



# Cumulative cross sections

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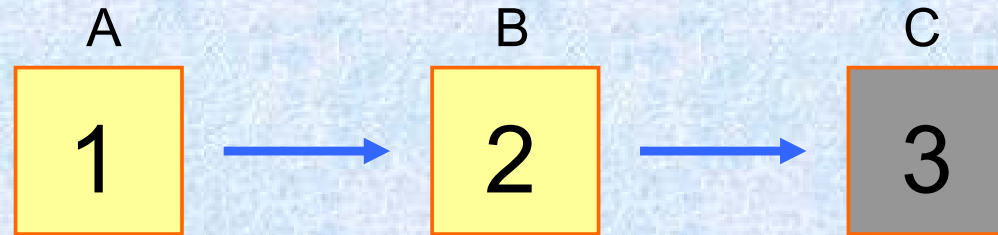
# Cumulative cross sections



What are the measured data ?

What are the reported data ?

What are the compiled data ?



<b>Br 75</b> 96.7 m β <sup>+</sup> 1.7, 2.0... γ 287, 141...	<b>Br 76</b> 1.31 s 16.2 h β <sup>+</sup> 3.4 3.9... γ 559, 657 1857... IT 57... e <sup>-</sup> γ 45, e <sup>-</sup> σ <sub>cap</sub> 224	<b>Br 77</b> 4.28 m 57.04 h IT 106, e <sup>-</sup>	<b>Br 78</b> 6.46 m β <sup>+</sup> 2.6... γ 614...	<b>Br 79</b> 4.86 s 50.69 IT 207 σ 2.5 + 8.3
<b>Se 74</b> 0.89 σ 50	<b>Se 75</b> 119.78 d β <sup>-</sup> 265, 136, 280 121, 401... σ 330	<b>Se 76</b> 9.37 σ 22 + 63	<b>Se 77</b> 17.36 s 7.63 IT 162 σ 41.5	<b>Se 78</b> 23.77 σ 0.38 + 0.05
<b>As 73</b> 80.3 d ε no β <sup>+</sup> γ 53... e <sup>-</sup>	<b>As 74</b> 17.77 d β <sup>+</sup> 0.9, 1.5... β <sup>-</sup> 1.4... γ 596, 635...	<b>As 75</b> 100 σ 4.0	<b>As 76</b> 26.24 h β <sup>-</sup> 3.0 γ 559, 657 1216..., e	<b>As 77</b> 38.79 h β <sup>-</sup> 0.7... γ 239, 521 250... g

Definition 1

$$\sigma_{2cum} = \sigma_2 + f\sigma_1$$



## Activation method

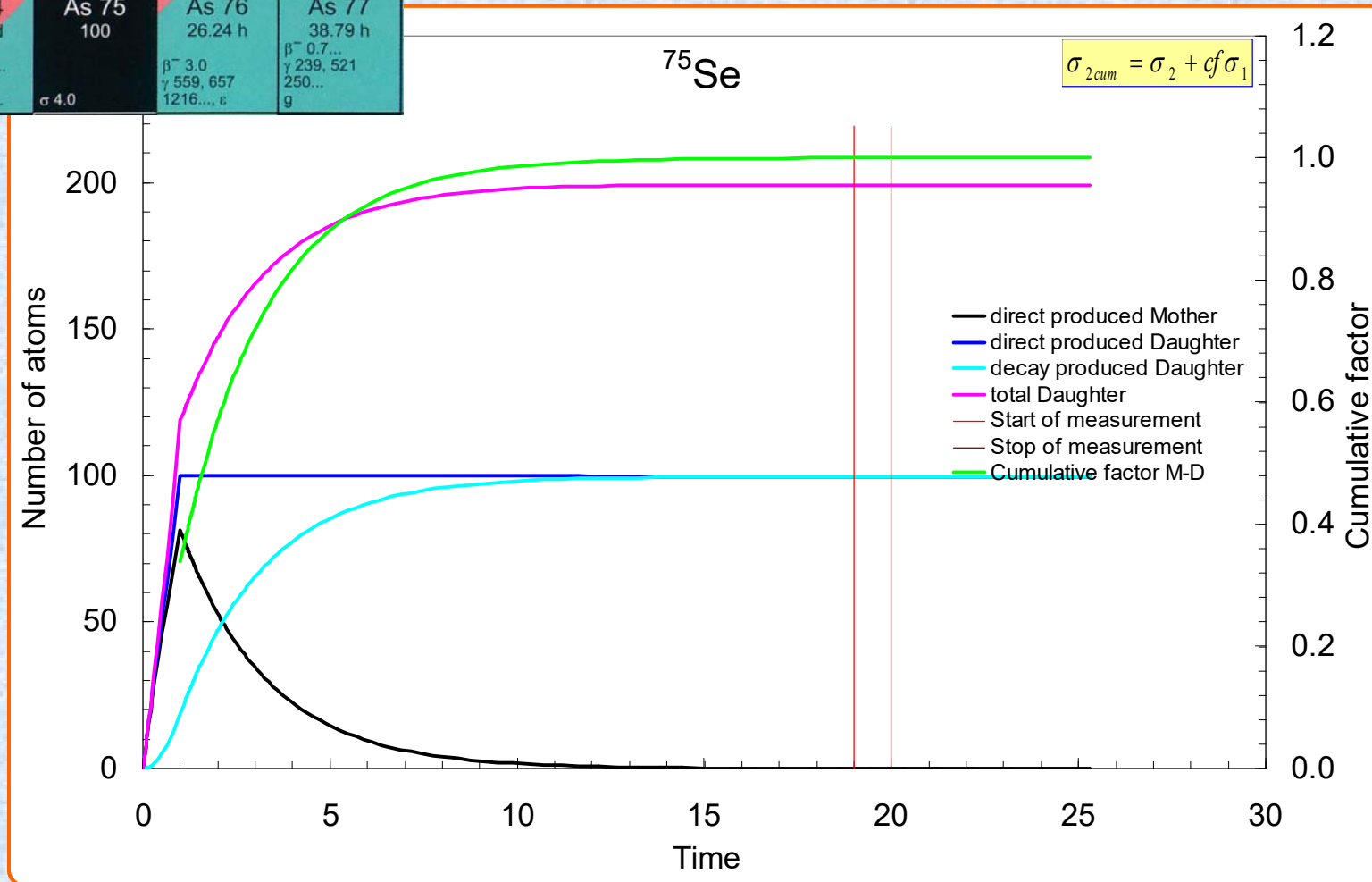
<b>Br 75</b> 96.7 m $\beta^+$ 1.7, 2.0... $\gamma$ 287, 141...	<b>Br 76</b> 1.31 s 16.2 h $\beta^+$ 3.4 3.9... $\gamma$ 559, 657 IT 57... $\gamma$ 45, e <sup>-</sup> $\sigma_{th}$ 224	<b>Br 77</b> 4.28 m 57.04 h $\beta^+$ ... $\gamma$ 239, 521 297... IT 106, e <sup>-</sup>	<b>Br 78</b> 6.46 m $\beta^+$ 2.6... $\gamma$ 614...	<b>Br 79</b> 4.86 s 50.69 IT 207 $\sigma$ 2.5 + 8.3
<b>Se 74</b> 0.89 $\sigma$ 50	<b>Se 75</b> 119.78 d $\beta^-$ $\gamma$ 265, 136, 280 121, 401... $\sigma$ 330	<b>Se 76</b> 9.37 $\sigma$ 22 + 63	<b>Se 77</b> 17.36 s 7.63 IT 162 $\sigma$ 41.5	<b>Se 78</b> 23.77 $\sigma$ 0.38 + 0.05
<b>As 73</b> 80.3 d $\beta^-$ no $\beta^+$ $\gamma$ 53... e <sup>-</sup>	<b>As 74</b> 17.77 d $\beta^+$ 0.9, 1.5... $\beta^-$ 1.4... $\gamma$ 596, 635...	<b>As 75</b> 100 $\sigma$ 4.0	<b>As 76</b> 26.24 h $\beta^-$ 3.0 $\gamma$ 559, 657 1216..., e	<b>As 77</b> 38.79 h $\beta^-$ 0.7... $\gamma$ 239, 521 250... g

$$T_{1/2}(1) < T_{1/2}(2)$$

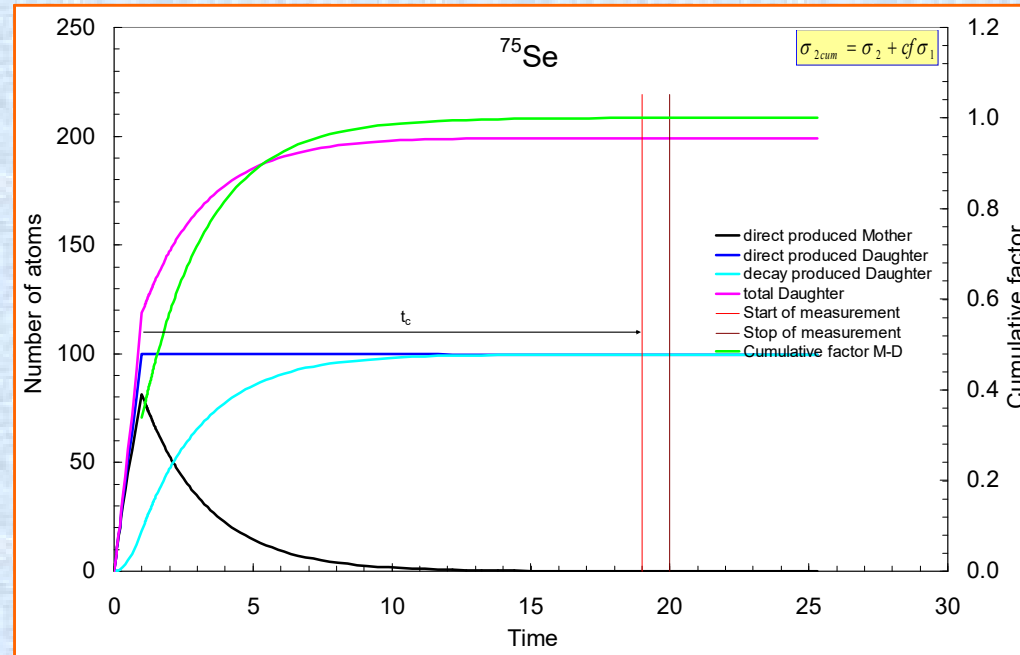
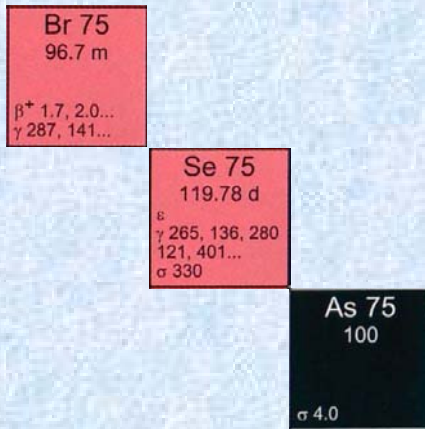
**Br 75**  
96.7 m  
 $\beta^+$  1.7, 2.0...  
 $\gamma$  287, 141...

**Se 75**  
119.78 d  
 $\beta^-$   
 $\gamma$  265, 136, 280  
121, 401...  
 $\sigma$  330

**As 75**  
100  
 $\sigma$  4.0



## Activation method



$$\sigma_{2,cum} = \frac{\lambda_2 T_{\gamma,cum}}{\epsilon_d \epsilon_\gamma N_t N_b (1 - e^{-\lambda_2 t_b}) e^{-\lambda_2 t_c} (1 - e^{-\lambda_2 t_m})} = \sigma_2 + cf\sigma_1$$

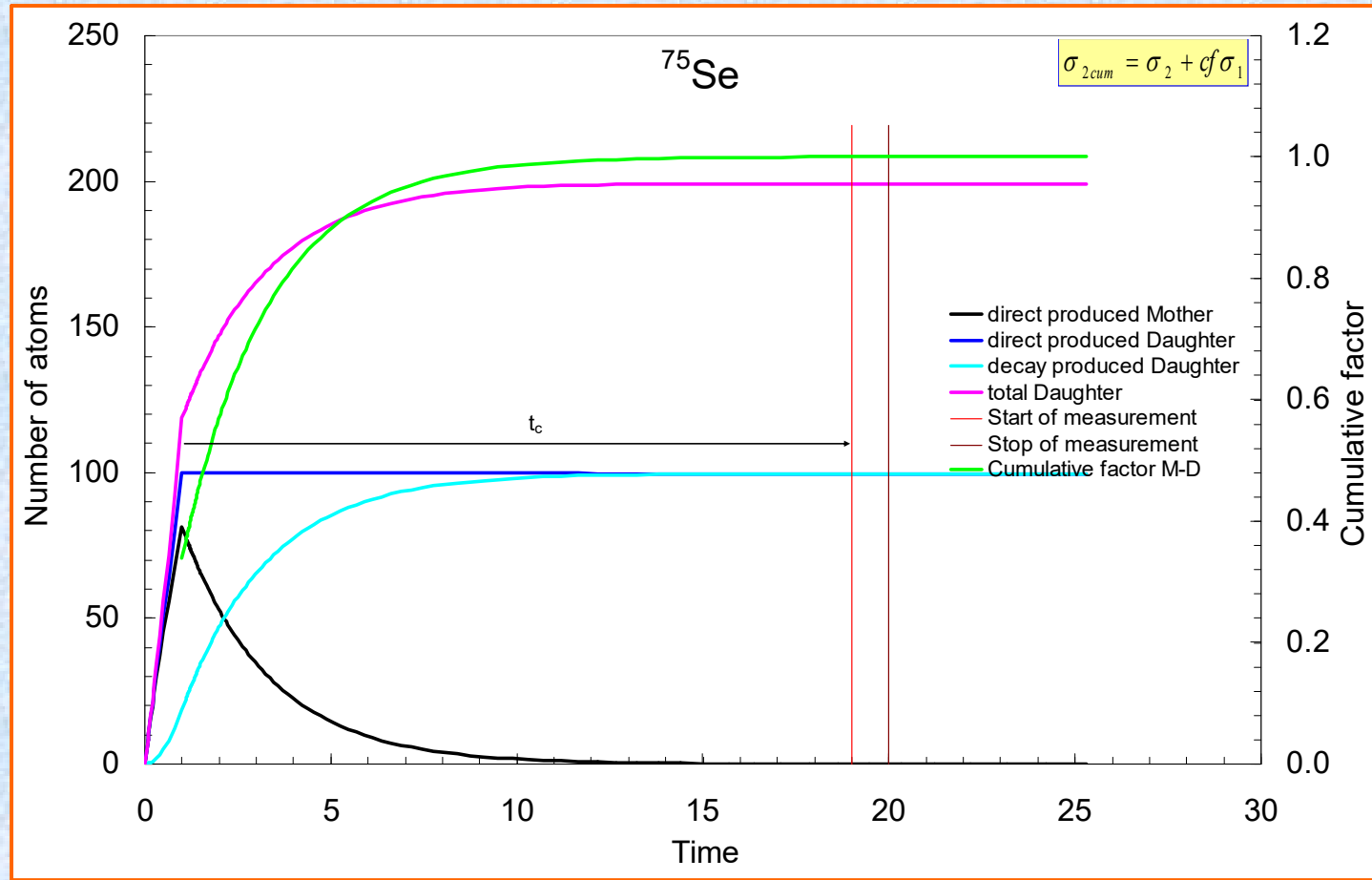
$$c = \frac{\lambda_1}{\lambda_1 - \lambda_2} \left( 1 - \frac{\lambda_2}{\lambda_1} \frac{\lambda_2 (1 - e^{-\lambda_1 t_b}) e^{-\lambda_1 t_c} (1 - e^{-\lambda_1 t_m})}{\lambda_1 (1 - e^{-\lambda_2 t_b}) e^{-\lambda_2 t_c} (1 - e^{-\lambda_2 t_m})} \right)$$

## Activation method

$c$  is time dependent

$$c = \frac{\lambda_1}{\lambda_1 - \lambda_2} \left( 1 - \frac{\lambda_2}{\lambda_1} \frac{\lambda_2 (1 - e^{-\lambda_1 t_b}) e^{-\lambda_1 t_c} (1 - e^{-\lambda_1 t_m})}{\lambda_1 (1 - e^{-\lambda_2 t_b}) e^{-\lambda_2 t_c} (1 - e^{-\lambda_2 t_m})} \right)$$

$$T_{1/2}(1) < T_{1/2}(2)$$



Br 75  
96.7 m  
 $\beta^+$  1.7, 2.0...  
 $\gamma$  287, 141...

Se 75  
119.78 d  
 $\beta^-$  265, 136, 280  
 $\gamma$  121, 401...  
 $\sigma$  330

As 75  
100  
 $\sigma$  4.0

$$\sigma_{2cum} = \sigma_2 + cf\sigma_1$$

$$c = \frac{\lambda_1}{\lambda_1 - \lambda_2} > 1$$

$$C=1.00056$$

## Activation method

### Definition 1

$$\sigma_{2cum} = \sigma_2 + f\sigma_1$$

### Definition 2

$$\sigma_{2cum} = \sigma_2 + cf\sigma_1$$

$$C=1.00056$$

conditional  
supracumulative

Yu.E. Titarenko et al.,  
Phys. Rev. C65(2002)064610

Br 75 96.7 m $\beta^+$ 1.7, 2.0... $\gamma$ 287, 141... $\sigma$ 50	Br 76 1.31 s 16.2 h $\beta^+$ 3.4 3.9... $\gamma$ 559, 657 1857... $\sigma$ 224	Br 77 4.28 m 57.04 h $\beta^+$ 2.39, 521 297... $\sigma$ 22 + 63	Br 78 6.46 m $\beta^+$ 2.6... $\gamma$ 614... $\sigma$ 41.5	Br 79 4.86 s 50.69 IT 207 $\sigma$ 2.5 + 8.3
Se 74 0.89 $\sigma$ 50	Se 75 17.78 d $\beta^+$ 0.9, 1.5... $\beta^-$ 1.4... $\gamma$ 596, 635... $\sigma$ 4.0	Se 76 9.37 $\sigma$ 22 + 63	Se 77 17.36 s 7.63 IT 162 $\sigma$ 41.5	Se 78 23.77 $\sigma$ 0.38 + 0.05
As 73 80.3 d $\beta^+$ no $\beta^-$ 53... $\sigma$ 50	As 74 17.77 d $\beta^+$ 0.9, 1.5... $\beta^-$ 1.4... $\gamma$ 596, 635... $\sigma$ 4.0	As 75 100 $\sigma$ 4.0	As 76 26.24 h $\beta^-$ 3.0 $\gamma$ 559, 657 1216... $\sigma$ 41.5	As 77 38.79 h $\beta^-$ 0.7... $\gamma$ 239, 521 250... $\sigma$ 41.5

REACTION (34-SE-76(P,X)34-SE-75,CUM,SIG)

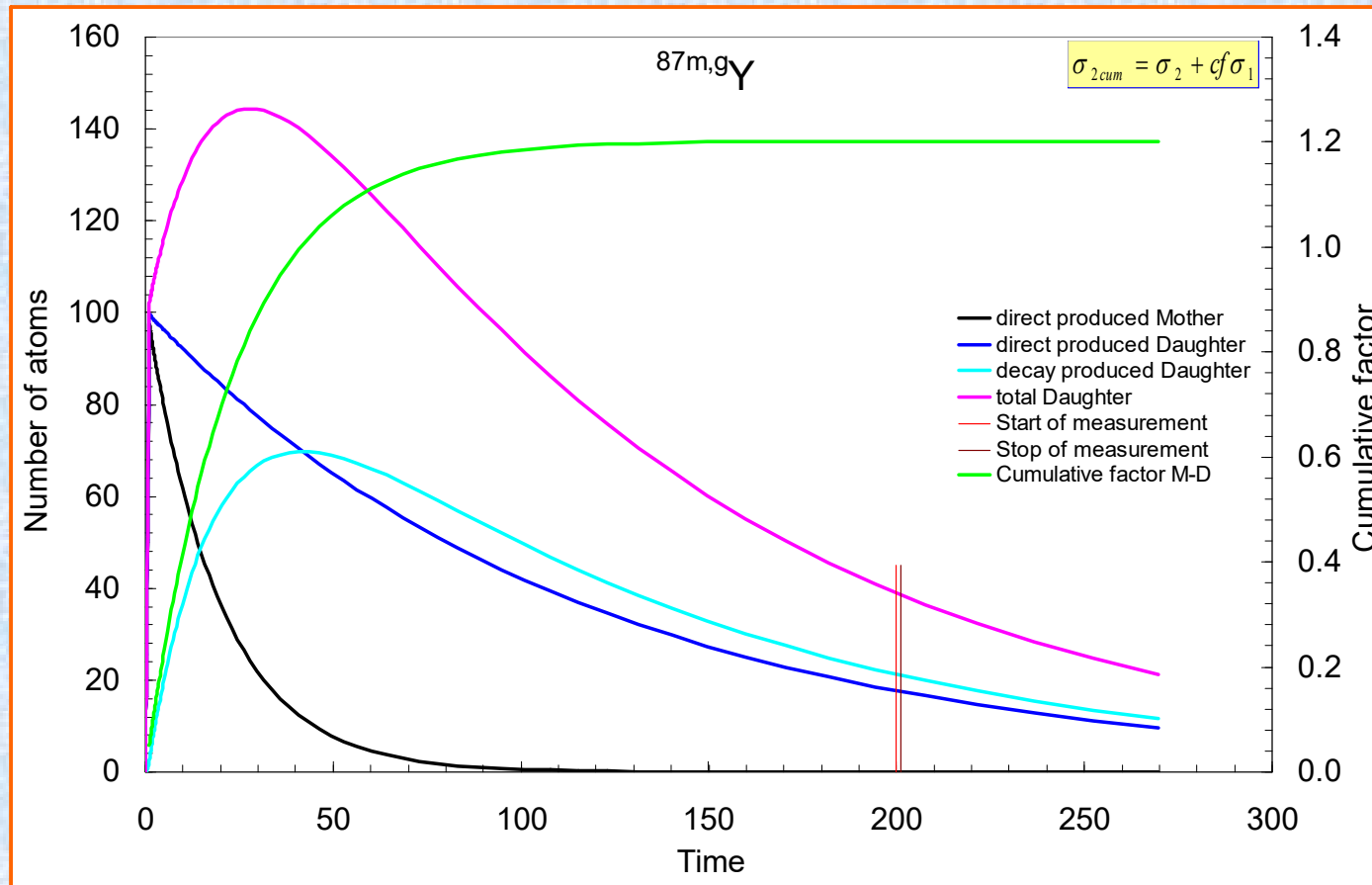
REACTION (34-SE-76(P,X)34-SE-75,SCUM,SIG)

### LEXFOR

CUM Data given includes the feeding via radioactive decay of another nuclide (and via isomeric transition when it exists). To be used only with process codes X or F.

## Activation method

Y 87		Y 88	
13.37 h	79.8 h	106.626 d	
IT 381	$\epsilon$ , $\beta^+$ , $\gamma$ 485	$\epsilon$ , $\beta^+$ , $\gamma$ 1836, 898...	
Sr 86	Sr 87		
9.86	2.815 h	7.00	
$\sigma$ 0.81 + 0.23	IT 389	$\sigma$ 16	



REACTION (38-SR-87(P,X)39-Y-87-G,M+,SIG)

REACTION (38-SR-87(P,X)39-Y-87-G,SCUM,SIG)

$$\sigma_{2cum} = \sigma_2 + cf\sigma_1$$

C=1.2018

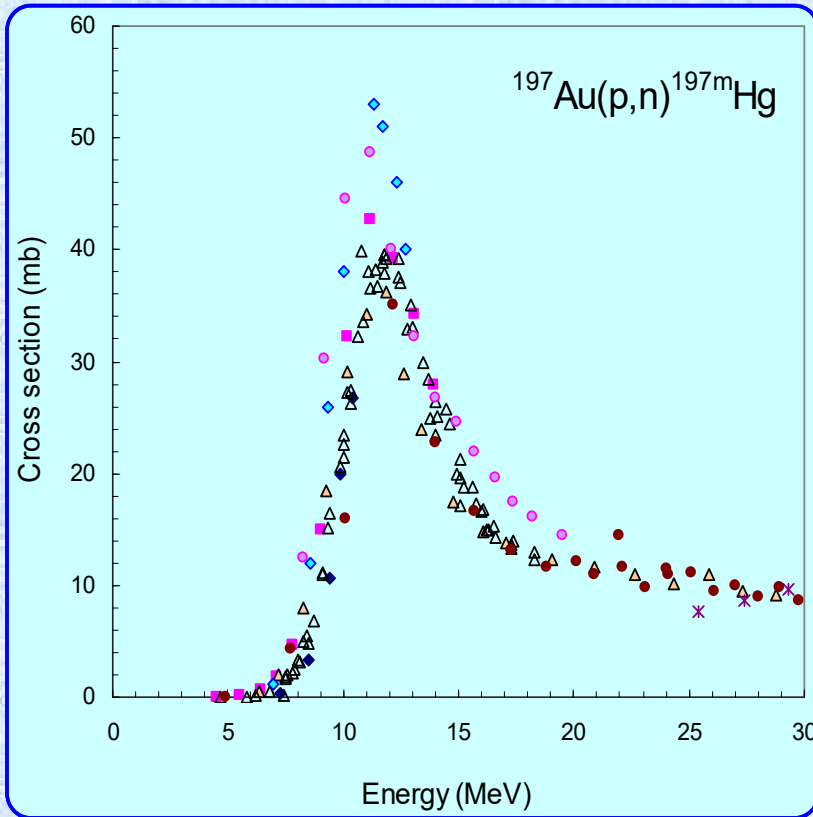
f=0.9843



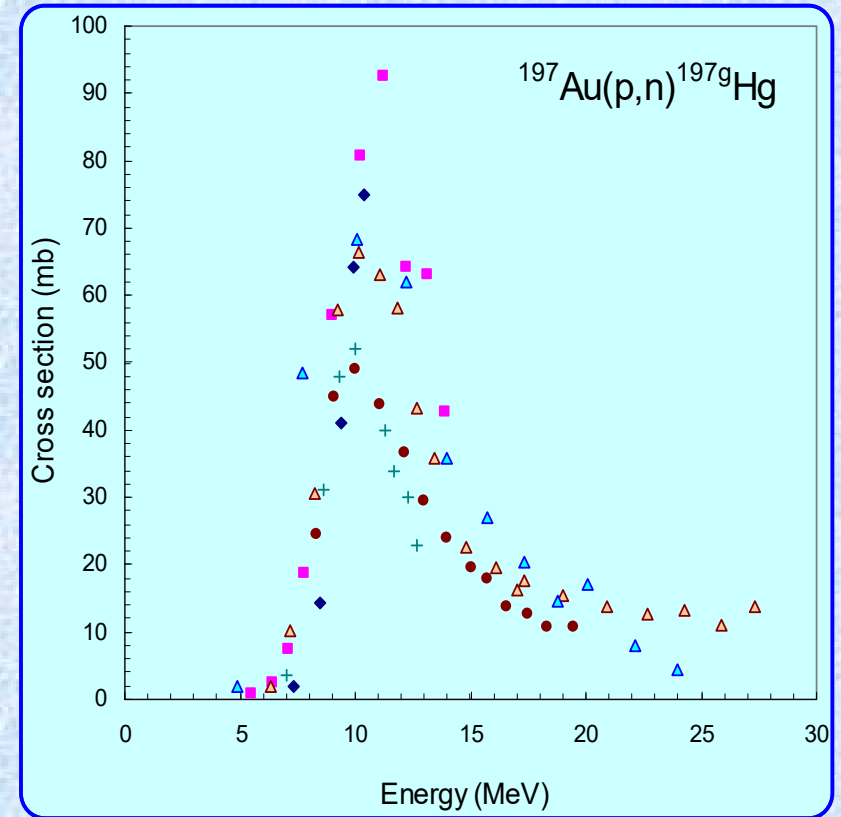
## Activation method

isotopes	T <sub>1/2</sub> (h) perent	T <sub>1/2</sub> (h) daughter	N <sub>max</sub> tc (h)	decay 100% tc (h)	ratio T <sub>1/2</sub> g/m	c factor	N <sub>100</sub> /N <sub>max</sub>
<sup>195m,g</sup> Au	0.008	4464	0.099	0.2	526927	1.000002	0.995
<sup>52m,g</sup> Mn	0.4	134.2	2.3	3.5	381.6	1.003	0.990
<sup>58m,g</sup> Co	9.1	1700.6	59.4	100.0	186.9	1.005	0.975
<sup>57</sup> Ni- <sup>57</sup> Co	36.0	6523.2	235.0	400.0	181.2	1.006	0.973
<sup>191m,g</sup> Os	13.1	369.6	51.7	148.0	28.2	1.037	0.785
<sup>123</sup> Cs- <sup>123</sup> Xe	0.1	2.1	0.1	0.6	21.2	1.049	0.825
<sup>90m,g</sup> Y	3.2	64.0	10.8	35.9	20.1	1.052	0.700
<sup>86m,g</sup> Y	0.8	14.7	2.3	8.3	18.7	1.057	0.694
<sup>196m<sub>2</sub>,g</sup> Au	9.6	148	30.2	112.0	15.4	1.069	0.607
<sup>56</sup> Ni- <sup>56</sup> Co	145.8	1853.7	430.9	1740.0	12.7	1.085	0.530
<sup>197m,g</sup> Pt	1.6	19.9	4.2	18.0	12.5	1.087	0.539
<sup>199m,g</sup> Pb	0.2	1.5	0.1	1.9	7.4	1.157	0.373
<sup>123</sup> Xe- <sup>123</sup> I	2.1	13.2	3.9	27.0	6.4	1.186	0.216
<sup>87m,g</sup> Y	13.4	79.8	26.9	176.0	6.0	1.201	0.193
<sup>93m,g</sup> Tc	0.7	2.8	0.7	9.9	3.8	1.358	0.055
<sup>198m,g</sup> Tl	1.9	5.3	1.8	31.0	2.8	1.545	0.0082
<sup>197m,g</sup> Hg	23.8	64.1	27.0	420.0	2.7	1.590	0.0046
<sup>198m,g</sup> Au	54.5	64.7	12.0	3820.0	1.2	6.374	7.19489E-24
<sup>76</sup> Kr- <sup>76</sup> Br	14.6	16.2	1.6	1630.0	1.1	10.125	1.39669E-40

## Activation method



Hg 197		Hg 198	
23.8 h	64.14 h	9.97	
IT (195), e <sup>-</sup> γ 134...	β <sup>-</sup> 77 γ 191...	σ 0.017 + 2	
Au 196		Au 197	
9.6 h	6.1 s	6.1669 d	7.73 s
IT (175) e <sup>-</sup> γ 148 188... (85)	β <sup>-</sup> 0.3 γ 366 353	γ 279...	IT 130... e <sup>-</sup> γ 279... σ 0.008 + 98.7



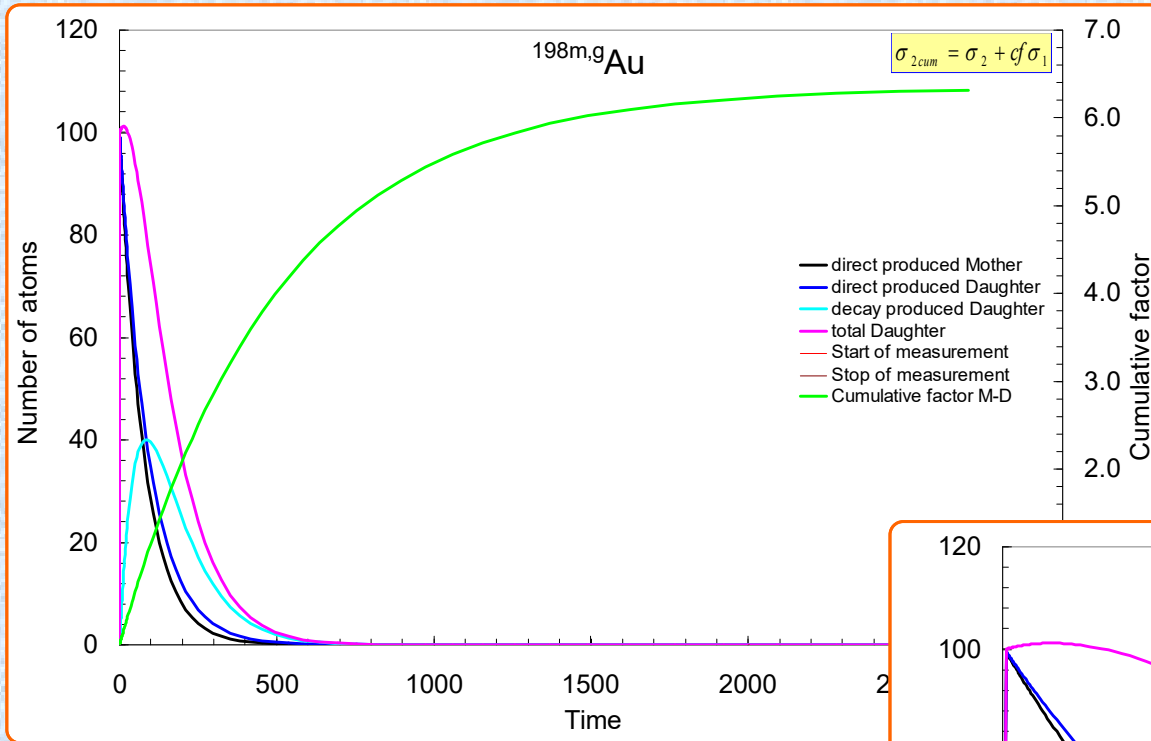
$$\sigma_{2cum} = \sigma_2 + cf\sigma_1$$

$T_{1/2}(m)=23.8 \text{ h}$   
 $T_{1/2}(g)=64.1 \text{ h}$   
 $C=1.590$

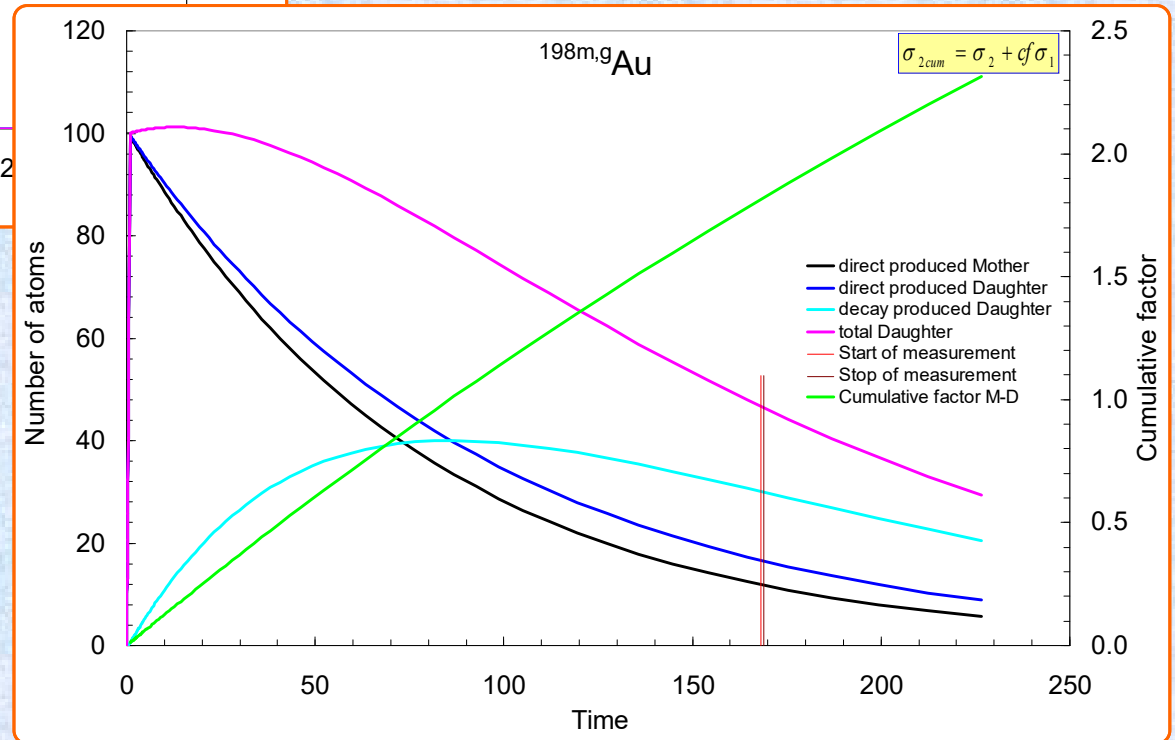
REACTION (79-AU-197(P,N)80-HG-197-M,,SIG)

REACTION (79-AU-197(P,N)80-HG-197-G,,SIG)

## Activation method

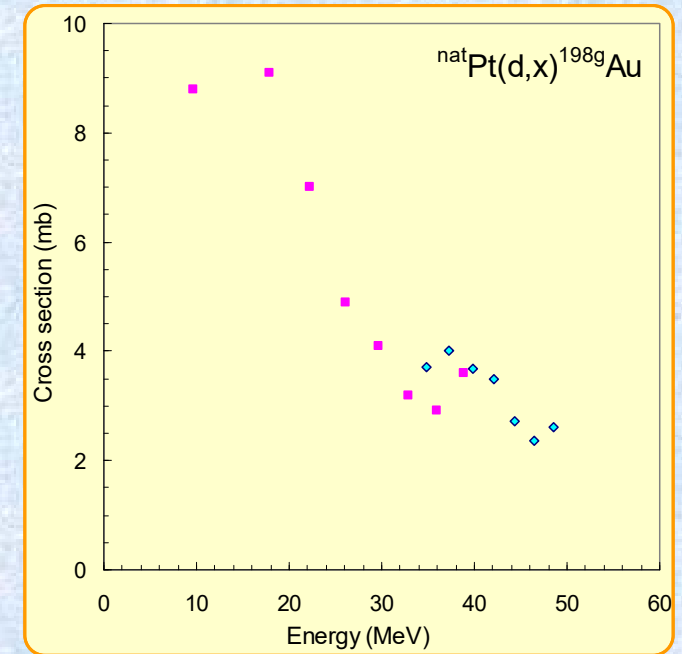
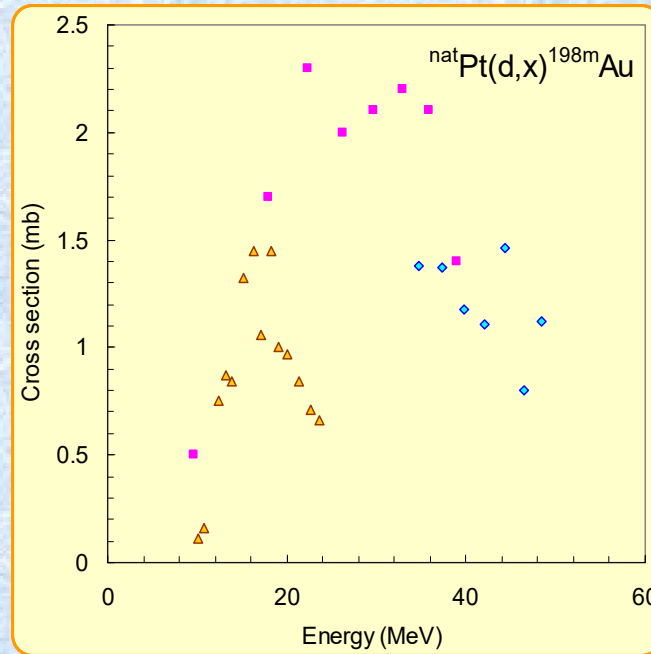
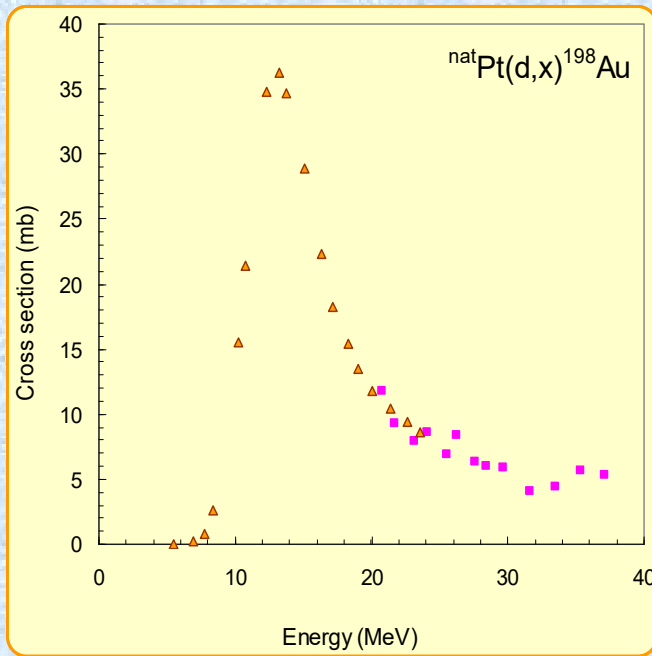


$T_{1/2}(m) = 2.272 \text{ d}$   
 $T_{1/2}(g) = 2.6948 \text{ d}$   
 $C = 6.374$



<b>Hg 197</b> 23.8 h IT (165), e <sup>-</sup> γ 134, e <sup>-</sup> σ 0.017 + 2	<b>Hg 198</b> 64.14 h 9.97 σ 0.017 + 2	<b>Hg 199</b> 42.67 m 16.87 IT 374... e <sup>-</sup> γ 158... σ 2100	<b>Hg 200</b> 23.10 σ ~1
<b>Au 196</b> 9.6 h 8.1 s 6.1669 d IT (175) e <sup>-</sup> γ 148 (65) 333 σ 28 σ <sub>tot</sub> <5E-6	<b>Au 197</b> 7.73 s 100 IT 130... e <sup>-</sup> γ 279... σ 0.008 + 98.7	<b>Au 198</b> 2.272 d 2.6948 d IT (115), e <sup>-</sup> γ 215, 97 180, 204... σ 25100	<b>Au 199</b> 3.139 d β <sup>-</sup> 0.3, 0.5... γ 158, 208... g σ ~30
<b>Pt 195</b> 4.010 d 33.78 IT (129...) e <sup>-</sup> γ 99, 130... σ 28 σ <sub>tot</sub> <5E-6	<b>Pt 196</b> 25.21 σ 0.045 + 0.55	<b>Pt 197</b> 95.41 m 19.8915 h IT 346, e <sup>-</sup> γ 53, e <sup>-</sup> β <sup>-</sup> 0.7 m	<b>Pt 198</b> 7.356 σ 0.3 + 3.1

## Activation method



<b>Hg 197</b> 23.8 h IT (165), e <sup>-</sup> γ 134, e <sup>-</sup> γ 77 m	<b>Hg 198</b> 9.97 σ 0.017 + 2	<b>Hg 199</b> 42.67 m 16.87 IT 374... e <sup>-</sup> γ 158... σ 2100	<b>Hg 200</b> 23.10 σ ~1
<b>Au 196</b> 9.6 h IT (175) e <sup>-</sup> γ 148 198... e <sup>-</sup> , m <sub>1</sub>	<b>Au 197</b> 8.1 s 6.1669 d 7.73 s 100 IT 130... e <sup>-</sup> σ 0.008 + 98.7	<b>Au 198</b> 2.272 d 2.6948 d IT (115), e <sup>-</sup> γ 215, 97 180, 204... σ 25100	<b>Au 199</b> 3.139 d β <sup>-</sup> 0.3, 0.5... γ 158, 208... g σ ~30
<b>Pt 195</b> 4.010 d IT (129...) e <sup>-</sup> γ 99, 130... σ 28 σ <sub>tot</sub> <SE-6	<b>Pt 196</b> 33.78 25.21 σ 0.045 + 0.55	<b>Pt 197</b> 95.41 m 19.8915 h IT 346, e <sup>-</sup> γ 53, e <sup>-</sup> β <sup>-</sup> 0.7 m	<b>Pt 198</b> 7.356 σ 0.3 + 3.1

REACTION (98-PT-0(D,X)97-AU-198,,SIG)

REACTION (98-PT-0(D,X)97-AU-198-M,,SIG)

REACTION (98-PT-0(D,X)97-AU-198-G,,SIG)

$$\sigma_{2cum} = \sigma_2 + f\sigma_1$$

$$\sigma_{2cum} = \sigma_2 + cf\sigma_1$$

$$T_{1/2}(m) = 2.272 \text{ d}$$

$$T_{1/2}(g) = 2.6948 \text{ d}$$

$$C = 6.374$$

## Activation method

### Some Conclusions

- The cumulative cross section measured (properly) by **activation** method is always higher than the sum of the corresponding cross sections
- The “c” cumulative factor is **time dependent**
- Cumulative cross section for a pair of isotopes with  **$c > 1.4$**  cannot be measured properly, since it requires long cooling time, and remaining activity is  $< 1\%$
- The m/g or m/(m+g) isomer ratios depend on the measurement of the cumulative cross section
- Using activation method deducing the cross section for the ground state or for the daughter isotope requires consideration of the cumulative factor
- Only an early measurement can be performed for a pair of isotopes with similar half-lives, that provides lower cumulative cross section, therefore correction is needed
- For a decay chain the linear combination of the individual cross section is applied

$$\sigma_{3cum} = \sigma_3 + c_2 f \sigma_2 + c_1 g \sigma_1$$



# Cumulative cross sections



## Activation method

What data are measured ?

What data are reported ?

What data are compiled ?