# Experimental Studies of the Induced Radioactivities in a Uranium Target

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## 1. Introduction

Uranium is attractive as a spallation target material for producing intense neutron beams owing to its high expected neutron yield and its high density. However, from a safety point of view, special attention must be paid to the level of induced radioactivity as this will be greater than that experienced with other common target materials such as iron, copper or tungsten.

In Japan uranium is designated legally as a nuclear fuel material and before it can be used as a spallation target material, the potential hazards must be analysed so that the



safety of the source can be guaranteed.

This paper deals with the results of a preliminary study on this subject.

## 2. Experiment

Blocks of depleted uranium coated with polyurethane sheet of 15 μm thickness were assembled together with sealed powder specimens of yellow cake for the activity measurement as shown in Fig. 1. The target was exposed to $6.1 \times 10^{13}$ protons of 500 MeV at the beam dump of the Booster Synchrotron at KEK. Profiles of the proton beam as monitored by a carbon (paper) detector[1] just before the target are shown in Fig. 2. The exposure time was 239 seconds.

## 3. Radiation Levels due to the Induced Activities

The radiation levels on and around the assembly were measured with GM survey meters, an ionization chamber and a NaI(Tl) gamma-ray detector. Table 1 lists the results of the measurements made immediately after and also 1 hour after the irradiation. Fig. 3 shows the decrease in the radiation level from the 0.5 cm thick block (#1) for cooling times between 1 and 1,000 hours. For comparison, the similar curve for 600 MeV protons as measured by Barbier[2] is also displayed in the figure after normalisation to the same number of protons and quantity of U-238. The exposure rate at 1 m for a cooling time of 1 hour is exactly the same as that given by Barbier. A predicted decay curve as computed from the levels of the identified dominant nuclides at the cooling time of 644 hours

is also plotted in the figure. For the latter, the longer the cooling time the steeper the curve, although at these extended cooling times there might be possible compensations from longer lived radionuclides which are buried in the γ-ray spectra obtained in earlier measurements.

## 4. Induced Beta-Activities

Fig. 4 shows the absorption characteristics of the induced β-rays from the yellow cake specimens inserted between the uranium blocks. The appearances of the five curves are very similar, which implies that the energies of the β-rays are almost the same and hence independent of the position in the target. Fig. 5 displays the spatial distributions of the β-ray yield at various cooling times. Absorption characteristics are also independent of the cooling time.

Examples of the γ-ray spectra from the yellow cake No. 2 measured with a Ge(Li) detector are shown in Fig. 6. They are rather complicated and identification of radionuclides is therefore not an easy task. The identifications given in the figure are incomplete but the dominant nuclides seem to originate from fission, in contrast to the case of a tungsten target where the dominant nuclides derive from spallation.[3)]

Estimated absolute values of the saturated activities for the nuclides of Te-132, Sr-91 and Ru-105 were calculated. The results are shown in Fig. 7.

The sample for the γ-ray spectroscopic measurements were prepared from the yellow cake specimen by dissolution in nitric acid. The concentration of U-238 in the sample was $1.34 \times 10^{19}$ $^{238}$U/2.5 × 2.5 cm$^2$.



## 5. Induced Alpha-Activities

The energy spectra of α-particles emitted from the irradiated specimens were measured with a gridded-ionisation chamber.[4)] A typical energy spectrum obtained from specimen No. 1 which had been placed on the front face of the block (Fig.1) is shown in Fig. 8. The increased emission rates of α-particles are listed in Table 2.

The concentration of U-238 in the sample for the α-ray measurements was $1.33 \times 10^{18}$ U/2.5 × 2.5 cm$^2$. The backing material was stainless-steel.

The increased emission rate at the front surface of the target was found to be much higher than those at different depths, although why is not yet clear.

## 6. Conclusion

The radiation levels produced around the irradiated U-target block were measured and their decay behaviours monitored.

Most of the induced activity was found to be due to the fission products.

However, this experiment was a preliminary one and for more complete information further work is required.

Nevertheless, we hope that the outcome of the present study will be useful in assisting the design of future experiments utilising U-targets.

References

1) N. Watanabe, S. Ikeda and Y. Ishikawa: KENS Target Station, Proc. ICANS-IV (1981).

2) Marcel Barbier: Induced Radioactivity, North-Holland Publishing Company, Amsterdam-London (1969), p.209.

3) H. Hirayama: to be published.

4) M. Miyajima: "Two Stage Single Gridded Ionisation Chamber", to be published.



Tables

Table 1. Radiation levels on and around the assembly after the irradiation

Table 2. Summary of the measurements of alpha-activities

Figure Captions

Fig. 1 Layout of the assembly subjected to irradiation by the proton beam

Fig. 2 Incident proton beam profiles

Fig. 3 Decay of the level of the induced radioactivity at 1 m from the front surface of the 5 mm-thick block (———— : present, —·—·—: by Barbier, - - - - - - : predicted)

Fig. 4 Absorption characteristics of the induced beta-rays in the yellow cake specimens

Fig. 5 Spatial distribution of the beta-ray yield at various cooling times

Fig. 6 Gamma-ray spectra and trial identification of radionuclides (Specimen No. 2)

Fig. 7 Saturated activities of Te-132, Sr-91 and Ru-105 as typical decay products

Fig. 8 Typical measured α-particle energy spectrum (Depth 0 mm)

Fig. 1

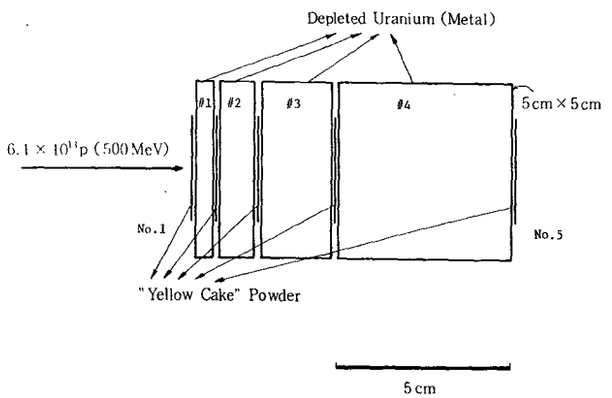



Fig. 2

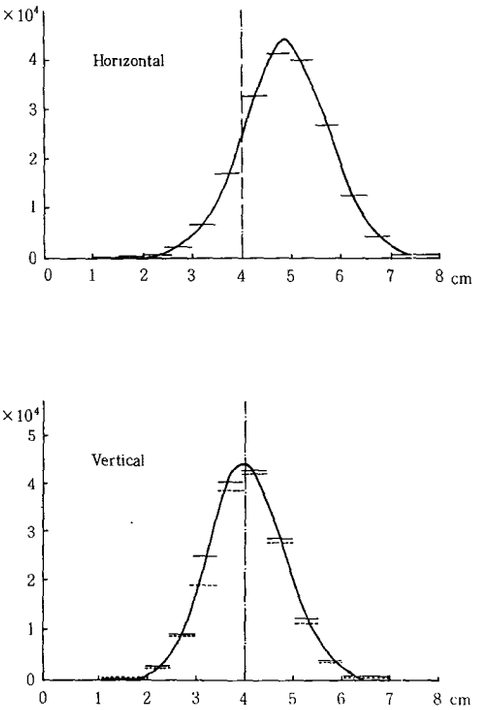



Table 1

Exposure Rate

Immediately after the irradiation (as whole)

| | |
|---|---|
| Front surface | 25 R/h |
| Rear surface | 12 〃 |

after 1 hour cooling (blocks)

| | at 30 cm | at 1 m | at surface |
|---|---|---|---|
| 5 mm F | 28 mR/h | 3 mR/h | 1.7 R/h |
| R | 20 | 3 | 1.4 |
| 10 mm F | 50 | 7 | 0.9 |
| R | 50 | 6 | 0.9 |
| 20 mm F | 80 | 9 | 1.1 |
| R | 80 | 9 | 1.1 |
| 50 mm F | — | 14 | 1.2 |
| | 100 | 8 | 1.1 |

F : front surface
R : rear surface

Table 2

α-Activity

Increased Emission Rates of α-Particles
(Relative to that of Natural U-238 in Equilibrium)

| Depth (mm) | I.E.R. (%) | Cooling Time (days) | Measuring Time (sec) |
|---|---|---|---|
| 0 | 19.0 | 5 | $4 \times 10^4$ |
| 5 | 3.1 | 2 | $1 \times 10^4$ |
| 15 | 2.0 | 4.4 | $4 \times 10^4$ |
| 35 | 4.6 | 0.3 | $1.6 \times 10^4$ |
| 85 | 1.4 | 1.3 | $4 \times 10^3$ |

Irradiation: $6.1 \times 10^{13}$ protons of 500 MeV
(100 pulses, 239 sec)
1980. 7. 16 (12:46 ~ 12:50)

Samples : For Irradiation $4.46 \times 10^{18}$U/2.5cm × 2.5 cm
For Measurement $1.33 \times 10^{18}$U/

Measurement: Gridded Ionisation Chamber

Fig.3

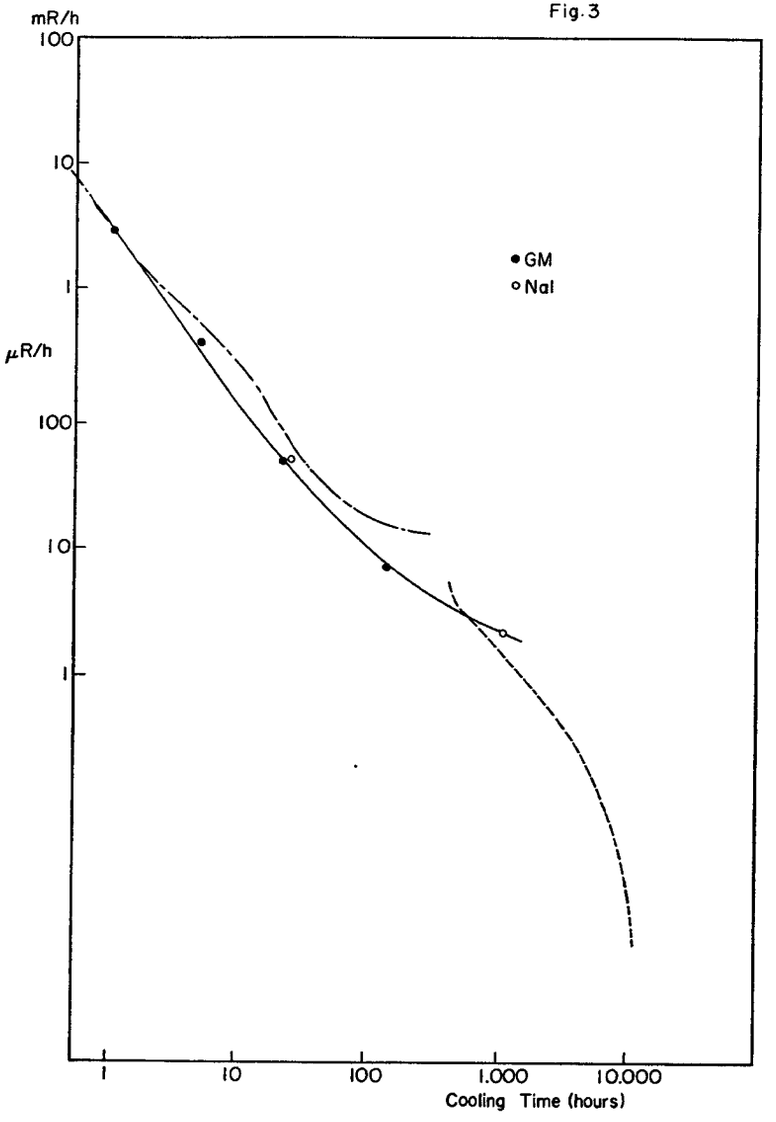

mR/h
100
10
1
μR/h
100
10
1
● GM
○ NaI
1
10
100
1.000
10.000
Cooling Time (hours)



Fig.4

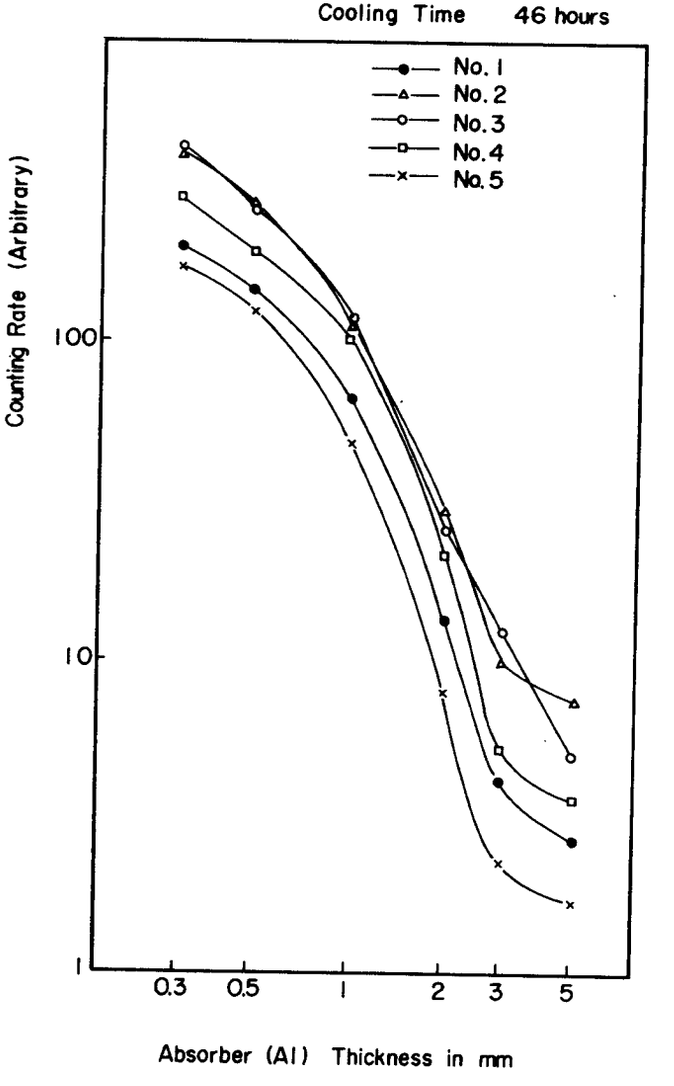

Cooling Time 46 hours
No. 1
No. 2
No. 3
No. 4
No. 5
Counting Rate (Arbitrary)
100
10
1
0.3
0.5
1
2
3
5
Absorber (Al) Thickness in mm

Fig. 6

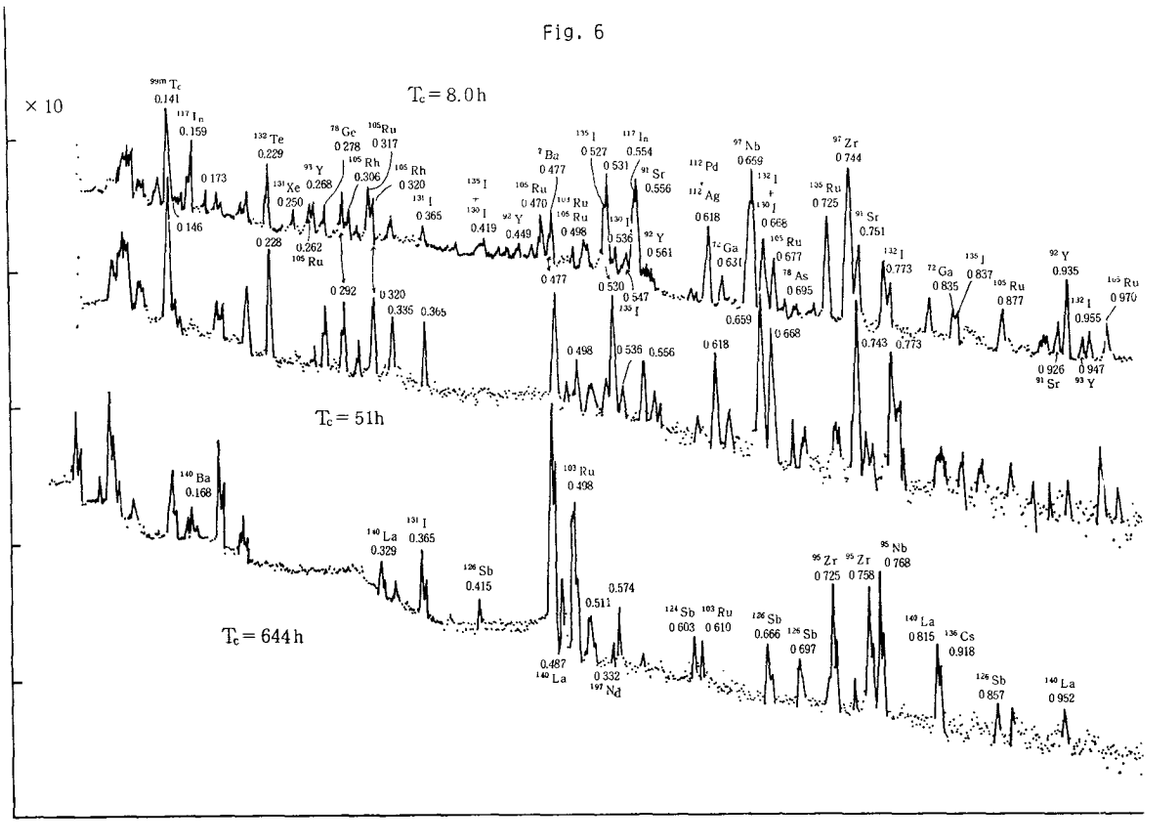

× 10
Tc = 8.0 h
Tc = 51 h
Tc = 644 h



Fig. 5

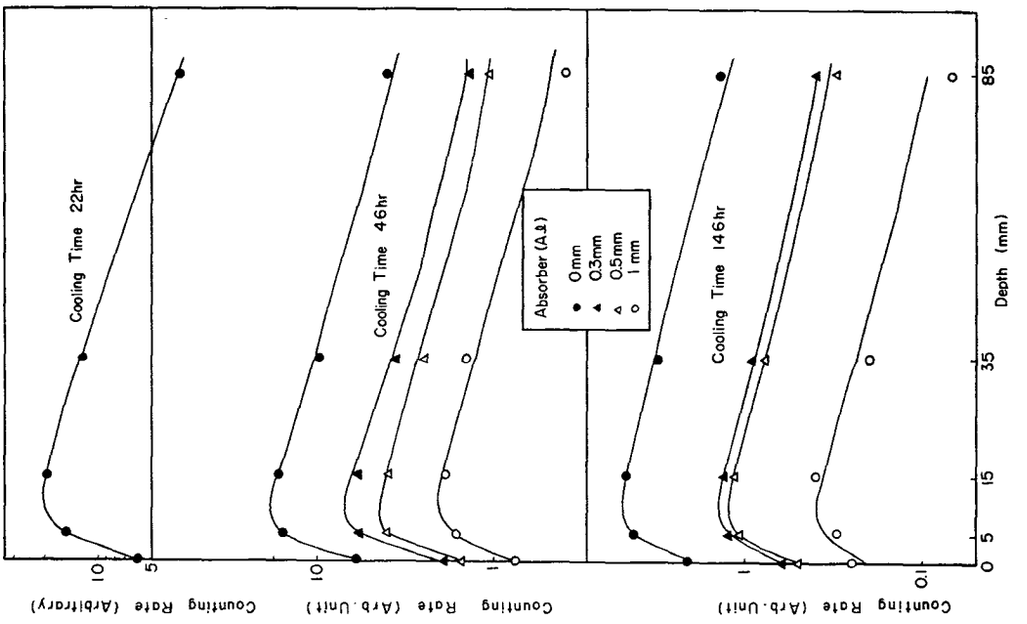

Cooling Time 22hr
Cooling Time 46hr
Cooling Time 146hr
Absorber (Al)
0mm
0.3mm
0.5mm
1 mm
Counting Rate (Arbitrary)
Counting Rate (Arb. Unit)
Depth (mm)

Fig. 7

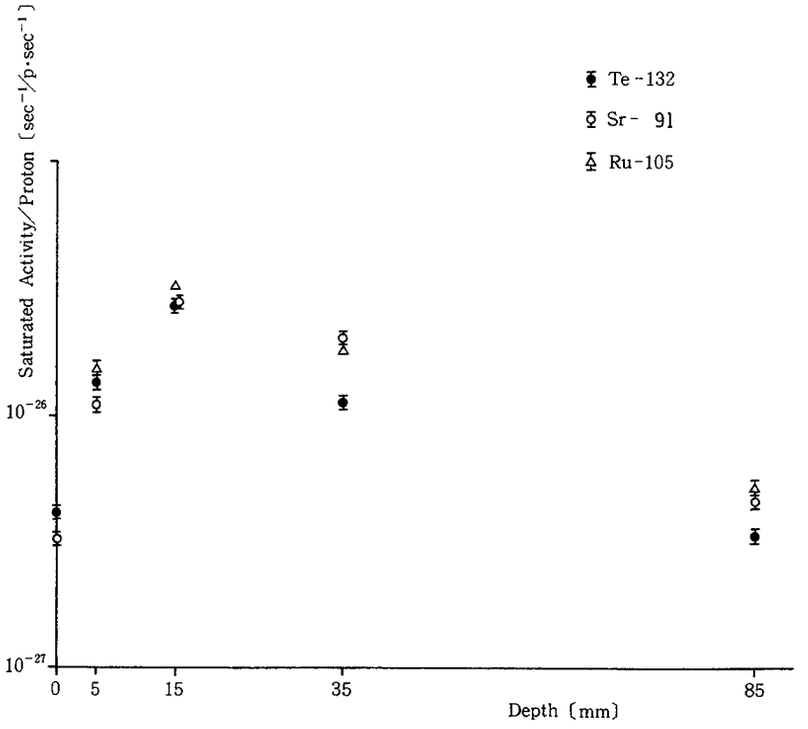
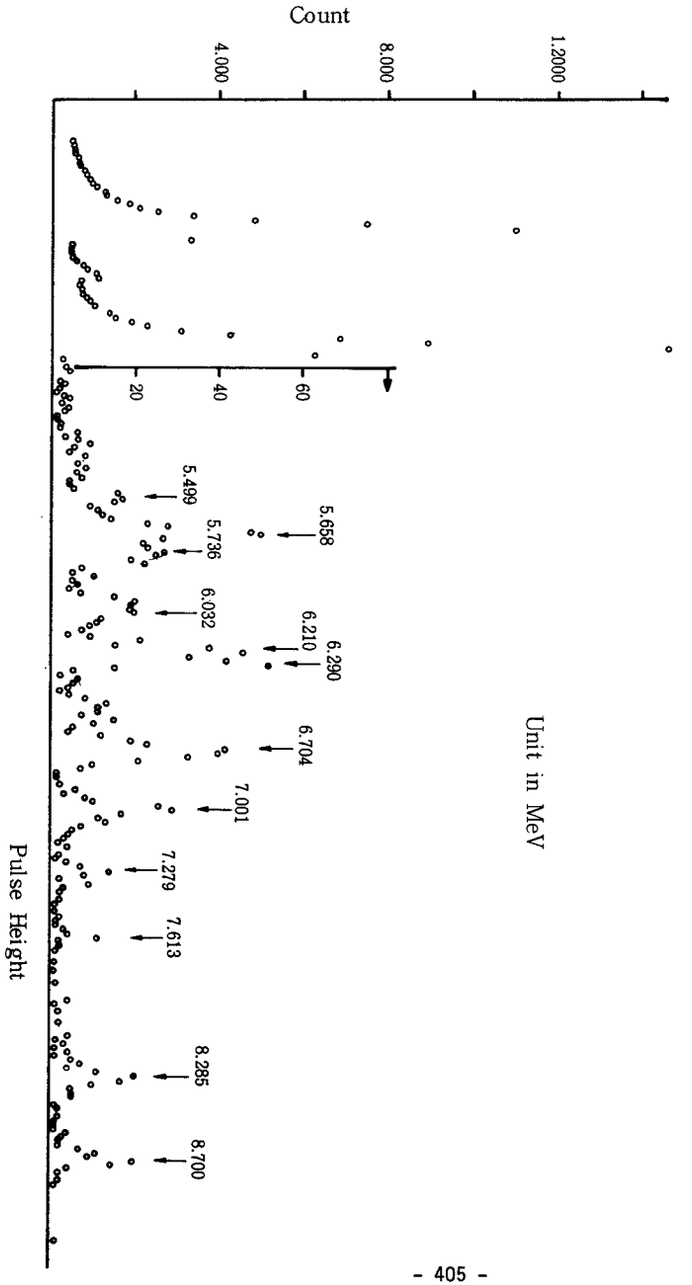

Saturated Activity/Proton [sec⁻¹/p·sec⁻¹]
10⁻²⁶
10⁻²⁷
0
5
15
35
85
Depth [mm]
Te-132
Sr- 91
Ru-105



Fig. 8


Count
4.000
8.000
1.2000
20
40
60
(U-238)
4.195
(U-234)
4.768
5.499
5.658
5.736
6.032
6.210
6.290
6.704
7.001
7.279
7.613
8.285
8.700
Unit in MeV
Pulse Height