, a dose assessment has been conducted for an alternative Brookside Resident scenario that includes the following assumptions:

a. The indoor occupancy fraction for exposure to contaminated sediments underneath the house is increased from ¼ to ½.

b. An area of elevated activity is located underneath the house.

c. The resident consumes vegetables grown a garden located on the property that contains soil contaminated with radionuclides of PBRF origin.

The alternative Brookside Resident scenario is summarized in Table 8. The house is assumed to have a 2000 ft^2 floor plan area (186 m^2), the same as in the original Brookside Resident scenario. The area of the contaminated zone that extends beneath the house is 93 m^2, or ½ of the floor plan area. The contaminated zone is comprised of three layers, a 6 in. surface layer and two 9 in. subsurface layers. The local elevated activity source is 3.14 m^2 in area and is comprised of three layers, each 6 in. thick.

Table 8 also shows the activity concentrations of each source model layer. The contaminated zone layer concentrations are the same as assumed in the original Brookside Resident scenario. The garden is comprised of the same contaminated sediment-soil material as the contaminated zone source underneath the house. However due to tilling, the garden contaminated zone source is assumed to be comprised of a single layer 9 in thick with Cs-137 and Co-60 activity concentrations obtained as the thickness-weighted average of the activity concentrations in the three-layer contaminated zone underneath the house.

Table 8, Summary of Key Parameters for Alternative Brookside Resident Scenario Dose Calculation

Source Term Component	Area (m^2)	Source & Cover Thickness (in)	Principal Pathways	Occupancy	Cs-137 Concentration (pCi/g)	Co-60 Concentration (pCi/g)
Cont. Zone layer 1, under house	93	6 0	Direct	2191 h/y, OF = 0.25 (0.5 x 0.5)	9.80E-01	1.10E-01
Cont. Zone layer 2, under house	93	9 6	Direct	2191 h/y, OF = 0.25 (0.5 x 0.5)	1.42E+00	1.40E-01
Cont. Zone layer 3, under house	93	9 15	Direct	2191 h/y, OF = 0.25 (0.5 x 0.5)	1.20E+00	1.40E-01
Elev. local Area layer 1 under house;	3.14	6 0	Direct	74 h/y, OF=0.0084 (0.5 x 3.14/186)	5.78E+01	1.60E+00
Elev. local Area layer 2 under house	3.14	6 12	Direct	74 h/y, OF=0.0084 (0.5 x 3.14/186)	7.24E+01	6.53E-01
Elev. local Area layer 3 under house	3.14	6 18	Direct	74 h/y, OF=0.0084 (0.5 x 3.14/186)	2.05E+01	2.88E-01
Contaminated Zone in Garden	186	9 0	Direct, Plant Consumption	123 h/y OF= 0.014	1.23E+00	1.33E-01

Results of the alternative Brookside Resident dose assessment are shown in Table 9. The table compares the results with the Brookside Resident dose calculated in TBD-08-006. The calculated dose to the Brookside Resident is increased from 0.924 ± 0.44 to 1.34 ± 0.68 mrem/y when the assumptions in the RAI comment are incorporated. The alternate scenario is essentially a combination of the Suburban Gardener and Brookside Resident scenarios.

Table 9, Comparison of Brookside Resident Alternative Scenario with TBD-08-006 Results

Source Term Component and Dose Pathway	Cs-137 (mrem/y)		Co-60 (mrem/y)		Total (mrem/y)	
	TBD-08-006	Alternate	TBD-08-006	Alternate	TBD-08-006	Alternate
Cont. Zone layer 1	2.17E-01	3.69E-01	1.03E-01	1.75E-01	3.20E-01	5.44E-01
Cont. Zone layer 2	4.53E-02	1.25E-01	2.81E-02	6.72E-02	7.34E-02	1.92E-01
Cont. Zone layer 3	1.81E-02	3.00E-02	1.15E-02	1.96E-02	2.96E-02	4.96E-02
Elev. local Area layer 1	3.20E-01	2.06E-01	3.66E-02	2.37E-02	3.57E-01	2.30E-01
Elev. local Area layer 2	1.24E-01	7.67E-02	5.65E-03	3.56E-03	1.29E-01	8.03E-02
Elev. local Area layer 3	1.43E-02	8.28E-03	1.06E-03	6.36E-04	1.53E-02	8.92E-03
Garden - Total	NA	1.69E-01	NA	6.03E-02	NA	2.30E-01
Garden - Plant	NA	5.41E-02	NA	5.95E-03	NA	6.01E-02
Total	7.38E-01	9.85E-01	1.86E-01	3.50E-01	9.24E-01	1.34E+00

ATTACHMENTS:

Attachment 4-1	RESRAD Case Run Reports for Alternative Brookside Resident Scenario, with Index	214 pages
Attachment 4-2	EXCEL file print-out showing dose calculation details	1 page

5. **Comment:** Additional justification is needed for the assumption that the gardener would not garden on and consume plants from a local area of elevated concentration.

Basis: The Suburban Gardener scenario includes the dose from the consumption of plant products that have been grown in soil containing Cs-137 and Co-60 at concentrations equal to the average concentration in Section 1 of the Plum Brook. However, there are areas of the Plum Brook that have concentrations of these radionuclides that are much higher than the average amount. Though some mixing with clean soil would be likely to occur when removing sediments from the Plum Brook and placing them in a garden, it is, possible that a garden that has soil that has been supplemented with sediment from the brook could have concentrations of radionuclides that are higher than the average concentration in the Plum Brook.

Path Forward: Provide justification for turning the plant ingestion pathway off for the calculation of dose from elevated areas in the garden scenario or provide a revised dose assessment that includes this pathway.

NASA Response: The dose assessment for the Suburban Gardner exposure scenario has been revised. The local area of elevated activity has been placed within the garden and the plant ingestion pathway turned on. Table 10 summarizes key RESRAD parameter values for the original and revised dose calculations. The table identifies the affected parameters and summarizes the changes in assumptions. Table 11 presents the results of the revised dose calculations for the elevated activity source and compares the pathway and total doses to the original results.

Table 10, Summary of RESRAD Parameter Values for Revised Suburban Gardener Scenario

RESRAD Parameter	TBD-08-006 Dose Assessment	Revised Dose Assessment	Comment
Principal contaminated zone area (size of garden)	186 m^2	186 m^2	No change
Local elevated activity source area	3.14 m^2	3.14 m^2	No change
Plant ingestion pathway for local elevated activity area	Off	On	Pathway turned on for revised assessment
Length of contaminated zone parallel to aquifer for local elevated activity source	NA	2 m	Not a sensitive parameter, but changed to be consistent with the physical model
Outdoor occupancy fraction (OF) for local elevated activity source	0.014 (122 h/y)	0.0007 (6 h/y)	The OF was incorrectly set at 0.014 for initial assessment. In the revised assessment, it is assumed that the Gardner occupies elevated area at most 5% of the time. The area of the elevated activity source is only 1.7% of the garden area.
Fraction of contaminated food obtained from garden	0.5	NA	0.5 is RESRAD default for gardens < 1000 m^2 in area
Fraction of contaminated food obtained from local elevated activity source	NA	0.0169	Fraction of contaminated food from the elevated area source is set as the ratio of elevated activity area to the entire garden area (3.14/186)

Table 11, Suburban Gardener Revised Dose Calculation Results and Comparison with Initial Results

Source Term Component and Dose Pathway	Cs-137 (mrem/y)		Co-60 (mrem/y)		Total (mrem/y)	
	TBD-08-006	Revised	TBD-08-006	Revised	TBD-08-006	Revised
Cont. Zone 3 in Total	4.31E-02	4.31E-02	1.42E-02	1.42E-02	5.73E-02	5.73E-02
Cont. Zone 3 in Plant	1.43E-02	1.43E-02	1.57E-03	1.57E-03	1.59E-02	1.59E-02
Elev. local Area layer 1; 6 in Total	4.70E-01	7.98E-02	5.39E-02	4.27E-03	5.24E-01	8.40E-02
Elev. local Area layer 1; 6 in Plant	NA	5.64E-02	NA	1.59E-03	NA	5.80E0-2
Elev. local Area layer 2; 6 in Total	1.83E-01	7.89E-02	8.36E-03	1.06E-03	1.92E-01	8.00E-02
Elev. local Area layer 2; 6 in Plant	NA	7.03E-02	NA	6.46E-04	NA	7.09E-02
Elev. local Area layer 3; 6 in Total	2.15E-02	2.07E-02	1.60E-03	3.57E-04	2.31E-02	2.11E-02
Elev. local Area layer 3; 6 in Plant	NA	1.98E-02	NA	2.83E-04	NA	2.01E-02
Total Dose (1)	7.18E-01	2.22E-01	7.80E-02	1.99E-02	7.96E-01	2.42E-01
Total Plant Pathway Dose	1.43E-02	1.61E-01	1.57E-03	4.09E-03	1.59E-02	1.65E-01

The plant consumption pathway dose is increased from 1.59E-02 to 1.65E-01 mrem/y as a result of placing the elevated activity local area source within the garden and activating the food consumption pathway for this source. The plant consumption pathway is now the dominant pathway; the dose contribution from this pathway is increased from 2% in the TBD-8-006 report to 68% in the revised dose assessment.

However, the total dose to the Suburban Gardener receptor is reduced due to correcting the outdoor occupancy fraction for direct exposure to the elevated activity source. The direct exposure time to this source is reduced from 122 h/y to 6 h/y as explained in Table 10. As a result of this correction, the total scenario dose is reduced from 7.96E-01 mrem/y to 2.42 E-01 mrem/y.[17]

The attachments to this response provide supporting information for the revised dose assessment.

[17] Adjustments to parameters affecting the direct soil ingestion and inhalation pathways were not made for the elevated activity area dose calculations. The dose contribution from these pathways is negligible.

ATTACHMENTS:

Attachment 5-1	RESRAD Case Run Reports for Revised Suburban Gardner Scenario, with Index	97 pages
Attachment 5-2	EXCEL file print-out showing dose calculation details	1 page

6. **Comment:** It is unclear how the concentration of Cs-137 used for the Country Club Maintenance Worker scenario was derived.

Basis: The footnotes to Table 17 in PBRF-TBD-08-005 state that the concentrations used for the Country Club Maintenance Scenario are based on data presented in Table 11. However, Table 17 lists a value of 1.38 pCi/g for the single layer average concentration, but this value does not appear in Table 11.

Path Forward: Provide an explanation of how the value of 1.38 pCi/g of Cs-137 was derived for the source term for the Country Club Maintenance Worker.

NASA Response: Footnote 3 to Table 17 of TBD-08-005 states: "The PBCC Maintenance worker is assumed to be exposed to a layer of fill three in. thick placed along a golf cart path. The fill concentration is the average concentration measured in samples collected from the PBCC Ponds and spoil piles. Data from SR-33 Package Sample Data Report. (Appendix B)."

Referring to Appendix B of TBD-08-005 (page 50 of 101) Survey Package SR-33 Sample data Report, the average concentration of Cs-137 measured in 41 samples is reported as 1.38 ± 1.84 E+00 pCi/g.

The footnote then identifies Table 11 as the data source for Cs-137 concentrations for the three-layer local elevated area source.

7. **Comment:** It is not clear what thickness is assumed for the contaminated zone in the elevated local area calculation for the Country Club worker.

Basis: Appendix B of PBRF-TBD-08-006 states that a contaminated zone thickness of 6 inches is used in the RESRAD calculation for the elevated local area for Cs-137 for the Country Club Worker scenario (File 02100903). However, this RESRAD calculation seems to have been run with a 3 inch thickness for the contaminated zone.

Path Forward: Clarify which value is the correct contaminated zone thickness for this scenario and provide revised RESRAD calculations if necessary.

NASA Response: The reviewer is correct – the RESRAD case (file No. 02100903) was incorrectly setup; using 3 in. (0.076 m) instead of 6 in. (0.152 m) for the "Thickness of contaminated zone". The RESRAD case was run with the correct thickness, 0.152 meters. The resultant probabilistic dose for unit concentration of Cs-137 is 8.12 ± 5.0 E-02 mrem/y, whereas the dose reported in TBD-08-006 for this source term component was 5.62 ± 3.87 E-02 mrem/y. This change results in an increase of 45% in the calculated dose.

However, in reviewing the dose calculation for the Country Club Worker scenario, it is found that the occupancy fraction assumed for calculating the dose from the elevated local area source is incorrect. The occupancy fraction used, 0.051, (450 hours/y) is the same as for the large area (600 m^2) contaminated zone source component. This is logically inconsistent. The worker is assumed to spend 15 hours per week in the immediate vicinity of the golf cart path performing landscape maintenance activities. The worker receives exposure from contaminated sediment placed as fill along a section of the cart path. The path section is 100 meters long and the fill covers an area of 600 m^2. The worker cannot be simultaneously exposed for the entire exposure period, to both the average concentration in the 600 m^2 contaminated zone and to the 28.3 m^2 elevated local area source (which is < 5% of the main contaminated zone area).

Alternate approaches to arrive at an occupancy fraction for the local area source are examined. The underlying assumption is that the worker spends an equal fraction of time at each "point" in the contaminated zone. The principal dimension of the elevated area source is 6 meters (diameter) and the main contaminated zone is 100 meters long. On this basis, 6% of the time could be spent in the immediate vicinity of the elevated area source. Alternately, the occupancy fraction could be obtained by apportioning the 450 hours by the ratio of the local source area (28.3 m^2) to the main contaminated zone area (600 m^2), a factor of 0.047 or about 5%. For conservatism, it is assumed that the worker is exposed to the elevated area source for 10% of the 450 h/y, or 45 h/y.

The Country Club Worker exposure scenario dose calculations for the local elevated area source were re-run using a value of 0.0051 for the "fraction of time spent outdoors". This results in a reduction of the calculated dose from the local elevated area source to the Country Club Worker from 9.37 ± 8.07 E-01 mrem/y, to 1.29 ± 1.16 E-01 mrem/y. The total dose is reduced from 1.17 ± 0.61 E+00, as reported in TBD-08-006, to 3.61 ± 2.23 E-01 mrem/y.

ATTACHMENTS:

Attachment 7-1	RESRAD Case Run Reports for Revised Country Club Worker Scenario, with Index	70 pages
Attachment 7-2	EXCEL file print-out showing dose calculation details	1 page

8. **Comment:** The configuration of contamination assumed in the conceptual model in RESRAD for the calculation of dose from the aquatic food pathway is significantly different than the configuration of residual radioactivity present in the Plum Brook.

Basis: The conceptual model used by RESRAD to calculate the concentration of radionuclides in surface water assumes that the contamination is present in soil. The radionuclides are modeled as leaching into the groundwater and being transported to a surface water body. However, the radionuclides at the Plum Brook are already present in the sediments in the stream. This difference in configuration of the radionuclides may be significant enough that the conceptual model in RESRAD does not adequately calculate the concentration in the surface water.

Path Forward: Provide justification that the way that RESRAD models the fish pathway is conservative for modeling the aquatic food pathway dose from the radionuclides present in the Plum Brook, or use an alternative model for calculating the aquatic food pathway dose. One possible alternative approach would be to perform calculations similar to those described in Regulatory Guide 1.109.

NASA Response: The reviewer is correct in that the conceptual model for calculation of the dose from the fish ingestion pathway is not accurately presented as shown in Figure 8 of PBRF-TBD-08-006. The conceptual model should place the contaminated zone immediately adjacent to the surface water with no intervening uncontaminated zones. The contaminated zone is in-effect also the saturated zone. The corrected schematic of the fish pathway conceptual model is provided as Attachment 1. Implementation of the pathway dose calculation in RESRAD is accomplished through use of the mass balance water transport model and specifying zero thickness for the intervening unsaturated zone.

As a check on implementation of the fish ingestion pathway dose from a single radionuclide, the RESRAD equations can be reduced to the following:

$$H = DCF \times FC \times CF \times FWR \times WSR \times DF \text{ where:}^{18} \qquad \text{(Equation 3)}$$

H = Dose in mrem/y per pCi/g

DCF = Dose Conversion Factor, (mrem per pCi ingested)

FC = dietary factor, annual fish consumption (kg/y)

CF = Fraction of food (fish) that is contaminated (unit less)

FWR = fish/water concentration ratio, bioaccumulation factor (L/kg)

WSR = water-to-sediment ratio, ratio of surface water concentration to sediment concentration ($1/K_d$), where K_d is the equilibrium distribution coefficient (g/L)

DF = dilution factor, ratio of source area to watershed area (unit less).

[18] Equation 3 is derived from equations in the RESRAD User's Manual (ANL/EAD-4) Section 3.2 and Appendix-E with some modification of symbols for ease of interpretation.

Principal assumptions are:

- Equilibrium conditions
- The water-to-sediment concentration is obtained as the reciprocal of K_d, the equilibrium distribution coefficient; there is no attenuation (dispersion) of radioactivity in hydrologic transport from the contaminated zone to surface water.
- The watershed area is reduced to equal the area of the contaminated zone to eliminate dilution of the radionuclide contaminant in the surface water body occupied by the fish
- The dose is calculated for a single radionuclide with no radioactive daughters
- Radioactive decay during the exposure period is neglected; the half-life of the radionuclide is comparable to or greater than the exposure period.

A key assumption relating to the assumption of equilibrium conditions is that fish caught in the estuary have continually occupied the surface water column above and adjacent to the contaminated zone and obtained all their food from the water and benthic layer.

Equation 3 is used to check the RESRAD results for the fish ingestion pathway dose from Cs-137 in the principal contaminated zone source. Parameter values used in this check calculation and the calculated result are presented in Table 12.

Table 12, Check Calculation Summary for Cs-137 Fish Ingestion Pathway Dose

Parameter	Symbol	Units	Value	Source/comment
Cs-137 Dose Conversion Factor	DCF	mrem per pCi	5.00E-05	RESRAD Default
Dietary Factor – Fish Consumption	FC	kg/y	5.4	RESRAD Default
Contaminated Fraction of Food	CF	Unit less	0.5	RESRAD Default
Bioaccumulation factor	FWR	L/kg	2.0 E03	RESRAD Default
Cs-137 K_d	1/WSR	ml/g	4600	RESRAD Default
Contaminated Zone Area		m^2	1500	Developed per TBD-08-006
Watershed area		m^2	1500	assumption
Result - dose	H	Mrem/y per pCi/g	5.87E-02	calculated

The result shown in Table 12 represents an upper limit of the Cs-137 fish consumption dose calculated with RESRAD. To confirm this, the results of a RESRAD case run with the same values of key parameters is shown to be 5.78 E-02 (deterministic) mrem/y per pCi/g. This shows that the method used in the RESRAD calculation of dose from the fish pathway is conservative.

During the evaluation described above, discrepancies were identified in the probabilistic dose calculations for the fish consumption pathway. As a result, the fish pathway dose calculations reported in TBD-08-006 have been revised. Table 13 shows the Recreationist doses for the various source term components and compares the revised results with the original results reported in PBRF-TBD-08-006.

Table 13, Comparison of Recreationist Scenario Revised Dose Calculations with TBD-08-006 Results

Source Term Component and Dose Pathway	Cs-137 (mrem/y)		Co-60 (mrem/y)		Total (mrem/y)	
	TBD-08-006	Revised (2)	TBD-08-006	Revised (2)	TBD-08-006	Revised (2)
Cont. Zone layer 1; 6 in.	3.28E-02	3.28E-02	2.92E-02	2.92E-02	6.21E-02	6.21E-02
Cont. Zone layer 2; 12 in.	5.69E-03	5.69E-03	NA	NA	5.69E-03	5.69E-03
Cont. Zone layer 3; 12 in.	7.39E-04	7.39E-04	NA	NA	7.39E-04	7.39E-04
Elev. local Area layer 1; 6 in.	4.14E-01	4.14E-01	NA	NA	4.14E-01	4.14E-01
Elev. local Area layer 2; 12 in.	9.72E-02	9.72E-02	NA	NA	9.72E-02	9.72E-02
Elev. local Area layer 3; 12 in.	2.74E-02	2.74E-02	NA	NA	2.74E-02	2.74E-02
Cont. Zone layer 1; 6 in. Co-60 fish	NA	NA	9.09E-04	6.00E-03	9.09E-04	6.00E-03
Cont. Zone 30 in. for Cs-137 Fish	2.65E-02	4.90E-02	NA	NA	2.65E-02	4.90E-02
Elev. local Area 30 in. for CS-137 Fish	1.23E-02	2.28E-02	NA	NA	1.23E-02	2.28E-02
Total	6.17E-01	6.50E-01	3.01E-02	3.52E-02	6.47E-01	6.85E-01
Total Fish Consumption	3.88E-02	7.18E-02	9.09E-04	6.00E-03	3.97E-02	7.78E-02

Table 13 Notes:

1. Doses are obtained as the product of dose from unit concentration and the concentration in each source term component. The assumed concentrations have not changed.
2. Revised dose results are highlighted in red font.

Table 13 shows that the revised dose calculation resulted in an increase in the total Recreationist dose from 6.47 E-01 to 6.75 E-01 mrem/y. This is due to the increase in the fish pathway dose; from 3.97E-02 to 6.78 E-02 mrem/y, an increase of 70% [19].

[19] In the original dose calculations for the fish pathway, the probabilistic results were significantly higher than the deterministic results and showed very large uncertainties. Parameter sampling distributions selected for probabilistic dose calculations were evaluated as the potential source of the problem. It was found that the default RESRAD distribution for the K_d, (Lognormal – N) appeared to introduce bias into the results. A vector (array) of sampled values was examined and it was observed that the distribution of sampled values of K_d was skewed; favoring low K_d values (86% of the values were less than 4600 ml/g, the default K_d value). Also, variation of the sampled values was large (coefficient of variation > 300%). The sampling distribution for K_d was changed to a triangular distribution (minimum = 2300, mode = 4600, maximum = 9200). This change brought probabilistic doses more in line with deterministic results and reduced the dose uncertainties significantly as compared to the original results.

ATTACHMENTS:

Attachment 8-1	Graphic - Conceptual Model for Fish Ingestion Pathway – Plum Brook Estuary	1 page
Attachment 8-2	RESRAD Case Run Reports for Revised Recreationist Scenario, with Index	40 pages
Attachment 8-3	EXCEL file printout showing dose calculation details	1 page

9. **Comment**: Additional justification is needed for the assumed location of the fish in the Recreationist Scenario.

Basis: The dose to a recreationist who fishes in the Plum Brook is calculated based on the concentration of radionuclides present in the sediment in the Plum Brook Estuary (stream Section 4). The concentration of radionuclides in the sediment in this section is lower than the concentrations seen upstream. Additional information is needed to confirm that fish that could be consumed by humans are not present in the upstream segments of the Plum Brook.

Path Forward: Provide additional information about the fish located in the Plum Brook and provide justification for the assumption that the fish are only located in stream Section 4. Alternatively, provide a revised dose assessment that considers the concentration of radionuclides observed in the other stream sections.

NASA Response: The following is a summary of direct observations by NASA staff and contractors, who have spent considerable time in the Plum Brook immediate vicinity, and interviews with knowledgeable individuals[20]:

- Game fish may occasionally enter the Plum Brook Estuary, but it is not a preferred habitat
- Game fish seldom enter the stream in the flood plain below the Rt 6 overpass
- Fishermen have not been observed in the estuary or the flood plain
- Individual game fish have been observed in the Plum Brook at the Plum Brook Country Club in the upper flood plain, but only during high-water, or flood conditions
- Only very small fish and minnows are observed in the stream meander sections under normal flow conditions.

From this it is concluded that the actual consumption of fish caught in the Plum Brook and the Plum Brook estuary is near zero, if not zero.

The conceptual model for the Recreationist Scenario fish consumption pathway assumes the fish habit is a closed surface water body; fish dwell and feed continually within a limited area of surface water that is in contact with contaminated sediments. That is, equilibrium conditions are achieved such that transfer of contaminants from sediment to water and water to fish are described by constant coefficients (bioaccumulation factor and K_d). In contrast to this, any fish caught in the Plum Brook estuary, flood plain or the stream meander sections are transients. Therefore there is little or no correlation between sediment Cs-137 concentration at the location where a fish is caught and dose from the fish consumption pathway. Fish caught upstream of the estuary in areas with higher sediment radionuclide concentrations would not actually yield a higher dose than fish caught in the estuary.

[20] Eric Weimer, Fisheries Biologist, OH Division of Natural Resources, Division of Wildlife and Mark Bauer, Superintendent, Plum Brook Country Club Golf Course.

The fish consumption pathway was added to the Recreationist scenario because it was the most conservative food pathway identified (consumption of venison was also considered). It is considered to represent a possible, but not plausible pathway. Doses calculated for the Recreationist Scenario represent conservative upper bound doses that received by members of the public who could come in contact with contaminated sediments in the Plum Brook stream mouth-estuary.

10. **Comment**: Staff cannot determine from PBRF-TBD-08-005 if NASA evaluated and identified any other liquid effluent discharge point(s) from the PBRF to the environment other than the primary liquid discharge point from PBRF to Pentolite Ditch and Plum Brook. If any other liquid effluent discharge point(s) are identified on site, please identify what streams or impoundments were used for these liquid effluent discharge points.

Basis: NASA states in Section 4.1 Plum Brook Overview, "The portion of Plum Brook impacted by radionuclides of PBRF origin lies between the confluence of Plum Brook with Pentolite Ditch and its terminus in Sandusky Bay. It is divided into four sections for characterization purposes, denoted as Sections 1 through 4. Section 1, lies between Pentolite Road, in the northern portion of the NASA Plum Brook Facility, and US Rt. 2. This portion of the stream was further divided into five subsections for characterization. These are identified as Sections A - E. They are shown in Figure 3."

Path Forward: Provide justification that any other liquid effluent discharge point(s) have been evaluated by NASA.

NASA Response: During historical assessment, characterization studies, preparation of the Decommissioning Plan and Final Status Survey Plan, and ongoing evaluations throughout the Decommissioning Project, NASA identified the following potential liquid effluent pathways:

1. Sanitary Sewage System
2. Precipitator Sludge Drying Basins
3. Storm Drainage System from the Assembly, Test, and Storage (ATS) Building and the connected Reactor Office Building (ROB).

The potential impact of these effluent pathways has been evaluated as described in the following:

Sanitary Sewage System: When the Reactor Facility was built on the site of the original Plum Brook Ordinance Works, two four-inch sewer lines were installed running in an East to West configuration along the northern and southern sides of the Reactor Facility. These lines received all of the sanitary drains from the facility and tied into the pre-existing Ordinance Works sewage system. This system was deactivated when the facility was shut down. These buried lines were classified during characterization as Class I Impacted areas and were extensively surveyed, characterized, and either decontaminated or slated for later excavation and removal. Portions to be removed at a later date were plugged or blocked to prevent migration of radioactive material.

During plant operation, an additional sanitary sewer line was added in 1964 to support the Assembly Test and Storage (ATS) Building and the attached Reactor Office Building (ROB). This line tied in to the Reactor Facility lines. After facility shutdown in 1973, the individual building sewage pumps were deactivated along with the sewage lift station near Pentolite Road. In 1976, the facility license was revised and the ATS Building and the ROB were removed from the license and released from license controls. The sewer lines from these buildings were physically isolated from the deactivated Reactor Facility systems in early 1980. Confirmatory sampling of sediments has been performed in the sewer systems from these buildings as part of

decommissioning, and additional confirmatory sampling is scheduled to be performed before license termination.

The Reactor Facility lines discharged to the Plum Brook Ordinance Works lines that are still in use today by Plum Brook Station. These lines discharged to a sewage treatment plant located off-site on Taylor Road. The effluents from that station discharged into Plum Brook. In the late 1990's, the sewage treatment plant was shut down and its influents rerouted to the Erie County's sanitary sewage system. The treatment plant was demolished in 2005/2006. As part of decommissioning, radiological characterization studies were performed on the site of the demolished treatment plant to confirm that the Reactor Facility had resulted in no radiological impact on the area. Any residual effect of the systems effluents to Plum Brook would have been assessed by the Plum Brook hydro-geological and radiological studies previously reported.

Preliminary characterization studies have been performed on the sewer lines from the Reactor Facility pumping station to the former treatment site and have found no significant licensed material. On-going studies are scheduled and will be completed prior to License Termination.

Precipitator Sludge Drying Basins: Two sludge drying basins are located outside the PBRF Fenced area at the north end of the facility. The drying basins were unlined earth pits located along Line 3 Road. They were square, 100x100 feet, with a mean depth of two and one half feet. An earthen dike provided with a sluice gate surrounded each basin. Overflow from the basins flowed over the sluice gates to a ditch that flowed north along Line 3 Road. This effluent path did not enter Pentolite Ditch via the WEMS. These basins received effluent sludge consisting of silt with waste lime and alum from the raw water processing system. When the precipitator sludge in the raw water treatment settling basins (designated as structures 1153 on the plant drawings) began to build up and thicken, it was pumped to the drying basins for air drying. When the material dried it was hauled to a dump site on the Plum Brook Station for disposal.

During Facility operation radioactive contamination was not expected in this system since it cleaned and softened raw water from Lake Erie for supply to the Reactor Facility. Even though no radioactivity was expected, discharges from the settling basins to the drying basins were routinely sampled and analyzed for radiological and chemical contaminants prior to discharge. As part of facility characterization, records of these analyses were reviewed and no incidences of exceeding the procedural discharge limits were found. Based on historical assessments performed during the decommissioning planning process, these basins and their effluent pathways were assessed and deemed to be non-impacted areas. Confirmatory sampling and surveys were performed in 2008 to verify this assessment.

ATS Building and ROB Storm Drains: The reactor Facility operated from 1961 through 1973. During that period, all storm drains, building roof drains, and ground water sumps were channeled together through the Water Effluent Monitoring System (WEMS) for release to Pentolite Ditch. The impact of these discharges has been assessed through characterization studies of Pentolite Ditch and Plum Brook. However, in 1976, the facility license was revised and the ATS Building and the ROB were removed from the license and released from license controls. The rest of the facility continued to discharge drains to the WEMS, but the ROB and the ATS Building storm drains were physically separated from the PBRF system. All storm

drains associated with the two buildings were routed through a new 18" line that ran to the north and discharged into a drainage ditch. This revision to discharge flow paths occurred after release surveys had been performed and were accepted by the NRC for releasing the two buildings from licensed control. Therefore, there are no radiological impacts expected from this drainage pathway. NASA plans to perform some degree of confirmatory survey and sampling in the drainage system prior to license termination.

These liquid effluent pathways were identified as part of the decommissioning planning and through on-going characterization studies. Evaluations of these liquid effluent pathways were performed as part of the characterization program or are currently scheduled for further characterization as part of the decommissioning program. As described above, NASA's assessments show that there is no known radiological impact from these effluent pathways and very low probability of discovering an unexpected impact. However, NASA plans to perform confirmatory evaluations of these assessments prior to license termination.

In addition to these effluent pathways, there were occasions, particularly for the 1985 Characterization Study and current decommissioning activities, where the water effluents from the PBRF site were processed through temporary lines directly to Plum Brook. This action was taken to by-pass the WEMS and Pentolite ditch path in order to afford access to Pentolite Ditch for the performance of characterization, remediation, and Final Status Survey related work. During these periods, effluents were monitored to ensure compliance with regulatory release limits. The procedures and monitoring results are available for inspection at PBRF. In addition, final confirmatory surveys will be performed in Plum Brook prior to final License Termination to verify the decommissioning activities have not resulted in additional release of contaminants to the environment.

11. **Comment**: Staff notes that Section 2 had a significantly lower number of sample results for Cs-137 as compared with sample results for Cs-137 for other Sections.

Basis: NASA states in PBRF-TBD-08-005 Section 5.3, Lower Meander - Section 2, that there were 16 sample results from all depths at the three locations. Whereas, in Table 8 for Section 1 for all locations there were 358 sample results, Table 11 for Section 3 for all locations there were 485 sample results, and Table 14 for Section 4, there were 292 sample results.

In addition, the sample results from stream Section 1 were used in calculating the dose to a Brook-Side Resident located in Section 2. However, it is unclear how it is known that the concentrations in this section are less than or equal to the concentrations in Section 1. Although the data do show that the average concentrations tend to be lower further downstream, there are areas of elevated concentration along the stream where sediments have deposited. The areas in Section 2 that were not sampled are significant in size and it is possible that areas of elevated concentration could have been missed.

Path Forward: Provide justification for the difference in the number of samples and sample results for Cs-137 in Section 2 when compared to the number of samples and sample results in the other sections. Also, provide justification for the use of Section 1 concentrations when modeling the dose from sediments located in Section 2.

NASA Response: It is agreed that the frequency of characterization samples from Stream Section 2 is lower than in the other sections of the Plum Brook. However, it is the position of NASA that sufficient characterization data has been obtained from the Plum Brook for the purpose of demonstrating compliance with 10CFR20 Subpart E release criteria using the dose modeling approach. This is because:

- The Plum Brook has been extensively characterized upstream and downstream of Section 2. The portions that have been extensively characterized comprise 75% of the stream course from Pentolite Ditch to Sandusky Bay.
- The response to Comment No. 12, provides evidence of a decreasing trend in Cs-137 (and Co-60) concentration vs. downstream distance from the confluence with Pentolite Ditch to Sandusky Bay.
- Doses reported in TBD-08-006 from exposure scenarios set in each of the four stream sections average 0.6 mrem/y with a maximum scenario dose slightly less than 1mrem/y (0.92). These represent a considerable margin of safety below 25 mrem/y dose criterion.

It is concluded that it is reasonable and justified to use sediment activity concentrations measured in Section 1 for assessment of doses from an exposure scenario setting in Section 2. Concentrations of Cs-137 and Co-60 in Section 1 represent upper bounds for assessment of doses to individuals under exposure scenarios set in the stream meander sections (comprising Stream Sections 1 and 2).

12. **Comment**: It is the staffs understanding that the duration of liquid discharge from PBRF to the Pentolite Ditch occurred between 1963 to 1973. During this period, heavy rains and flooding have occurred and have transported the contaminants downstream. The staff also notes that the sampling from Section 1 was initiated in 2005. Staff cannot determine the basis for why activity concentrations from Section 1 sample results would be conservative for Section 2.

Basis: NASA states in PBRF-TBD-08-005 Section 5.3, Lower Meander - Section 2, that the use of Section 1 sample results for establishing source term activity concentrations for an exposure scenario set in Section 2 provides additional conservatism.

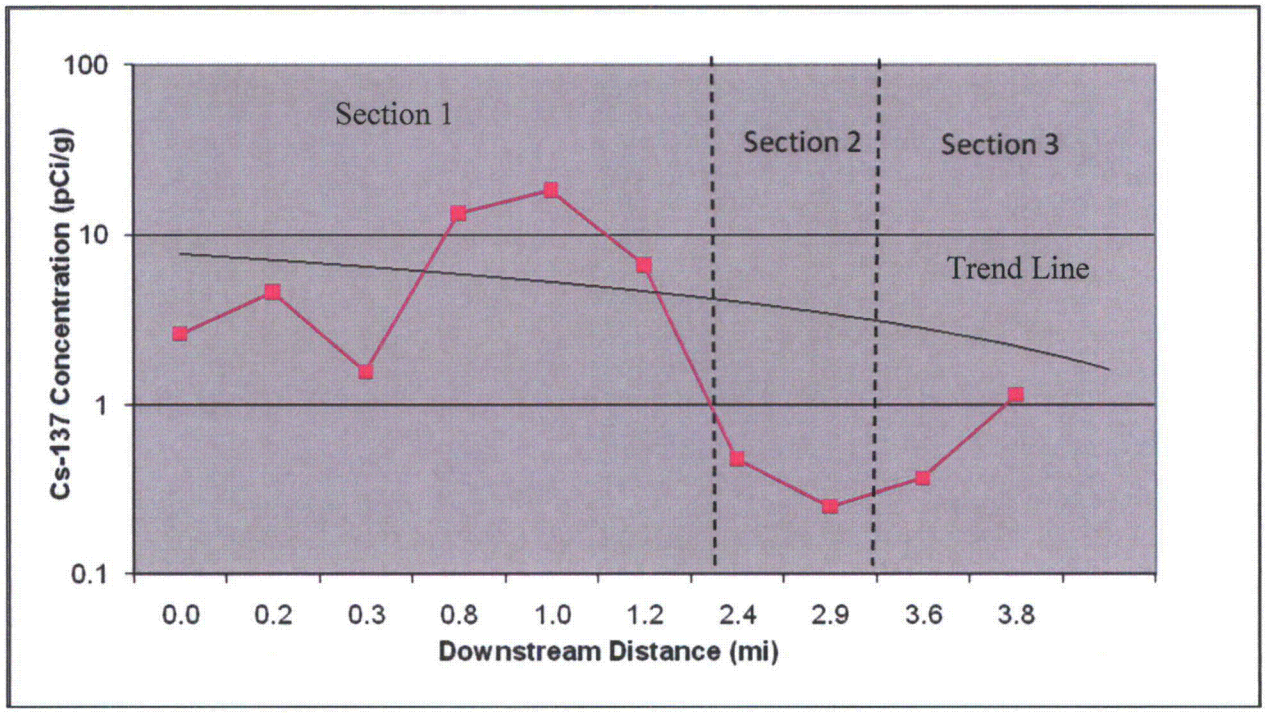
Path Forward: Provide justification for why Section 1 sample results would be conservative for Section 2.

NASA Response: The assumption that use of Plum Brook Section 1 characterization results for assessment of dose using an exposure scenario setting in stream Section 2 is conservative is based on the following:

- Results from the initial 2005 scoping survey show a decreasing trend in Cs-137 and Co-60 concentrations vs. downstream distance.
- Characterization data obtained subsequent to the 2005 characterization survey and reported in PBRF-TBD-08-005 also supports the assumption of a decreasing trend in Cs-137 (and Co-60) concentration with downstream distance over the stream course.

Figure 2 shows a decreasing trend in Cs-137 concentration vs. downstream distance. This figure was developed from data obtained during the initial scoping characterization survey performed in 2005 (Characterization Survey Package SVI-04). The trend line is a linear fit to the average of concentrations measured along the stream course from the Pentolite Ditch to US Rt. 6, a stream course distance of about 3.8 miles. It was developed from the data shown in Figure 12 in PBRF-TBD-08-005.

Figure 2, Cs-137 Concentration Trend – Plum Brook Sections 1 -3



Concentration trends in Stream Section 2 relative to the overall stream course can also be inferred from characterization samples of sediment taken upstream and downstream of Stream Section 2 (the lower meander section). Table 14 summarizes results from samples collected during extensive characterization surveys conducted during 2006 – 2008.

Table 14, Comparison of Cs-137 Measurements Upstream and Downstream of Section 2

Parameter	Upstream	Downstream
Total No. of Samples (1)	1664	1049
Fraction > MDA (%)	90	44
Average (pCi/g) (2)	3.8	2.2
Median (pCi/g) (2)	1.5	1.0
Maximum (pCi/g)	70.2	20.1

Table 14 Notes:

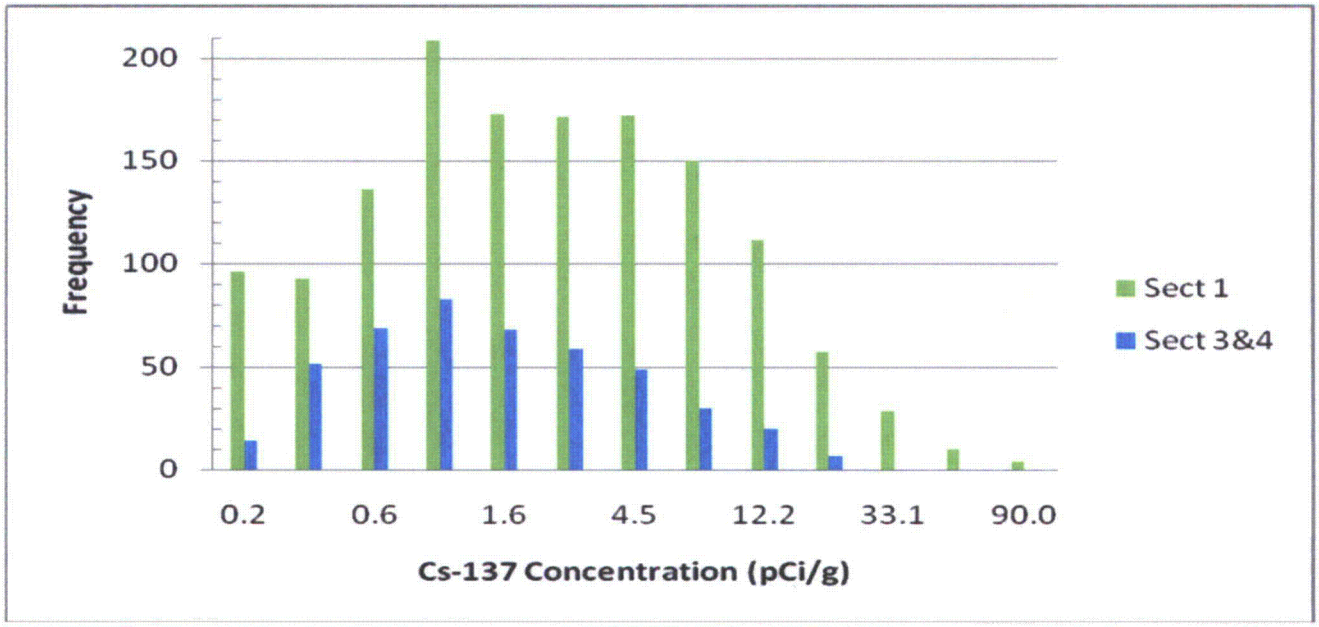
1. The total number of samples includes all samples collected at all depths – QC replicates are not included in the count.
2. Calculated from all sample results > minimum detectable activity (MDA).

The upstream sample results are obtained from the combined data in 15 characterization packages developed during the extensive characterization of Stream Section 1 during 2006-2008. The downstream results are obtained from five characterization packages developed to cover the

stream flood plain and estuary. [21] From comparison of the several measures shown in the table, it is seen that significant decreases are observed downstream of Section 2 relative to upstream. This is supporting evidence that concentrations of Cs-137 in sediments show a continuously decreasing trend with distance from Pentolite Ditch to Sandusky Bay.

An additional comparison is provided in Figure 3. It shows frequency distributions of Cs-137 concentration upstream and downstream of Stream Section 2. The frequency distributions in Figure 2 are derived from the same Cs-137 concentration data used to prepare Table 1. Note that the figures shows the frequency distribution of natural log-transformed activity concentrations

Figure 3, Upstream and Downstream Frequency Distributions of Cs-137 Concentration



The results presented in Table 14 and Figure 3 support the assumption of a decreasing trend in Cs-137 concentration downstream from Pentolite Ditch as shown in Figure 2.

[21] The upstream characterization packages include SR 5 - 12, 19, 20 and 45 – 49. The downstream characterization packages include SR 39, 41, 44, 53 and 54.

13. **Comment**: The extend/boundary of frequently flooded area in the meandering stream section and the flood plain section of the Plum Brook, since the release of Cs-137 in 1963, was not adequately shown on the map(s) along with the locations of sediment/soil samples.

Basis: During major flood events, Cs-137 contaminated sediment is re-suspended from the stream bed, transported by rising flood water over the banks, and deposited onto the surrounding low land areas. The flood in July of 1969, believed to be the largest in recent history, may have set the broadest flood boundary for the contaminated sediment from Plum Brook.

Path Forward: Based on the available historical aerial photos and/or other local hydrologic maps (e.g., 100-year flood map), define the floodplain extent/boundary for areas along Plum Brook during which significant flooding has occurred after 1963. Also, include figures with topographical data of the floodplain, which identifies low-lying areas that have a greater potential for fine-grain sediment deposition to establish if the impacted sediment/soil in the flooded areas/plain of Plum Brook are adequately characterized.

NASA Response: The extent of areas along the Plum Brook inundated by 100 year floods is shown in flood maps provided as attachments. Topographic maps of the Plum Brook showing elevations at 2 foot intervals are also provided.

ATTACHMENTS:

Attachment 13-1A	Map Number 39043C0095D, NFIP Flood Insurance Rate Map, Erie Co. Ohio. Shows area inundated by 100 year flood on Plum Brook from Clark Rd to just north of US Route 2 overpass.	1 page
Attachment 13-1B	Map Number 39043C0092D, NFIP Flood Insurance Rate Map, Erie Co. Ohio. Shows area inundated by 100 year flood on Plum Brook from 1375 ft. north of Hull Rd. to Sandusky Bay.	1 page
Attachment 13-2A	Sheet 138, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from north boundary of NASA Plum Brook site to 1300 ft. north of Clark Rd	1 page
Attachment 13-2B	Sheet 137, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from 800 ft. south of Botay-Taylor Rd intersection to St. Rt. 2	1 page
Attachment 13-2C	Sheet 136, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from St. Rt. 2 to Galloway Rd	1 page

Attachment 13-2D	Sheet 152, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from NE of Galloway Rd. to 800 ft. north of Hull Rd	1 page
Attachment 13-2E	Sheet 151, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from 800 ft. north of Hull Rd. to US Rt. 6 overpass	1 page
Attachment 13-2F	Sheet 180, Topographic Map, Erie County, Ohio, Perkins Twp. (two foot contour interval). Shows Plum Brook from US Rt. 6 overpass to confluence with Sandusky Bay	1 page

14. **Comment**: The morphological elements of Plum Brook should be accurately characterized to explain sediment erosion and deposition after the known release in 1968.

Basis: With a better understanding of the morphology of Plum Brook, sub-environments that have a greater potential to accumulate fine grained sediments (clays associated with Cs-137 adsorption) that have not undergone erosion since their initial deposition can be identified and sampled. A better understanding of the morphology will also aid in the understanding of sediments that have undergone re-suspension and re-deposition.

Path Forward: Provide references to other characterization reports that identify the most likely locations of initial deposition and re-deposition of contaminated sediments after 1963 throughout Plum Brook, or provide figures that identify the most likely locations for initial deposition and re-deposition throughout Plum Brook. The figures should also include all sampled locations for comparison.

NASA Response: A summary of the radiological characterization of the Plum Brook, Technical Basis Document PBRF-TBD-08-005, was previously provided to the NRC. Other characterization reports that discuss the most likely locations of deposited and re-deposited sediments were prepared by Haag Environmental Company, a consultant to NASA. The reports, also previously provided to the NRC, are:[22]

- "Development of Conceptual Model as Basis for Characterization Plan, Plum Brook Reactor Facility Perkins Township, Ohio", October 2007, submitted by NASA letter dated January 4, 2008
- "Characterization Report for Plum Brook Sediment in East Sandusky Bay", October 2007, submitted by NASA letter dated January 4, 2008
- "Characterization Report for Plum Brook Sediment in Ponds", December 2007, submitted by NASA letter dated January 4, 2008
- "Characterization Report for Plum Brook Sediment in Floodplain Wetlands", March 2008, submitted by NASA letter dated May 15, 2008
- "Characterization Report for Plum Brook Sediment in Stream Mouth Wetlands", April 2008, submitted by NASA letter dated April 9, 2008.

These reports describe the hydrology and physical structure (morphology) of the Plum Brook and deposition environments. They identify the most likely locations where sediments bearing Cs-137 of PBRF origin are deposited. Additional information describing characteristics of the Plum Brook and environs to identify low-lying areas where sediment deposition could occur was

[22] These reports were previously provided to the NRC for information. See letter from Plum Brook Reactor Facility Decommissioning Project to the US NRC dated May 15, 2008.

provided in the response to Comment No. 13. This included maps showing the 100 and 500-year flood inundation area boundaries and detailed topographic maps (2 ft. contours).

The attachments identified below include posting plots and other graphics which display the sampled locations along the Plum Brook Flood Plain and Stream Mouth (Estuary).

ATTACHMENTS:

Attachment 14-1	SR39 Posting Plot, Aerial photo of Plum Brook Estuary showing survey-sampling transects	1 page
Attachment 14-2	SR44 Investigative Samples Around Samples from SR39, Aerial photo of Lower Plum Brook Estuary showing survey-sampling transects with investigative samples	1 page
Attachment 14-3	SR41 Posting Plot, Aerial photo of Plum Brook Lower Flood Plain showing survey-sampling transects	1 page
Attachment 14-4	1969 Flood Record in Stream Mouth Wetland, Graphic of Plum Brook Estuary showing survey-sampling transects with color-coded sample results	1 page
Attachment 14-5	1969 Flood Record in Stream Mouth Wetland, Graphic of Plum Brook Estuary showing survey-sampling transects with color-coded sample results – with commentary	1 page
Attachment 14-6	Cs-137 Details in Flood Plain Area, Graphic of Plum Brook Flood Plain showing survey-sampling transects with color coded sample results	1 page

15. **Comment**: The initial scoping survey was conducted in 2005, with scan survey points primarily located at stream roadway over-crossing of the Plum Brook to avoid entering private property and due to safety access concerns.

Basis: The design of the subsequent Phase I and II sediment and soil characterization was based on the results of the initial scoping survey results. The approach to selecting the initial scan locations (stream roadway over-crossing) may potentially increase the chance of missing the highest contaminated sediments.

Path Forward: Provide a justification, for example based on the site conceptual model, that the initial scoping does not compromise the full characterization of the sediment along Plum Brook.

NASA Response: The characterization surveys that followed the initial 2005 scoping survey (Characterization Package SVI-04) were motivated by that initial survey. However, selection of scan and sampling locations was not based on accessibility from roadway overcrossings as in the initial 2005 survey. The subsequent Phase I survey comprised sampling locations established on a systematic grid pattern along the stream course. Phase II consisted of 100% scan surveys of both sides of the stream banks followed by collection of samples at locations where scans indicated the presence of elevated activity. This was followed by the Phase III, or Bounding surveys, where gamma scans, fixed gamma measurements and samples were collected to delineate areas of elevated activity identified in the Phase I and II characterization surveys. These surveys, in combination provide assurance that the stream sediments with the highest concentrations of Cs-137 have been identified.

16. **Comment**: Based on the Characterization Report for Plum Brook Sediment in East Sandusky Bay, it appears that sediment samples were not collected along and west of the previous stream channel after Plum Brook entered the Sandusky Bay, and the extent of sediment with Cs 137 was not defined to the west of the stream channel.

Basis: Stream maps and areal photos of Plum Brook indicated water previously flowed through Sandusky Bay to the North, then turned west upon reaching the Cedar point bar (Figure 4), and the sediment samples collected were primarily located to the northeast along the current flow channel (Figure 4 and Figure 12).

Path Forward: Provide an explanation or justification that there is no need for additional sediment sampling along the previous stream channel to the west within the bay.

NASA Response: It is NASA's position that additional sampling in Sandusky Bay is not justified for evaluation of potential dose to members of the public from radionuclides of PBRF origin in the Bay. In the evaluation which followed the characterization of Plum Brook and the Bay, no exposure scenario was identified for the Bay that yields a dose that is distinguishable from zero. Also, it is concluded from further investigation of East Sandusky Bay characteristics, that it is unlikely there is an un-measured "plume" of cesium-bearing sediments of PBRF origin to the west of the area sampled. Supporting information is provided as follows:

1. A conceptual model of sediment distribution is presented based on updated information on conditions in East Sandusky Bay during the period from the late 1950s to the present. Our conclusion is that sediment delivered from the Plum Brook has not moved preferentially to the west, but has moved mostly north and eastward from the time of major floods in 1968-69 to the present.

2. A review has been conducted of potential exposure pathways and the source term for an assessment of doses to members of the public from exposures to sediments in East Sandusky Bay. It is concluded that:

    a. The dose is bounded by the previously calculated dose for the Recreationist Scenario, wherein an individual is assumed to occupy the banks of the Plum Brook Estuary (river mouth) and consume fish caught there.

    b. The Cs-137 inventory in East Sandusky Bay sediments is dominated by that from atmospheric weapons testing. Published information is provided on fallout deposition and results of measurements of Cs-137 concentrations in sediments at nearby estuary that is not impacted by PBRF operations.

Conceptual Model of Sediment Distribution in East Sandusky Bay [23]

The Plum Brook empties into the eastern arm of Sandusky Bay, a shallow water body that lies between the Cedar Point Causeway on the west and Cedar Point Road on the east.[24] It is bordered by and separated from Lake Erie by the five mile long Cedar Point sandbar to the north. During the period of interest, from the late 1960s to the present, this part of Sandusky Bay has been water-filled because of historically high Lake Erie water levels. This is illustrated by aerial photos taken in 1958, 1971, 1986 and 2009 (see Attachments 16-1 through 16-4). The East Bay is hydraulically connected to the main Sandusky Bay via three 42 foot long channels under the Cedar Point Causeway and to Lake Erie via a 45 foot channel under Cedar Point Road at the east end of the East Bay. None-the-less, water exchange between the East Bay and the main Sandusky Bay and Lake Erie is highly restricted by the Cedar Point sandbar and Causeway.

Most of the sediment from the Plum Brook and the other streams feeding into East Sandusky Bay is delivered during storm events expedited by increased water velocity, high volume flow rates and high winds. An estimate of the mass of fine sediments delivered to the East Bay is provided in the second part of this response. Once sediments are delivered to the East Bay, their distribution is influenced by water movement in the absence of storms, which is most of the time. Under normal conditions, the East Bay is a relatively quiescent body of water that is buffered from Lake Erie offshore currents and from water flows in the main part of Sandusky Bay.

In the absence of storm influences, the prevailing direction of water movement in the East Bay is from west to east. Water movement in this shallow water body is strongly influenced by wind direction, which is predominantly from the southwest. [25] There is also a west-to-east influence driven by water movement in the main portion of Sandusky Bay toward Lake Erie, a small fraction of which can enter the East Bay through the Cedar Point Causeway.

The attached aerial photos from 1958, 1971, 1986 and 2009 show the East Sandusky Bay in the vicinity of the Plum Brook stream mouth. In the 1971 and 2009 photos in particular, plumes of deposited material in the vicinity of the Plum Brook stream mouth can be discerned. They are seen to be oriented predominantly towards the northeast.

---

[23] The conceptual model of sediment distribution was developed with the assistance of subject matter experts. Aerial photos of the Plum Brook Estuary and East Sandusky Bay and descriptions of man-made and natural features were provided by Mr. Ken Fortney of the Erie County Engineer's Office. Peter Richards, PhD, Senior Research Scientist, National Center for Water Quality Research, Heidelberg University, provided data on sediment loading in the Sandusky River as an analogue for estimating sediment delivery to the East Sandusky Bay. He also assisted with interpretation of aerial photos and provided insights on fine sediment behavior in fresh water estuarine environments.

[24] Water depths in the East Bay range from a few inches along the south shore to several feet in the mid-portion. A channel has been dredged along the western end, east of the Cedar Point Causeway, for pleasure boat access.

[25] See NASA Safety and Mission Assurance Directorate, "Decommissioning Plan for the Plum Brook Reactor Facility", Revision 6, July 2008, Section 8.4.2, Climate and Air Quality,

Discussion of Exposure Pathways and Source Term for Dose Assessment

An assessment of the dose to members of the public from exposure to sediments in East Sandusky Bay requires identification of possible exposure pathways and estimation of activity concentrations for the dose modeling source term.

The only potential exposure pathway involving contaminated sediments in the Bay is the fish consumption pathway. The potential dose from fish consumption is bounded by the Recreationist Scenario dose assessment, whereby an individual consumes fish caught in the Plum Brook Estuary, upstream of the Bay. As reported in the response to RAI Comment No. 8, the dose from fish consumption is calculated to be 7.8E-02 mrem/y. It is noted that the source term Cs-137 concentrations used in the Recreationist Scenario are greater than Cs-137 concentrations measured in Bay sediments.

The inventory of Cs-137 in the Bay and the nearby Lake Erie shoreline and estuarine environments is dominated by Cs-137 from atmospheric fallout, mostly from weapons testing. [26] Results of measurements reported in 2008 of Cs-137 in sediments in the nearby Old Woman Creek Estuary show concentrations ranging from 2 to 8.5 pCi/g, with the maximum concentration measured at 10 cm depth.[27]

An estimate of fallout Cs-137 concentration in East Sandusky Bay sediments is developed below. The average Cs-137 concentration is obtained as the quotient of the Cs-137 inventory and the total fine sediment mass. First, the mass of fine sediments delivered to and retained in the East Bay during the period 1958 to 2008 is estimated. The details are shown in Table 15.

Table 15, Estimated Mass of Fine Sediment Delivered to East Sandusky Bay

Source Compartment	Surface Area (km^2)	Sediment Mass Delivered 1958 - 2008 (g)
Plum Brook watershed	17.9	6.18E+10
Pipe Creek Watershed	85.0	2.93E+11
Total	102.9	3.55E+11
Total Sediment Retained		1.03E+11

[26] Techniques are available to discriminate between Cs-137 of PBRF origin and that of fallout origin (analysis of Cs: Pu ratios, for example). Personal communication, Prof. Gerald Matisoff, Department of Geological Sciences, Case Western Reserve University, May 7, 2008.

[27] B. Bernal and W. Mitsch, " Estimating Carbon Sequestration in a Great Lakes Coastal Wetland Using Radiometric Dating", Ohio State University School of Environment and Natural Resources, Graduate Student Poster Competition, March 2008. http://hndl.handle.net/1811/31891.

Table 16 shows that an estimated 15.6 Ci of fallout Cs-137 was deposited on the East Sandusky Bay and the surrounding watershed during the period from 1958 to the present. This is obtained from the product of the average cumulative deposition density of 140 mCi/km^2 (derived from data reported in NCRP Report No. 154 [28]) and the surface area of the receiving watersheds. The current inventory is estimated to be about 0.3 Ci. The net fraction retained in the East Bay takes into account: a) the fraction deposited on the watershed that is delivered to the Estuary & Bay, b) the fraction of fine sediment that is retained in the East Bay over time and c), the decrease due to radioactive decay. For this estimate a = 0.2, b = 0.29 and c = 0.35, as explained below.

Table 16, Estimated Fallout Cs-137 Deposition in East Sandusky Bay

Source Compartment	Surface Area (mi^2)	Surface Area (km^2)	Cumulative Deposited (Ci)	Net Fraction Retained	Current Inventory (Ci)
Plum Brook Watershed (1)	6.92	17.9	2.51	0.0203	0.05
Pipe Creek Watershed	32.8	85.0	11.89	0.0203	0.24
E Sandusky Bay (2)	3.25	8.4	1.18	0.0203	0.02
Totals	43.0	111.3	15.6		0.32

Table 16 notes:

1. The area of the Plum Brook watershed includes the adjacent Hemminger Ditch watershed. The watershed area of a small stream to the east of Plum Brook is not included.
2. Fallout deposition directly on the surface of East Sandusky Bay is included. The fraction retained in deposited sediment is assumed to be the same as for sediments delivered from watersheds.

Delivery ratios of suspended sediments in the nearby Old Woman Creek watershed have been reported to be between 21 and 25%. A value of 20% is assumed here. [29]The fraction of fine sediments retained over the long-term is estimated to be 29%. [30] For the reduction in Cs-137 activity due to radioactive decay, about 1.5 half-lives have elapsed since peak fallout deposition in the mid 1960s. This yields a factor of 0.35.

The total mass of Cs-137 bearing sediments delivered to the East Sandusky Bay is estimated to be about 355,000 metric tons (3.55 E+11 g.) as shown in Table 15. This estimate is obtained by applying suspended sediment delivery data for the Sandusky River. The average mass delivered per year, 6.90 E+07 grams per year per km^2 watershed area, is multiplied by the surface area of

[28] See NCRP Report No 154, "Cesium-137 in the Environment: Radioecology and Approaches to Assessment and Management", 2007. The mean cumulative deposition density in the Northern Hemisphere at 40 to 50 degrees latitude is reported in Table 3.6 as 5,168 Bq/m^2.

[29] Evans, et. al, "A GIS Model to Calculate Sediment Yields from a Small Rural Watershed, Old Woman Creek, Erie and Huron Counties, Ohio", Ohio J. of Science 97:3 (44-52), 1997.

[30] Old Woman Creek National Estuarine Research Reserve, "The Movement of Sediment in the Old Woman creek Watershed", Technical Bulletin No. 1, June 2002.

the East Bay watersheds.[31] The total mass delivered is obtained by multiplying the average mass delivered yearly by 50 years, the period from 1958, when atmospheric weapons testing was initiated, to the present. The total mass of sediment retained in the East Bay is obtained by adjusting the total mass delivered by 0.29, the fraction of sediments retained over the long-term, as described above.

The estimated average fallout Cs-137 concentration in East Bay sediments can then be obtained as the quotient of 0.32 Ci (3.2 E+11 pCi) and 1.03 E+11 g, or ~ 3.1 pCi/g. This is in line with concentrations of fallout Cs-137 measured in nearby Old Woman Creek Estuary sediments.

For comparison, the concentration of PBRF derived Cs-137 in East Bay sediments is obtained from fallout deposition inventories and sediment mass budgets. It is assumed that the entire inventory estimated to have been released from the PBRF, 5 to 7 mCi, is retained in East bay sediments. The average concentration thus obtained in the 1.03 E+11 g of sediment is approximately 0.05 to 0.07 pCi/g.

ATTACHMENTS:

Attachment 16-1A	Photograph File# PW-2V-137, 1958 aerial photo showing the Plum Brook stream Mouth and East Sandusky Bay to the north	1 page
Attachment 16-1B	Photograph File# PW-2V-126, 1958 aerial photo showing eastern end of Sandusky Bay	1 page
Attachment 16-2A	Photograph File# 317, 1971 aerial photo showing Plum Brook from Hull to Cleveland Rd. (US Route 6) and the lower half of the estuary	1 page
Attachment 16-2B	Photograph File#, 353, 1971 aerial photo showing the Plum Brook estuary opening into East Sandusky Bay	1 page
Attachment 16-3	Photograph File# Sheet 150, 1986 aerial photo showing the Plum Brook Estuary and East Sandusky Bay to the north	1 page
Attachment 16-4	Photograph File#, 2009 Aerial, 2009 aerial photo of East Sandusky Bay showing the Plum Brook Estuary	1 page

[31] The average mass of fine (suspended) sediment delivered from the Sandusky River Watershed to Sandusky Bay each during the period 1975 – 2008 is 6.9 E+07 g/y. Data provided by Peter Richards, Sr. Research Scientist, National Center for Water Quality Research, Heidelberg University.

17. **Comment**: In assessing the residual radioactivity and demonstrating that the stream bed and banks of Plum Brook between Plum Brook Station boundary and Sandusky Bay meet the radiological criteria for unrestricted use, NASA should also assess any dose contribution from any radionuclides of PBRF origin in groundwater that may result in potential exposure through drinking water.

Basis: Transport of any radionuclides of PBRF origin in groundwater may result in potential exposure through drinking water.

Path Forward: Provide information describing the assessment of any groundwater contamination impacts including potential dose contribution from all pathways (including groundwater) to offsite receptors consistent with the release criteria.

NASA Response: Assessment of water-dependent pathway doses from PBRF radionuclides has been performed for two exposure scenarios:

1. Dose assessments have been performed for a Plum Brook residential scenario with the drinking water pathway activated.
2. Results of RESRAD dose calculations for water-dependent pathway doses to the Resident Farmer from PBRF soils are summarized. They represent bounding dose calculations for water-dependent doses for radionuclides of PBRF origin.

From these dose assessments, it is concluded that there is no exposure to offsite receptors from the contaminants of concern, Cs-137 and Co-60, via groundwater exposure pathways.

Plum Brook Residential Scenario with Drinking Water- Pathway. A study was performed to assess potential doses from contaminated sediments in the Plum Brook via transport to groundwater. The Suburban Gardner exposure scenario was selected as being representative of scenarios where a resident could consume water from a well that draws from groundwater underlying the Plum Brook. It is noted that this is a hypothetical exposure scenario, because:

- groundwater in the vicinity of the PBRF and Plum Brook is not considered potable. [32]
- there are no known public uses of groundwater in the affected region.[33]

Dose calculations were performed for unit concentrations of Cs-137 and Co-60. The contaminated zone was an area of surface soil or sediment contamination 186-m^2 in area and 3-inches thick. This corresponds to the garden contaminated with sediment-fill assumed for the Suburban Gardner Scenario as described in the response to Comment No. 5. The drinking water pathway was activated and the resident was assumed to consume 100 % of his or her drinking water from a local well. The initial cases were run with hydrology parameter values as reported in the PBRF Technical basis Document PBRF-TBD-08-006. Attachment 17-1 contains an index of the case run reports. The index presents the total dose and drinking water pathway dose for

[32] See, "Water Resources of Erie County", Ohio State University, Food, Agricultural and Biological Engineering, Fact Sheet AEX-480.22-98, 1998.
[33] Personal Communication, Eric Dodrill, Erie County Water Conservation District, Sandusky, OH, 9/3/2009.

each case. It is seen that for the base case, no dose is received for water ingestion. That is, neither Cs-137 nor Co-60 reaches the saturated zone at any time after placement of the contamination (doses were calculated for times 0, 3, 10, 30 100 and 1000 years). This model assumes a single unsaturated zone of 3 meters thickness.

The RESRAD model assumptions were then modified to enhance transport of Cs-137 and Co-60 from surface deposits into the saturated zone. To this end, the intervening unsaturated zone was removed. This places the contaminated sediments in direct contact with the groundwater bearing formation (the saturated zone). As a result, small, but finite doses were obtained. Figure 4 shows the dose curve for Cs-137. The figure shows that initial breakthrough of cesium occurs in year 0 and the annual dose peaks at 8.75 E-06 mrem/y in year 30.

Figure 4, Cs-137 Dose from Drinking Water – Unsaturated Zone Removed

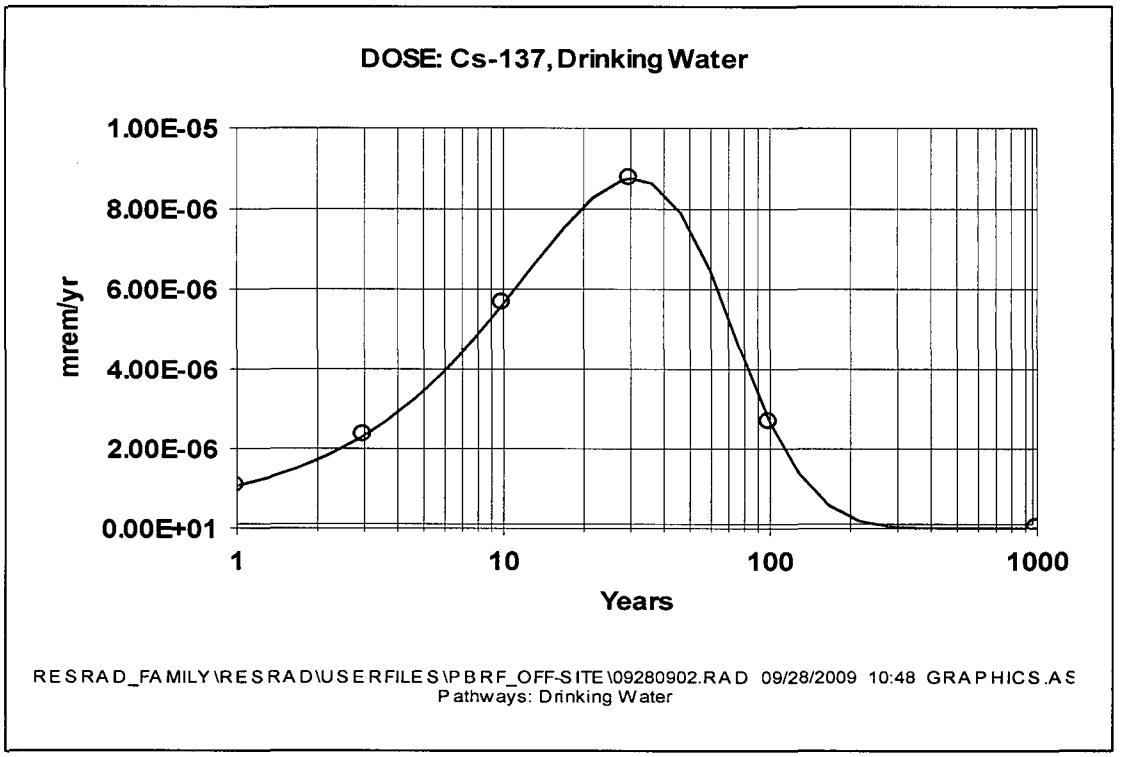
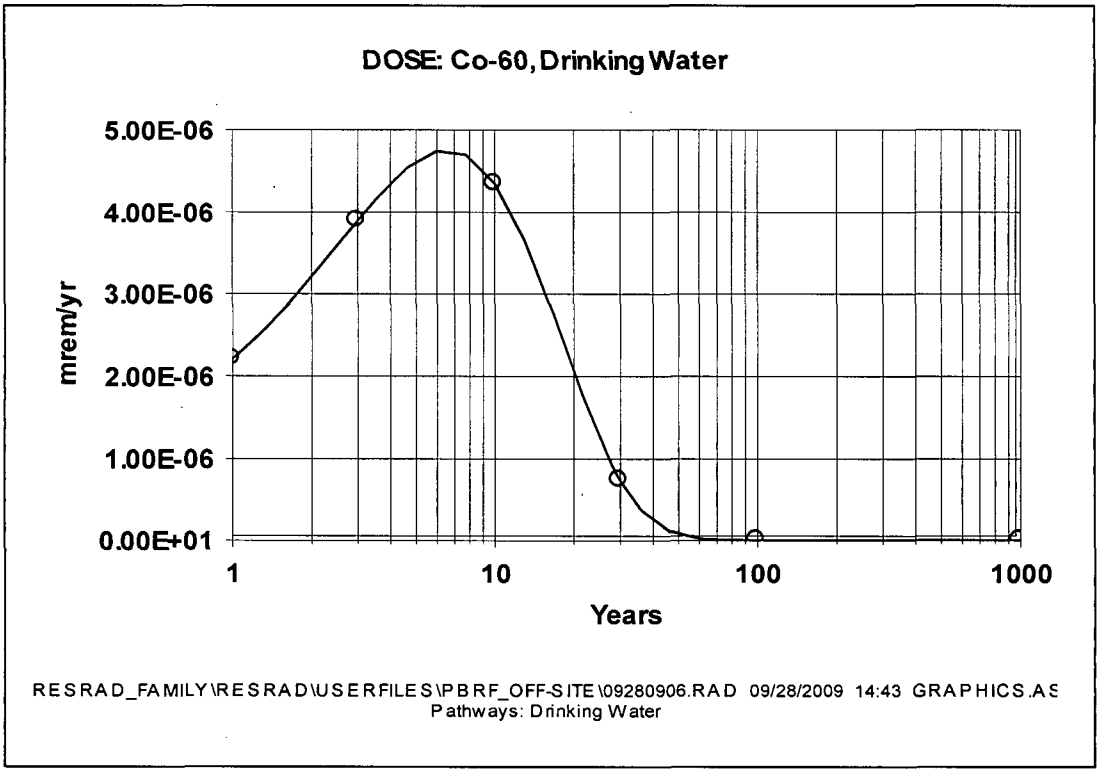


Figure 5 shows the Co-60 dose curve. It shows that breakthrough of Co-60 also occurs in year 0 and the annual dose peaks in year six at about 4.75 E-06 mrem/y.

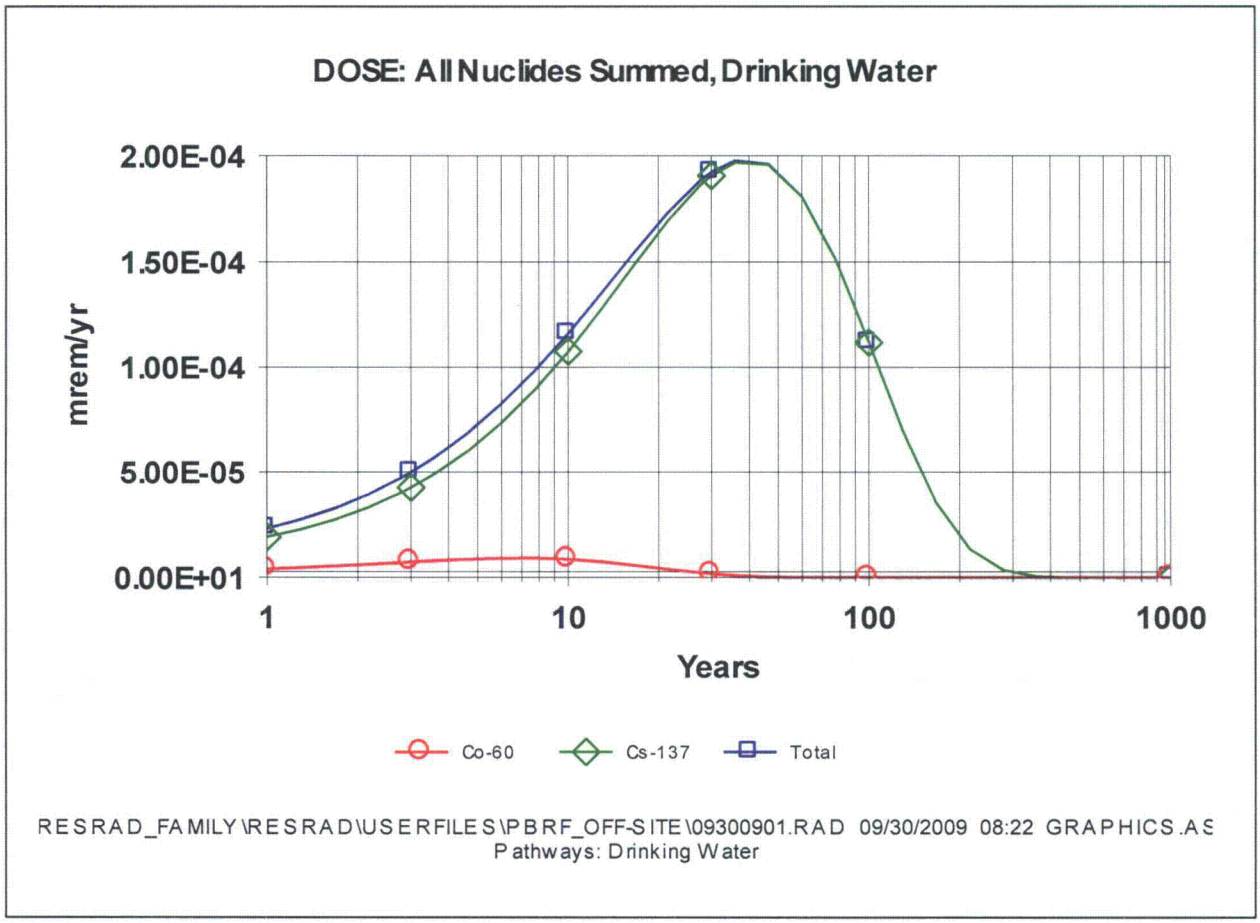
Figure 5, Co-60 Dose from Drinking Water – Unsaturated Zone Removed



Sensitivity analysis was performed to evaluate the upper bound calculated dose from contaminated groundwater. Parameters analyzed for sensitivity included source dimensions (area and thickness). Results of the sensitivity analysis are provided in Attachment 17-2. From this analysis it is seen that the drinking water dose from Cs-137 remains less than 1 E-05 mrem/y per pCi/g, when the source area is increased by a factor of five (from 186 m^2 to 930 m^2) and the source thickness also by a factor of five (from 3 inches to 15 inches). Similarly, the drinking water dose from Co-60 remains less than 5.5 E-06 mrem/y per pCi/g.

A bounding case was calculated. This case modeled the extreme assumptions that a large area of sediment (930 m^2 in area and 15 in thick), uniformly contaminated with Cs-137 at 72.4 pCi/g and Co-60 at 1.6 pCi/g is in direct contact with the saturated zone. These are the highest concentrations measured in Plum Brook sediments. The calculated drinking water dose is less than 2 E-04 mrem/y (maximum dose occurs at about year 35). This result is shown in Figure 6.

Figure 6, Drinking Water Bounding Dose



Water-Dependent Pathway Doses for Resident Farmer. Assessment of doses from potential groundwater pathways was performed as part of the dose assessment for development of DCGLs for PBRF soils. This was reported in the Plum Brook Reactor Facility Final Status Survey Plan. [34] The RESRAD calculation for the Resident Farmer Scenario included the water-dependent pathways: drinking water, fish consumption, and consumption of plants, meat and milk produced on contaminated soil on the PBRF site. The source term radionuclides for this dose calculation are listed (with concentrations) in Table 17.

[34] NASA Safety and Mission Assurance Directorate, Plum Brook Reactor Facility, Final Status Survey Plan for the Plum Brook Reactor Facility, Revision 1, February 2007, Attachment B, Addendum 1,"RESRAD Reports for Surface Soil Scenario Dose Assessment".

Table 17, Soil Radionuclide Mixture for PBRF Resident Farmer Dose Assessment

Radionuclide	Initial Soil Concentration (pCi/g)
Am-241	1.50E-01
Am-243	1.60E-01
C-14	2.11E+00
Cm-245	2.20E-01
Co-60	1.68E+00
Cs-137	5.85E+01
Eu-155	7.60E-01
H-3	2.27E+01
I-129	5.30E-01
Nb-94	3.00E-01
Ni-63	6.96E+00
Pu-238	1.7E-01
Pu-239	1.60E-01
Sr-90	5.49E+00
U-236	1.20E-01

The water-dependent pathway dose results from this dose calculation are given in Table 18. It shows that the peak dose, 8.93 mrem/y, is delivered in year 30, primarily from I-129.

Table 18, Water-dependent Pathway Doses for PBRF Resident Farmer

Pathway	Dose (mrem/y) at Time After Placement						
	0 y	1y	10y	30y	100y	300y	1000y
Drinking Water	9.38E-02	2.97E-01	6.05E-19	3.53E+00	1.01E-01	3.67E-03	2.65E-02
Fish	1.62E-04	5.43E-04	1.20E-21	2.58E-01	2.49E-02	5.09E-04	4.84E-04
Plant	4.18E-02	1.47E-01	3.52E-19	2.00E+00	6.14E-02	2.16E-03	1.49E-02
Meat	5.01E-03	2.06E-02	6.44E-20	3.49E-01	1.16E-02	3.53E-04	1.28E-04
Milk	2.02E-02	6.75E-02	1.54E-19	2.79E+00	1.49E-02	2.69E-03	1.26E-03
Total Dose	1.61E-01	5.33E-01	1.18E-18	8.93E+00	2.14E-01	9.38E-03	4.33E-02
Principal Radionuclide	H-3	H-3	H-3	I-129	Sr-90	Sr-90&Ni-63	U-236

It is concluded that this dose calculation bounds, by orders of magnitude the dose for any occupancy scenario involving contaminated Plum Brook sediments. The Principal contributing factors are:

1. Source term size is much greater.
2. Conservative values are used for key parameters – RESRAD default values.
3. The nuclides which contribute most of the dose: tritium, Sr-90 and I-129 are not measured in Plum Brook sediments.
4. Neither Cs-137 nor Co-60, the principal sediment contaminants reach the saturated zone.

ATTACHMENTS:

Attachment 17-1	RESRAD case run reports with index	89 pages
Attachment 17-2	Sensitivity Analysis for Plum Brook Drinking Water Pathway Dose Assessment, Figures	4 pages