



Case 2

Acute inhalation of fission products

A path through the GL

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Vienna, 18 – 20 April 2005

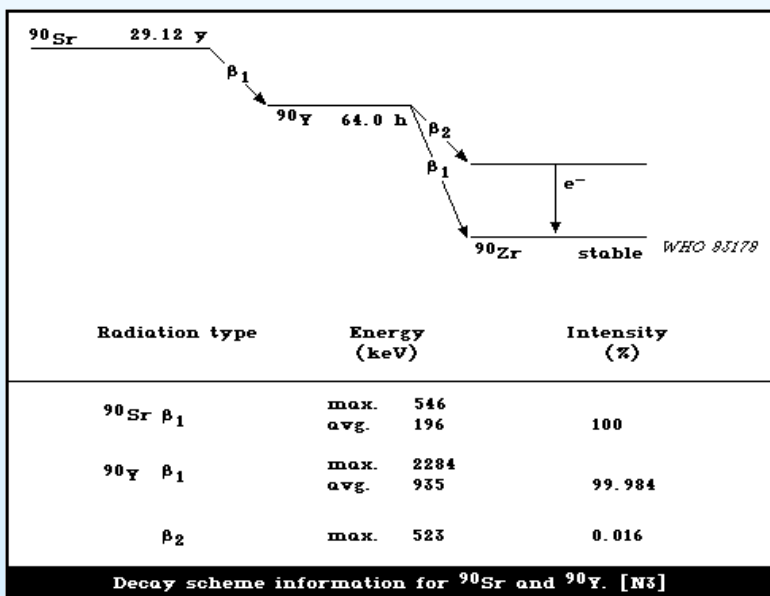
Presentation of the case description

- The accident took place in a facility in which they reprocess graphite used in a reactor.
- A dust explosion of graphite containing fission products begins the contamination.
- A man aged 46 was involved.
- Actions taken: External decontamination, nose swab and monitoring (via whole body measurements and urine and faecal samples) were immediately set.

Information

- No air monitoring
- Chemical form : Graphite with fission products. Likely to be insoluble for strontium.
- Physical characteristics : aerosol
- Positive nose blow : ^{90}Sr activity of 1.9 kBq was found.
- No intervention used (blocking, chelating etc.)

Urine activity data for ^{90}Sr

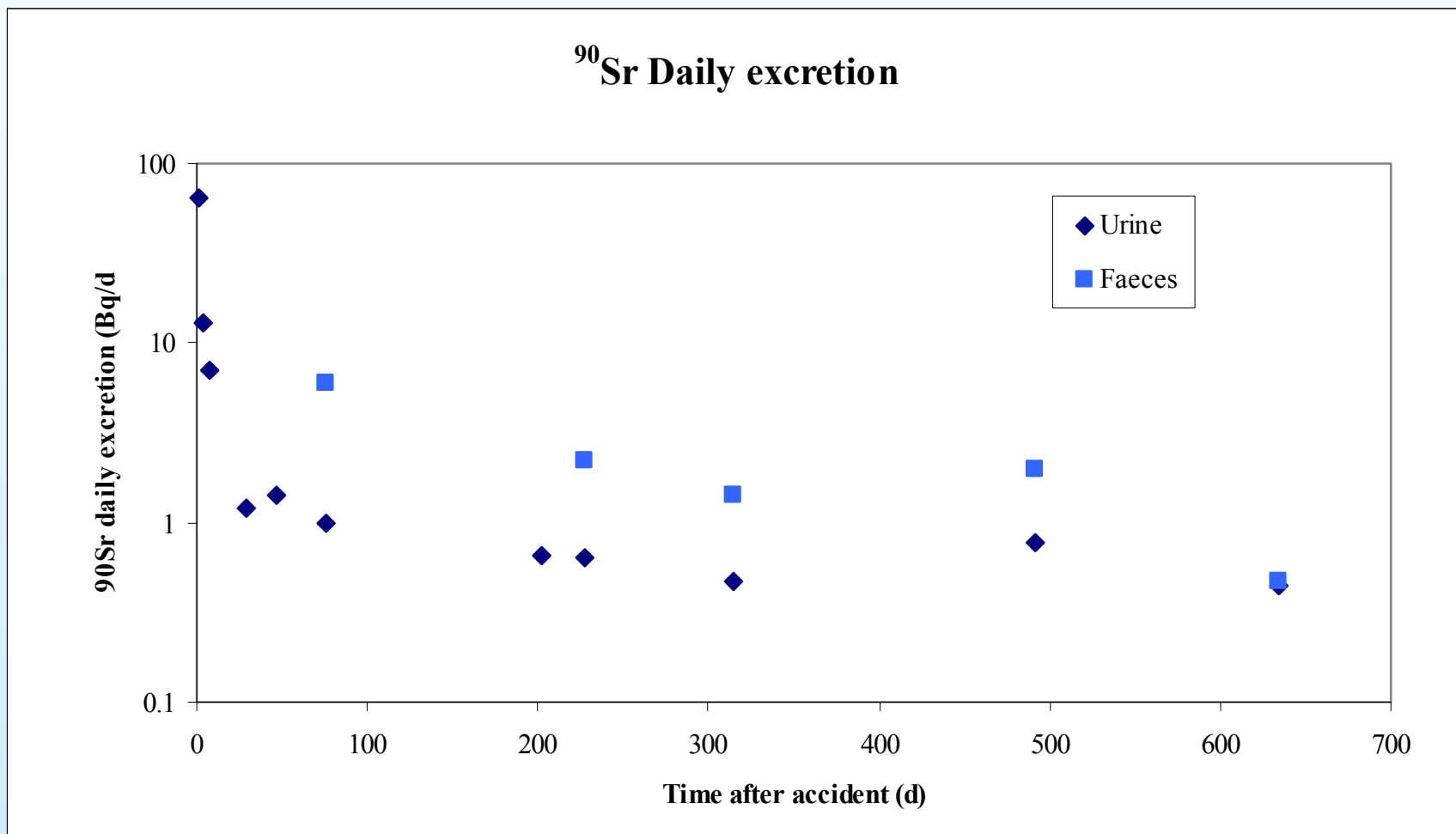


Time of measurement after intake. (d)	Daily urine excretion rate of $^{90}\text{Sr}/^{90}\text{Y}$ (Bq/d)
1	65
4	13
7	7.1
29	1.2
47	1.4
76	1.0
202	0.66
227	0.64
314	0.47
492	0.78
634	0.45

Feces activity data for ^{90}Sr

Time of measurement after intake. (d)	Daily fecal excretion rate of $^{90}\text{Sr}/^{90}\text{Y}$ (Bq/d)
76	5.9
227	2.2
314	1.4
492	2.0
634	0.47

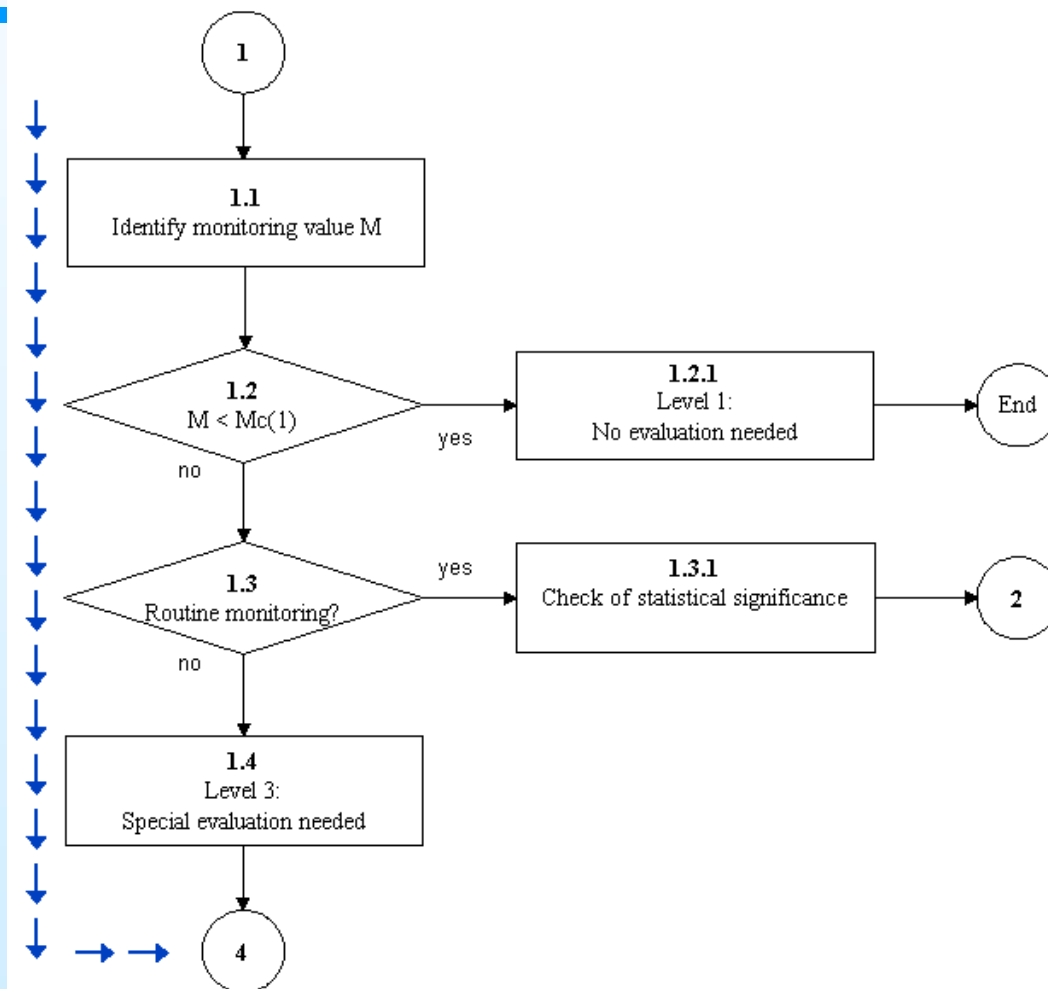
Urine and Faeces data for ^{90}Sr



1. A walk through the case using the guidelines

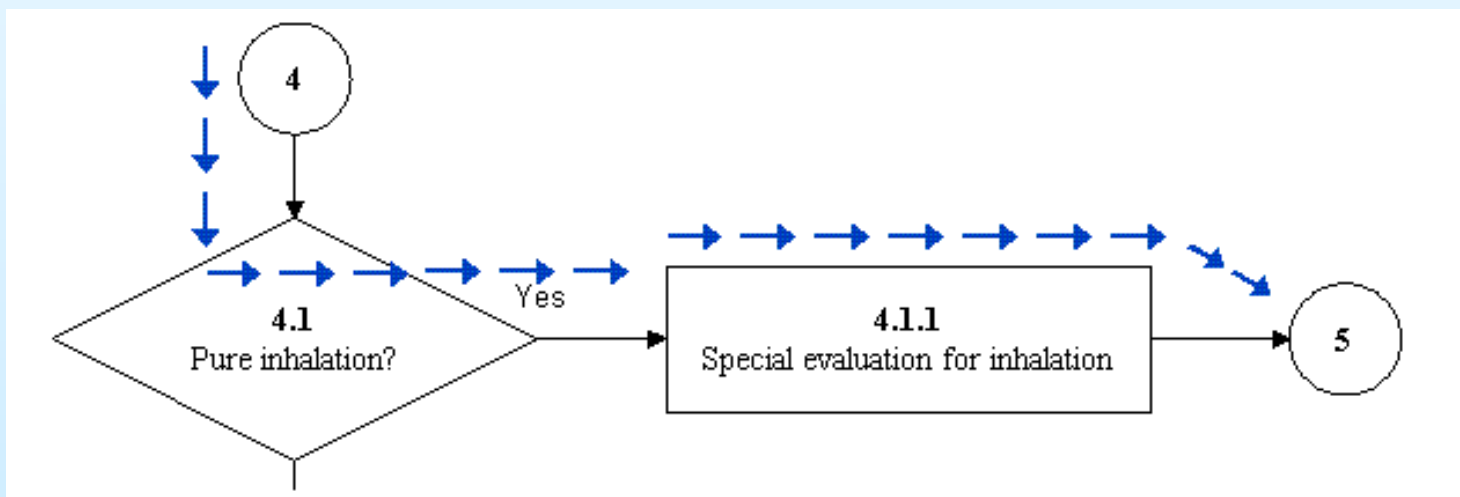
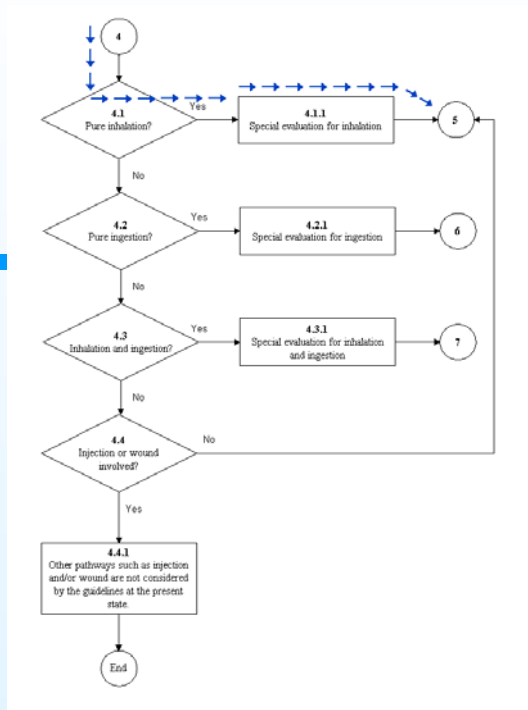
Step	Indication	Comment	Action to be performed
1.1	Identification of monitoring value M	The first datum of WB measurement has been considered = 70 kBq. For ^{90}Sr the value is 65 Bq/d.	Go to step 1.2
1.2	Comparison with $M_c(1)$	70 kBq is greater of the maximum value for the critical monitoring quantity reported in the guidelines for ^{137}Cs . M_c is equal to 2 kBq for $T=360$ d. For ^{90}Sr the value of 65 Bq/d is greater than 0.4 Bq/d ($T=90$ d) so there is also in this case the indication to proceed in the evaluation .	$M > M_c$; go to step 1.3.
1.3	Test on routine monitoring	The case is the description of an accident, so typically this is special monitoring .	Go to step 1.4
1.4	Special evaluation	Special evaluation needed.	Go to step 4

Step 1



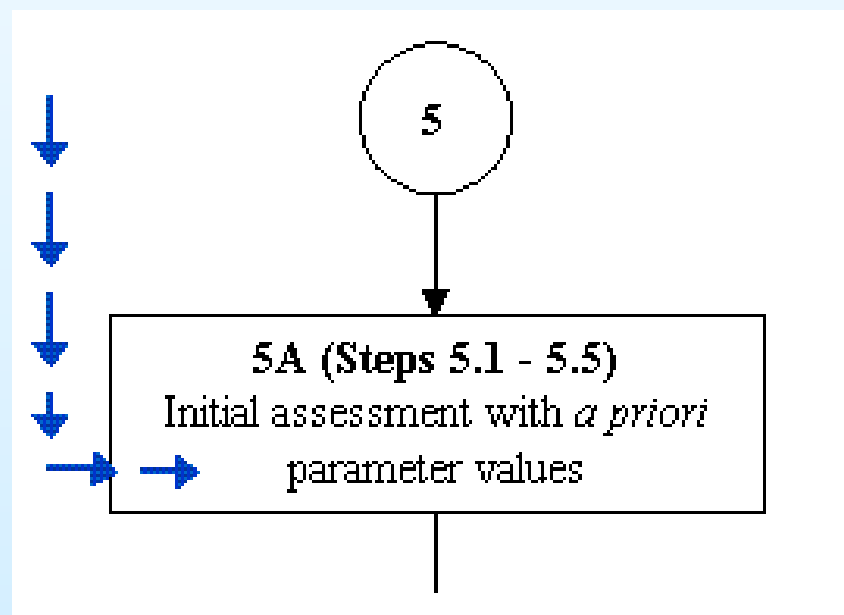
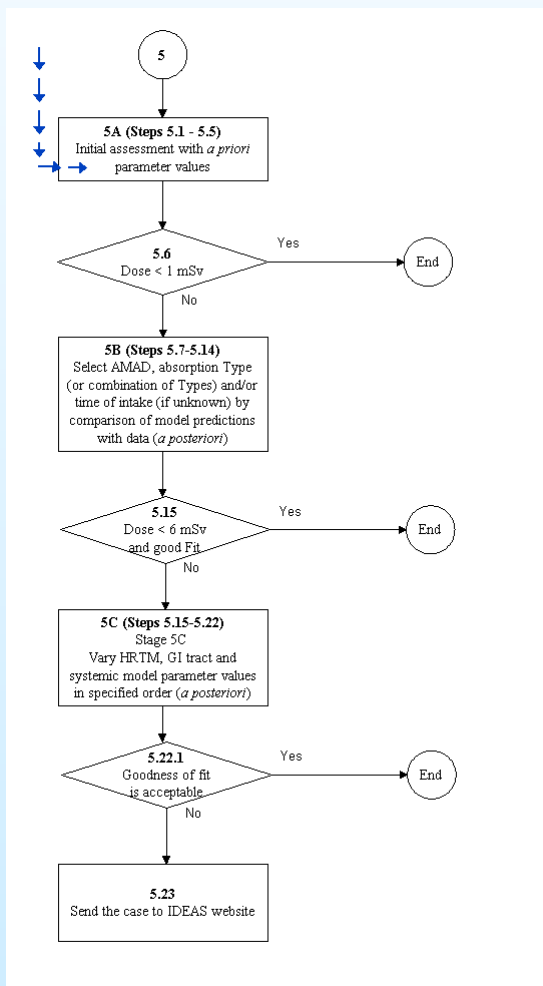
Step 4

Step	Indication	Comment	Action to be performed
4	Special procedure	A special procedure is requested in case of special monitoring	Go to 4.1
4.1	Test for pure inhalation	In this case there is evidence of the presence of ⁹⁰ Sr activity in the nose. For both radionuclides it is assumed a pure inhalation.	Go to 4.4.1
4.1.1	Special evaluation for pure inhalation	Indication of special evaluation for pure inhalation.	Go to 5



Step 5

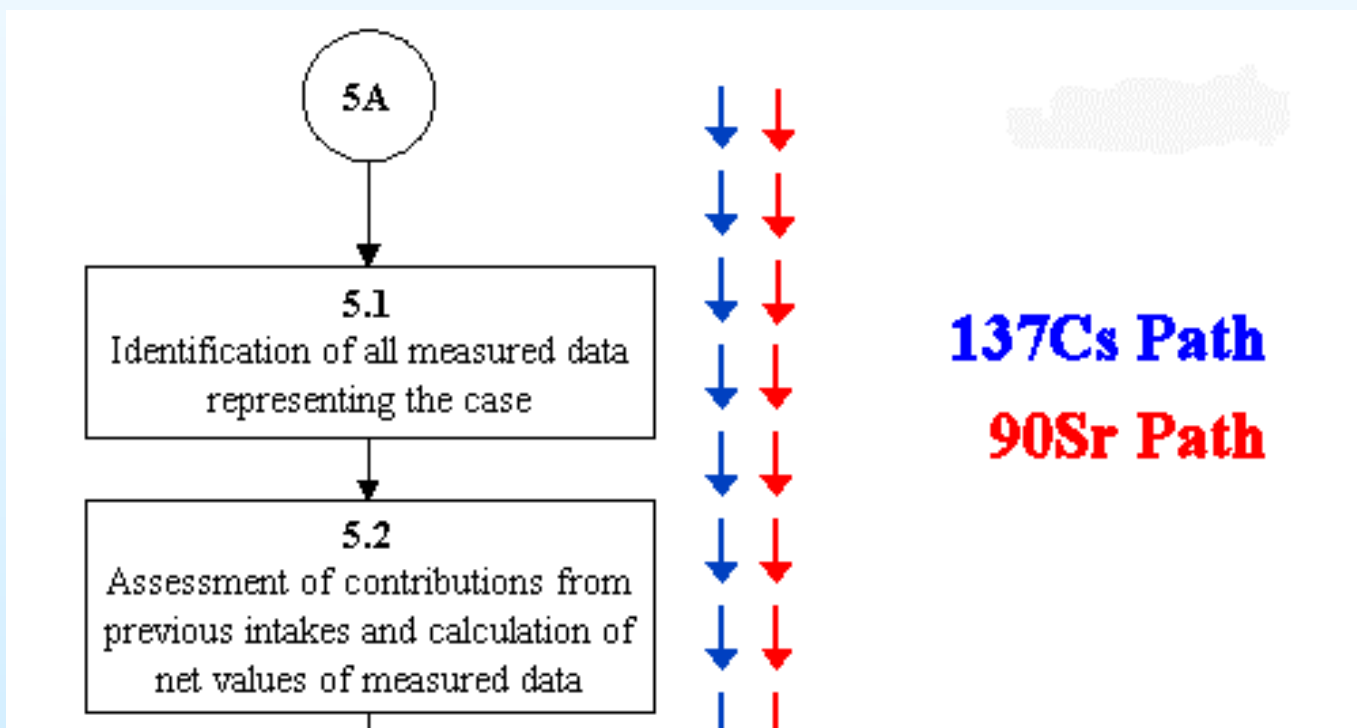
Step	Indication	Comment	Action to be performed
5	Subdivision in 5A, 5B and 5C	In the GL is indicated that the stage 5A is the same as the Stage 3 “Standard procedure” but the main difference is that there are more data.	Go to 5A



Step 5A – 5.2

Step	Indication	Comment	Action to be performed
5A– 5.1	Identification of all measured data representing the case	<p>In this case there are 11 urine and 5 faeces data for ⁹⁰Sr.</p> <p>For urine measurements (⁹⁰Sr) the GL in Table 2.3 give three different values related to a true 24-h sample (SF= 1.1), a simulated 24-h based on gravity normalization (SF=1.3) and spot urine samples (SF=2). Indication for Pu urine samples is indicated as comment and the value of SF=1.8 has been reported.</p> <p>It has been assumed a value of SF=1.8 for Sr urine data.</p> <p>For feces measurements the GL in Table 2.3 provide a range of values (3 < SF < 7) instead of a single value.</p> <p>It has been assumed a value of SF=3 for Sr faeces data.</p> <p>No need to operate further process for urine and faeces data as already presented as Bq/d (not concentration or else).</p>	Go to 5.2
5.2	Contribution from previous intakes	No need to evaluate contribution from previous intakes as in the case description there is no indication related to routine measurements previous the incident.	Go to 5.3

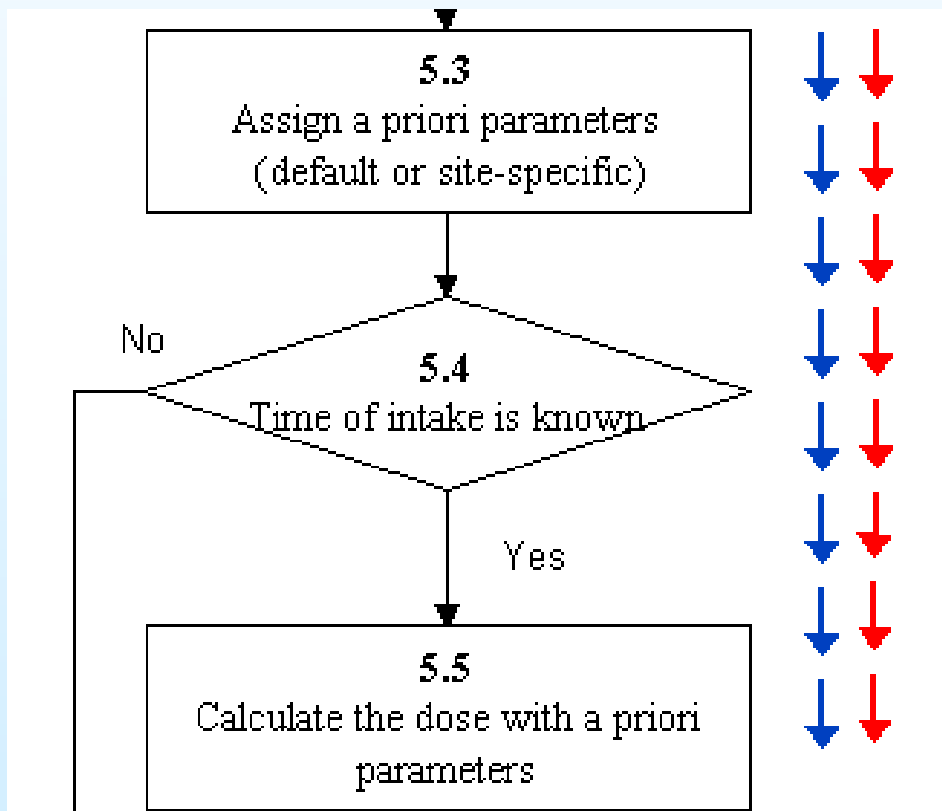
Step 5A – 5.2



Step 5.3 – 5.5

5.3	Assignment a priori parameters	As indicated in the GL: those for Unspecified compounds in Table 3.2 For Sr: single intake, time of intake known, Inhalation, Type F, $f_1=0.3$, AMAD = 5 μm .	Go to 5.4
5.4	Check for knowledge of time of intake	The time of intake in this case is known.	Go to 5.5
5.5	Calculate the dose with a priori parameters	The evaluation of dose is performed via the evaluation of intake and the use of correct dose coefficient. The dose coefficient has been calculated on the base of the same model used for the calculation of retention excretion functions.	Go to 5.6

Step 5.3 – 5.5



Fit for ^{90}Sr

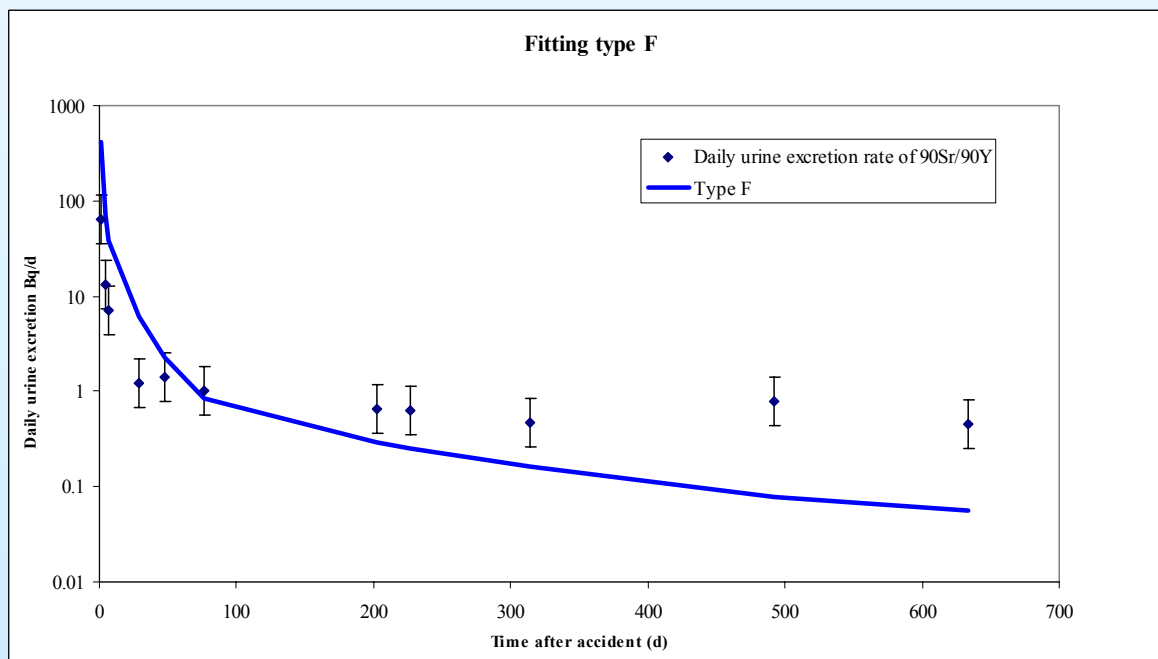
^{90}Sr

Only Urine data

All urine data (AMAD = 5 μm)	Intake (Bq)	E(50) (Sv)	χ^2_o (Dof=10)	Probability
Type F, f1=0.3	6045	1.81E-04	70.2	4.1E-11

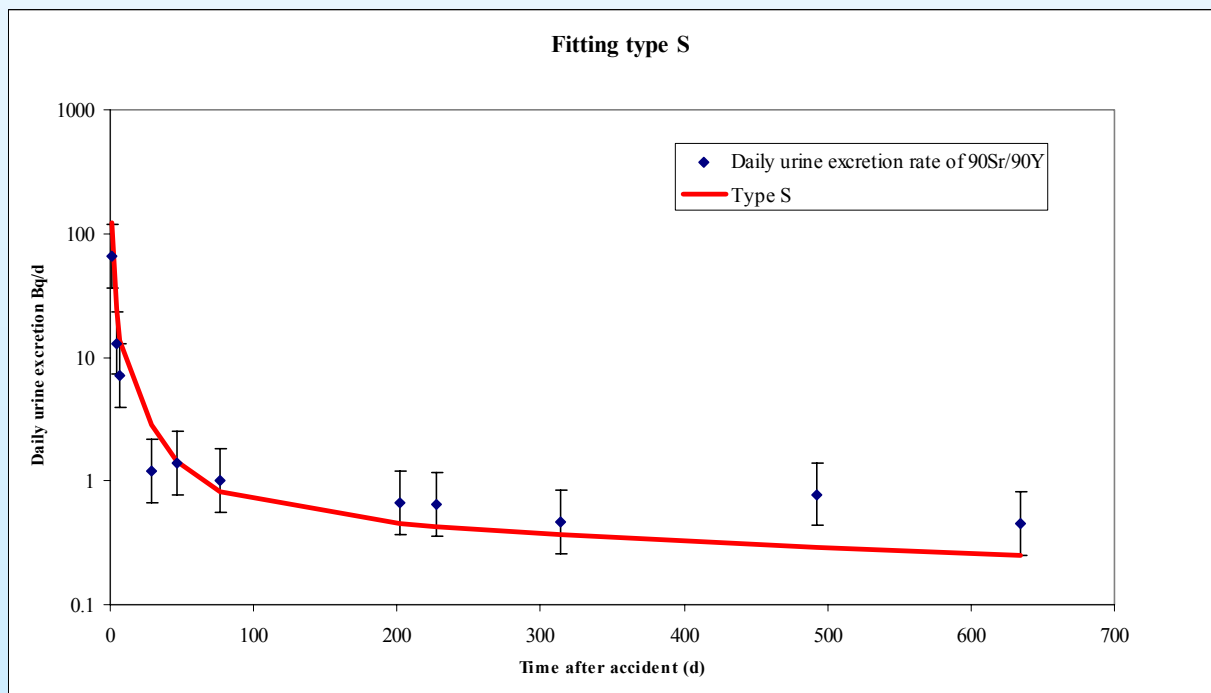
$$I = N \sqrt{\prod_{i=1}^N \left(\frac{M_i}{R_i} \right)}$$

$$\chi_0^2 = \sum_{i=1}^N \left(\frac{\ln(M_i) - \ln(I \cdot R_i)}{\ln(SF)} \right)^2$$



Fit for ^{90}Sr

All urine data (AMAD = 5 μm)	Intake (Bq)	E(50) (Sv)	χ^2_o (Dof=10)	Probability
Type S, f1= 0.01`	152165	1.17E-02	10.8	0.37



Step 5.6 – 5.6.1

5.6	Test for $E(50) < 1$ mSv	In case of ^{90}Sr $E(50) < 1$ mSv for type F, but for type S $E(50) > 1$ mSv . The fitting indicates a type S behaviour. It has been assumed a Type S absorption.	For ^{90}Sr go to 5B.
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Final estimation for ^{137}Cs :

Intake = 103590 Bq;

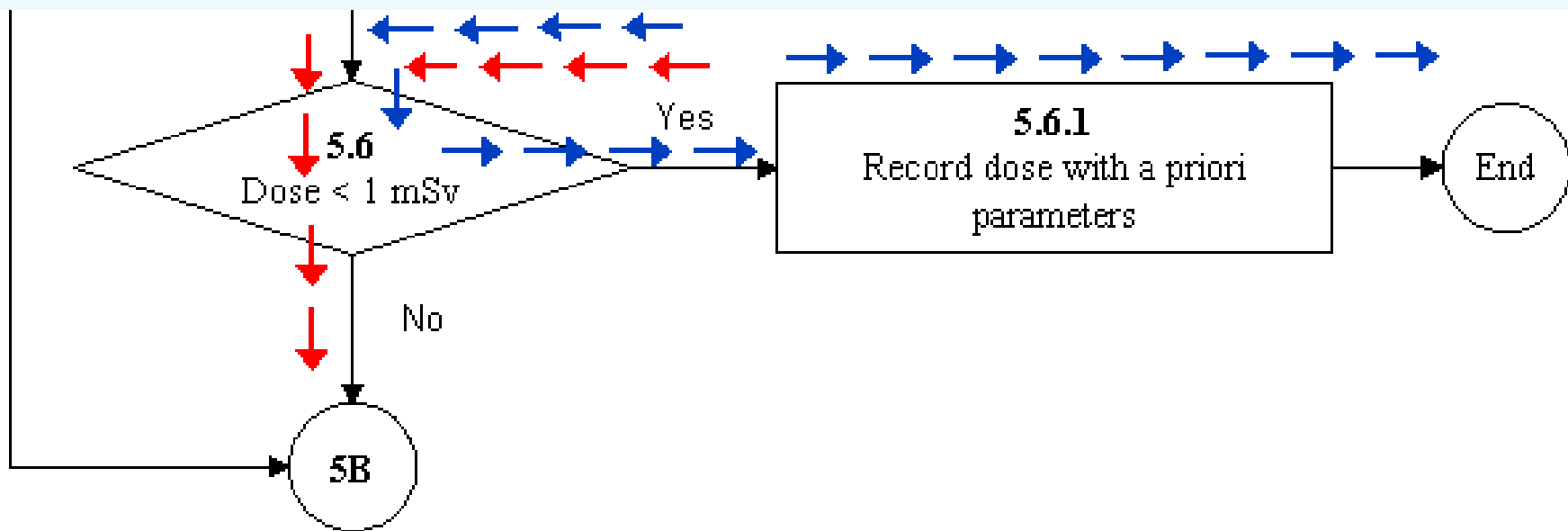
$e(50) = 6.7\text{E-}9$ Sv/Bq;

$E(50) = 0.694$ mSv;

Observed- $\chi^2 = 6.2$;

Dof = 6.

Step 5.6 – 5.6.1



Step 5.7 – 5.11

90Sr Path

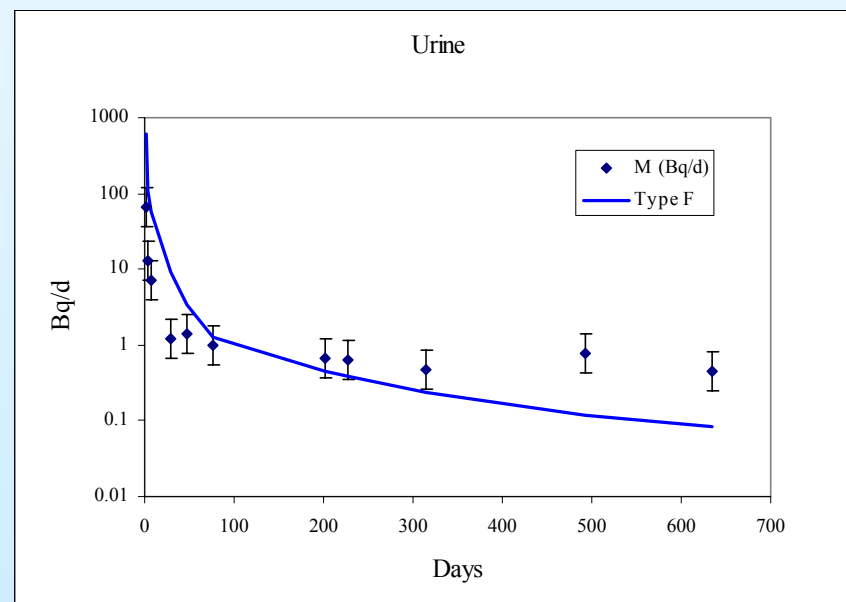
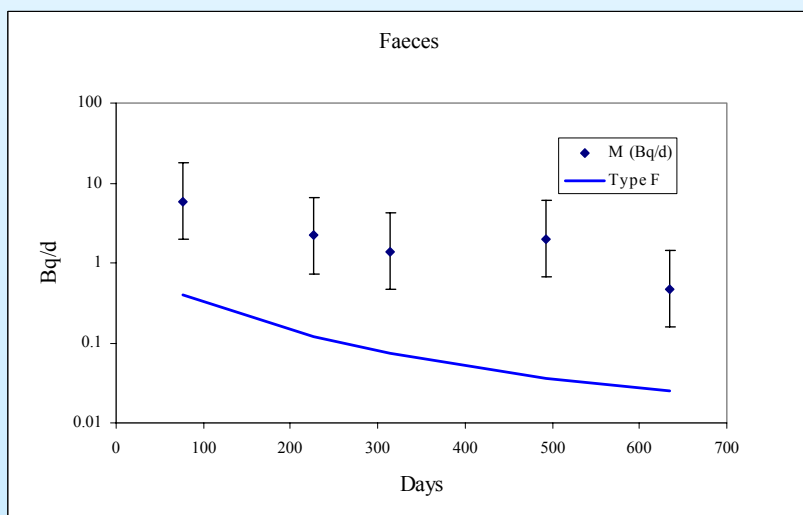
5B 5.7	Test for the number of relevant data	Considering the column related to $1\text{mSv} < D < 6 \text{ mSv}$ in the corresponding table of GL, there are more than 3 urine data in an interval of 30 days.	Go to 5.8
5.8	Test if the time of intake is known	In this case the time of intake is known.	Go to 5.9
5.9	Test on lung and faeces measurements	In this case early lung measurements are not available. Faeces measurements are available not early than 76 days post incident.	Go to 5.11
5.11	Assessment of dose by fitting of the absorption type.	The evaluation of dose for Type F and S, using urine data have been already reported in step 5.5. In that step it has been adopted the S absorption type for the ^{90}Sr . New evaluations considering both datasets (urine and faeces) simultaneously (see equations in next slide) provide the reported values.	Go to 5.11.1

Fitting of both datasets

$$\ln(I) = \frac{\sum_{i=1}^{N_U} \left(\frac{\ln\left(\frac{M_{U_i}}{R_{U_i}}\right)}{(\ln SF_U)^2} \right) + \sum_{i=1}^{N_F} \left(\frac{\ln\left(\frac{M_{F_i}}{R_{F_i}}\right)}{(\ln SF_F)^2} \right)}{\sum_{i=1}^{N_U} \frac{1}{(\ln SF_U)^2} + \sum_{i=1}^{N_F} \frac{1}{(\ln SF_F)^2}}$$

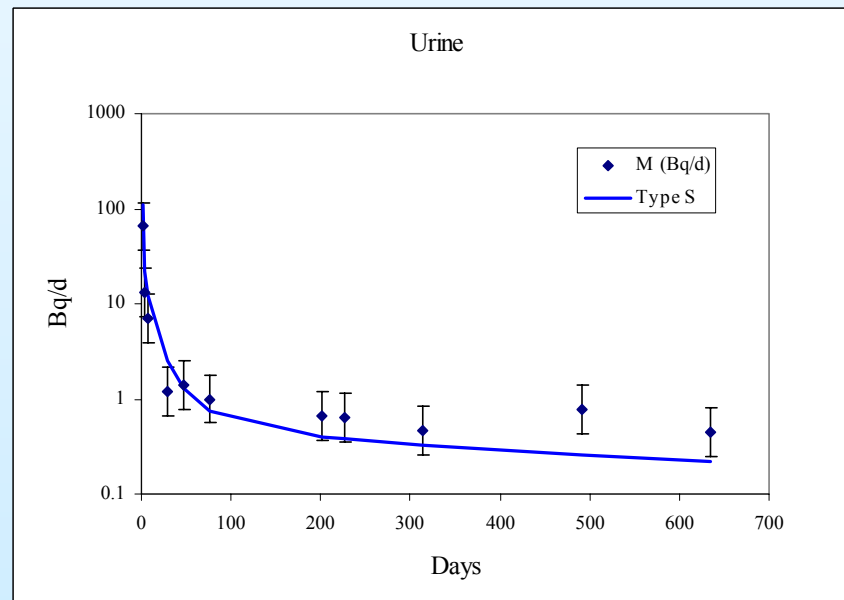
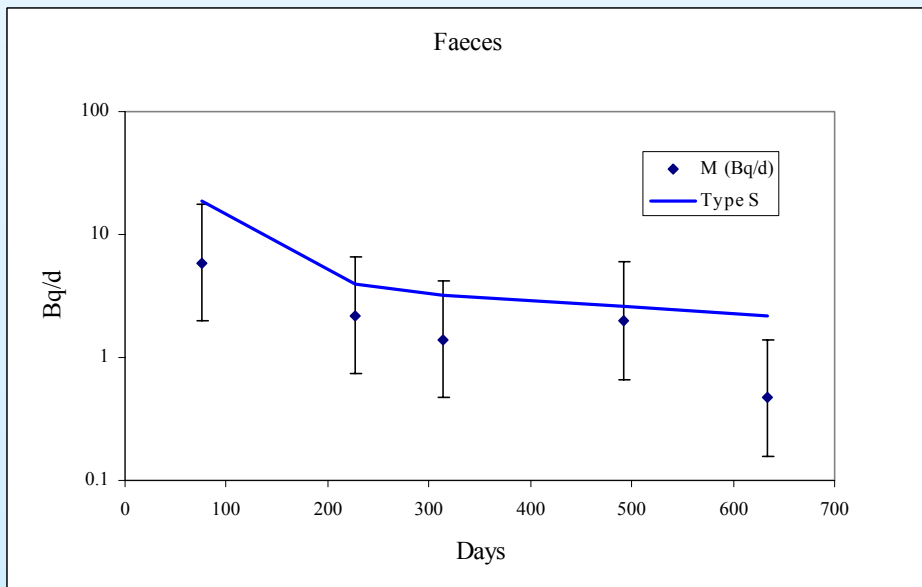
Both Urine and Faeces data (AMAD = 5 μ m)	Intake (Bq)	E(50) (Sv)	χ^2_o (Dof=15)	Probability
Type F, fl=0.3	9051	2.72E-04	116.15	1E-17

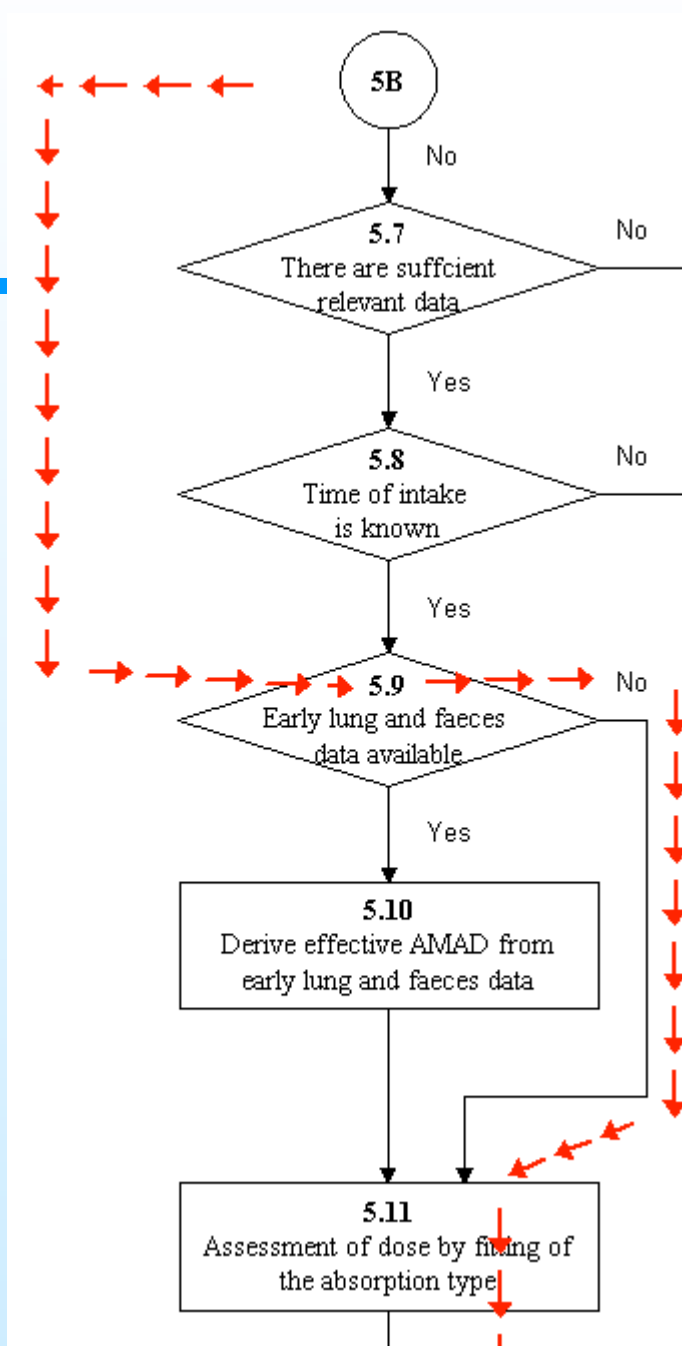
$$\chi^2_o = \sum_{i=1}^{N_U} \left(\frac{\ln(M_{U_i}) - \ln(I \cdot R_{U_i})}{\ln(SF_U)} \right)^2 + \sum_{i=1}^{N_F} \left(\frac{\ln(M_{F_i}) - \ln(I \cdot R_{F_i})}{\ln(SF_F)} \right)^2$$



Fitting of both datasets

Both Urine and Feces data (AMAD = 5 μm)	Intake (Bq)	E(50) (Sv)	χ^2_{\circ} (Dof=15)	Probability
Type S, f1 = 0.01'	135837	1.046E-02	15.21	0.436



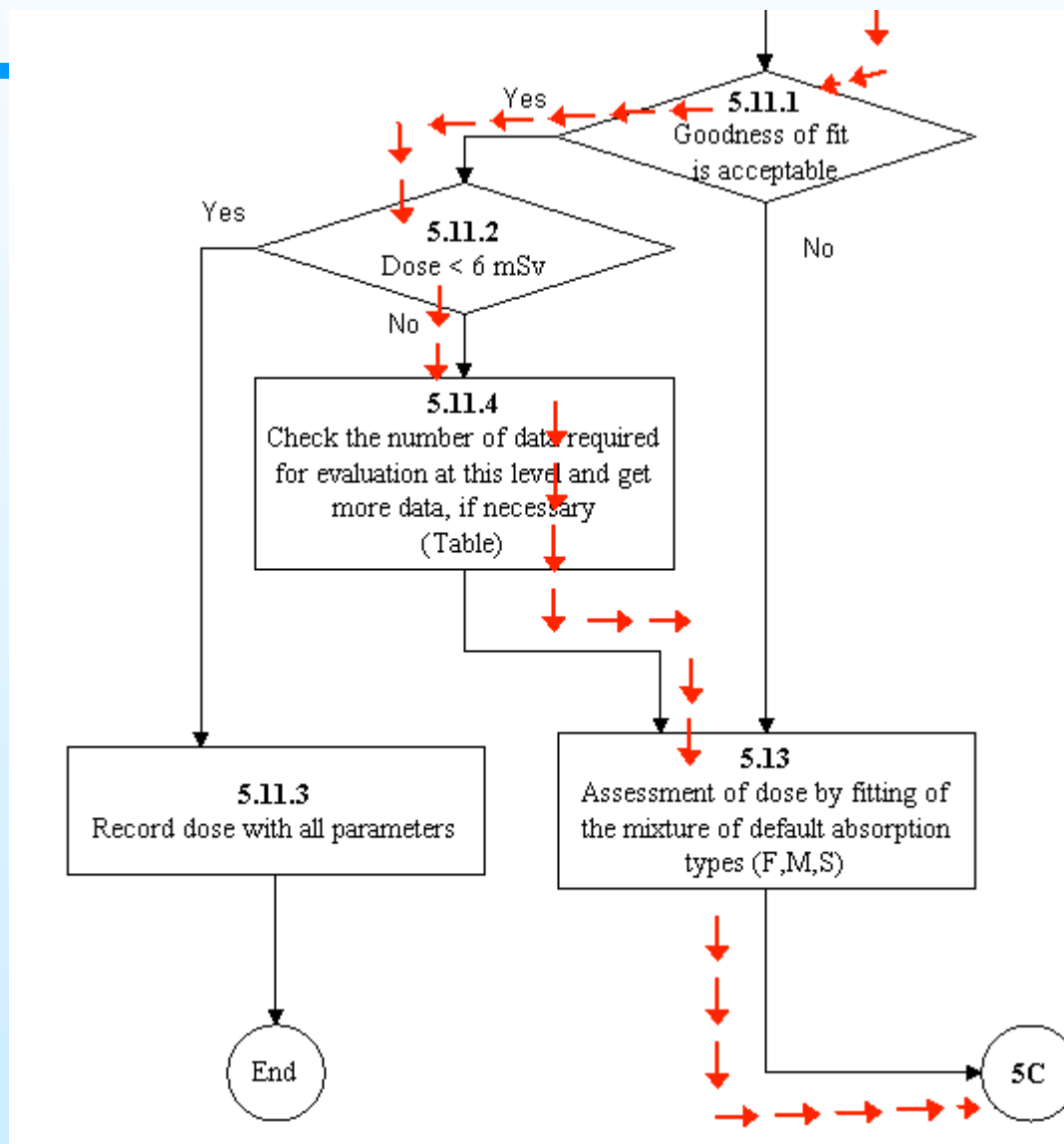


Step 5.7 – 5.11

Step 5.11.1 – 5.13

5.11.1	Test of acceptance of Gof	In the text “Criteria for rejecting fit” of the GL the equation to calculate the observed value of chi-squared statistic is related to normal distribution of measurement data. The criteria has been applied on the log-transformed data as reported in equation of slide 19. Fit for type F is thus rejected, while fit for type S is accepted ($p > 0.05$) .	Go to 5.11.2
5.11.2	Test for $E(50) > 6$ mSv	The dose for Type S is 10.46 mSv: thus it is above 6 mSv	Go to 5.11.4
5.11.4	Check for number of data	As in step 5.7 but for $E(50) > 6$ mSv. There are more than 3 urine data available in a 30 d period (4) but no more than 3 faeces data points in the same 30 d period (1 st data at day 76).	Go to 5.13
5.13	Assessment of dose by fitting a mixture of types	The fit of all the data using a mixture of type F and S does not improve the fitting as the smaller chi-squared value is that related to “only type S”. With a fraction of 1.7% type F, the fit is rejected for the procedure with $p=0.05$ (doses > 6 mSv). See table in next slide.	Go to 5C

Step 5.11.1 – 5.13



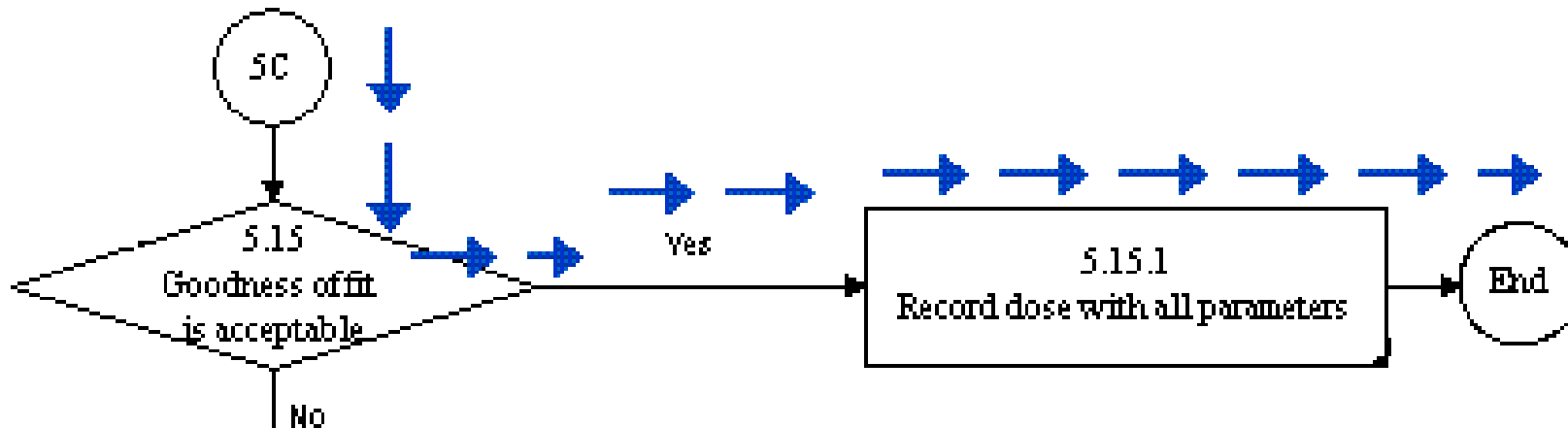
Fitting of mixed types

Fraction F	Fraction S	Chi-squared	Probability	Fit	Intake F (Bq)	Intake S (Bq)	E(50) (Sv)
0	1	15.21	0.436	Accepted	0	135837	0.0105
0.001	0.999	15.90	0.389	Accepted	132	131628	0.0101
0.002	0.998	16.57	0.345	Accepted	256	127751	0.0098
0.005	0.995	18.54	0.235	Accepted	592	117710	0.0091
0.01	0.99	21.58	0.119	Accepted	1058	104717	0.0081
0.015	0.985	24.32	0.060	Accepted	1443	94756	0.0073
0.017	0.983	25.33	0.046	Rejected	1580	91368	0.0071
0.02	0.98	26.78	0.031	Rejected	1771	86782	0.0067

Step 5C- 5.15.5

Step	Indication	Comment	Action to be performed
5C 5.15	Test on goodness of fit	The better fit has been evaluated with type S. The fit is not rejected by the “Criteria of rejection of fit”: the procedure can stop.	Go to 5.15.1
5.15.1	Record dose with all parameters	The values of the evaluation are: Type S - Intake = 135.8 kBq, E(50)=0.01046 Sv, $\chi^2_o = 15.21$, p = 0.436 .	END

Step 5C- 5.15.5



Estimation for ^{90}Sr :

Intake = 135837 Bq;

$e(50) = 7.7\text{E-}8 \text{ Sv/Bq};$

$E(50) = 10.5 \text{ mSv};$

Observed- $\chi^2 = 15.21;$

Dof = 15.

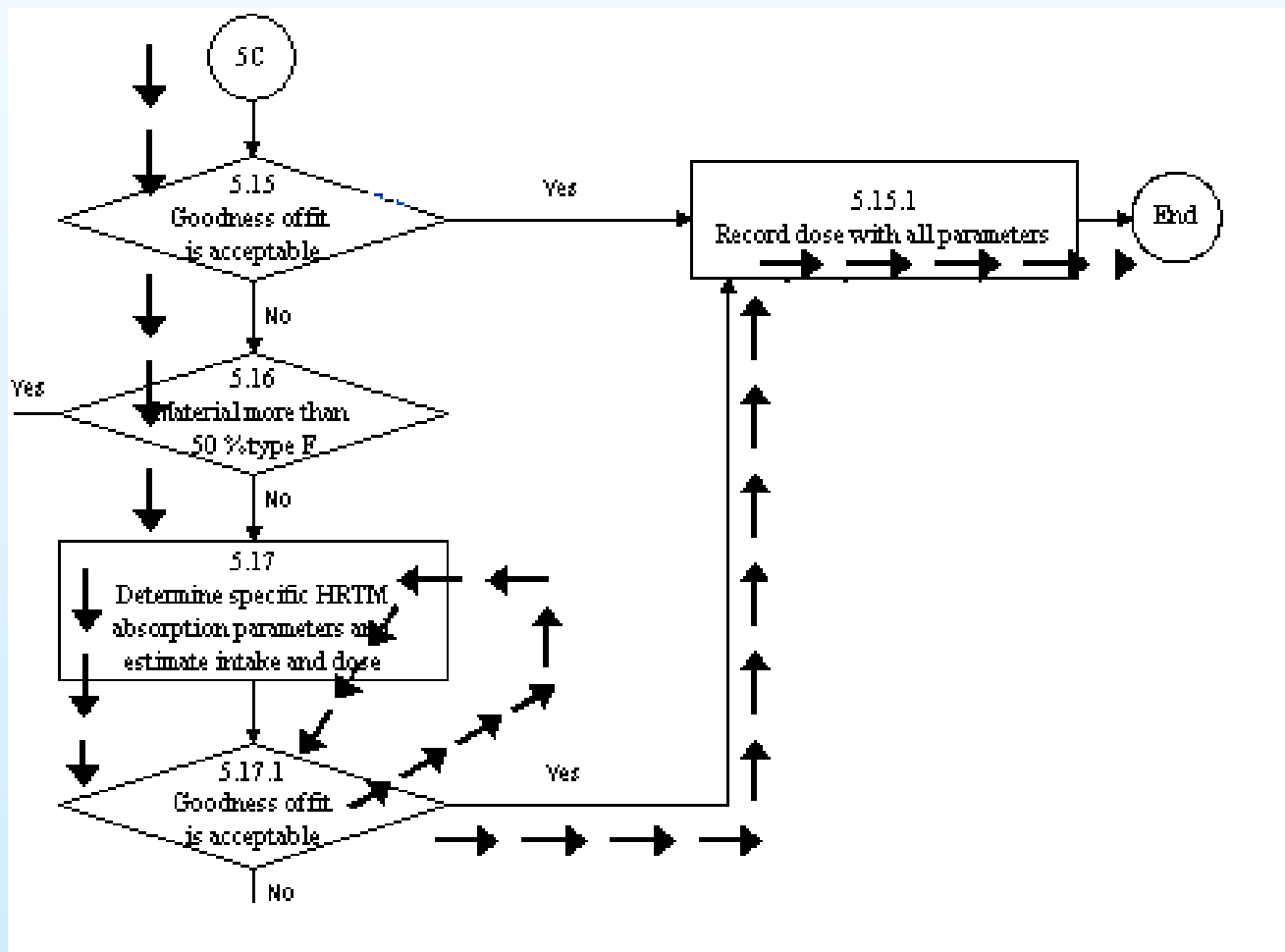
Alternative path

Step 5.16 – 5.17 – 5.15.1

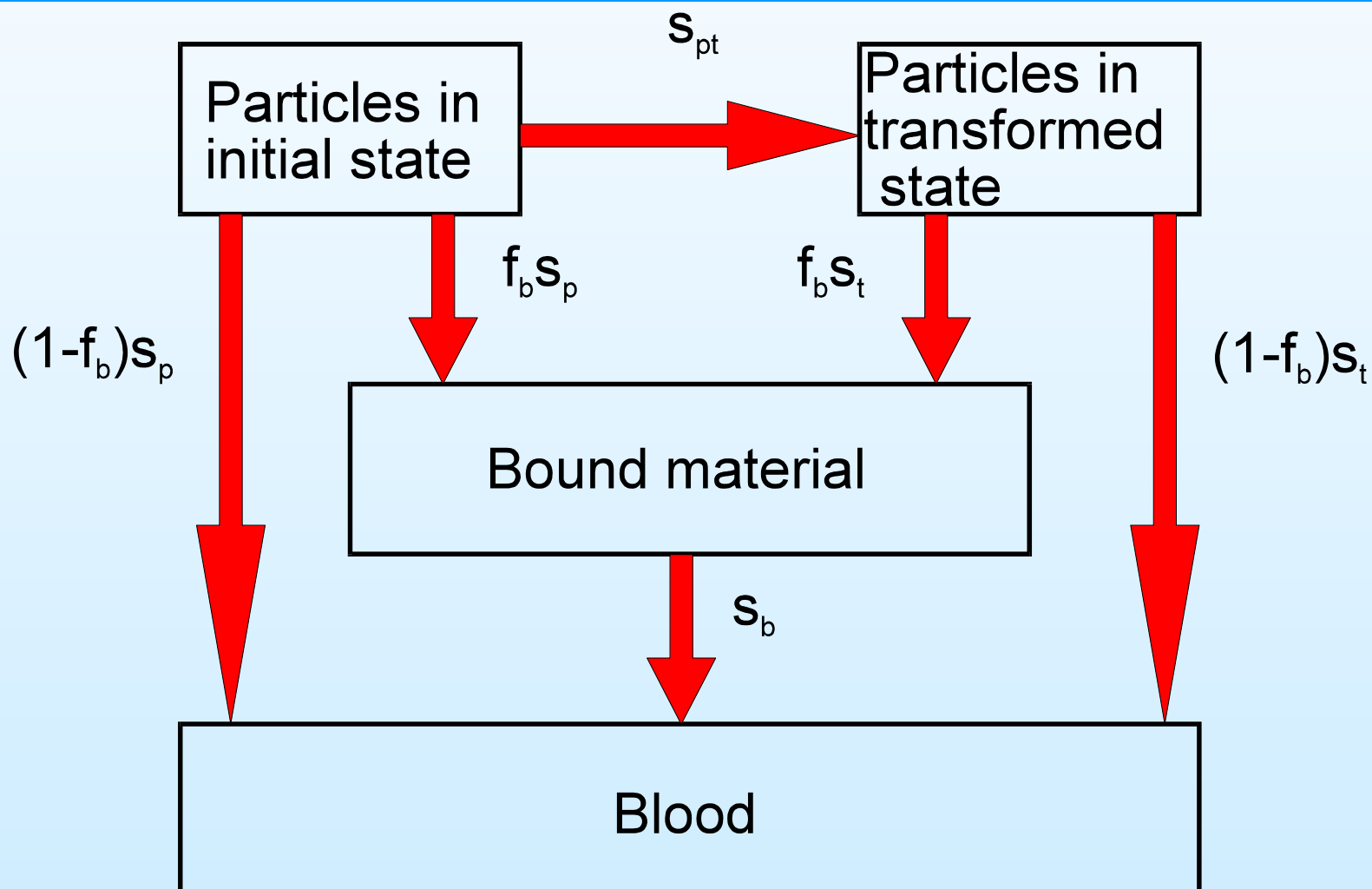
Step	Indication	Comment	Action to be performed
5.16	Test on material	No, the material considered type F is less than 50%.	Go to 5.17
5.17	Determine specific absorption parameters	To increase the urinary excretion at times greater than 200 d, I have tried to increase the parameter related to the final dissolution rate from the compartment “Particles in Transformed state” S_t . Instead of a value equal to $1E-4 d^{-1}$ a trial and error evaluation has been performed using values between $3E-4 d^{-1}$ and $1E-3 d^{-1}$ considering that the long term excretion seems more governed by a M type compound. The other 2 parameters S_p and S_{pt} are maintained to the original type S values namely: $0.1 d^{-1}$ and $100 d^{-1}$. I have used IMBA code.	Go to 5.17.1
5.17.1	Test on goodness of fit	The trial and error evaluation permits to obtain the values of Table 2 in which the observed chi-squares values are reported. As can be seen the minimum value of observed chi-squares is reached for a value of $5E-4 d^{-1}$. With the modification of parameter S_t a reduction of a factor of 2 in intake evaluation can be reached.	Go recursively to 5.17 Then go to 5.15.1
5.15.1	Record dose with all parameters	For the evaluation using Type S and the modified parameter $S_t = 5E-4 d^{-1}$ the values of the evaluation of ^{90}Sr are as follows: Intake = 67152 Bq; $E(50) = 3.43 mSv$, observed-chi-squared = 2.79. The estimated $E(50)$ is a factor of 3 less than the previous evaluation of pure type S.	END

Alternative path

Step 5.16 – 5.17 – 5.15.1



Compartmental representation of absorption to blood



Value of S_t and χ_0^2

S_t value $\times 10^{-4}$ [d ⁻¹]	χ_0^2	Intake (Bq)
3	4.09	85290
4	3.03	74598
4.5	2.84	
4.7	2.80	
4.8	2.79	
4.9	2.79	
5.0	2.79	67152
5.2	2.80	
5.5	2.84	
6	2.96	61620
8	3.92	53900
10	5.21	48740

$$\ln(I) = \frac{\sum_{i=1}^{N_U} \left(\frac{\ln\left(\frac{M_{U_i}}{R_{U_i}}\right)}{(\ln SF_U)^2} \right) + \sum_{i=1}^{N_F} \left(\frac{\ln\left(\frac{M_{F_i}}{R_{F_i}}\right)}{(\ln SF_F)^2} \right)}{\sum_{i=1}^{N_U} \frac{1}{(\ln SF_U)^2} + \sum_{i=1}^{N_F} \frac{1}{(\ln SF_F)^2}}$$

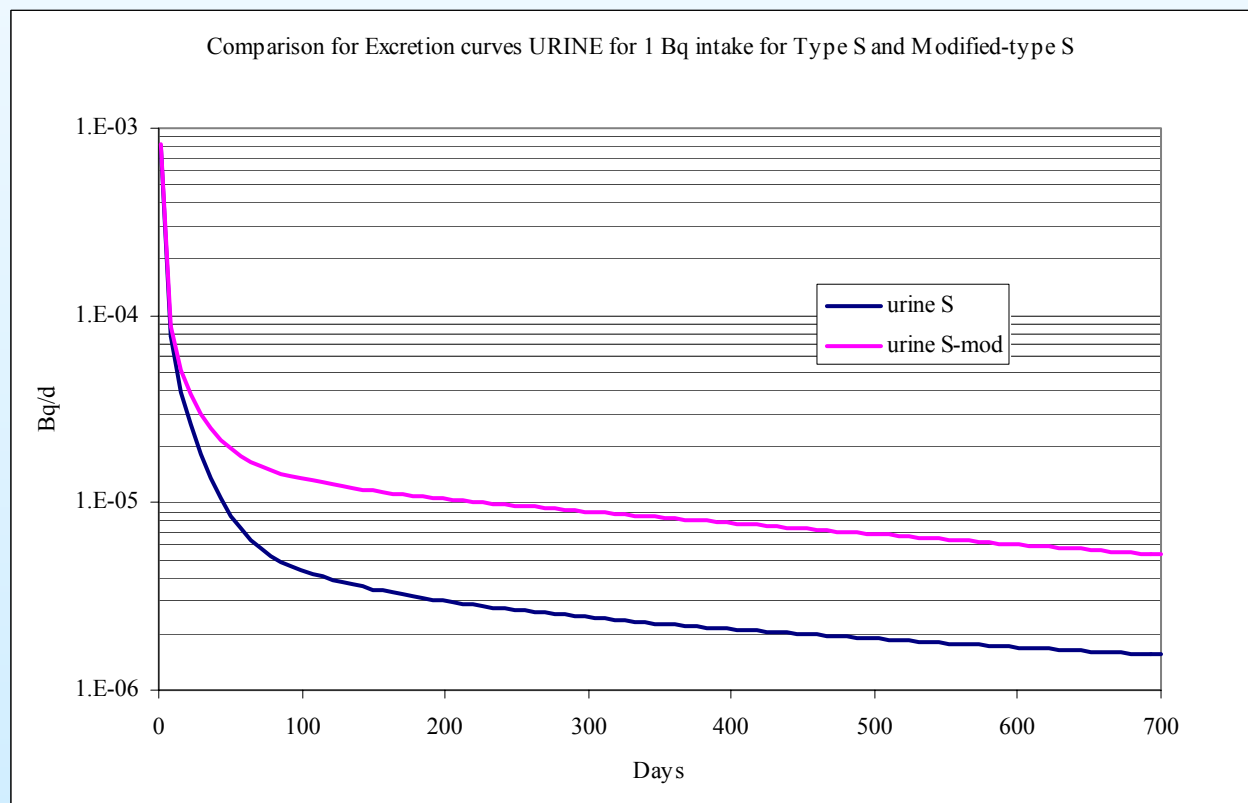
$$\chi_0^2 = \sum_{i=1}^{N_U} \left(\frac{\ln(M_{U_i}) - \ln(I \cdot R_{U_i})}{\ln(SF_U)} \right)^2 + \sum_{i=1}^{N_F} \left(\frac{\ln(M_{F_i}) - \ln(I \cdot R_{F_i})}{\ln(SF_F)} \right)^2$$

$$SF_U = 1.8$$

$$SF_F = 3$$

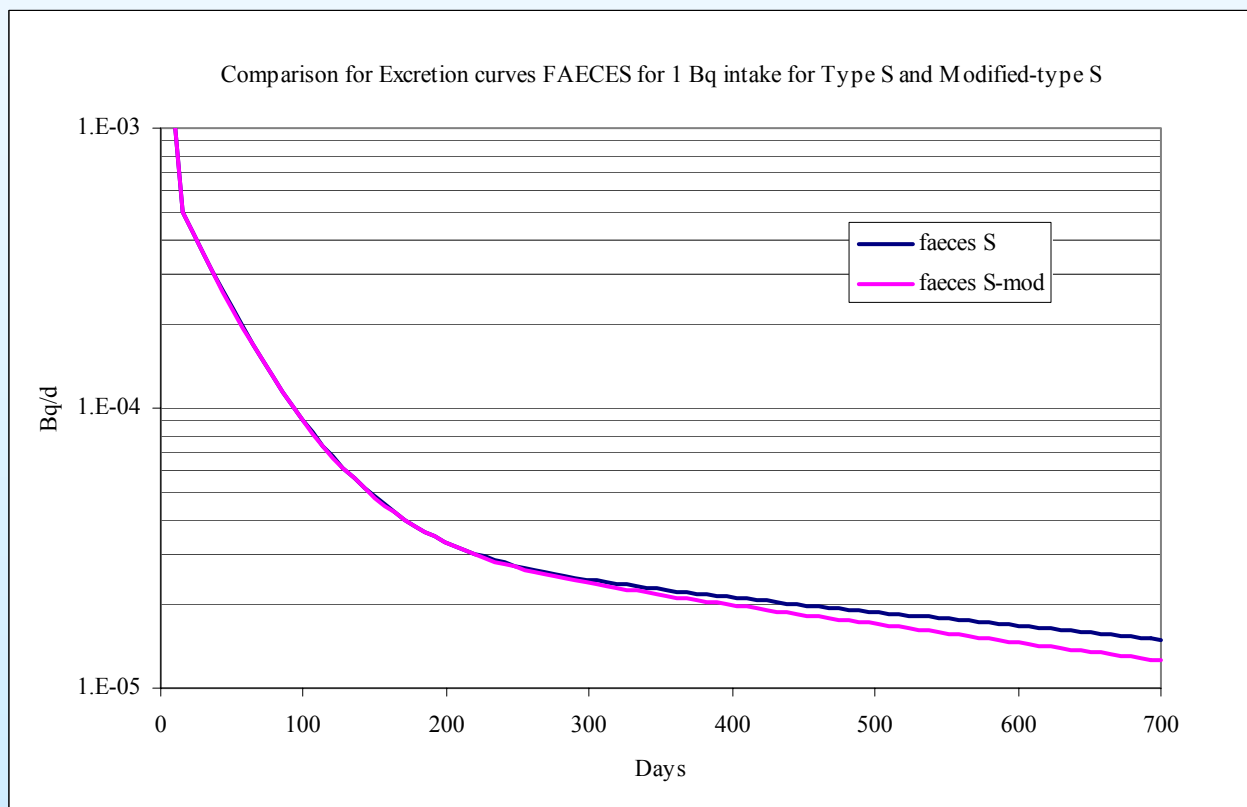
Modified excretion curves Urine

Urine excretion: increased

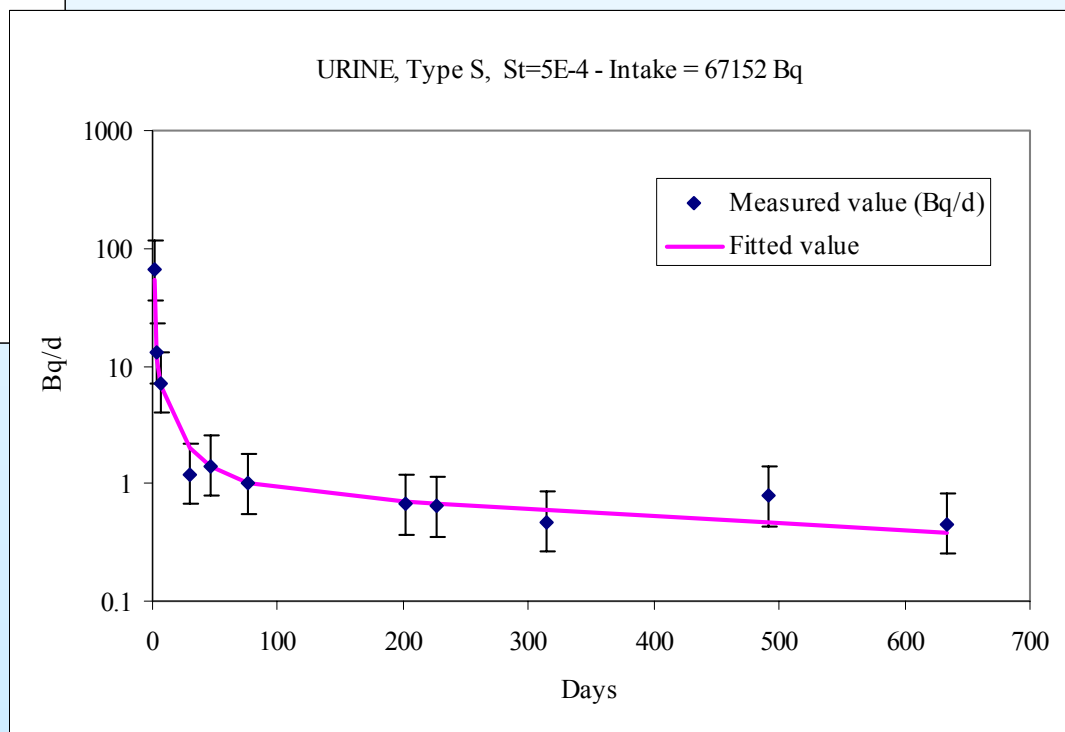
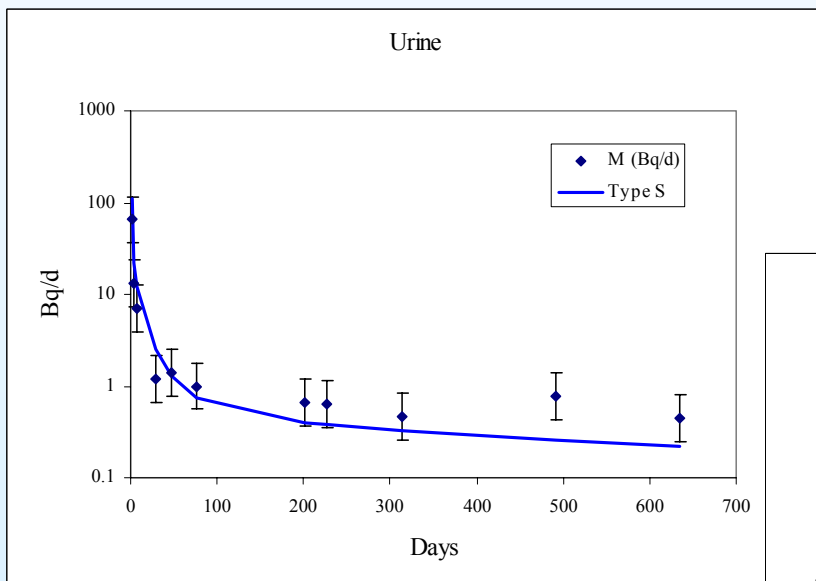


Modified excretion curves Faeces

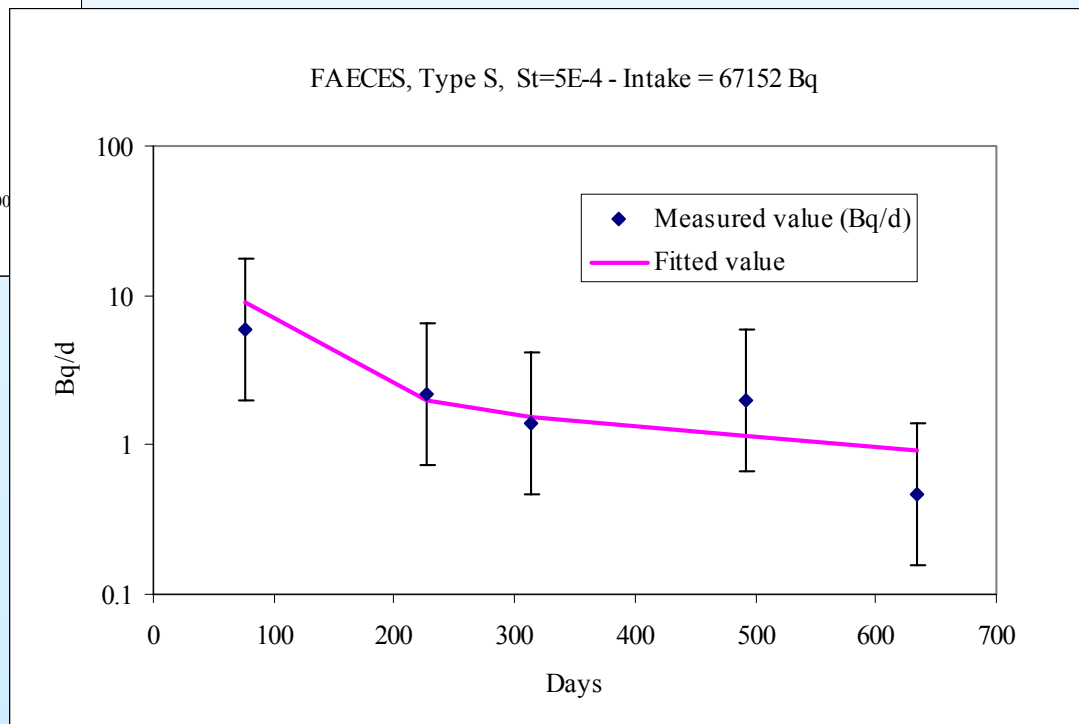
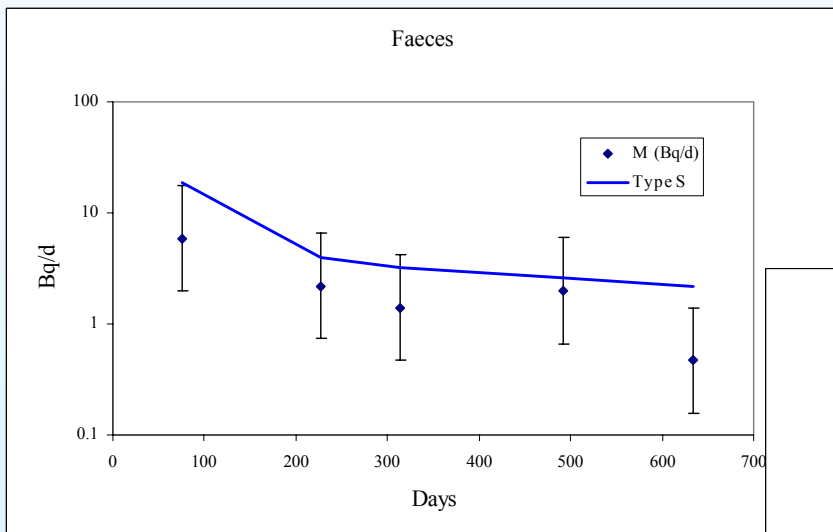
Faeces excretion: unchanged up to 300 d and then slightly decreased



Best fit = Modified S - Urine



Best fit = Modified S - Faeces



Final estimation for ^{90}Sr :

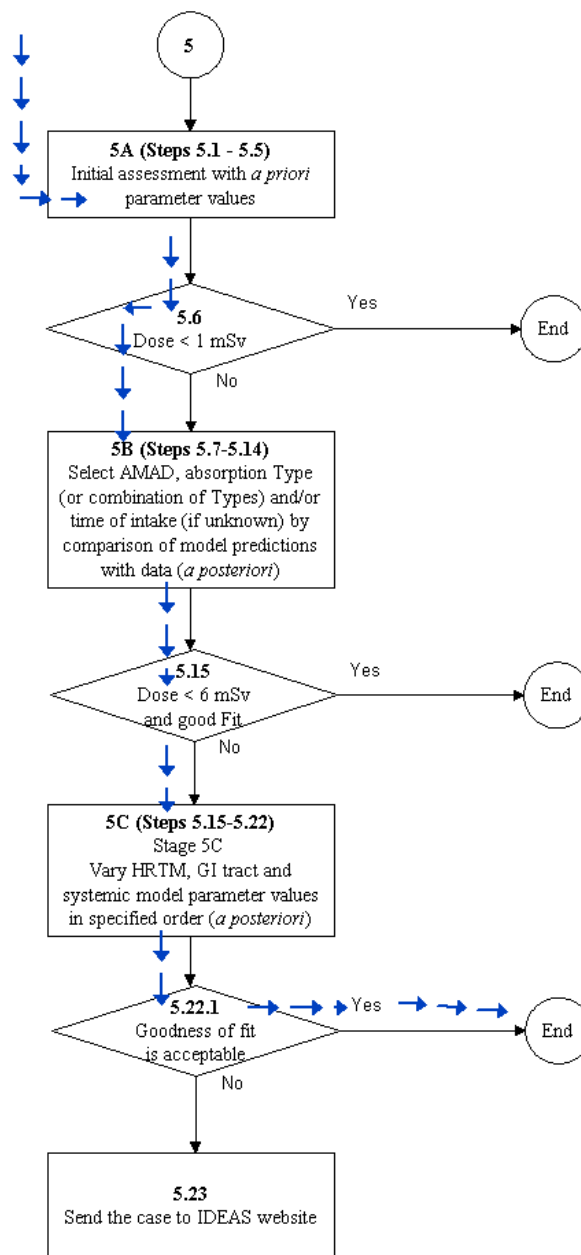
Intake = 67152 Bq;

$e(50) = 5.1\text{E-}8 \text{ Sv/Bq};$

$E(50) = 3.4 \text{ mSv};$

Observed- $\chi^2 = 2.79;$

Dof = 15.





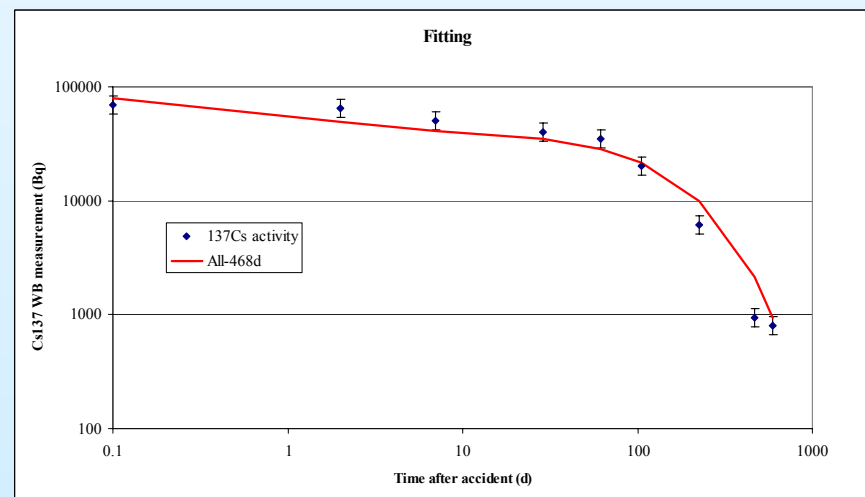
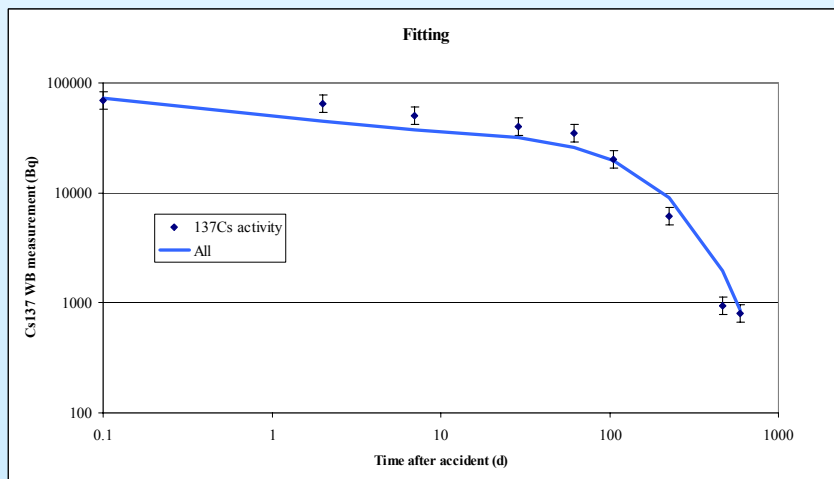
Fit for ^{137}Cs

^{137}Cs

$$I = \sqrt[N]{\prod_{i=1}^N \left(\frac{M_i}{R_i} \right)}$$

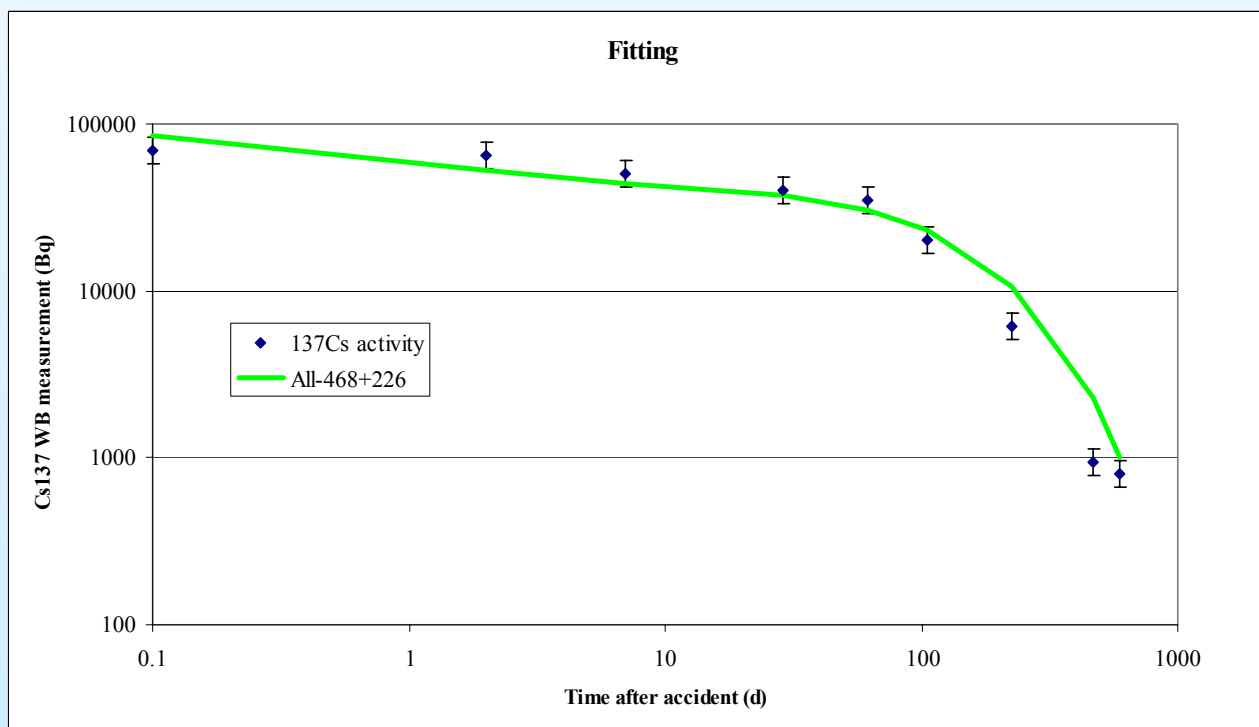
N of data	Intake (Bq)	E(50) (Sv)	χ^2_o	Probability
All	88342	5.92E-04	32.0 (Dof=8)	9.2E-05
All except day 468	96793	6.49E-04	14.0 (Dof=7)	0.052

$$\chi^2_o = \sum_{i=1}^N \left(\frac{\ln(M_i) - \ln(I \cdot R_i)}{\ln(SF)} \right)^2$$



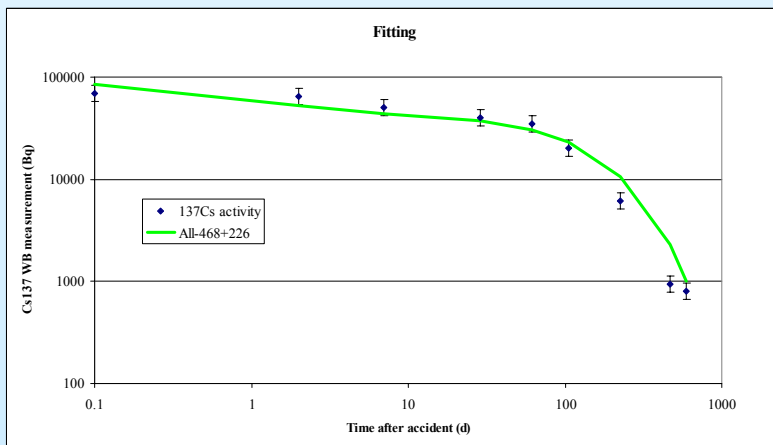
Fit for ^{137}Cs

N of data	Intake (Bq)	E(50) (Sv)	χ^2_o (Dof=6)	Probability
All except day 468 and 226	103590	6.94E-04	6.2	0.402



Step 5.6 – 5.6.1

5.6	Test for $E(50) < 1$ mSv	In the case of ^{137}Cs $E(50) < 1$ mSv as it is 0.69 mSv. In case of ^{90}Sr $E(50) < 1$ mSv for type F, but for type S $E(50) > 1$ mSv . The fitting indicates a type S behaviour. It has been assumed a Type S absorption.	For ^{137}Cs go to 5.6.1 For ^{90}Sr go to 5B.
5.6.1	Record dose with a priori parameters	For ^{137}Cs : single intake, time of intake known, Inhalation, Type F, $f_1=1$, AMAD = 5 μm , SF=1.2, discharge of data points at 468 and 226 d, Intake = 103.6 kBq, $E(50)=6.9\text{E-}4$ Sv, observed-chi-squared = 6.2 .	END



Final estimation for ^{137}Cs :

Intake = 103590 Bq;

$e(50) = 6.7\text{E-}9$ Sv/Bq;

$E(50) = 0.694$ mSv;

Observed- $\chi^2 = 6.2$;

Dof = 6.