Some General Results from a Calculation of a TRAM Assembly

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1. INTRODUCTION

A calculation of the performance of a full target, reflector and moderator (TRAM) assembly corresponding closely to the current design to be installed, has recently been completed [1]. In this paper, a selection of some of the results of a more general nature are presented; those concerning the performance of SNS are included elsewhere in these proceedings [2].

2. THE EFFECT OF FISSION

The calculational model used for fission has been described elsewhere [3]; essentially it only makes a distinction of detail between fission induced by particles in the hundreds of MeV region compared to, for example, that induced by MeV neutrons. For this section we look at processes in the isolated target Uranium; numbers are normalised to per proton incident at the target.

2.1 Neutron Production. An approximate account of the energy interchange in the high energy cascade is shown in Table I; quantities underlined are 'known' from analysis of the particle transport whilst the rest are deduced; 'Particle' energies include a value of 7.5 MeV/nucleon for separation energy.

There are 21.4 neutrons of energy ≤15 MeV released, which account for ~30% of the incident proton's Kinetic energy. The entries on the second line show ~35 MeV of 239 MeV binding energy released by fission goes to create extra neutrons (~3 extra).

TABLE I: ENERGY INTERCHANGE DURING HIGH ENERGY CASCADE IN TARGET - UNITS ARE MEV/INCIDENT PROTON

	Energy Sources		Energy Sinks		
Process	Incident Protons' Kinetic Energy	Nuclear Binding Energy	Escape	Deposited as Heat	Nuclear Excitation
Ionisation loss for primary protons	$\underline{230}$	-	-	$\underline{230}$	-
1.3 Fissions	171	239	-	$\underline{204}$	206
0.5 spallations	66	-	-	-	66
High Energy Escapes	$\underline{315}$	-	$\underline{145}$(a)	$\underline{170}$	-
Low Energy Neutrons	-	-	$\underline{237}$(b)	-	$-\underline{237}$
Residual Excitation	-	-	-	$\underline{18}$	$\underline{-18}$
γ Production	18	-	-	$\underline{18}$	-
Other Evaporations	-	-	7	$\underline{10}$	-17
	$\underline{800}$	239	389	$\underline{650}$	$\underline{0}$
	1039		1039		

Notes (a) Escapes from surface of target and includes 7.5 MeV/ nucleon separation energy.

(b) Escapes from nucleus and includes 7.5 MeV/nucleon separation energy.

Roughly 15 neutrons are evaporated from fission fragments due to the transfer of primary excitation energy from the intranuclear cascade. Evaporation from the lighter mass fission fragments leads to a harder neutron spectrum; Fig 1 shows the average Kinetic energy for neutrons evaporated as a function of excitation energy, from masses typical of Uranium interactions. The harder evaporation spectrum will lead to increased fissions induced by these neutrons in transport to the surface of the target; the neutron induced fission cross section for ^{238}U is shown in Fig 2.

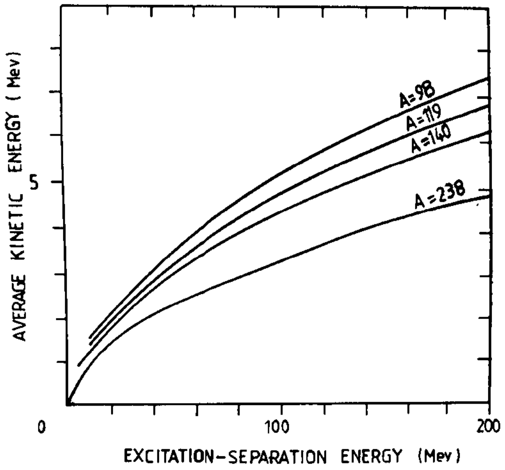

Fig 1 *The average Kinetic Energy for neutrons evaporated from mass 238,140,119 and 98 AMU nuclei, as a function of excitation minus separation energy.*

That is: High energy particle induced fissions increase neutron production by two distinct processes; (i) The transfer of binding to nuclear excitation energy and hence extra neutron evaporation (ii) an increase of evaporation-neutron induced fissions, because of the harder spectrum from the lighter mass of the fission fragments.

The mean energy for sub-15 MeV neutrons produced in the cascade is 3.6 MeV, whilst that of the neutrons escaping the surface of the target is ~2 MeV. The high energy end of the neutron spectrum will be responsible for inducing fissions and productive (n, xn) reactions, but will induce lower nuclear excitation energies than for instance high energy fissions and consequently (see Fig 1) have a lower average Kinetic energy.

The surface escape neutron intensity is 24.7: The extra 3.3 neutrons come from the balance of 5.5 neutrons created

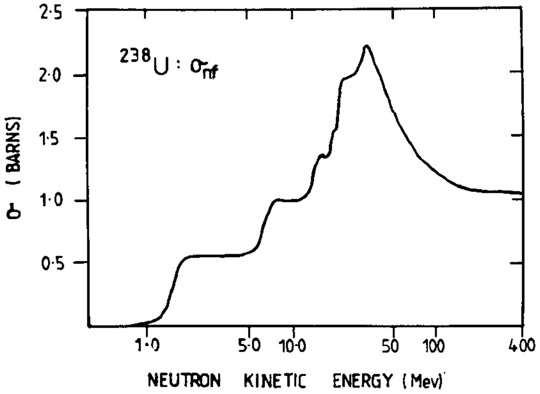

Fig 2 *The cross-section for ^{238}U (n,xnf) as a function of incident neutron energy.*

in 1.8 fissions, 0.7 neutrons created in (n, xn) reactions and 1.1 neutrons absorbed. It is estimated that 80% of these escape neutrons come from fission events.

2.2 <u>Energy deposition</u>. In table I roughly 2/3 of the energy deposition in the high energy cascade comes from ionisation loss (primary protons and secondary charged particles). The majority of the binding energy released in fission is taken by recoil of the fission fragments under their mutual couloub repulsion. The 21.4 neutrons released are accompanied by an energy deposition of 650 MeV (i.e. 30 MeV/neutron).

Neutron transport from production point to target surface leads to a further deposition of 330 MeV, almost all of which comes from fission fragment recoil. This energy is deposited in creating an extra 3.3 neutrons, that is, ~100 MeV/<u>extra</u> neutron. This component of the energy deposition leads to a strong variation of energy deposition with target size [e.g. a 10 x 10 x 30 cm^3 solid Uranium block gave 740 MeV in releasing 25.4 neutrons for the high energy cascade, and 590 MeV during neutron transport with the creation of an extra 5 neutrons].

2.3 Nuclide production in spallation. Fission leads to the production of two nuclei well displaced in mass from the parent. The spallation products from the calculation [1] are shown as a contour plot in the charge-mass plane in Fig 3.

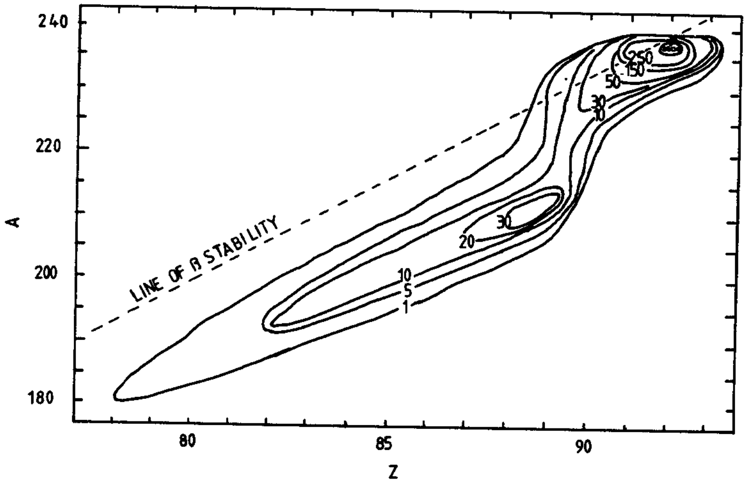

Fig 3 Products from ^{238}U high energy particle induced spallation reactions. Intensities are in arbitary units. The parent nucleus $[^{238}U_{92}]$ is marked with an X.

A feature of this plot is the lack of low mass Uranium, Protactinium and Thorium isotopes due to the competition of fission. Fission probabilities for isotopes in the actinide region are independent of nuclear excitation energy once above a threshold of ~6 MeV [3]; their values are also significantly less than 1. The fission probability for an element increases as the isotope mass decreases [i.e. on neutron emission], but will decrease with the evaporation of a proton. Evaporation is biased toward neutron emission, particularly for the early stages, and for heavy nuclei [4].

This means that nuclei de-exciting via the most probable evaporation path will also have an enhanced chance of fissioning due not only to multiple chances but also to the increasing probablity at each stage; this will lead to a loss of the low mass isotopes of, for example, U, Pa and Th as spallation products as may be seen in Fig 3. A second consequnce of fission competition is that the highly excited fragments which would be destined to evaporate many nucleons, will also preferentially fission due to having many more chances to fission during their evaporation chain. This leads to a supression of the continued widening of the mass range typical of non-fissioning systems under increased bombardment energy.

3. THE EFFECT OF THE PRESENCE OF THE REST OF THE ASSEMBLY

In section 2, the results are for an isolated target. In Fig 4 is shown a visual picture of the overall energy balance for the TRAM assembly.

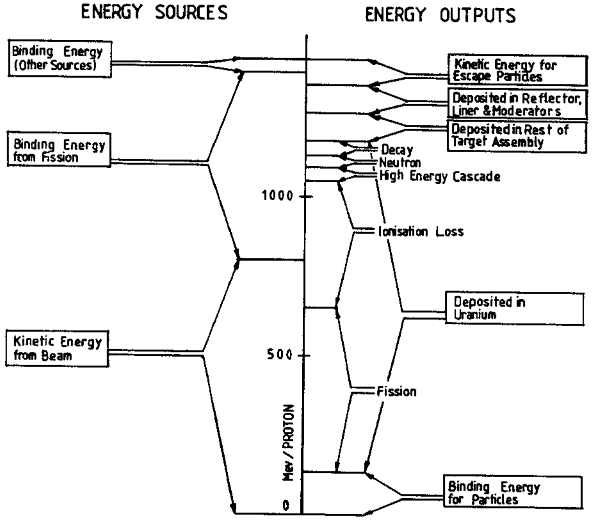

Fig 4 Energy balance for the Target, Reflector, Moderator assembly.

For energy sources, the contribution of "Binding Energy (other sources)" is from reactions like $^{10}B(n,\alpha)^{7}Li$ in the decoupler. The dominance of energy deposition in the target is clearly seen. The extension of the high energy cascade into the full system makes significant contributions to energy depositions in the components outside the target. e.g. Just over half the energy deposited in the reflector.

There is also some extra low energy neutron production [equivalent to 1.7 neutrons/proton]. The presence of material also causes neutrons to be reflected back to the target Uranium; these induce further ^{238}U fissions and lead to an ~4% increase in the prompt target energy deposition; these also cause a roughly 3-fold increase in radiative capture. Radiative capture is responsible for ~25% of the total target activity. Target activity varies with irradiation time but typically lies in the region 20 → 30 Bq/proton, with the associated decay power giving another 4% contribution to the total thermal load.

REFERENCES

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[4] K J le Couteur — Proc. Phys. Soc. A63, 259 (1950)