

**USTUR Final Report to NIOSH/OCAS**  
**Contract No. 211-2006-M-15078**

**Transfer of USTUR Data Concerning Rocky Flats Cases**

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## **PREAMBLE**

### **Purpose**

The goal of this work was to provide NIOSH with plutonium and americium concentration data in selected organs voluntarily donated by USTUR registrants who had worked at the DOE Rocky Flats facility. These data should help NIOSH evaluate the biokinetic behavior of highly insoluble forms of plutonium (Super S) and also help evaluate the adequacy of lung counting of  $^{241}\text{Am}$  at Rocky Flats as a means of predicting the lung content of plutonium.

### **Background**

The US Transuranium and Uranium Registries (USTUR) hold tissue radiochemical analysis data for 108 voluntary Rocky Flats donors. In addition to the results of radiochemical analyses of autopsy tissues donated at the time of death, the Registries also hold results of bioassay (urine, in vivo and sometimes fecal data), and a listing of the incidents associated with each case. Four cases are whole body donations. These, and the 104 partial body donation cases, have documented exposures to a variety of conditions throughout the history of the site, including small chip fires, wounds, and exposures during the large fires. The USTUR case data should provide a significant resource to define realistic bounding conditions for characterizing exposure at Rocky Flats and other sites where Super S materials were present.

### **Scope of work**

The USTUR maintains electronic files including the radiochemical results from autopsy tissues, bioassay, and incident information which supported the tasks described above. However, this project was not a simple perfunctory transfer of data. While these data were in electronic form, most were not in a 'summary' format that allowed external evaluation without reference to the hardcopy case files (which may be many hundreds of pages) or additional data validation. NIOSH required an electronic transfer of data suitable for use by an external agency for these cases, with no personal identifiers included in the file. In addition to autopsy data, NIOSH also required the transfer of urinalysis, fecal, and lung counting data for each case in a manner which NIOSH could reasonably handle for evaluation with the IMBA Expert™ OCAS-Edition intake and dose assessment software.

NIOSH required that the radiochemical results of the autopsy include the following data:

- Whole organ weight (or weight of identified tissue such as the femur)
- Radiochemical sample weight
- Measured concentration, and its uncertainty, for  $^{239+240}\text{Pu}$  and  $^{241}\text{Am}$  in each organ or tissue

For partially sampled organs (e.g. the skeleton in Partial body donations), NIOSH requested that USTUR should estimate the content (and average concentration) of these radionuclides in the whole skeleton. The organ content/bioassay data of special interest to NIOSH are:

- Lungs
- Thoracic lymph nodes
- Axillary lymph nodes (in the case of a wound)
- Liver (total liver estimate)
- Total skeleton
- Results of urine, fecal and whole body counts. Dates of any chelation therapy should be included.

NIOSH also required the (privacy-redacted) work history and incident files for all submitted cases. Also, following receipt of a duly signed confidentiality statement (USTUR Form 106 – USTUR Policy on Scientific Collaboration and Data Access) from the Director, Office of Compensation Analysis and Support (OCAS), NIOSH required that USTUR provide to OCAS the registrant’s social security number in each case. This would enable OCAS to compare the exposure and work history data previously obtained by OCAS for individual EEOICPA claimants with that compiled by USTUR for Registries research.

NIOSH awarded Contract No. 211-2006-M-15078 to Washington State University on November 4<sup>th</sup>, 2005. This provided partial support of USTUR’s work on this special project.

**Cited example of NIOSH’s proposed use of the data**

The liver is a concentrating organ for plutonium and also an organ with very long retention. Evaluation of the ratio of the liver to thoracic (lung and lymph node) content as a function of time since intake provides a simple, yet effective, means of evaluating the translocation of plutonium from the lungs to the systemic compartments. Very low liver/lung ratios as compared to the ICRP type S ratio of 1.6 at 10,000 days indicate that the case is a good candidate for evaluation for Super S. Evaluating the USTUR cases for incidents which do (and which don’t) fit into this model will be useful. These Super S cases (such as a known ‘Super S’ Case #0821 – from Mound Laboratories) can also be used to evaluate the Super S model being developed as a Technical Information Basis (TIB) by NIOSH’s ORAU team.

**USTUR DATA DELIVERED**

**Catalog of USTUR Rocky Flats (ROC) data resource**

Prior to NIOSH’s contract award, USTUR provided to OCAS the following electronic data files (on September 14<sup>th</sup>, 2005):

1. “Rocky Flats Registrants by Incident Date.xls” – List of all 1,740 recorded (de-identified) exposure incidents stratified by “date of occurrence.” This could be used, for example, to identify all USTUR case numbers involved in a particular incident, such as the 1965 plutonium fire.

2. “Rocky Flats Registrants by Case Number.xls” – List of all 1,740 recorded (de-identified) exposure incidents stratified by “USTUR case number.”
3. “ROC\_WB\_Living.xls” – List of (6 still living) currently registered Rocky Flats whole-body donors (de-identified USTUR case numbers).
4. “ROC\_WB\_Deceased.xls” – List of (6 deceased) Rocky Flats whole-body donations (de-identified USTUR case numbers).
5. “ROC\_RO\_Living.xls” – List of (40 still living) currently registered Rocky Flats partial-body donors (de-identified USTUR case numbers).
6. “ROC\_RO\_Deceased.xls” – List of (109 deceased) Rocky Flats partial-body donations (de-identified USTUR case numbers).
7. “ROC\_RO\_Inactive.xls” – List of (89) Rocky Flats withdrawn (inactive) partial-body donors (de-identified USTUR case numbers).

### **USTUR Registrant data files provided**

For each of the 4 whole-body donation and 104 partial-body donation cases, USTUR prepared electronic copies (in Adobe® Portable Document Format – PDF) of all paper records held in the Registries’ primary files. All personal-identifiable information, e.g., donor name, social security number, worker code number(s), next-of-kin-name(s), private addresses, date-of-birth, treating physician name(s), funeral home information, was redacted electronically (permanently removed) from these files, before transmission to NIOSH. For most cases (where available in the Registries’ primary records), the following PDF data files were included, in separate sub-folders under the numbered case folder:

1. “r\_r\_XXXX\_Audit\_Records.pdf” – Case file check list, chain of custody records, etc., where “XXXX” is the four-digit USTUR case identification number, and “r\_r\_” confirms that the file was redacted (and independently checked) by USTUR personnel.
2. “r\_r\_XXXX\_Correspondence.pdf” – Explanatory/clarifying correspondence about the case, including any workplace case reports or publications (when available).
3. “r\_r\_XXXX\_Autopsy\_Radiochemistry.pdf” – Case death certificate and/or autopsy report (where available), with USTUR record of any tissue samples added to the National Human Radiobiology Tissue Repository (NHRTR), original laboratory paper records of radiochemical tissue analysis results, sampled tissue weights, etc.

4. “r\_r\_XXXX\_Exposure\_Bioassay.pdf” – Paper records/descriptions of workplace exposure incidents and associated “health physics” data involving Case XXXX, with all original bioassay data records, including urine, fecal, nose blow, whole body or chest count, wound monitoring, and historical (workplace) estimates of body burden and/or dose (where available). In cases with a large amount of data, the paper records (and pdf files) were categorized separately as “Dosimetry”, “Excreta”, “Exposure” and/or “Incident” data.

In addition to the PDF files containing USTUR’s (privacy-redacted) primary paper records, for each case, spreadsheet data files (Microsoft® Excel®) were also provided. These were produced directly from USTUR’s internal server SQL database. The spreadsheet files were:

1. “HP\_XXXX.xls” – List of individual “health physics” (de-identified) data entries extracted by USTUR personnel from the original (primary) paper records for Case XXXX.
2. “RC\_XXXX.xls” – List of tissue radiochemical analysis results extracted by USTUR personnel from the original radiochemistry laboratory reports.

In order to provide NIOSH with highly reliable data for this study, USTUR carried out rigorous quality assurance and validation of all derived tissue concentrations directly from the original laboratory records of the primary measured quantities, including the originally reported values of net count rates and tissue weights. The resulting validated tissue concentrations for each case were compiled in each “RC\_XXXX.xls” file as additional worksheets. These worksheets contained: (i) results for  $^{239+240}\text{Pu}$ ,  $^{238}\text{Pu}$ , and/or Pu-gross- $\alpha$  concentration in tissues (as available) in a standardized, easily readable format, and (ii) results for  $^{241}\text{Am}$  concentration in tissues (where available), and the  $^{241}\text{Am}.$  $^{239+240}\text{Pu}$  activity ratios observed for each tissue, again in an easily readable format. Tables 1 and 2 are examples of these worksheets, showing the validated data for Pu and Am, respectively, in partial-body donation Case 0727. The worksheets constructed to present the tissue results from the four whole-body donation cases included all (> 100) measured samples in each case.

For both partial-body donations and whole-body donations, it is necessary to estimate (project) the total skeletal radionuclide contents from the reported measurements on sampled bones. In all four whole-body donation cases, the radionuclide contents of approximately half the skeleton were measured directly (bones from the right side of the body, with alternate vertebrae and ribs). The total skeletal contents were then calculated by assuming bilateral symmetry, and interpolation of measured concentrations in vertebrae and ribs to the adjacent (non-sampled) bones. For the 86 partial-body donation cases with reported (measurable) skeletal radionuclide contents, the total skeletal activities and average skeletal activity-concentrations were estimated from the results reported for the sampled bones (from one to several in each case).

**Table 1: Case 0727 - Tissue Radiochemical Summary of Pu-α.**

Tissue	Autopsy Wt (g)	RadChem Wet Wt (g)	Wet Conc. <sup>239+240</sup> Pu (Bq/Kg)	SD	Total <sup>239+240</sup> Pu Activity (Bq)
Lung, left	1450	1269	2.18E+01	3.76E-01	2.77E+01
<b>Lungs, total</b>	<b>2310</b>	<b>-</b>	<b>2.18E+01</b>	<b>3.76E-01</b>	<b>6.04E+01</b>
Lymph nodes, TB	-	1.66	6.01E+01	5.20E+00	9.97E-02
<b>LNTH, total<sup>a</sup></b>	<b>15</b>	<b>-</b>	<b>6.01E+01</b>	<b>6.20E+00</b>	<b>9.01E-01</b>
Liver, partial	-	606.8	5.53E+00	1.45E-01	3.35E+00
<b>Liver, total</b>	<b>1404</b>	<b>-</b>	<b>5.53E+00</b>	<b>1.45E-01</b>	<b>7.76E+00</b>
<b>Skeleton</b>					
Clavicle, SE	-	15.87	6.97E-01	1.35E-01	1.11E-02
Clavicle, Shaft	-	14.53	5.14E-01	1.34E-01	7.46E-03
<b>Clavicle, total</b>	<b>-</b>	<b>30.4</b>	<b>6.10E-01</b>	<b>9.51E-02</b>	<b>1.85E-02</b>
Rib	-	38.08	1.41E-01	2.98E-02	5.36E-03
Sternum, body	-	37.5	4.63E-01	7.60E-02	1.74E-02
Sternum, xiphoid	-	4.2	2.07E+00	4.24E-01	8.71E-03
Sternum, total	-	41.7	6.25E-01	2.16E-01	2.61E-02
<b>Total of sampled bones</b>	<b>-</b>	<b>110.2</b>	<b>4.53E-01</b>	<b>-</b>	<b>5.00E-02</b>
<b>Skeleton<sup>a</sup></b>	<b>10500</b>	<b>-</b>	<b>6.28E-01</b>	<b>1.04E-01</b>	<b>6.60E+00</b>

<sup>a</sup>Autopsy weight for Reference Man ICRP Publ. 89 (2002).  
Liver weight on the autopsy report is 1550 g; on the RadChem sheet the autopsy weight is 1404.2 g, but did not find the source of this number. Autopsy weight may include tumor.

**Conversion Factors from Sampled Bone Pu Concentration to Whole Skeleton - from 9 Whole-body Cases**

Case #:	0193 <sup>(a)</sup>	0208 <sup>(b)</sup>	0212 <sup>(b)</sup>	0213 <sup>(b)</sup>	0242 <sup>(b)</sup>	0744 <sup>(b)</sup>	0259 <sup>(b)</sup>	0262 <sup>(b)</sup>	0269 <sup>(b)</sup>	Mean	± S.D.	% R.E.
<b>Clavicle Factor:</b>	1.04	1.00	1.18	0.87	1.05	1.00	0.81	1.14	-	1.01	0.12	12.3%
<b>Rib Factor:</b>	0.77	0.74	0.74	0.86	0.68	1.20	0.64	1.81	1.05	0.94	0.37	39.4%
<b>Sternum Factor:</b>	1.24	1.29	1.03	1.18	0.95	-	0.65	0.94	0.92	1.02	0.21	20.3%

<sup>(a)</sup>From Filipy et al. (2003); <sup>(b)</sup>From James et al. (2003); <sup>(c)</sup>From James et al. (in press); <sup>(d)</sup>From James et al. (in press).

**Projected Skeletal Conc. (Bq/kg):**

	0.63	0.61	0.72	0.53	0.64	0.61	0.49	0.69	-	0.62	0.08	12.3%
<b>Clavicle Only:</b>	0.63	0.61	0.72	0.53	0.64	0.61	0.49	0.69	-	0.62	0.08	12.3%
<b>Rib Only:</b>	0.11	0.10	0.10	0.12	0.10	0.17	0.09	0.25	0.15	0.13	0.05	39.4%
<b>Sternum Only:</b>	0.77	0.81	0.64	0.74	0.59	-	0.41	0.59	0.58	0.64	0.13	20.3%

**Best Estimate of Mean Skeletal Concentration (Bq/kg) is:** 0.63 ± 0.10 Using sampled clavicle and sternum values only.

**Best Estimate of Total Skeletal Activity (Bq) is:** 6.60

<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (Lungs) =	1.79%	±	0.11%
<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (LN) =	1.73%	±	1.26%
<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (Liver) =	1.61%	±	0.28%
<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (Clavicle) =	-	±	< MDA
<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (Rib) =	-	±	< MDA
<sup>238</sup> Pu/ <sup>239+240</sup> Pu Fraction (Sternum) =	-	±	< MDA

**Table 2: Case 0727 - Tissue Radiochemical Summary of <sup>241</sup>Am.**

Tissue	Autopsy Wt (g)	RadChem Wet Wt (g)	Wet Conc. <sup>241</sup> Am (Bq/Kg)	SD	<sup>241</sup> Am/ <sup>239+240</sup> Pu Fraction	Total <sup>241</sup> Am Activity (Bq)
Lung, left	1450	1269	6.86E+00	1.61E-01	3.14E-01	8.71E+00
<b>Lungs, total</b>	<b>2310</b>	<b>-</b>	<b>6.86E+00</b>	<b>1.61E-01</b>	<b>3.14E-01</b>	<b>1.59E+01</b>
Lymph nodes, TB	-	1.66	1.31E+01	2.11E+00	2.18E-01	2.17E-02
<b>LNTH, total<sup>a</sup></b>	<b>15</b>	<b>-</b>	<b>1.31E+01</b>	<b>2.11E+00</b>	<b>2.18E-01</b>	<b>1.96E-01</b>
Liver, partial	-	606.8	6.23E-01	3.91E-02	1.13E-01	3.78E-01
<b>Liver, total</b>	<b>1404</b>	<b>-</b>	<b>6.23E-01</b>	<b>3.91E-02</b>	<b>1.13E-01</b>	<b>8.75E-01</b>
<b>Skeleton</b>						
Clavicle, SE	-	15.87	1.46E-01	1.10E-01	2.09E-01	2.32E-03
Clavicle, Shaft	-	14.53	2.08E-01	1.38E-01	4.06E-01	3.03E-03
<b>Clavicle, total</b>	<b>-</b>	<b>30.4</b>	<b>1.76E-01</b>	<b>8.82E-02</b>	<b>2.88E-01</b>	<b>5.34E-03</b>
Rib	-	38.08	1.86E-01	7.03E-02	1.32E+00	7.09E-03
Sternum, body	-	37.5	2.61E-01	6.80E-02	5.64E-01	9.79E-03
Sternum, xiphoid	-	4.2	3.09E-01	3.72E-01	1.49E-01	1.30E-03 < MDA
Sternum, total	-	41.7	2.66E-01	1.89E-01	4.25E-01	1.11E-02
<b>Total of sampled bones</b>	<b>-</b>	<b>110.2</b>	<b>2.13E-01</b>	<b>-</b>	<b>4.71E-01</b>	<b>2.35E-02</b>
<b>Skeleton<sup>a</sup></b>	<b>10500</b>	<b>-</b>	<b>2.96E-01</b>	<b>-</b>	<b>4.71E-01</b>	<b>3.11E+00</b>

<sup>a</sup>Autopsy weight for Reference Man ICRP Publ. 89 (2002).  
<sup>b</sup>The <sup>241</sup>Am content of the skeleton was estimated by multiplying the estimated total <sup>239+240</sup>Pu skeletal content by the <sup>241</sup>Am/<sup>239+240</sup>Pu ratio determined by summing the <sup>241</sup>Am and <sup>239+240</sup>Pu activities in the sampled clavicle, rib and sternum.

Filipy et al. (2003) developed simple linear and multiple regression models for estimating the total skeletal actinide concentrations on the basis of bone samples collected at autopsies of partial-body tissue donors. Their analysis related the concentrations measured in a clavicle, patella, rib, sternum and vertebral wedge for 8 whole-body donations to the calculated average skeletal concentrations in each case. However, application of the published multiple regression coefficients to the collection of Rocky

Flats partial-body cases with reported  $^{239+240}\text{Pu}$ , results for several bones yielded highly uncertain estimates of the overall skeletal concentration, as indicated by a projected relative standard deviation of the estimated value often exceeding 100%. Also, the published multiple regression coefficients for  $^{238}\text{Pu}$  and  $^{241}\text{Am}$  included negative terms to represent the contribution from some types of bone, a meaningless statistical construct. Therefore, for this NIOSH study, USTUR developed the more direct (and accurate) approach of using the matrix of relative concentration factors (and their standard deviations) observed for the various types of sampled bone in the 8 whole-body cases studied by Filipy et al. (2003), supplemented by an additional case study (James et al. in press<sup>b</sup>). The resulting “skeletal extrapolation matrix” is shown in Table 3.

**Table 3: Conversion Factors from Individual Bone Pu Concentration to Whole Skeleton - from 9 Whole-body Cases**

Case #:	0193 <sup>(a)</sup>	0208 <sup>(a)</sup>	0212 <sup>(a)</sup>	0213 <sup>(a)</sup>	0242 <sup>(a)</sup>	0744 <sup>(a)</sup>	0259 <sup>(b)</sup>	0262 <sup>(c)</sup>	0269 <sup>(d)</sup>			
Skeletal Conc. (Bq/kg):	5.83	10.9	10.9	20.2	42.2	8.62	10.53	2.69	109.5			
Rib Conc. (Bq/kg):	7.57	14.7	14.8	23.4	62.4	7.19	16.4	1.49	104			
Calvarium <sup>(e)</sup> Conc. (Bq/kg):	8.99	12.0	13.7	31.2	30.3	14.7	12.5	3.65	220			
Sternal Conc. (Bq/kg):	4.71	8.43	10.6	17.1	44.6	-	16.1	2.87	119			
Vertebral Conc. (Bq/kg):	5.32	17.6	14.6	19.1	54.1	8.49	16.7	3.72	117			
Patella Conc. (Bq/kg):	4.83	8.78	5.28	14.2	32.9	6.81	6.35	3.04	5.69			
Clavicle Conc. (Bq/kg):	5.62	10.9	9.21	23.2	40.3	8.62	13.0	2.37	18.2			
Femoral Shaft Conc. (Bq/kg):	5.05	7.17	8.44	16.4	31.1	7.34	10.3	2.18	182			
										Mean	± S.D.	% R.E.
Rib Factor:	0.77	0.74	0.74	0.86	0.68	1.20	0.64	1.81	1.05	0.94	0.37	39.4%
Calvarium Factor:	0.65	0.91	0.80	0.65	1.39	0.59	0.84	0.74	-	0.82	0.26	31.2%
Sternal Factor:	1.24	1.29	1.03	1.18	0.95	-	0.65	0.94	0.92	1.02	0.21	20.3%
Vertebral Factor:	1.10	0.62	0.75	1.06	0.78	1.02	0.63	0.72	0.94	0.84	0.18	21.8%
Patella Factor:	1.21	1.24	2.06	1.42	1.28	1.27	1.66	0.89	-	1.38	0.35	25.5%
Clavicle Factor:	1.04	1.00	1.18	0.87	1.05	1.00	0.81	1.14	-	1.01	0.12	12.3%
Femoral Shaft Factor:	1.15	1.52	1.29	1.23	1.36	1.17	1.02	1.23	-	1.25	0.15	11.9%

<sup>(e)</sup> Average concentration of frontal, 2 parietal, occipital and 2 temporal bones of the skull.

Table 3 shows the calculated average  $^{239+240}\text{Pu}$  concentration for the whole skeleton in USTUR’s whole-body cases 0193, 0208, 0212, 0213, 0242, 0744, 0259, 0262, and 0269, together with the average concentration measured in samples of the rib, calvarium, sternum, vertebrae, patella, clavicle, and femoral shaft. The resulting matrix of factors by which each measured bone concentration is multiplied by to give the measured overall skeletal concentration is given in the bottom 7 rows of the table, together with the mean value of this factor for each different bone sample, and the standard deviation between all cases examined. Clearly, the extrapolation factor determined for the sampled clavicle and femoral shaft is the least variable over the examined cases, with a relative standard deviation of about 12%. The rib samples had the highest relative standard deviation, of about 40%. It should be noted that, for case 0269, the extrapolation factors determined for the calvarium, patella, clavicle and femoral shaft are clearly outside the ‘normal’ range of values found in the other eight whole-body cases. This ‘abnormality’ resulted because case 0259 (from Hanford) was aggressively chelated (James et al. in press<sup>b</sup>). The observed extrapolation factors for these specific bones were excluded from the matrix used in this NIOSH study.

Table 1 illustrates how elements of the extrapolation matrix shown in Table 3 are applied to extrapolate the  $^{239+240}\text{Pu}$  concentrations measured in the clavicle and sternum of partial-body donation case 0727 to evaluate the average skeletal concentration. In this case, the skeletal concentration projected from the 38 g rib sample was rejected, as an ‘outlier’. Applying the matrix of extrapolation factors obtained for the clavicle and sternum gave an estimated overall skeletal concentration of 0.63 Bq kg<sup>-1</sup>, with a

propagated standard deviation of  $0.10 \text{ Bq kg}^{-1}$ . For the estimated skeletal wet weight of 10.5 kg (corresponding to ICRP Reference Man), the estimated total skeletal  $^{239+240}\text{Pu}$  content was therefore 6.6 Bq, a similar amount to the estimated total liver content (7.8 Bq). In this case, the measured  $^{239+240}\text{Pu}$  activity concentration in the liver was  $5.53 \text{ Bq kg}^{-1}$  with a standard deviation of  $0.14 \text{ Bq kg}^{-1}$ , which can be compared with the measured “thoracic” concentration (lungs + thoracic lymph nodes) of about  $22 \text{ Bq kg}^{-1}$  (total thoracic activity 51.3 Bq). The observed “liver:thoracic” activity-ratio in this case was therefore about 0.15, i.e., substantially lower than the “notional” value of 1.6 considered to typify inhaled “Type S” plutonium.

#### **Use of $^{238}\text{Pu}$ data**

In case 0727, the lungs, thoracic lymph nodes, and liver contained measurable amounts of  $^{238}\text{Pu}$  (Table 1). The measured  $^{238}\text{Pu}/^{239+240}\text{Pu}$  fractions were  $1.79\% \pm 0.11\%$ ,  $1.73\% \pm 1.26\%$ , and  $1.61\% \pm 0.28\%$ , respectively. There is no statistically significant difference between these values. Since the  $^{238}\text{Pu}/^{239+240}\text{Pu}$  fraction in material handled at Rocky Flats (and other DOE sites) varied substantially over time (as demonstrated in the collection of USTUR donor datasets delivered to NIOSH), the observation that the  $^{238}\text{Pu}$  fraction is the same for lung and systemic (liver) activity indicates a single inhalation intake of one type of Pu material. Other datasets show significant differences between the  $^{238}\text{Pu}/^{239+240}\text{Pu}$  ratio for the lungs and systemic organs, indicating multiple intakes involving different Pu materials and/or the occurrence of significant intake via a puncture wound.

#### **Use of $^{241}\text{Am}$ data**

In case 0727, the  $^{241}\text{Am}/^{239+240}\text{Pu}$  fraction is significantly different between the lungs and liver, and also between the liver and skeleton (Table 2). These differences demonstrate significantly different retention biokinetics for Am and Pu in the systemic organs; a common observation in these radiochemical analysis datasets.

#### **Use of “Health Physics” data**

The “HP\_0727.xls” file for case 0727 contains 669 record entries, beginning with a urine sample result for uranium (0 dpm) on 7/3/1953 through to estimates of the total effective dose equivalent (EDE) made on 12/31/1996 (based on 10CFR835 and ICRP30). The records include wound counts (from 6/29/1956 – all “background”), positive  $^{241}\text{Am}$  chest counts (from the earliest count in 7/10/1969 onwards) and positive Pu-in-urine results (from  $1.5 \text{ dpm d}^{-1}$  measured on 1/7/1966). It would be informative to assess the Pu urinary excretion data and chest counts using IMBA Expert™ OCAS/ORAU-Edition (James et al. 2004) to determine whether these data are consistent with the indication of a single (dominant) inhalation intake (in 1966). If this were so, the “residence time” for the Pu material in case 0727 would be 13,132 d, i.e., somewhat longer than the 10,000 d “notional” value used for the “Type S” Pu comparison.

## Catalog of case data batches delivered to NIOSH

The validated USTUR case data files were delivered to NIOSH in four batches, each on a DVD-ROM disk as follows:

Batch	Date	USTUR Case Files
1	12/9/2005	0023, 0024, 0025, 0026, 0027, 0028, 0029, 0030, 0031, 0441, 0444, 0446, 0460
2	1/27/2006	0032, 0033, 0034, 0035, 0036, 0037, 0038, 0040, 0041, 0042, 0043, 0044, 0045, 0046, 0047, 0048, 0049, 0050, 0051, 0052, 0053, 0054, 0055, 0056, 0057, 0058, 0215, 0216, 0228, 0229, 0231, 0232, 0233, 0239, 0244, 0252, 0256, 0420, 0427, 0458, 0821
3	2/13/2006	0039, 0085, 0087, 0092, 0096, 0097, 0105, 0108, 0142, 0146, 0161, 0188, 0191, 0194, 0199, 0200, 0202, 0260, 0423, 0425, 0498, 0706, 0727, 0744, 0782, 0796, 0837
4	2/15/2006	0083, 0084, 0086, 0088, 0091, 0095, 0098, 0099, 0103, 0140, 0158, 0183, 0184, 0185, 0186, 0187, 0196, 0205, 0207, 0210, 0214, 0217, 0412*, 0439, 0445, 0461, 0469, 0492, 0503*, 0720*, 0817*, 0991*

\*USTUR's tissue radiochemistry analyses not yet complete for these cases.

At the supplementary request of NIOSH, USTUR provided the Excel® spreadsheet file "RF\_Summary\_May\_10\_2006.xls" which lists (by USTUR case and batch number) the measured  $^{239+240}\text{Pu}$  and  $^{241}\text{Am}$  concentrations in the lungs, thoracic lymph nodes (LNTH), liver and skeleton, in  $\text{Bq kg}^{-1}$  wet tissue weight (where available).

### Further consideration of the systemic:lung activity ratio for Type S Pu

Figure 1 shows the ratio of Pu contents in Reference Man, for liver:(lungs + LNTH), skeleton: (lungs + LNTH), and the geometric mean of these values, calculated as a function of time since a single acute intake of Type S plutonium. The software suite IMBA Professional Plus (UK Health Protection Agency, 2006) was used to calculate these values, by treating the skeletal activity as a "User Defined" bioassay quantity. The following "User Defined" bioassay function was derived and used:

Bioassay function for User Defined was User Defined  
 $a(i), \quad \text{lam}(i)$   
 $-1.732771907600570\text{E}-01, 1.222634372991430\text{E}+00$   
 $4.000845049866820\text{E}+00, 3.378190411195400\text{E}-01$   
 $9.917117160599870\text{E}-02, 3.356883706230930\text{E}-04$   
 $3.582175562837100\text{E}+00, 4.048328268209290\text{E}-05$   
 $-4.331077844157510\text{E}+00, 3.378183376984510\text{E}-01$   
 $-3.177836749392350\text{E}+00, 4.570692211946840\text{E}-05$   
 Blood retention:  $1.0000\text{E}-07$

These (exact) parameter values can be entered into NIOSH's IMBA Expert™ OCAS/ORAU-Edition (James et al. 2004) in order to use the software to calculate total skeletal retention of plutonium for these, or any other, assumed intake conditions.

**Figure 1: Ratios of Systemic Organ Content : Thoracic Content for Type 'S' <sup>239</sup>Pu Calculated as a Function of Time Since Acute Intake**

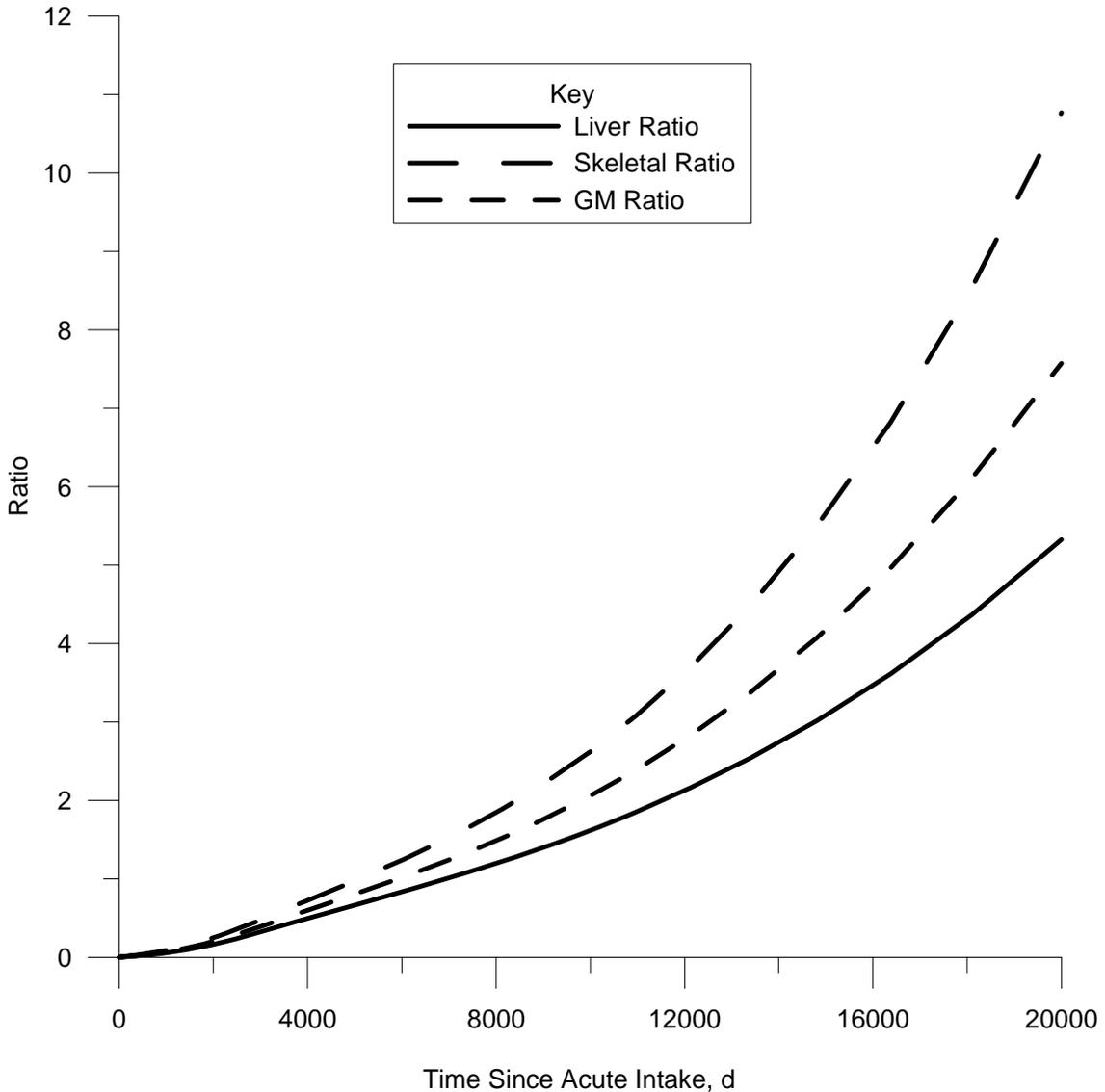


Figure 1 shows that the systemic:lung ratios are predicted to increase rather strongly with time since the assumed acute intake (inhalation) of the ICRP default (Type S) plutonium aerosol (ICRP; 1994). Thus, at 10,000 d after intake, the ratios are 1.62:1, 2.62:1 and 2.06:1, for the liver, skeletal, and geometric mean ratios, respectively. At about 13,000 d, the suspected 'retention time' for case 0727, these ratios would have increased to about 2.54:1, 4.49:1 and 3.38:1, respectively. Of course, these 'expectation' values apply only to ICRP's Reference Man (exhibiting the Pu biokinetic behavior in systemic organs

defined in ICRP Publication 67; ICRP, 1993). Published USTUR studies have demonstrated substantial variability in the liver:skeletal activity ratio observed in individual cases. Therefore, the geometric mean of liver and skeletal activity (or the sum of these activities) may well provide a more stable index of the total systemic translocation from the lungs than just the liver:lung ratio.

## Summary of Pu tissue concentrations

Table 4 summarizes the  $^{239+240}\text{Pu}$  concentrations measured in the lungs, thoracic lymph nodes (LNTH), liver and skeleton, and their estimated standard deviations (where available), in USTUR's 108 Rocky Flats cases reported to NIOSH.

**Table 4:**  $^{239+240}\text{Pu}$  Tissue Concentrations at Autopsy in Rocky Flats Cases

Case No.	Batch No.	Pu- $\alpha$ Wet Concentration (Bq kg <sup>-1</sup> )							
		Lungs		LNTH		Liver		Skeleton	
		Measured	$\pm 1 \sigma$	Measured	$\pm 1 \sigma$	Measured	$\pm 1 \sigma$	Measured	$\pm 1 \sigma$
0023	1	3.51E+00	-	2.29E+01	-	5.32E+00	-	1.45E+00	3.0E-01
0024	1	2.28E-01	-	No data	-	Unreliable	-	3.17E-02	6.0E-03
0025	1	5.69E+00	-	6.80E-01	-	6.44E-01	-	2.32E-01	9.1E-02
0026	1	No data	-	No data	-	6.59E-01	-	No data	-
0027	1	2.42E+00	-	1.75E+00	-	6.42E-01	-	No data	-
0028	1	1.63E+03	-	1.42E+01	-	5.20E+00	-	2.72E+00	1.1E+00
0029	1	4.48E+01	-	2.76E+02	-	4.13E+00	-	1.38E-01	2.8E-02
0030	1	2.14E+00	-	2.98E+00	-	5.12E-01	-	8.95E-02	1.8E-02
0031	1	6.80E+01	-	5.67E+01	-	1.56E+02	-	1.24E+02	2.5E+01
0032	2	7.50E-01	-	3.31E-01	-	1.94E-01	-	1.60E-01	3.2E-02
0033	2	2.82E+01	-	1.58E+01	-	3.95E+00	-	6.80E-01	1.4E-01
0034	2	9.66E+01	-	3.55E+01	-	1.00E+00	-	1.17E-01	2.4E-02
0035	2	2.72E-02	-	5.70E-01	-	2.07E-01	-	2.69E-01	5.5E-02
0036	2	5.70E+02	-	4.04E+02	-	4.95E+00	-	4.37E-01	2.7E-01
0037	2	1.46E+00	-	1.43E+00	-	1.74E+00	-	3.93E-01	8.0E-02
0038	2	5.38E-01	-	7.69E-01	-	1.30E-01	-	1.22E-01	2.7E-02
0039	3	4.40E+00	-	7.12E+00	-	1.60E-01	-	8.98E-02	1.8E-02
0040	2	1.39E-03	-	1.43E+01	-	1.86E-01	-	No data	-
0041	2	4.68E-01	-	1.12E+00	-	Lost	-	<LOD	-
0042	2	2.65E+02	-	2.82E+03	-	3.55E-01	-	5.79E-02	2.8E-02
0043	2	2.02E-01	-	2.67E+00	-	1.83E-01	-	2.82E-01	5.7E-02
0044	2	6.89E+00	-	5.48E+01	-	5.05E-01	-	2.13E-01	4.6E-02
0045	2	2.80E+01	-	2.57E+01	-	2.48E+00	-	3.36E-01	2.3E-01
0046	2	2.96E-01	-	1.87E+01	-	2.53E-02	-	7.09E-01	2.8E-01
0047	2	1.73E+00	-	No data	-	2.55E-01	-	8.77E-02	3.7E-02
0048	2	1.20E+02	-	5.33E+02	-	5.14E+01	-	2.58E+00	1.2E+00
0049	2	9.85E+00	-	1.34E+01	-	1.23E+00	-	1.11E-01	2.0E-02
0050	2	7.66E-01	-	9.95E+00	-	9.14E-02	-	3.14E-02	1.2E-02
0051	2	1.36E+01	-	3.62E+01	-	7.73E+00	-	1.09E+00	6.4E-01
0052	2	2.88E-01	-	No data	-	3.36E-02	-	No data	-
0053	2	3.72E+00	-	1.06E+01	-	4.58E-01	-	6.74E-02	1.4E-02

**Table 4: Contd.**

Case No.	Batch No.	Pu-α Wet Concentration (Bq kg <sup>-1</sup> )							
		Lungs		LNTH		Liver		Skeleton	
		Measured	± 1 σ	Measured	± 1 σ	Measured	± 1 σ	Measured	± 1 σ
0054	2	3.62E-01	-	3.21E+00	-	1.34E-01	-	1.61E-01	6.3E-02
0055	2	2.80E+00	-	1.09E+01	-	1.70E+00	-	2.10E-01	7.0E-02
0056	2	3.44E-01	-	1.66E+01	-	No data	-	8.55E-02	7.1E-02
0057	2	9.87E-01	-	1.89E+00	-	6.71E-02	-	1.61E-01	3.0E-02
0058	2	1.51E+01	1.3E+00	7.60E+00	6.3E-01	7.71E+00	6.2E-01	9.62E-01	3.9E-01
0083	4	1.31E-02	-	8.95E-02	-	9.79E-02	-	3.80E-02	1.0E-02
0084	4	Unreliable	-	1.25E-01	-	2.73E-02	-	4.20E-02	4.7E-02
0085	3	2.83E+01	-	1.53E+03	-	9.31E-01	-	1.64E-01	6.0E-02
0086	4	1.92E-03	2.4E-03	< LOD	-	1.55E-02	-	< LOD	-
0087	3	1.46E+01	-	9.30E+01	-	8.05E+00	-	6.16E-01	2.4E-01
0088	4	7.62E-01	7.7E-02	5.96E+00	2.8E+00	No data	-	< LOD	-
0091	4	2.49E-02	6.4E-03	< LOD	-	7.42E-02	1.3E-02	< LOD	-
0092	3	4.47E+00	2.6E-01	5.82E+01	5.9E+00	1.85E+00	1.5E-01	2.59E-01	1.0E-01
0095	4	6.16E+00	2.9E-02	<LOD	1.5E+00	1.96E-02	5.8E-03	< LOD	3.0E-02
0096	3	3.16E+00	2.2E-01	2.08E+02	3.1E+01	4.68E-01	5.4E-02	8.63E-02	1.8E-02
0097	3	1.51E+02	6.9E+00	5.69E+02	5.5E+01	1.10E+01	9.3E-01	3.47E+00	1.1E+00
0098	4	1.30E+00	9.8E-02	1.88E+01	3.3E+00	8.68E-01	6.7E-02	1.13E-01	4.1E-02
0099	4	1.07E-01	1.5E-02	< LOD	3.9E-01	6.14E-03	3.2E-03	< LOD	-
0103	4	2.48E-02	9.3E-03	< LOD	1.7E-02	1.92E-02	2.4E-03	1.13E-01	4.1E-02
0105	3	1.75E+03	1.0E+01	1.56E+04	1.3E+03	2.13E+01	1.4E+00	5.43E+00	1.9E+00
0108	3	3.55E+02	9.4E+00	with lungs	-	8.07E+01	3.4E+00	5.41E+00	2.4E+00
0140	4	7.59E-02	1.1E-02	< LOD	2.2E-01	7.22E-03	6.7E-03	< LOD	-
0142	3	5.80E+00	2.1E-01	5.27E+01	9.1E+00	1.54E+01	4.6E-01	2.18E+00	6.3E-01
0146	3	7.85E+01	4.1E+00	8.99E+02	6.2E+01	4.15E-01	3.7E-02	8.25E-01	3.2E-01
0158	4	7.01E-02	2.0E-02	1.65E+00	7.6E-01	3.18E-02	9.5E-03	< LOD	-
0161	3	4.43E+00	3.2E-01	1.95E+01	1.0E+00	3.63E+00	2.5E-01	6.67E-01	5.4E-01
0183	4	1.37E-02	1.1E-02	5.30E+00	5.2E-01	1.05E-02	7.9E-03	< LOD	-
0184	4	<LOD	-	5.14E+00	4.8E-01	9.15E-02	3.1E-02	< LOD	-
0185	4	1.17E-01	2.8E-02	<LOD	1.7E+00	< LOD	6.4E-02	< LOD	-
0186	4	1.18E-01	1.3E-02	3.15E+00	9.8E-01	9.11E-02	1.1E-02	< LOD	-
0187	4	4.83E-01	6.2E-02	No data	-	7.96E-01	8.2E-02	3.97E-01	1.5E-01
0188	3	1.80E+01	4.6E-01	4.32E+01	1.7E+00	1.61E+01	4.8E-01	1.41E+00	5.3E-01
0191	3	1.01E+02	5.2E+00	9.75E+02	4.8E+01	5.38E+01	3.0E+00	4.49E+00	1.4E+00
0194	3	2.58E+01	1.3E+00	7.72E+01	4.7E+00	4.48E-01	4.5E-02	7.51E-01	2.8E-01
0196	4	1.10E-01	3.8E-02	2.16E+00	7.8E-01	3.11E-02	1.6E-02	< LOD	-
0199	3	8.91E+00	3.8E-01	1.99E+01	1.8E+00	7.15E-01	8.1E-02	3.41E-01	1.7E-01
0200	3	1.52E+01	1.2E+00	7.74E+01	5.7E+00	1.04E+00	8.8E-02	9.63E-02	2.0E-02
0202	3	7.94E+03	1.8E+02	1.98E+04	3.8E+02	1.08E+02	3.6E+00	2.57E+01	1.2E+01
0205(WB)	4	7.14E-02	5.7E-03	4.26E+00	1.0E+00	7.27E-02	3.7E-03	1.92E-02	5.8E-03
0207	4	2.13E-01	4.3E-02	8.84E+00	3.4E+00	9.08E-02	2.1E-03	< LOD	-
0210	4	3.29E+00	3.2E-01	2.36E+02	6.8E+00	3.92E-01	2.5E-02	3.87E-01	1.8E-01
0214	4	2.16E-02	2.6E-03	4.31E-02	2.3E-02	9.35E-02	5.0E-03	1.32E-01	4.5E-02
0215	2	9.81E+01	3.1E+00	7.35E+02	2.0E+01	9.31E+01	2.2E+00	6.99E+00	3.2E+00
0216	2	2.27E+02	5.6E+00	4.43E+03	1.1E+02	6.42E+01	1.6E+00	8.64E+00	3.4E+00
0217	4	1.18E+01	3.3E-01	No data	-	5.77E-01	2.6E-02	1.37E+00	8.7E-01
0228	2	3.13E-02	2.5E-03	2.43E+00	1.8E-01	4.99E-02	3.0E-03	1.03E-01	9.0E-02

**Table 4: Contd.**

Case No.	Batch No.	Pu-α Wet Concentration (Bq kg <sup>-1</sup> )							
		Lungs		LNTH		Liver		Skeleton	
		Measured	± 1 σ	Measured	± 1 σ	Measured	± 1 σ	Measured	± 1 σ
0229	2	9.90E-01	2.7E-02	1.86E+01	5.5E-01	1.86E+00	5.0E-02	1.40E-01	8.0E-02
0231	2	7.60E-02	5.1E-03	9.73E-02	5.8E-02	7.70E-02	2.6E-03	8.91E-03	2.4E-03
0232	2	2.65E-01	8.7E-03	1.50E+00	2.2E-01	4.88E-02	2.7E-03	1.57E-02	9.0E-03
0233	2	9.73E-01	2.5E-02	4.68E+01	6.3E+00	1.28E-01	5.2E-03	4.27E-02	1.8E-02
0239	2	2.68E-02	3.9E-03	1.40E+00	2.1E-01	2.00E-02	1.5E-03	7.64E-03	7.0E-03
0244	2	5.34E+00	1.1E-01	7.55E+01	2.4E+00	2.54E+00	7.1E-02	8.88E-01	3.0E-01
0252	2	4.78E+01	1.3E+00	1.63E+02	5.6E+00	2.61E+01	9.2E-01	1.76E+00	3.6E-01
0256	2	7.67E+01	1.5E+00	1.66E+02	4.5E+00	1.31E+01	3.9E-01	4.85E+00	1.2E+00
0260	3	7.43E+00	-	No data	-	1.04E+00	-	5.72E-01	2.3E-01
0420	2	2.00E+01	4.9E-01	4.78E+02	1.1E+01	1.06E+01	2.9E-01	1.25E+00	4.6E-01
0423	3	4.42E+00	1.4E-01	4.01E+01	2.2E+00	6.15E-01	5.1E-02	3.06E-01	8.0E-02
<b>0425(WB)</b>	3	1.16E+02	3.0E+00	1.93E+03	4.1E+01	8.51E+00	1.5E-02	2.46E+00	-
0427	2	1.19E+01	2.7E-01	1.67E+02	4.9E+00	4.85E+00	1.3E-01	4.24E-01	2.3E-01
0439	4	1.17E+00	1.3E-01	4.75E+01	1.8E+00	1.65E+00	6.3E-02	-	-
0441	1	1.10E-01	6.8E-03	9.40E-01	2.9E-01	6.20E-02	5.5E-03	4.97E-01	4.7E-01
0444	1	1.61E+01	-	1.92E+02	5.9E+00	4.45E+00	1.5E-01	1.07E+00	1.3E-01
0445	4	4.04E-02	1.2E-02	1.84E+00	7.0E-01	4.96E-02	1.2E-02	1.18E-01	4.3E-02
0446	1	3.90E-01	2.4E-02	3.91E+00	1.2E+00	1.25E-01	7.6E-03	9.40E-02	3.5E-02
0458	2	6.29E+00	1.7E-01	7.16E+01	3.7E+00	8.17E-01	4.9E-02	5.79E-01	1.4E-01
0460	1	9.65E-02	1.7E-02	2.45E+00	2.0E+00	4.16E-02	1.1E-02	1.33E-01	5.3E-02
0461	4	1.63E-01	1.1E-02	2.38E+01	2.4E+00	2.50E-02	2.4E-03	6.30E-02	2.5E-02
0469	4	2.85E-02	5.0E-03	4.58E-01	6.1E-02	1.10E-01	2.5E-02	1.80E-02	1.1E-02
0492	4	3.68E-02	8.7E-03	1.75E+00	3.6E-02	4.73E-02	7.8E-03	Unreliable	-
0498	3	1.36E+01	3.2E-01	1.16E+02	3.3E+00	7.47E+00	2.0E-01	1.88E+00	6.8E-01
<b>0706(WB)</b>	3	6.10E+01	1.3E+00	2.88E+02	1.0E+01	3.56E+02	5.8E+00	2.81E+01	-
0727	3	2.18E+01	3.8E-01	6.01E+01	5.2E+00	5.53E+00	1.5E-01	6.28E-01	1.0E-01
<b>0744(WB)</b>	3	3.69E+01	8.1E-01	1.43E+03	2.5E+01	1.25E+01	2.3E-01	8.66E+00	-
0782	3	2.59E+00	8.3E-02	3.10E+00	4.0E-01	3.13E-01	1.0E-02	1.28E-02	5.0E-03
0796	3	1.25E+01	2.2E-01	1.51E+02	4.2E+00	5.37E+00	1.2E-01	1.34E+00	7.1E-01
0821	2	1.08E+03	2.2E+01	No data	-	1.98E+01	5.3E-01	2.29E+00	1.2E+00
0837	3	1.65E+01	4.4E-01	8.59E+01	6.5E+00	5.25E+00	1.5E-01	1.09E+00	2.1E-01

**Summary of Pu tissue contents and activity ratios**

**Data ranked by increasing liver:thoracic <sup>239+240</sup>Pu activity ratio**

Table 5 lists the tissue contents of <sup>239+240</sup>Pu activity measured in 108 Rocky Flats cases, together with the total “thoracic” organ content (the sum of lung and thoracic lymph node activities), and the calculated activity ratios liver:thoracic, skeletal:thoracic, and the geometric mean of these two ratios (where available). In this table, the case data are ranked by increasing value of the liver:thoracic activity ratio. In 15 of the 102 cases (14.7%) with measured values, the liver:thoracic activity ratio exceeds 1.62 (the “notional” index of a Type S Pu inhalation intake). These cases are highlighted in the table by shaded rows [top 15 rows in continuation (part 3) of Table 5].

**Table 5: USTUR Rocky Flats Cases Ranked by Liver:Thoracic <sup>239+240</sup>Pu Activity Ratio at Time of Death**

Case No.	Batch	Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	H <sub>g</sub>
0042	2	309	42.4	0.42	0.61	351	0.0012	0.0017	0.0014
0028	1	1627	0.29	4.82	28.6	1627	0.003	0.018	0.007
0095	4	5.55	-	0.026	-	5.55	0.005	-	-
0146	3	86.4	13.5	0.75	8.7	99.9	0.007	0.087	0.026
0034	2	152	0.53	1.75	1.23	153	0.011	0.008	0.010
0036	2	720	13.8	8.60	4.59	734	0.012	0.006	0.009
0202	3	13900	297	173	226	14197	0.012	0.016	0.014
0194	3	45.2	2.28	0.81	7.9	47.5	0.017	0.17	0.053
0105	3	1920	234	38.4	57.0	2154	0.018	0.026	0.022
0085	3	48.0	23.0	1.4	1.7	71	0.020	0.024	0.022
0821	2	1044	-	28.6	24.0	1044	0.027	0.023	0.025
0423	3	7.64	1.20	0.51	3.2	8.84	0.058	0.36	0.14
0460	1	0.12	0.037	0.0089	1.40	0.15	0.058	9.1	0.72
0099	4	0.20	0.0024	0.012	-	0.20	0.059	-	-
0140	4	0.11	-	0.0069	-	0.11	0.063	-	-
<b>0425(WB)</b>	3	185	29.0	13.6	25.1	214	0.064	0.117	0.086
0039	3	3.21	0.11	0.23	0.89	3.3	0.070	0.27	0.14
0046	2	0.40	0.21	0.046	7.40	0.61	0.075	12.2	0.96
0461	4	0.19	0.36	0.042	0.66	0.54	0.077	1.22	0.31
0057	2	1.08	0.043	0.098	1.70	1.1	0.087	1.51	0.36
0210	4	2.63	3.55	0.54	4.10	6.2	0.087	0.66	0.24
0096	3	5.06	3.12	0.80	0.91	8.2	0.097	0.11	0.10
0097	3	194	8.54	20.6	36.4	203	0.102	0.18	0.14
0053	2	4.62	0.16	0.50	0.71	4.8	0.105	0.15	0.13
0044	2	6.82	0.96	0.85	2.24	7.8	0.109	0.29	0.18
0045	2	46.2	0.39	5.13	3.53	46.6	0.110	0.076	0.09
0200	3	15.2	1.38	1.84	1.01	16.6	0.111	0.061	0.082
0233	2	0.88	0.72	0.21	0.45	1.6	0.129	0.28	0.19
0199	3	14.9	1.13	2.09	3.6	16.0	0.130	0.22	0.17
0217	4	9.40	-	1.27	14.4	9.4	0.135	1.53	0.45
0029	1	49.3	4.14	7.44	1.45	53.4	0.139	0.027	0.06
0727	3	50.4	0.90	7.8	6.6	51.3	0.151	0.13	0.14
0049	2	10.1	0.66	1.65	1.20	10.8	0.153	0.11	0.13
0050	2	0.84	0.14	0.16	0.33	0.98	0.167	0.34	0.24
0256	2	127	10.6	23.4	50.9	138	0.170	0.37	0.25
0052	2	0.36	-	0.068	-	0.36	0.188	-	-
0782	3	2.07	0.047	0.40	0.13	2.1	0.190	0.061	0.11
0444	1	21.3	2.9	4.8	11.2	24.2	0.198	0.46	0.30
0025	1	5.69	0.15	1.16	2.44	5.8	0.199	0.42	0.29
0183	4	0.024	0.080	0.021	-	0.10	0.203	-	-
0185	4	0.14	-	0.030	-	0.14	0.211	-	-
0047	2	1.55	0.012	0.36	0.92	1.6	0.232	0.59	0.37
0040	2	1.18	0.21	0.33	-	1.4	0.240	-	-
0232	2	0.32	0.046	0.094	0.17	0.36	0.261	0.47	0.35
0260	3	11.2	-	2.98	6.0	11.2	0.266	0.53	0.38

**Table 5 (Contd.): Part 2**

Case No.	Batch	Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	H <sub>g</sub>
0033	2	26.5	0.24	7.12	7.14	26.7	0.266	0.27	0.27
0837	3	21.8	1.29	6.28	10.7	23.1	0.272	0.46	0.36
0032	2	1.13	-	0.35	1.68	1.13	0.310	1.5	0.68
0458	2	4.71	1.07	1.85	6.1	5.78	0.320	1.1	0.58
0420	2	38.4	7.16	14.6	13.2	45.6	0.320	0.29	0.30
0796	3	21.9	2.3	7.8	13.3	24.2	0.322	0.55	0.42
<b>0744(WB)</b>	3	71.4	21.4	30.0	86.7	92.8	0.323	0.93	0.55
0216	2	244	61.6	107	90.7	306	0.350	0.30	0.32
0030	1	2.35	0.05	0.92	0.95	2.4	0.384	0.39	0.39
0441	1	0.19	0.014	0.081	5.2	0.21	0.387	25.1	3.1
0207	4	0.44	0.13	0.24	-	0.57	0.415	-	-
0108	3	373	-	158	56.8	373	0.424	0.15	0.25
0196	4	0.11	0.032	0.059	-	0.14	0.428	-	-
0446	1	0.97	0.0038	0.42	0.99	0.97	0.435	1.0	0.66
0038	2	0.42	0.024	0.197	1.28	0.44	0.447	2.9	1.1
0098	4	1.56	0.28	0.83	1.19	1.84	0.448	0.65	0.54
0054	2	0.40	0.042	0.20	-	0.44	0.453	-	-
0427	2	14.3	2.5	7.6	4.5	16.8	0.454	0.27	0.35
0027	1	2.42	0.03	1.16	-	2.5	0.473	-	-
0092	3	5.66	1.08	3.23	2.7	6.7	0.479	0.40	0.44
0158	4	0.070	0.030	0.049	-	0.10	0.493	-	-
0055	2	4.57	0.24	2.57	2.20	4.8	0.534	0.46	0.49
0244	2	6.45	1.13	4.1	9.3	7.6	0.541	1.23	0.82
0498	3	16.4	1.74	11.9	21.9	18.1	0.656	1.2	0.89
0058	2	16.7	0.11	11.2	10.1	16.8	0.666	0.60	0.63
0051	2	21.3	1.11	15.2	11.4	22.4	0.678	0.51	0.59
0048	2	4.84	0.36	3.76	27.1	5.2	0.723	5.2	1.9
0087	3	16.9	2.18	14.2	6.5	19.1	0.744	0.34	0.50
0445	4	0.056	0.028	0.063	1.20	0.083	0.749	14.4	3.3
0188	3	36.4	1.94	28.9	14.8	38.3	0.754	0.39	0.54
0186	4	0.22	0.047	0.21	-	0.27	0.774	-	-
<b>0205(WB)</b>	4	0.11	0.064	0.15	0.20	0.17	0.860	1.17	1.0
0043	2	0.28	0.076	0.32	2.96	0.36	0.897	8.30	2.7
0191	3	80.7	14.8	88.8	42.2	95.5	0.930	0.44	0.64
0228	2	0.040	0.043	0.077	-	0.082	0.936	-	-
0239	2	0.013	0.021	0.033	0.080	0.034	0.974	2.3	1.5
0215	2	94.6	12.1	109	73.4	107	1.02	0.69	0.84
0252	2	35.9	2.59	40.4	18.5	38.5	1.05	0.48	0.71
0187	4	0.97	-	1.19	4.20	0.97	1.23	4.34	2.3
0492	4	0.035	0.026	0.076	-	0.061	1.23	-	-
0161	3	4.87	0.292	6.53	7.0	5.2	1.27	1.4	1.3
0439	4	1.29	0.71	2.97	3.1	2.0	1.49	1.55	1.5

**Table 5 (Contd.): Part 3 – Cases with Liver:Thoracic Activity Ratio > 1.62:1 (or Not Measured)**

Case No.	Batch	Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	Hg
0091	4	0.041	0.019	0.10	-	0.061	1.65	-	-
0231	2	0.076	0.0014	0.14	0.71	0.077	1.86	9.2	4.1
0229	2	1.01	0.28	2.88	1.47	1.3	2.24	1.1	1.6
0023	1	3.57	0.37	9.57	15.2	3.9	2.43	3.9	3.1
0142	3	8.64	0.79	24.2	22.9	9.4	2.57	2.4	2.5
0469	4	0.037	0.0069	0.12	0.18	0.044	2.75	4.09	3.4
0037	2	1.18	0.021	3.48	4.13	1.2	2.90	3.4	3.2
0103	4	0.015	-	0.044	1.19	0.015	2.91	78.3	15.1
0031	1	95.8	0.85	321	1298	96.7	3.32	13.4	6.68
0035	2	0.049	0.027	0.33	-	0.076	4.33	-	-
0706(WB)	3	84.2	4.3	403	257	88.5	4.55	2.9	3.6
0086	4	0.0058	-	0.028	-	0.0058	4.83	-	-
0214	4	0.015	-	0.10	1.40	0.015	6.93	93	25
0083	4	0.016	0.0013	0.15	0.39	0.017	8.89	23	14
0084	4	0.0037	0.0019	0.0574	0.45	0.0056	10.29	81	29
0024	1	0.20	< LOD	< LOD	0.34	0.20	-	1.7	-
0056	2	0.57	0.25	-	0.90	0.82	-	1.1	-
0041	2	0.77	0.10	-	-	0.87	-	-	-
0088	4	1.26	0.20	-	-	1.46	-	-	-
0026	1	-	-	1.55	-	-	-	-	-
0184	4	-	0.21	0.18	-	-	-	-	-

The following cases have a measured liver:thoracic activity ratio > 1.62 (the notional index of inhaled Type S Pu):

- 0023
- 0031
- 0035
- 0037
- 0083
- 0084
- 0086
- 0091
- 0103
- 0142
- 0214
- 0229
- 0231
- 0469
- 0706(WB).

These higher observed ratios may indicate:

- Inhalation intake of Pu with higher solubility than Type ‘S’;
- Multiple intakes, including significant uptake from a puncture wound;
- Variability in the systemic Pu biokinetics between individuals.

In order to draw more definitive conclusions from these data, it is necessary to consider the provided “health physics” records and bioassay analysis data in each case.

**Data ranked by increasing skeletal:thoracic <sup>239+240</sup>Pu activity ratio**

Table 6 ranks the above case data by increasing value of the skeletal:thoracic activity ratio. In 18 of the 86 cases (21%) with measured values, this activity ratio exceeds 2.62 (the “notional” index of a Type S Pu inhalation intake). These cases are again highlighted in the table by shaded rows [top 18 rows in continuation (part 3) of Table 6].

**Table 6: USTUR Rocky Flats Cases Ranked by Skeletal:Thoracic <sup>239+240</sup>Pu Activity Ratio at Time of Death**

Case No.	Batch	<sup>239+240</sup> Pu Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	µg
0042	2	309	42.4	0.42	0.61	351	0.0012	0.0017	0.0014
0036	2	720	13.8	8.60	4.59	734	0.012	0.006	0.009
0034	2	152	0.53	1.75	1.23	153	0.011	0.008	0.010
0202	3	13900	297	173	226	14197	0.012	0.016	0.014
0028	1	1627	0.29	4.82	28.6	1627	0.003	0.018	0.007
0821	2	1044	-	28.6	24.0	1044	0.027	0.023	0.025
0085	3	48.0	23.0	1.4	1.7	71	0.020	0.024	0.022
0105	3	1920	234	38.4	57.0	2154	0.018	0.026	0.022
0029	1	49.3	4.14	7.44	1.45	53.4	0.14	0.027	0.06
0200	3	15.2	1.38	1.84	1.01	16.6	0.11	0.061	0.082
0782	3	2.07	0.047	0.40	0.13	2.1	0.19	0.061	0.11
0045	2	46.2	0.39	5.13	3.53	46.6	0.11	0.076	0.09
0146	3	86.4	13.5	0.75	8.7	99.9	0.007	0.087	0.026
0096	3	5.06	3.12	0.80	0.91	8.2	0.10	0.11	0.10
0049	2	10.1	0.66	1.65	1.20	10.8	0.15	0.11	0.13
<b>0425(WB)</b>	3	185	29.0	13.6	25.1	214	0.064	0.117	0.086
0727	3	50.4	0.90	7.8	6.6	51.3	0.15	0.13	0.14
0053	2	4.62	0.16	0.50	0.71	4.8	0.11	0.15	0.13
0108	3	373	-	158	56.8	373	0.42	0.15	0.25
0194	3	45.2	2.28	0.81	7.9	47.5	0.017	0.17	0.053
0097	3	194	8.54	20.6	36.4	203	0.10	0.18	0.14
0199	3	14.9	1.13	2.09	3.6	16.0	0.13	0.22	0.17
0033	2	26.5	0.24	7.12	7.14	26.7	0.27	0.27	0.27
0427	2	14.3	2.5	7.6	4.5	16.8	0.45	0.27	0.35
0039	3	3.21	0.11	0.23	0.89	3.3	0.070	0.27	0.14
0233	2	0.88	0.72	0.21	0.45	1.6	0.13	0.28	0.19
0044	2	6.82	0.96	0.85	2.24	7.8	0.11	0.29	0.18
0420	2	38.4	7.16	14.6	13.2	45.6	0.32	0.29	0.30

**Table 6 (Contd.): Part 2**

Case No.	Batch No.	Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	Hg
0216	2	244	61.6	107	90.7	306	0.35	0.30	0.32
0050	2	0.84	0.14	0.16	0.33	0.98	0.17	0.34	0.24
0087	3	16.9	2.18	14.2	6.5	19.1	0.74	0.34	0.50
0423	3	7.64	1.20	0.51	3.2	8.84	0.058	0.36	0.14
0256	2	127	10.6	23.4	50.9	138	0.17	0.37	0.25
0188	3	36.4	1.94	28.9	14.8	38.3	0.75	0.39	0.54
0030	1	2.35	0.05	0.92	0.95	2.4	0.38	0.39	0.39
0092	3	5.66	1.08	3.23	2.7	6.7	0.48	0.40	0.44
0025	1	5.69	0.15	1.16	2.44	5.8	0.20	0.42	0.29
0191	3	80.7	14.8	88.8	42.2	95.5	0.93	0.44	0.64
0055	2	4.57	0.24	2.57	2.20	4.8	0.53	0.46	0.49
0837	3	21.8	1.29	6.28	10.7	23.1	0.27	0.46	0.36
0444	1	21.3	2.9	4.8	11.2	24.2	0.20	0.46	0.30
0232	2	0.32	0.046	0.094	0.17	0.36	0.26	0.47	0.35
0252	2	35.9	2.59	40.4	18.5	38.5	1.05	0.48	0.71
0051	2	21.3	1.11	15.2	11.4	22.4	0.68	0.51	0.59
0260	3	11.2	-	2.98	6.0	11.2	0.27	0.53	0.38
0796	3	21.9	2.3	7.8	13.3	24.2	0.32	0.55	0.42
0047	2	1.55	0.012	0.36	0.92	1.6	0.23	0.59	0.37
0058	2	16.7	0.11	11.2	10.1	16.8	0.67	0.60	0.63
0098	4	1.56	0.28	0.83	1.19	1.84	0.45	0.65	0.54
0210	4	2.63	3.55	0.54	4.10	6.2	0.087	0.66	0.24
0215	2	94.6	12.1	109	73.4	107	1.0	0.69	0.84
<b>0744(WB)</b>	3	71.4	21.4	30.0	86.7	92.8	0.32	0.93	0.55
0446	1	0.97	0.0038	0.42	0.99	0.97	0.44	1.0	0.66
0458	2	4.71	1.07	1.85	6.1	5.78	0.32	1.1	0.58
0056	2	0.57	0.25	-	0.90	0.82	-	1.1	-
0229	2	1.01	0.28	2.88	1.47	1.3	2.2	1.1	1.6
<b>0205(WB)</b>	4	0.11	0.064	0.15	0.20	0.17	0.86	1.17	1.0
0498	3	16.4	1.74	11.9	21.9	18.1	0.66	1.2	0.89
0461	4	0.19	0.36	0.042	0.66	0.54	0.077	1.22	0.31
0244	2	6.45	1.13	4.1	9.3	7.6	0.54	1.23	0.82
0161	3	4.87	0.292	6.53	7.0	5.2	1.3	1.4	1.3
0032	2	1.13	-	0.35	1.68	1.13	0.31	1.5	0.68
0057	2	1.08	0.043	0.098	1.70	1.1	0.087	1.51	0.36
0217	4	9.40	-	1.27	14.4	9.4	0.14	1.53	0.45
0439	4	1.29	0.71	2.97	3.1	2.0	1.49	1.55	1.5
0024	1	0.20	< LOD	< LOD	0.34	0.20	-	1.7	-
0239	2	0.013	0.021	0.033	0.080	0.034	0.97	2.3	1.5
0142	3	8.64	0.79	24.2	22.9	9.4	2.6	2.4	2.5

**Table 6 (Contd.): Part 3 – Cases with Skeletal:Thoracic Activity Ratio > 2.62:1 (or Not Measured)**

Case No.	Batch No.	Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	Hg
0706(WB)	3	84.2	4.3	403	257	88.5	4.6	2.9	3.6
0038	2	0.42	0.024	0.197	1.28	0.44	0.45	2.9	1.1
0037	2	1.18	0.021	3.48	4.13	1.2	2.9	3.4	3.2
0023	1	3.57	0.37	9.57	15.2	3.9	2.4	3.9	3.1
0469	4	0.037	0.0069	0.12	0.18	0.044	2.75	4.09	3.4
0187	4	0.97	-	1.19	4.20	0.97	1.23	4.34	2.3
0048	2	4.84	0.36	3.76	27.1	5.2	0.72	5.2	1.9
0043	2	0.28	0.076	0.32	2.96	0.36	0.90	8.30	2.7
0460	1	0.12	0.037	0.0089	1.40	0.15	0.06	9.1	0.72
0231	2	0.076	0.0014	0.14	0.71	0.077	1.9	9.2	4.1
0046	2	0.40	0.21	0.046	7.40	0.61	0.08	12.2	0.96
0031	1	95.8	0.85	321	1298	96.7	3.3	13.4	6.68
0445	4	0.056	0.028	0.063	1.20	0.083	0.75	14.4	3.3
0083	4	0.016	0.0013	0.15	0.39	0.017	8.9	23	14
0441	1	0.19	0.014	0.081	5.2	0.21	0.39	25.1	3.1
0103	4	0.015	-	0.044	1.19	0.015	2.91	78.3	15.1
0084	4	0.0037	0.0019	0.0574	0.45	0.0056	10	81	29
0214	4	0.015	-	0.10	1.40	0.015	6.9	93	25
0095	4	5.55	-	0.026	-	5.55	0.005	-	-
0099	4	0.20	0.0024	0.012	-	0.20	0.059	-	-
0140	4	0.11	-	0.0069	-	0.11	0.063	-	-
0052	2	0.36	-	0.068	-	0.36	0.19	-	-
0183	4	0.024	0.080	0.021	-	0.10	0.20	-	-
0185	4	0.14	-	0.030	-	0.14	0.21	-	-
0040	2	1.18	0.21	0.33	-	1.4	0.24	-	-
0207	4	0.44	0.13	0.24	-	0.57	0.41	-	-
0196	4	0.11	0.032	0.059	-	0.14	0.43	-	-
0054	2	0.40	0.042	0.20	-	0.44	0.45	-	-
0027	1	2.42	0.03	1.16	-	2.5	0.47	-	-
0158	4	0.070	0.030	0.049	-	0.10	0.49	-	-
0186	4	0.22	0.047	0.21	-	0.27	0.77	-	-
0228	2	0.040	0.043	0.077	-	0.082	0.94	-	-
0492	4	0.035	0.026	0.076	-	0.061	1.23	-	-
0091	4	0.041	0.019	0.10	-	0.061	1.65	-	-
0035	2	0.049	0.027	0.33	-	0.076	4.3	-	-
0086	4	0.0058	-	0.028	-	0.0058	4.8	-	-
0041	2	0.77	0.10	-	-	0.87	-	-	-
0088	4	1.26	0.20	-	-	1.46	-	-	-
0026	1	-	-	1.55	-	-	-	-	-
0184	4	-	0.21	0.18	-	-	-	-	-

The following cases have a measured liver:thoracic activity ratio > 1.62 (the notional index of inhaled Type S Pu):

- 0023
- 0031
- 0037
- 0038
- 0043
- 0046
- 0048
- 0083
- 0084
- 0103
- 0187
- 0214
- 0441
- 0445
- 0460
- 0706(WB).

Again, these higher observed ratios may indicate:

- Inhalation intake of Pu with higher solubility than Type 'S';
- Multiple intakes, including significant uptake from a puncture wound;
- Variability in the systemic Pu biokinetics between individuals.

However, in order to draw more definitive conclusions from these data, it is again necessary to consider the provided "health physics" records and bioassay analysis data in each case.

**Data ranked by increasing geometric mean <sup>239+240</sup>Pu activity ratio**

Table 7 ranks the above case data by increasing value of the geometric mean of liver:thoracic and skeletal:thoracic activity ratio. In 17 of the 84 cases (20%) with measured values, this activity ratio exceeds 2.62 (the "notional" index of a Type S Pu inhalation intake). These cases are again highlighted in the table by shaded rows [top 17 rows in continuation (part 3) of Table 7].

**Table 7: USTUR Rocky Flats Cases Ranked by Geometric Mean of Liver:Thoracic and Skeletal:Thoracic <sup>239+240</sup>Pu Activity Ratio at Time of Death**

Case No.	Batch No.	<sup>239+240</sup> Pu Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	µg
0042	2	309	42.4	0.42	0.61	351	0.0012	0.0017	0.0014
0028	1	1627	0.29	4.82	28.6	1627	0.003	0.018	0.007
0036	2	720	13.8	8.60	4.59	734	0.012	0.006	0.009
0034	2	152	0.53	1.75	1.23	153	0.011	0.008	0.010
0202	3	13900	297	173	226	14197	0.012	0.016	0.014
0105	3	1920	234	38.4	57.0	2154	0.018	0.026	0.022
0085	3	48.0	23.0	1.4	1.7	71	0.020	0.024	0.022
0821	2	1044	-	28.6	24.0	1044	0.027	0.023	0.025
0146	3	86.4	13.5	0.75	8.7	99.9	0.007	0.087	0.026
0194	3	45.2	2.28	0.81	7.9	47.5	0.017	0.17	0.053
0029	1	49.3	4.14	7.44	1.45	53.4	0.14	0.027	0.06
0200	3	15.2	1.38	1.84	1.01	16.6	0.11	0.061	0.082
<b>0425(WB)</b>	3	185	29.0	13.6	25.1	214	0.064	0.117	0.086
0045	2	46.2	0.39	5.13	3.53	46.6	0.11	0.076	0.09
0096	3	5.06	3.12	0.80	0.91	8.2	0.10	0.11	0.10
0782	3	2.07	0.047	0.40	0.13	2.1	0.19	0.061	0.11
0053	2	4.62	0.16	0.50	0.71	4.8	0.11	0.15	0.13
0049	2	10.1	0.66	1.65	1.20	10.8	0.15	0.11	0.13
0097	3	194	8.54	20.6	36.4	203	0.10	0.18	0.14
0039	3	3.21	0.11	0.23	0.89	3.3	0.070	0.27	0.14
0727	3	50.4	0.90	7.8	6.6	51.3	0.15	0.13	0.14
0423	3	7.64	1.20	0.51	3.2	8.84	0.058	0.36	0.14
0199	3	14.9	1.13	2.09	3.6	16.0	0.13	0.22	0.17
0044	2	6.82	0.96	0.85	2.24	7.8	0.11	0.29	0.18
0233	2	0.88	0.72	0.21	0.45	1.6	0.13	0.28	0.19
0050	2	0.84	0.14	0.16	0.33	0.98	0.17	0.34	0.24
0210	4	2.63	3.55	0.54	4.10	6.2	0.087	0.66	0.24
0256	2	127	10.6	23.4	50.9	138	0.17	0.37	0.25
0108	3	373	-	158	56.8	373	0.42	0.15	0.25
0033	2	26.5	0.24	7.12	7.14	26.7	0.27	0.27	0.27
0025	1	5.69	0.15	1.16	2.44	5.8	0.20	0.42	0.29
0444	1	21.3	2.9	4.8	11.2	24.2	0.20	0.46	0.30
0420	2	38.4	7.16	14.6	13.2	45.6	0.32	0.29	0.30
0461	4	0.19	0.36	0.042	0.66	0.54	0.077	1.22	0.31
0216	2	244	61.6	107	90.7	306	0.35	0.30	0.32
0427	2	14.3	2.5	7.6	4.5	16.8	0.45	0.27	0.35
0232	2	0.32	0.046	0.094	0.17	0.36	0.26	0.47	0.35
0837	3	21.8	1.29	6.28	10.7	23.1	0.27	0.46	0.36
0057	2	1.08	0.043	0.098	1.70	1.1	0.087	1.51	0.36
0047	2	1.55	0.012	0.36	0.92	1.6	0.23	0.59	0.37
0260	3	11.2	-	2.98	6.0	11.2	0.27	0.53	0.38
0030	1	2.35	0.05	0.92	0.95	2.4	0.38	0.39	0.39
0796	3	21.9	2.3	7.8	13.3	24.2	0.32	0.55	0.42
0092	3	5.66	1.08	3.23	2.7	6.7	0.48	0.40	0.44
0217	4	9.40	-	1.27	14.4	9.4	0.14	1.53	0.45
0055	2	4.57	0.24	2.57	2.20	4.8	0.53	0.46	0.49

**Table 7 (Contd.): Part2**

Case No.	Batch No.	<sup>239+240</sup> Pu Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	µg
0087	3	16.9	2.18	14.2	6.5	19.1	0.74	0.34	0.50
0098	4	1.56	0.28	0.83	1.19	1.84	0.45	0.65	0.54
0188	3	36.4	1.94	28.9	14.8	38.3	0.75	0.39	0.54
<b>0744(WB)</b>	3	71.4	21.4	30.0	86.7	92.8	0.32	0.93	0.55
0458	2	4.71	1.07	1.85	6.1	5.78	0.32	1.1	0.58
0051	2	21.3	1.11	15.2	11.4	22.4	0.68	0.51	0.59
0058	2	16.7	0.11	11.2	10.1	16.8	0.67	0.60	0.63
0191	3	80.7	14.8	88.8	42.2	95.5	0.93	0.44	0.64
0446	1	0.97	0.0038	0.42	0.99	0.97	0.44	1.0	0.66
0032	2	1.13	-	0.35	1.68	1.13	0.31	1.5	0.68
0252	2	35.9	2.59	40.4	18.5	38.5	1.05	0.48	0.71
0460	1	0.12	0.037	0.0089	1.40	0.15	0.06	9.1	0.72
0244	2	6.45	1.13	4.1	9.3	7.6	0.54	1.23	0.82
0215	2	94.6	12.1	109	73.4	107	1.0	0.69	0.84
0498	3	16.4	1.74	11.9	21.9	18.1	0.66	1.2	0.89
0046	2	0.40	0.21	0.046	7.40	0.61	0.08	12.2	0.96
<b>0205(WB)</b>	4	0.11	0.064	0.15	0.20	0.17	0.86	1.17	1.0
0038	2	0.42	0.024	0.197	1.28	0.44	0.45	2.9	1.1
0161	3	4.87	0.292	6.53	7.0	5.2	1.3	1.4	1.3
0239	2	0.013	0.021	0.033	0.080	0.034	0.97	2.3	1.5
0439	4	1.29	0.71	2.97	3.1	2.0	1.49	1.55	1.5

**Table 7 (Contd.): Part 3 – Cases with Geometric Mean of Liver:Thoracic and Skeletal:Thoracic Activity Ratio > 2.06:1 (or Not Measured)**

Case No.	Batch No.	<sup>239+240</sup> Pu Organ Content, Bq					Activity Ratio		
		Lungs	LNTH	Liver	Skeleton	Thoracic	Liv/Thor	Skel/Thor	µg
0229	2	1.01	0.28	2.88	1.47	1.3	2.2	1.1	1.6
0048	2	4.84	0.36	3.76	27.1	5.2	0.72	5.2	1.9
0187	4	0.97	-	1.19	4.20	0.97	1.23	4.34	2.3
0142	3	8.64	0.79	24.2	22.9	9.4	2.6	2.4	2.5
0043	2	0.28	0.076	0.32	2.96	0.36	0.90	8.30	2.7
0023	1	3.57	0.37	9.57	15.2	3.9	2.4	3.9	3.1
0441	1	0.19	0.014	0.081	5.2	0.21	0.39	25.1	3.1
0037	2	1.18	0.021	3.48	4.13	1.2	2.9	3.4	3.2
0445	4	0.056	0.028	0.063	1.20	0.083	0.75	14.4	3.3
0469	4	0.037	0.0069	0.12	0.18	0.044	2.75	4.09	3.4
<b>0706(WB)</b>	3	84.2	4.3	403	257	88.5	4.6	2.9	3.6
0231	2	0.076	0.0014	0.14	0.71	0.077	1.9	9.2	4.1
0031	1	95.8	0.85	321	1298	96.7	3.3	13.4	6.68
0083	4	0.016	0.0013	0.15	0.39	0.017	8.9	23	14
0103	4	0.015	-	0.044	1.19	0.015	2.91	78.3	15.1
0214	4	0.015	-	0.10	1.40	0.015	6.9	93	25
0084	4	0.0037	0.0019	0.0574	0.45	0.0056	10	81	29
0024	1	0.20	< LOD	< LOD	0.34	0.20	-	1.7	-
0086	4	0.0058	-	0.028	-	0.0058	4.8	-	-
0183	4	0.024	0.080	0.021	-	0.10	0.20	-	-
0492	4	0.035	0.026	0.076	-	0.061	1.23	-	-
0228	2	0.040	0.043	0.077	-	0.082	0.94	-	-
0091	4	0.041	0.019	0.10	-	0.061	1.65	-	-
0035	2	0.049	0.027	0.33	-	0.076	4.3	-	-
0158	4	0.070	0.030	0.049	-	0.10	0.49	-	-
0196	4	0.11	0.032	0.059	-	0.14	0.43	-	-
0140	4	0.11	-	0.0069	-	0.11	0.063	-	-
0185	4	0.14	-	0.030	-	0.14	0.21	-	-
0099	4	0.20	0.0024	0.012	-	0.20	0.059	-	-
0186	4	0.22	0.047	0.21	-	0.27	0.77	-	-
0052	2	0.36	-	0.068	-	0.36	0.19	-	-
0054	2	0.40	0.042	0.20	-	0.44	0.45	-	-
0207	4	0.44	0.13	0.24	-	0.57	0.41	-	-
0056	2	0.57	0.25	-	0.90	0.82	-	1.1	-
0041	2	0.77	0.10	-	-	0.87	-	-	-
0040	2	1.18	0.21	0.33	-	1.4	0.24	-	-
0088	4	1.26	0.20	-	-	1.46	-	-	-
0027	1	2.42	0.03	1.16	-	2.5	0.47	-	-
0095	4	5.55	-	0.026	-	5.55	0.00	-	-
0026	1	-	-	1.55	-	-	-	-	-
0184	4	-	0.21	0.18	-	-	-	-	-

The following cases have a geometric mean of the measured liver:thoracic and skeletal:thoracic activity ratio > 2.06 (the notional index of inhaled Type S Pu):

- 0023
- 0031
- 0037
- 0043
- 0048
- 0083
- 0084
- 0103
- 0142
- 0187
- 0214
- 0229
- 0231
- 0441
- 0445
- 0469
- 0706(WB).

Again, these higher observed ratios may indicate:

- Inhalation intake of Pu with higher solubility than Type 'S';
- Multiple intakes, including significant uptake from a puncture wound;
- Variability in the systemic Pu biokinetics between individuals.

However, again, in order to draw more definitive conclusions from these data, it is necessary to consider the provided "health physics" records and bioassay analysis data in each case.

#### **Index of systemic:thoracic activity ratios by case number**

Table 8 gives an index (ranked by case number) of the measured systemic:thoracic <sup>239+240</sup>Pu activity ratios. All occurrences of a measured ratio **less than** the corresponding notional value for inhaled Type S Pu are highlighted in **bold**.

**Table 8: Index of Cases for Which a Measured Systemic:Thoracic Pu-Activity Ratio is Less Than the Notional Type S Value**

Case No.	Data Batch No.	Systemic:Thoracic Activity Ratio		
		Liver	Skeleton	Geometric Mean
0023	1	2.429	3.864	3.064
0024	1	-	<b>1.663</b>	-
0025	1	<b>0.199</b>	<b>0.417</b>	<b>0.288</b>
0026	1	-	-	-
0027	1	<b>0.473</b>	-	-
0028	1	<b>0.003</b>	<b>0.018</b>	<b>0.007</b>
0029	1	<b>0.139</b>	<b>0.027</b>	<b>0.061</b>
0030	1	<b>0.384</b>	<b>0.394</b>	<b>0.389</b>
0031	1	3.321	13.428	6.678
0032	2	<b>0.310</b>	<b>1.493</b>	<b>0.681</b>
0033	2	<b>0.266</b>	<b>0.267</b>	<b>0.267</b>
0034	2	<b>0.011</b>	<b>0.008</b>	<b>0.010</b>
0035	2	4.329	-	-
0036	2	<b>0.012</b>	<b>0.006</b>	<b>0.009</b>
0037	2	2.898	3.436	3.155
0038	2	<b>0.447</b>	<b>2.906</b>	<b>1.140</b>
0039	3	<b>0.070</b>	<b>0.268</b>	<b>0.137</b>
0040	2	<b>0.240</b>	-	-
0041	2	-	-	-
0042	2	<b>0.001</b>	<b>0.002</b>	<b>0.001</b>
0043	2	<b>0.897</b>	8.299	2.728
0044	2	<b>0.109</b>	<b>0.287</b>	<b>0.177</b>
0045	2	<b>0.110</b>	<b>0.076</b>	<b>0.091</b>
0046	2	<b>0.075</b>	12.171	<b>0.958</b>
0047	2	<b>0.232</b>	<b>0.592</b>	<b>0.371</b>
0048	2	<b>0.723</b>	5.206	<b>1.939</b>
0049	2	<b>0.153</b>	<b>0.112</b>	<b>0.131</b>
0050	2	<b>0.167</b>	<b>0.338</b>	<b>0.238</b>
0051	2	<b>0.678</b>	<b>0.509</b>	<b>0.587</b>
0052	2	<b>0.188</b>	-	-
0053	2	<b>0.105</b>	<b>0.149</b>	<b>0.125</b>
0054	2	<b>0.453</b>	-	-
0055	2	<b>0.534</b>	<b>0.457</b>	<b>0.494</b>
0056	2	-	<b>1.099</b>	-
0057	2	<b>0.087</b>	<b>1.514</b>	<b>0.363</b>
0058	2	<b>0.666</b>	<b>0.601</b>	<b>0.633</b>
0083	4	8.889	22.807	14.238
0084	4	10.287	80.645	28.802
0085	3	<b>0.020</b>	<b>0.024</b>	<b>0.022</b>
0086	4	4.828	-	-
0087	3	<b>0.744</b>	<b>0.341</b>	<b>0.504</b>
0088	4	-	-	-
0091	4	1.650	-	-
0092	3	<b>0.479</b>	<b>0.401</b>	<b>0.438</b>
0095	4	<b>0.005</b>	-	-
0096	3	<b>0.097</b>	<b>0.111</b>	<b>0.104</b>
0097	3	<b>0.102</b>	<b>0.180</b>	<b>0.135</b>
0098	4	<b>0.448</b>	<b>0.646</b>	<b>0.538</b>
0099	4	<b>0.059</b>	-	-
0103	4	2.908	78.289	15.088
0105	3	<b>0.018</b>	<b>0.026</b>	<b>0.022</b>
0108	3	<b>0.424</b>	<b>0.152</b>	<b>0.254</b>
0140	4	<b>0.063</b>	-	-
0142	3	2.566	<b>2.428</b>	2.496
0146	3	<b>0.007</b>	<b>0.087</b>	<b>0.026</b>
0158	4	<b>0.493</b>	-	-

**Table 8 (Contd.): Part 2**

Case No.	Data Batch No.	Systemic:Thoracic Activity Ratio		
		Liver	Skeleton	Geometric Mean
0161	3	1.265	1.356	1.310
0183	4	0.203	-	-
0184	4	-	-	-
0185	4	0.211	-	-
0186	4	0.774	-	-
0187	4	1.231	4.343	2.312
0188	3	0.754	0.386	0.539
0191	3	0.930	0.442	0.641
0194	3	0.017	0.166	0.053
0196	4	0.428	-	-
0199	3	0.130	0.225	0.171
0200	3	0.111	0.061	0.082
0202	3	0.012	0.016	0.014
0207	4	0.415	-	-
0210	4	0.087	0.663	0.240
0214	4	6.933	93.333	25.438
0215	2	1.022	0.688	0.838
0216	2	0.350	0.297	0.322
0217	4	0.135	1.532	0.455
0228	2	0.936	-	-
0229	2	2.238	1.142	1.599
0231	2	1.860	9.173	4.131
0232	2	0.261	0.471	0.350
0233	2	0.129	0.281	0.190
0239	2	0.974	2.339	1.509
0244	2	0.541	1.231	0.816
0252	2	1.050	0.481	0.710
0256	2	0.170	0.370	0.251
0260	3	0.266	0.534	0.377
0420	2	0.320	0.290	0.305
0423	3	0.058	0.362	0.145
0427	2	0.454	0.268	0.349
0439	4	1.485	1.550	1.518
0441	1	0.387	25.089	3.116
0444	1	0.198	0.465	0.303
0445	4	0.749	14.388	3.284
0446	1	0.435	1.014	0.664
0458	2	0.320	1.052	0.580
0460	1	0.058	9.080	0.725
0461	4	0.077	1.218	0.307
0469	4	2.753	4.095	3.357
0492	4	1.235	-	-
0498	3	0.656	1.207	0.890
0727	3	0.151	0.129	0.140
0782	3	0.190	0.061	0.108
0796	3	0.322	0.550	0.421
0821	2	0.027	0.023	0.025
0837	3	0.272	0.463	0.355
<b>0205(WB)</b>	4	<b>0.860</b>	<b>1.174</b>	<b>1.005</b>
<b>0425(WB)</b>	3	<b>0.064</b>	<b>0.117</b>	<b>0.086</b>
0706(WB)	3	4.553	2.903	3.636
<b>0744(WB)</b>	3	<b>0.323</b>	<b>0.934</b>	<b>0.550</b>

## Analysis of the distribution of systemic:thoracic activity ratios

### Liver:thoracic ratio

Figure 2 shows the frequency distribution of the logarithm (base ten) of the liver:thoracic activity ratio measured in 102 Rocky Flats cases. The figure also shows the lognormal distribution fitted to these data. The fitted median fraction ( $C_{\text{liver}}/C_{\text{thorax}}$ ) is 0.288, with a geometric standard deviation ( $\sigma_g$ ) of 5.6. As described earlier (in relation to Table 5), in 85% of cases, the measured liver:thoracic ratio was < the notional Type S value of 1.62.

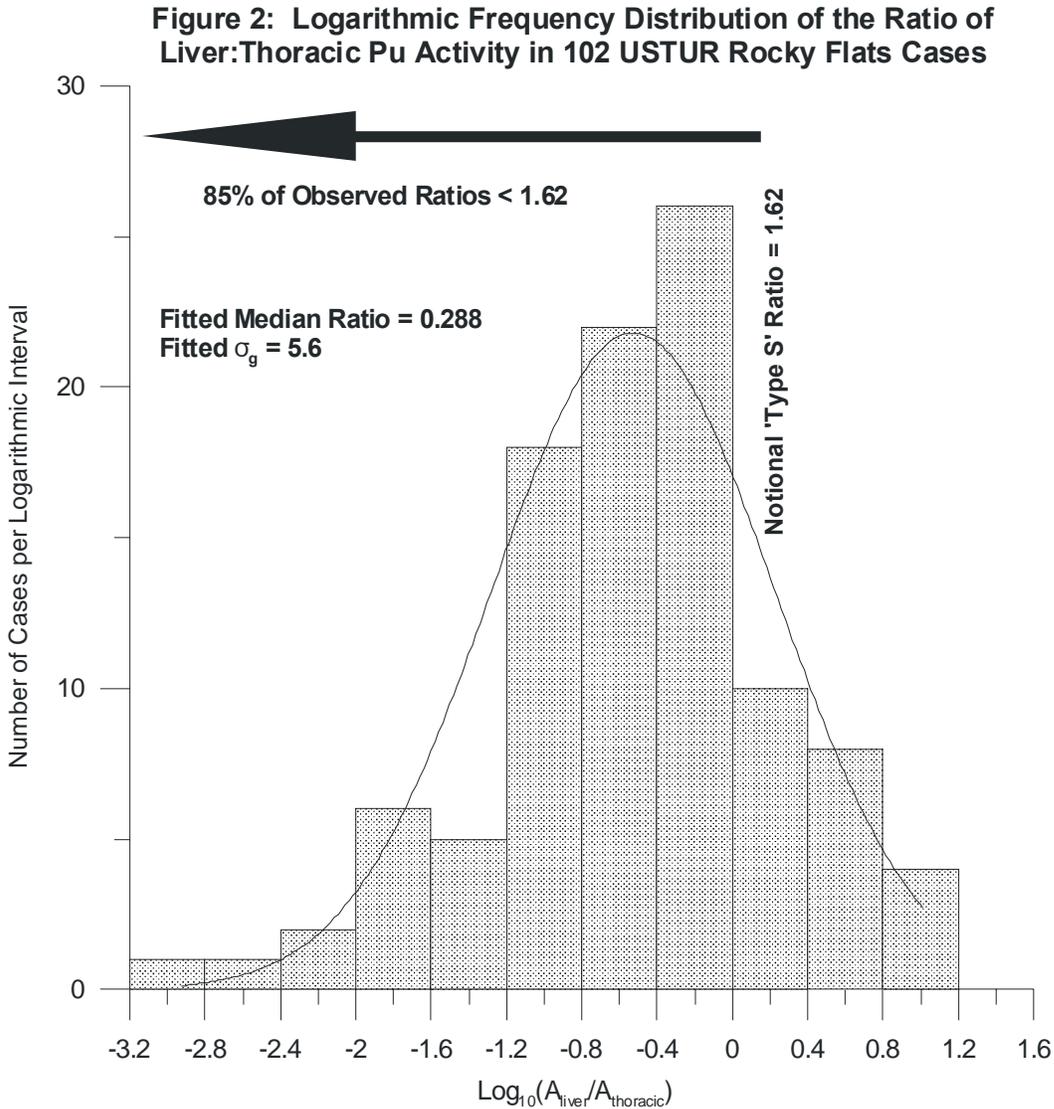
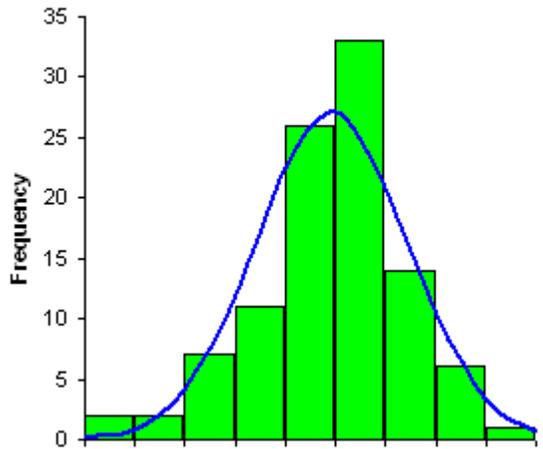
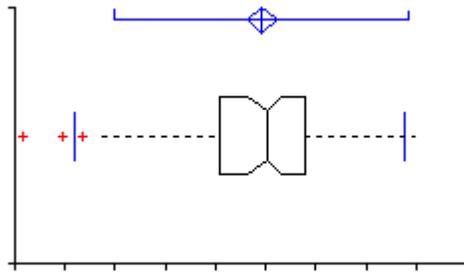


Figure 3 gives the statistical parameters of the fitted lognormal distribution. The Shapiro-Wilk test of normality showed that the hypothesis of a lognormal frequency distribution could be rejected ( $p = 0.0500$ ). The distribution was significantly skewed towards the low tail. In this test, the liver:thoracic ratios measured for cases 0042, 0028, and 0095 (low tail) were rejected as 'outliers.'

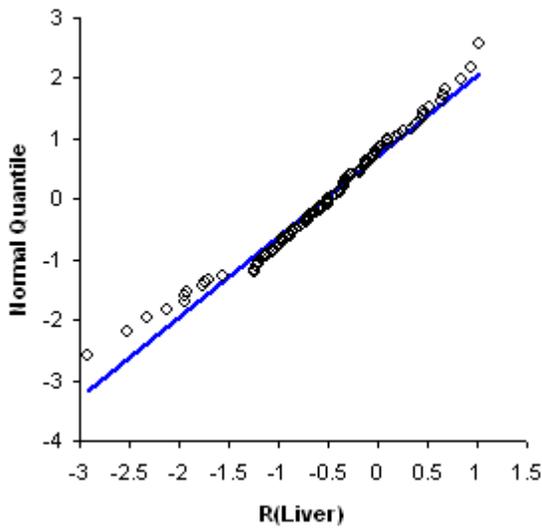
**Figure 3: Statistical Parameters of the  $\log_{10}(A_{\text{liver}}/A_{\text{thorax}})$  Distribution**



<b>n</b>	102
<b>Mean</b>	-0.5400
<b>95% CI</b>	-0.6871 to -0.3930
<b>Variance</b>	0.56064
<b>SD</b>	0.74876
<b>SE</b>	0.07414
<b>CV</b>	-139%



<b>Median</b>	-0.4913
<b>96.3% CI</b>	-0.6763 to -0.3443
<b>Range</b>	3.937
<b>IQR</b>	0.858
<b>Percentile</b>	
<b>2.5th</b>	-2.4100
<b>25th</b>	-0.9573
<b>50th</b>	-0.4913
<b>75th</b>	-0.0997
<b>97.5th</b>	0.8868



	<b>Coefficient</b>	<b>p</b>
<b>Shapiro-Wilk</b>	0.9750	0.0500
<b>Skewness</b>	-0.5664	0.0207
<b>Kurtosis</b>	0.7187	0.1517

### Skeletal:thoracic ratio

Figure 4 shows the frequency distribution of the logarithm (base ten) of the skeletal:thoracic activity ratio measured in 86 Rocky Flats cases. The figure also shows the lognormal distribution fitted to these data. The fitted median ratio is 0.597, with a geometric standard deviation ( $\sigma_g$ ) of 8.0. As described earlier (in relation to Table 6), in 79% of cases, the measured skeletal:thoracic ratio was < the notional Type S value of 2.62.

**Figure 4: Logarithmic Frequency Distribution of the Ratio of Skeletal:Thoracic Pu Activity in 86 USTUR Rocky Flats Cases**

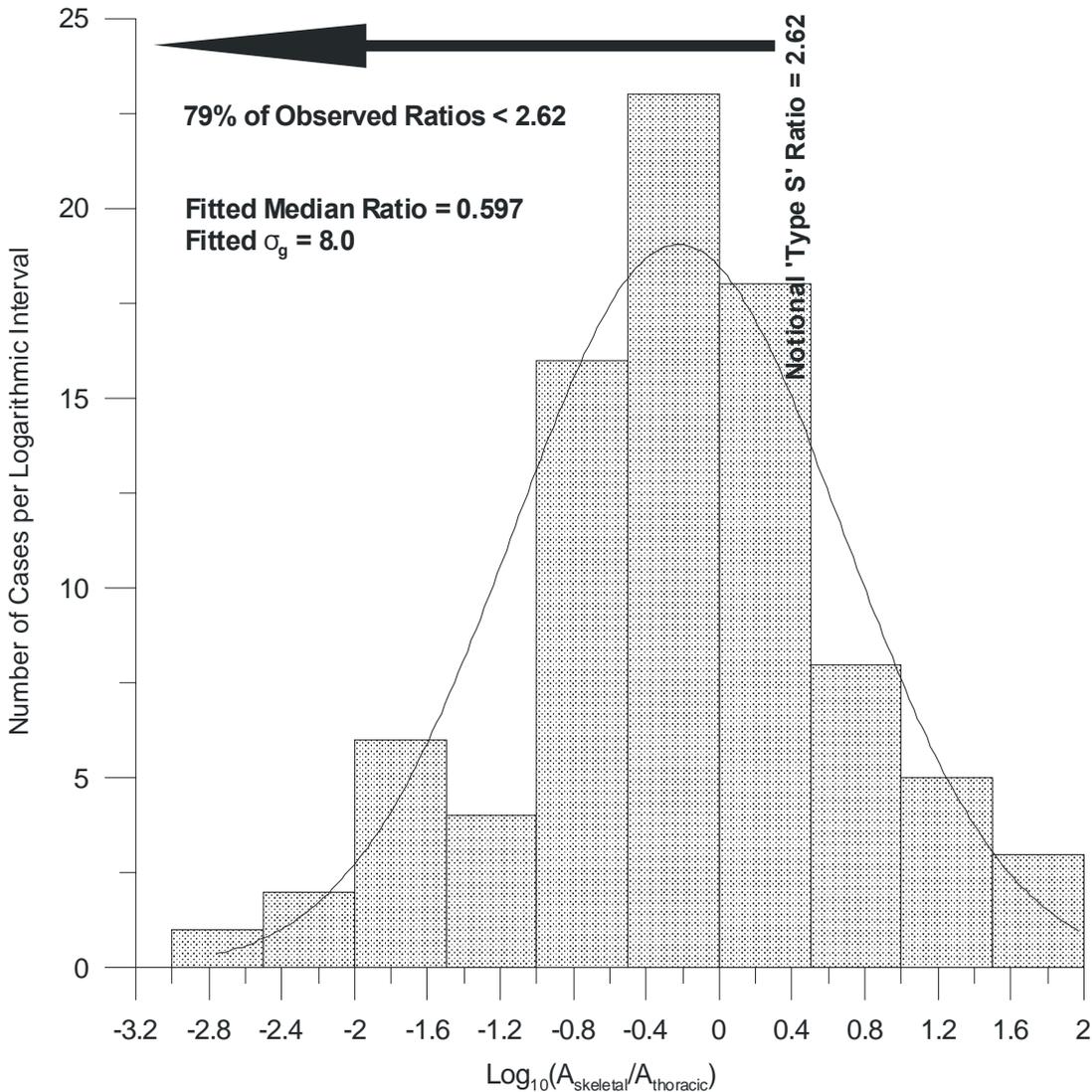
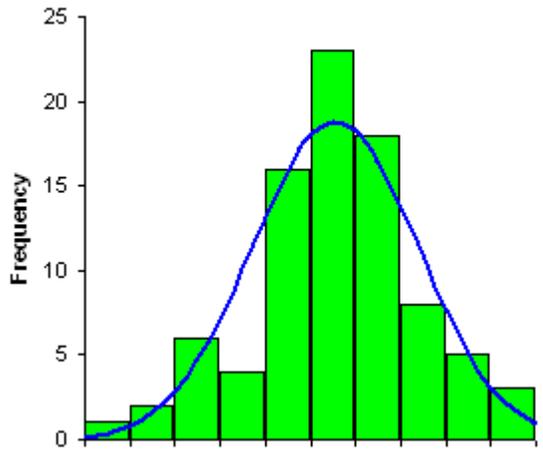
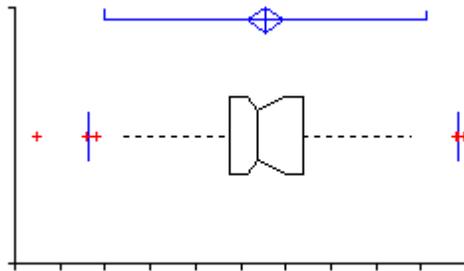


Figure 5 gives the statistical parameters of the fitted lognormal distribution. The Shapiro-Wilk test of normality showed that the hypothesis of a lognormal frequency distribution could not be rejected ( $p = 0.2859$ ). In this test, the skeletal:thoracic ratios measured for cases 0042, 0036, and 0034 (low tail) and cases 0084 and 0214 (high tail) were rejected as 'outliers.'

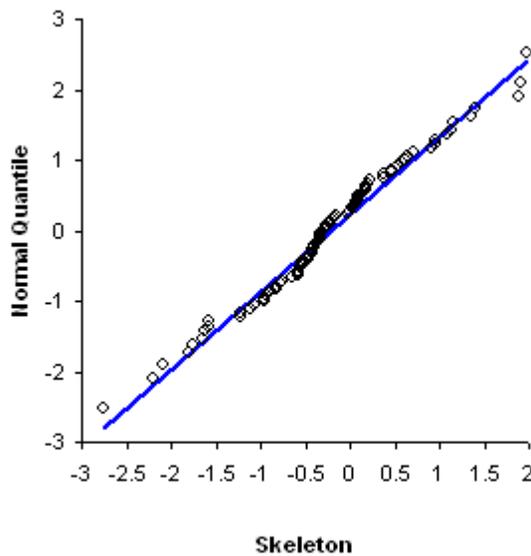
**Figure 5: Statistical Parameters of the  $\log_{10}(A_{\text{skeletal}}/A_{\text{thorax}})$  Distribution**



<b>n</b>	86
<b>Mean</b>	-0.2238
<b>95% CI</b>	-0.4181 to -0.0295
<b>Variance</b>	0.82150
<b>SD</b>	0.90637
<b>SE</b>	0.09774
<b>CV</b>	-405%



<b>Median</b>	-0.3059
<b>96.0% CI</b>	-0.4134 to 0.0058
<b>Range</b>	4.732
<b>IQR</b>	0.816
<b>Percentile</b>	
<b>2.5th</b>	-2.1847
<b>25th</b>	-0.6298
<b>50th</b>	-0.3059
<b>75th</b>	0.1865
<b>97.5th</b>	1.9043



	<b>Coefficient</b>	<b>p</b>
<b>Shapiro-Wilk</b>	0.9822	0.2859
<b>Skewness</b>	0.0064	0.9795
<b>Kurtosis</b>	0.5567	0.2540

### Geometric mean ratio

Figure 6 shows the frequency distribution of the logarithm (base ten) of the geometric mean of the liver:thoracic and skeletal:thoracic activity ratios measured in 84 Rocky Flats cases. The figure also shows the lognormal distribution fitted to these data. The fitted median ratio is 0.406, with a geometric standard deviation ( $\sigma_g$ ) of 6.1. As described earlier (in relation to Table 7), in 80% of cases, the measured geometric mean ratio was < the notional Type S value of 2.06.

**Figure 6: Logarithmic Frequency Distribution of the Ratio of Geometric Mean Pu Liver and Skeletal Activity ( $\mu_g$ ) : Lung Concentration in 82 USTUR Rocky Flats Cases**

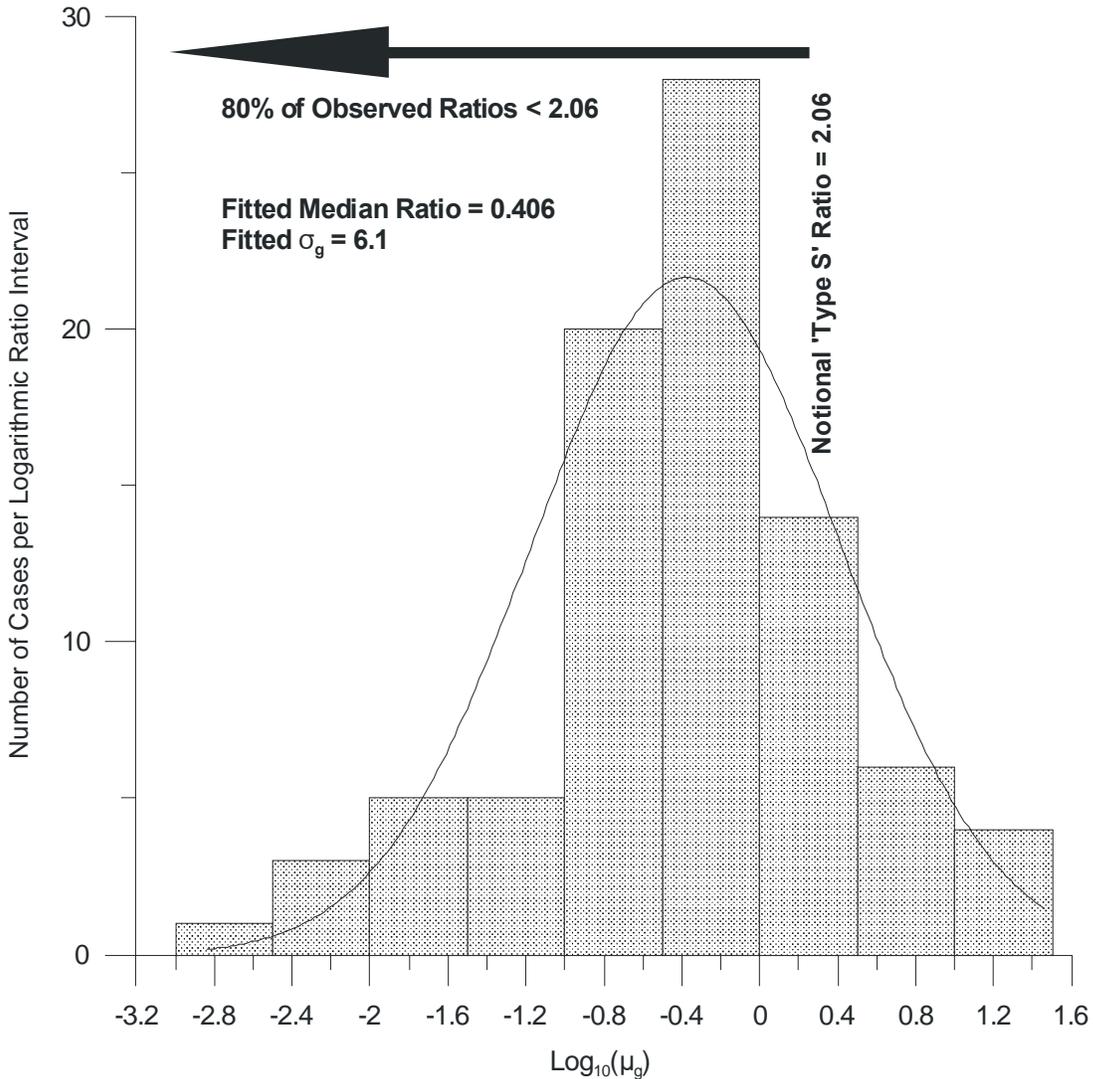
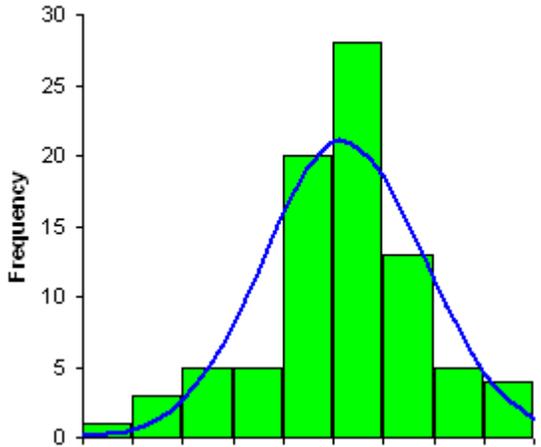
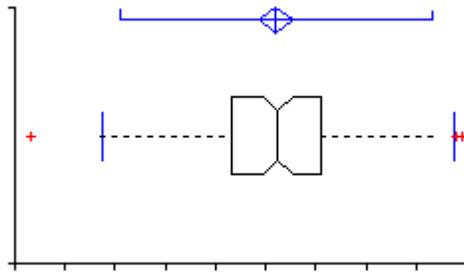


Figure 7 gives the statistical parameters of the fitted lognormal distribution. The Shapiro-Wilk test of normality showed that the hypothesis of a lognormal frequency distribution again could not be rejected ( $p = 0.1535$ ). In this test, the geometric mean ratios measured for case 0042 (low tail) and cases 0214 and 0084 (high tail) were rejected as 'outliers.'

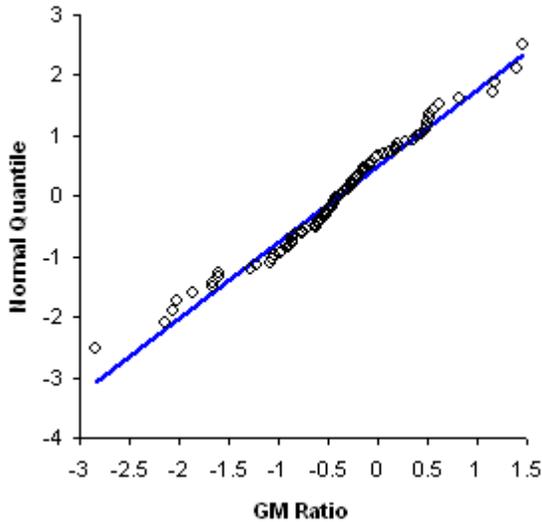
**Figure 7: Statistical Parameters of the  $\log_{10}(\mu_g)$  Distribution**



<b>n</b>	84
<b>Mean</b>	-0.3981
<b>95% CI</b>	-0.5701 to -0.2262
<b>Variance</b>	0.62771
<b>SD</b>	0.79228
<b>SE</b>	0.08644
<b>CV</b>	-199%



<b>Median</b>	-0.3929
<b>96.2% CI</b>	-0.5161 to -0.2311
<b>Range</b>	4.303
<b>IQR</b>	0.887
<b>Percentile</b>	
<b>2.5th</b>	-2.1326
<b>25th</b>	-0.8439
<b>50th</b>	-0.3929
<b>75th</b>	0.0431
<b>97.5th</b>	1.3771



	<b>Coefficient</b>	<b>p</b>
<b>Shapiro-Wilk</b>	0.9777	0.1535
<b>Skewness</b>	-0.3061	0.2347
<b>Kurtosis</b>	0.8169	0.1414

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