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LANSCE HIGH POWER (200 μA)
TARGET-MODERATOR-REFLECTOR-SHIELD

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We are in the process of upgrading the high-current target area at the Los Alamos Neutron Scattering Center (LANSCE, alias WNR)[1] to accept 200 μA of 800-MeV protons from our Proton Storage Ring.[2] In addition to higher-power operation, we had to consider changes in the LANSCE Target-Moderator-Reflector (TMR) system to accomodate an expanded user program.[3] Our recently retired 'T'-shape TMR (see Fig. 1) was a proven, efficient neutron production system;[4,5] other spallation neutron source target systems are hard-pressed to match its neutron production efficiency. The 'T'-shape TMR utilized wing-geometry, and had the ability to simultaneously service nine of the twelve LANSCE target area flight paths (see Fig. 2). Note in Fig. 2 the layout of the twelve LANSCE flight paths; there are four flight path clusters (three flight paths per cluster) at 90° to each other. This flight path arrangement presents an interesting challenge for moderator layouts with acceptable neutronic performance. A requisite requirement for the upgraded LANSCE target system was that all twelve flight paths be serviced simultaneously by moderators with specific neutronic characteristics.

As described in Reference 6, we have powerful calculational and experimental capabilities at Los Alamos to study spallation neutron source problems. We have done numerous computations (using the Los Alamos HETC/MCNP/HTAPE Monte Carlo code package)[7] for the new upgraded, high-performance LANSCE TMR system. We also made benchmark calculations of the 'T'-shape geometry (see Fig. 1) to compare with the enhanced LANSCE TMR design. We performed a benchmark experimental measurement of the LANSCE TMR geometry to verify computational predictions.

The new LANSCE target system design has four unique features:

- There is no crypt per se (a void region) surrounding the TMR.
- The target is not one piece, but split into two unequal segments separated by a void.

- Moderators are not located adjacent to the target as in conventional wing-geometry design. In the LANSCE target system, the moderators are located where there is no target material (that is, next to a void region).
- A conventional all beryllium reflector is not used; the LANSCE TMR employs a composite reflector/shield arrangement.

Results of our LANSCE target system studies can be summarized as follows:

- Compared to the customary all beryllium reflector used in pulsed spallation neutron sources, thermal neutron performance can be enhanced by 10-20% if a composite reflector-shield (inner beryllium region and outer nickel region) is used (see Fig. 3). The outer nickel region also acts as a neutron shield; hence, we can talk about a Target-Moderator-Reflector-Shield (TMRS). There may also be a cost benefit for the composite arrangement. The new LANSCE target system utilizes the TMRS concept.[8] Since the outer nickel region is cooled, the effect is the same as cooling the inner portion of a bulk shield. We are pursuing a split-target design. By splitting the target into upper and lower sections, we can position moderators between the targets in a 'flux-trap' geometry. These flux-trap moderators are viewed by the twelve existing LANSCE flight paths. Our split-target TMRS concept is illustrated in Fig. 4.

- We are continually trying to better understand and optimize the split-target, TMRS design. We recently performed a measurement of thermal neutron yields and pulse widths in 'standard' reflected wing-geometry for both solid and split targets. A cursory look at our experimental results show: a) the difference in thermal neutron yields between solid and split targets was as predicted, and b) for a cylindrical void space between targets of 5 cm diam x 10 cm long, there was no discernable difference in the thermal neutron pulse widths. It is also possible to 'significantly' enhance the moderator neutron yield from a flux-trap moderator by increasing the field-of-view (FOV) above the canonical 100 cm^2. For example, compared to a 10 x 10 cm FOV, a 12 x 12 cm FOV increases the moderator thermal neutron yield by a factor of 1.34 with a decrease in the average source brightness of ~10%; these effects are illustrated in Figs. 5 and 6. One significant advantage of our flux-trap geometry is that all flux-trap moderators are high intensity. Our calculations show that for realistic moderator locations (moderators starting 8 cm from proton beam center), there is no difference in moderator thermal neutron yield between wing geometry with a beryllium reflector and flux-trap geometry with a composite beryllium/nickel reflector.

- As seen in Fig. 4, there are four flux-trap moderators in the initial (startup) LANSCE TMRS. Three of the moderators are ambient temperature water. Two of the water moderators are heterogeneously poisoned at 2.5 cm with gadolinium and have cadmium decoupler/liners. These two moderators are referred to as 'high-intensity' moderators. The third water moderator is heterogeneously poisoned with gadolinium at 1.5 cm and has a boron decoupler/liner (1/e transmission at ~3 eV). This moderator is called the 'high-resolution' moderator. The poison neutronically defines the thickness of a moderator viewed by an experiment. The decoupler surrounds the moderator per se to neutronically isolate the moderator from the reflector. The liner is a material which 'lines' the void region through the reflector-shield where neutrons are extracted for experiments; the liner neutronically isolates the moderator 'viewed surface' from the reflector-shield. We recognize the need and importance of cold moderators, and the fourth flux-trap moderator is liquid para-hydrogen at 20-25 K.[9] Our liquid hydrogen moderator has a gadolinuim decoupler and a cadmium liner. Neutron yields, mean-emission-times, pulse widths, and pulse shapes for the high-intensity and high-resolution water moderators and the liquid hydrogen moderator are shown in Figs. 7-13. For a (decoupled) depleted uranium target with Rutherford Appleton Laboratory Spallation Neutron Source (RAL SNS) target design parameters,[10] the calculated average energy deposition (at the flux-trap moderator location) is ~2.7 mW/cm^3- μA, ~0.89 mW/cm^3- μA, and ~1.5 mW/cm^3- μA for water, liquid hydrogen, and aluminium, respectively.

- As described in Reference 2, there will be a need for the LANSCE TMRS to service more flight paths (in addition to the twelve shown in Fig. 2) to support an expanded user program. As seen in Fig. 4, these 'future' moderators are depicted as wing-moderators adjacent to the upper target. In reality these moderators would be adjacent to the void region upstream of the target (the moderators could also overlap part of the upper target as well). The feasibility of this approach is demonstrated in Fig. 14, where the location of a wing-moderator relative to the target is indicated. As can be seen in Fig. 14, the penalties in neutron intensity (relative to the optimum moderator location) are roughly the same whether the moderator is located fore or aft of the optimum position. The feasibility of drilling additional flight paths through the LANSCE bulk shield has been successfully demonstrated.

- Our initial LANSCE target is solid tungsten. The upper target size is 10-cm diameter by 7-cm long; the lower target size is 10-cm diameter by 27-cm long. The void region between the targets is 10-cm diameter by 14-cm long. After accounting for the effects of proton beam windows, the upper target length was set at the optimum value for thermal neutron yield (see Fig. 15). The calculated power in both tungsten targets is ~49 kW for 100 μA of 800-MeV protons.

- We intend to design and implement a depleted uranium (0.20 a% ^{235}U) target capable of handling 200 μA of 800-MeV protons. In our depleted uranium target studies, we found that neutrons resulting from low-energy ($E < 20$ MeV) neutron induced fissions in ^{235}U cause the following problems: a) artificial enhancement of the thermal neutron intensity, b) broadening of the thermal neutron pulses, and c) additional (unwanted) power generation in the target. For 200 μA of 800-MeV protons and a light water cooled depleted uranium target neutronically coupled to the LANSCE TMRS, we found:

    - About 7% of the thermal neutron intensity at the surface of a moderator originate with low-energy neutron induced fissions in 235-U. In general, these neutrons do not contribute to the useful neutron beam current, and may require decoupling a depleted uranium target.
    - The calculated standard deviation of the thermal neutron pulse at the moderator surface was ~78 μs (compared to ~23 μs for a decoupled target).
    - About 25 kW (out of ~215 kW total) of target power is attributable to low-energy neutron induced fissions in 235-U.

- The calculated neutronic gain for a decoupled depleted uranium target is compared to a tungsten target in Fig. 16; the gain in thermal neutron intensity for depleted uranium relative to tungsten is 1.42 ± 0.04. For this comparison we used decoupled RAL SNS target design parameters;[10] the tungsten target was solid. This comparison should be valid for proton currents where a tungsten target can be solid (up to ~100 μA of 800-MeV protons) and a depleted uranium target needs to be segmented for adequate cooling. For a coupled depleted uranium target, the calculated thermal neutron intensity gain (relative to tungsten) is 1.52 ± 0.06.

- For spallation neutron source applications, depleted uranium is a booster-target (albeit a relatively ineffecient one - 2.8 fissions/proton giving 3.5×10^{15} fissions/sec for 200 μA of 800-MeV protons). We will be studying more efficient booster-targets with a useful thermal neutron gain (the gain in neutron beam current to an experiment) of three over that attainable from a depleted uranium booster-target. Other possible booster-target materials are ^{233}U, ^{235}U, ^{237}Np, and ^{239}Pu. A scoping calculation of a ^{237}Np booster-target, yielded a power of ~2 MW (k_{eff} 0.80-0.84) for 200 μA of 800-MeV protons.[11] This preliminary calculation did not account for any engineering realities necessary in an actual high power booster-target design. High power booster-targets will present significant technological design problems (particularly in the areas of heat removal and materials). The advantages and disadvantages of booster-targets with respect to cost, complexity, gain in useful neutron beam current, beam current quality (signal-to-noise ratio, gamma-ray contamination, etc.) need further study.

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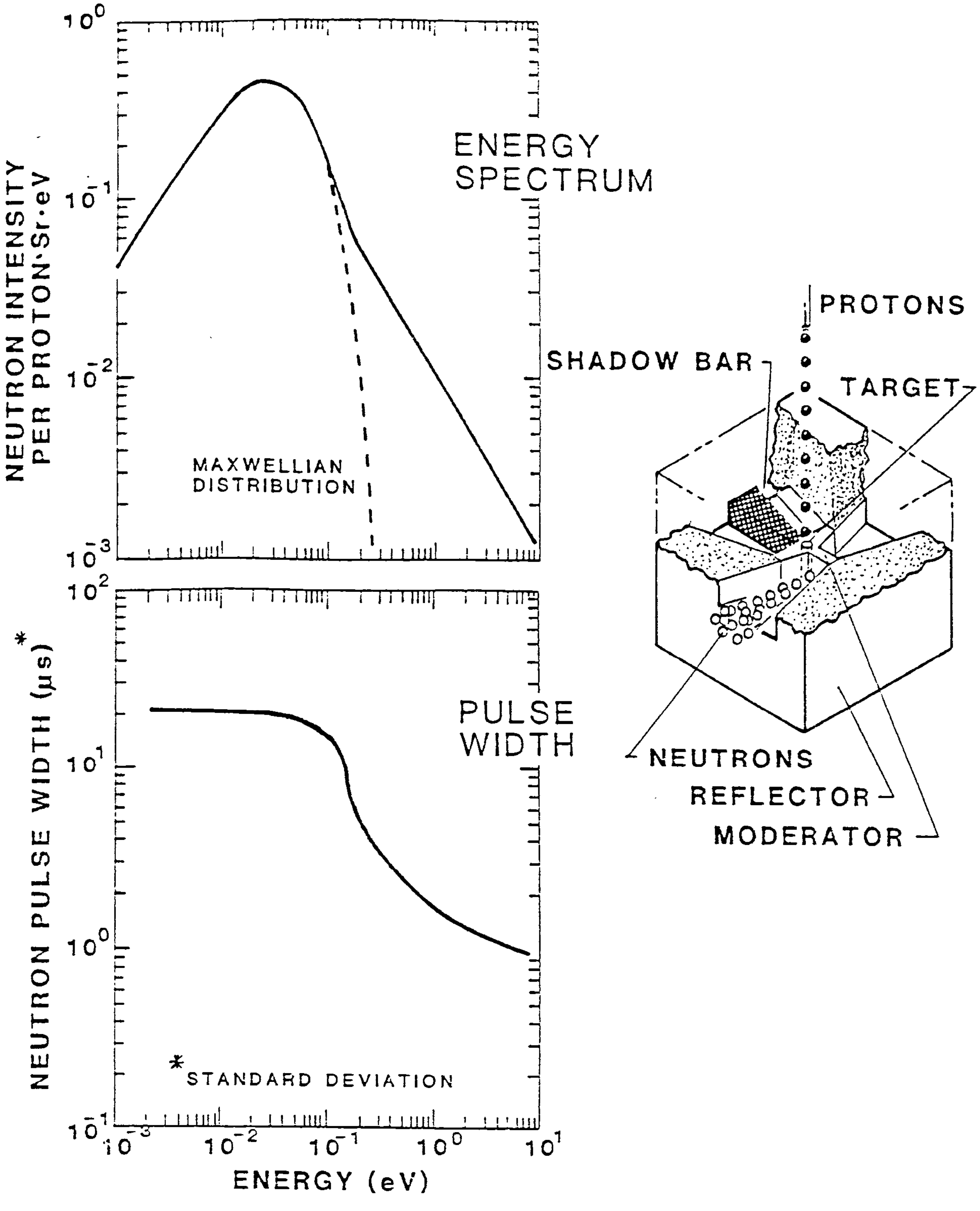
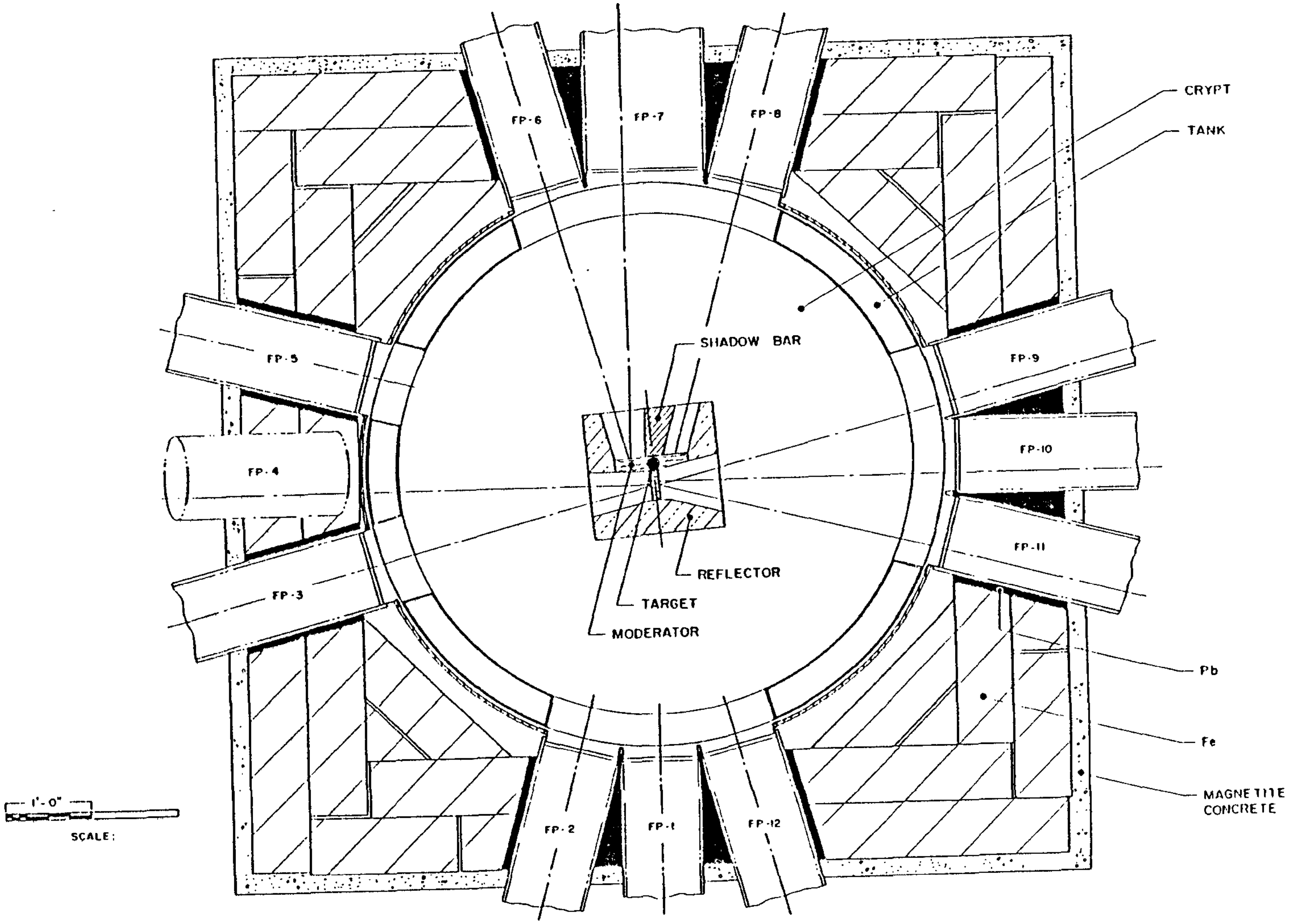


Fig. 1. Neutron surface-current and pulse width characteristics for the reflected T-shape (H_2O) moderator with a 10 by 10 cm field-of-view. The moderator is heterogeneously poisoned by Gd at a depth of 2.3 cm, and decoupled from the Be reflector by Cd.



WNR TARGET CAVITY

Fig. 2. Section thru the original WNR target cavity showing the orientation of the TMR (with the 'T'-shaped moderator) and the flight path configuration.

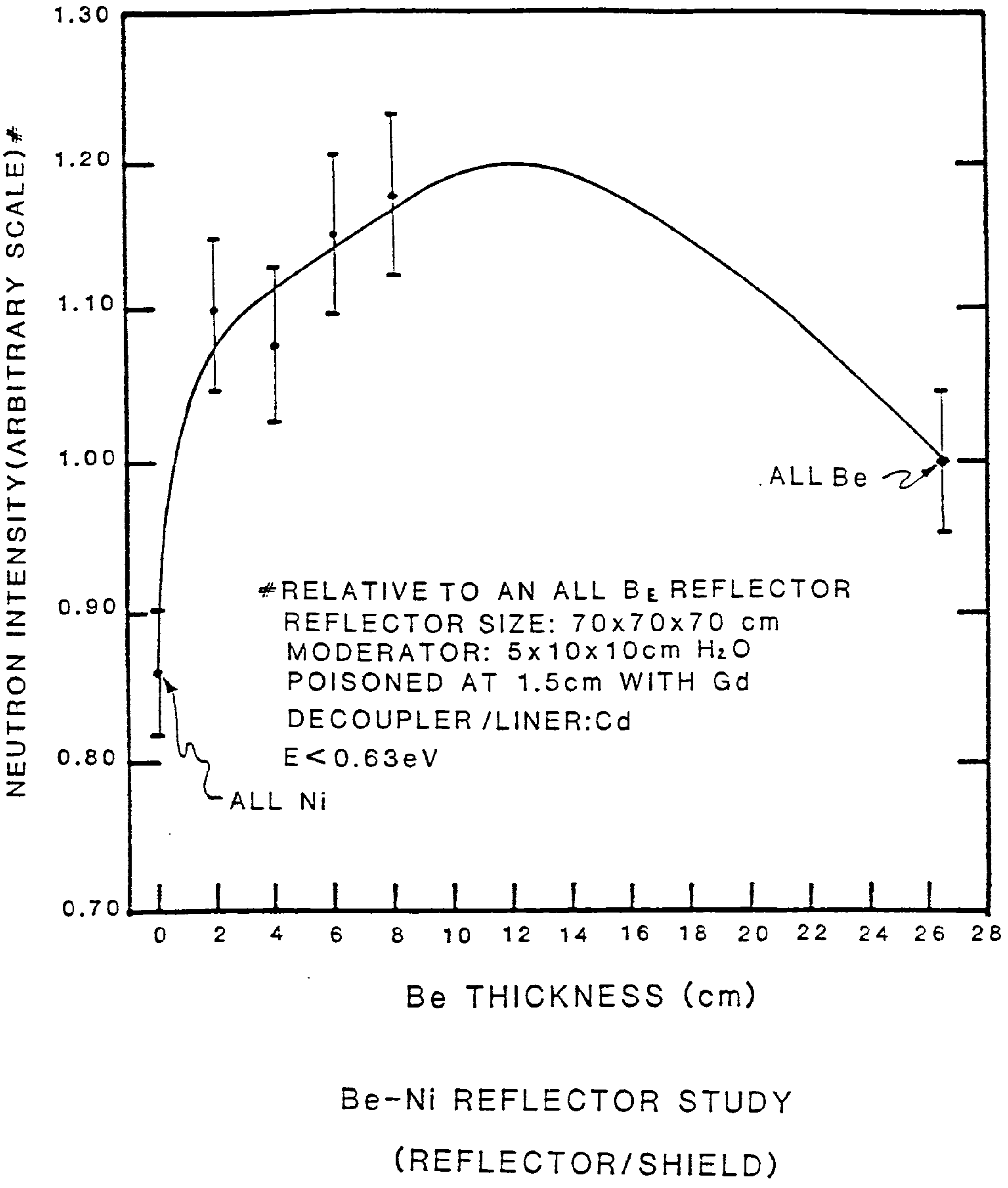


Fig. 3. Neutron surface-current for a composite beryllium/nickel reflector-shield. The computations were done for a moderator in wing-geometry. More definitive computations are underway.

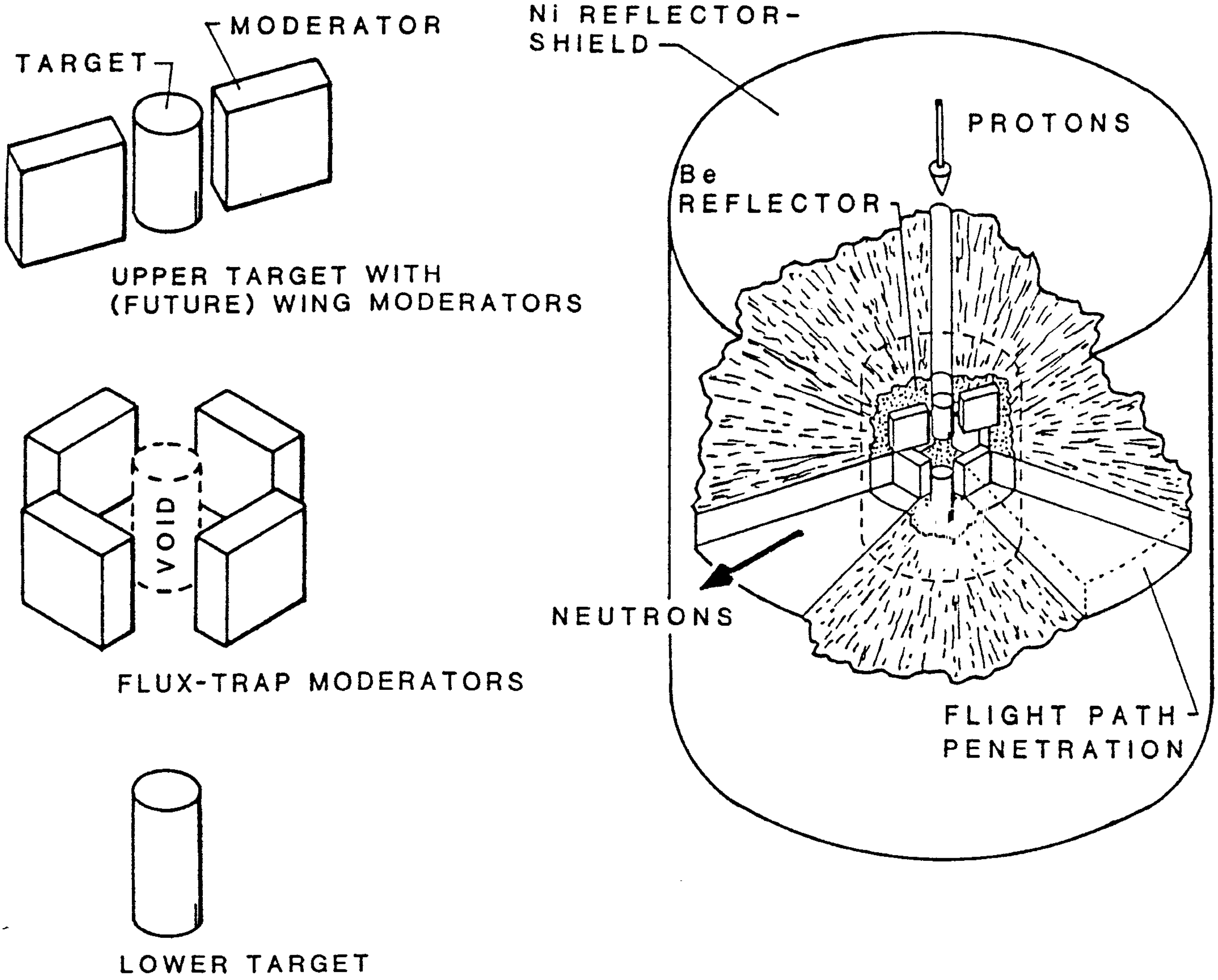


Fig. 4. Illustration of the upgraded/enhanced TMRS configuration for the LANSCE high-current target area. The 1-m-high assembly consists of a split-target, an inner Be reflector region, and an outer Ni reflector/shield. The twelve existing flight paths view the flux-trap moderators; new flight paths would look at wing-moderators in the upper target position.

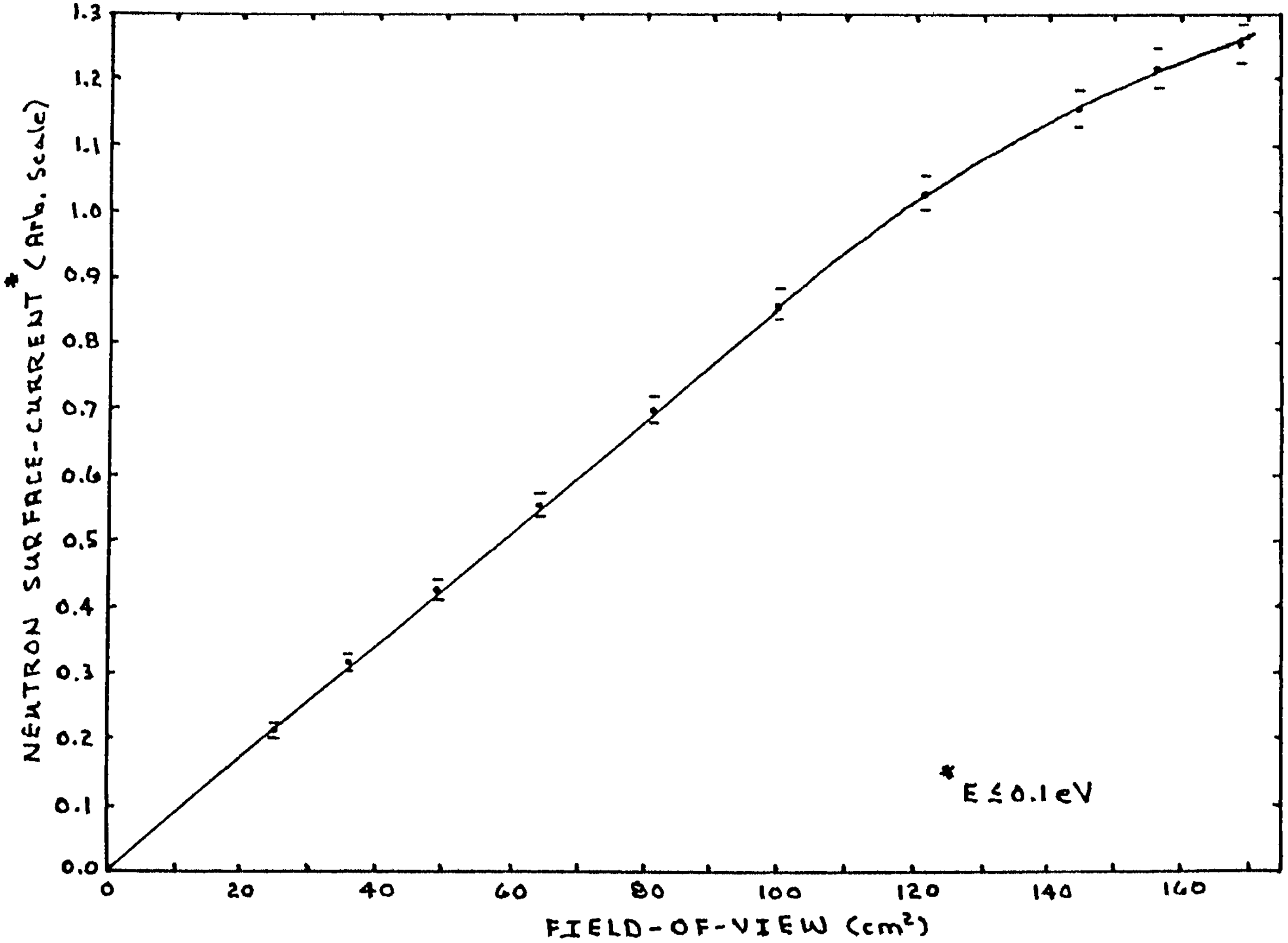


Fig. 5. Neutron surface-current from a high-intensity flux-trap H_2O moderator versus moderator field-of-view.

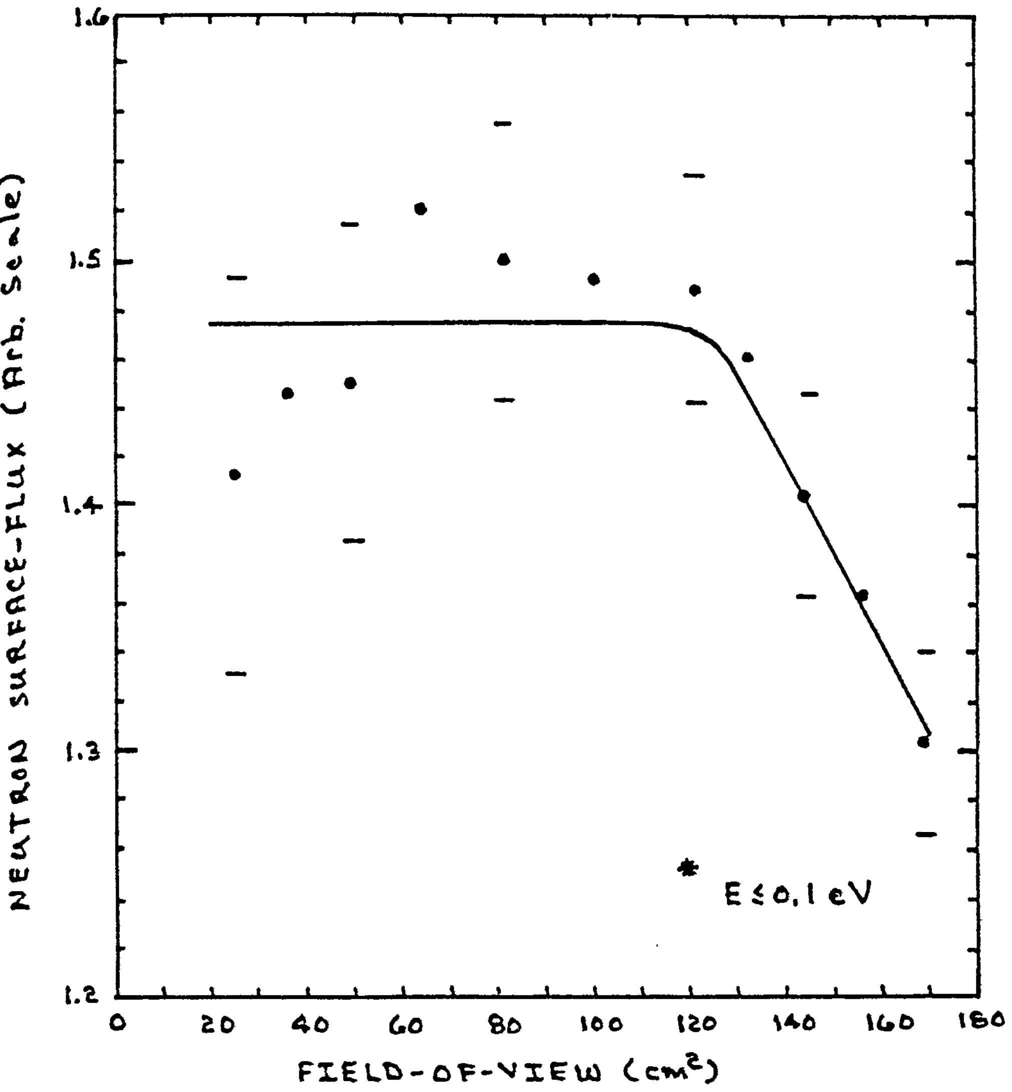


Fig. 6. Neutron surface-flux from a high-intensity flux-trap H_2O moderator versus moderator field-of-view. Neutron surface-flux is indicative of moderator brightness. The relative error in the calculation is approximately ±5%.

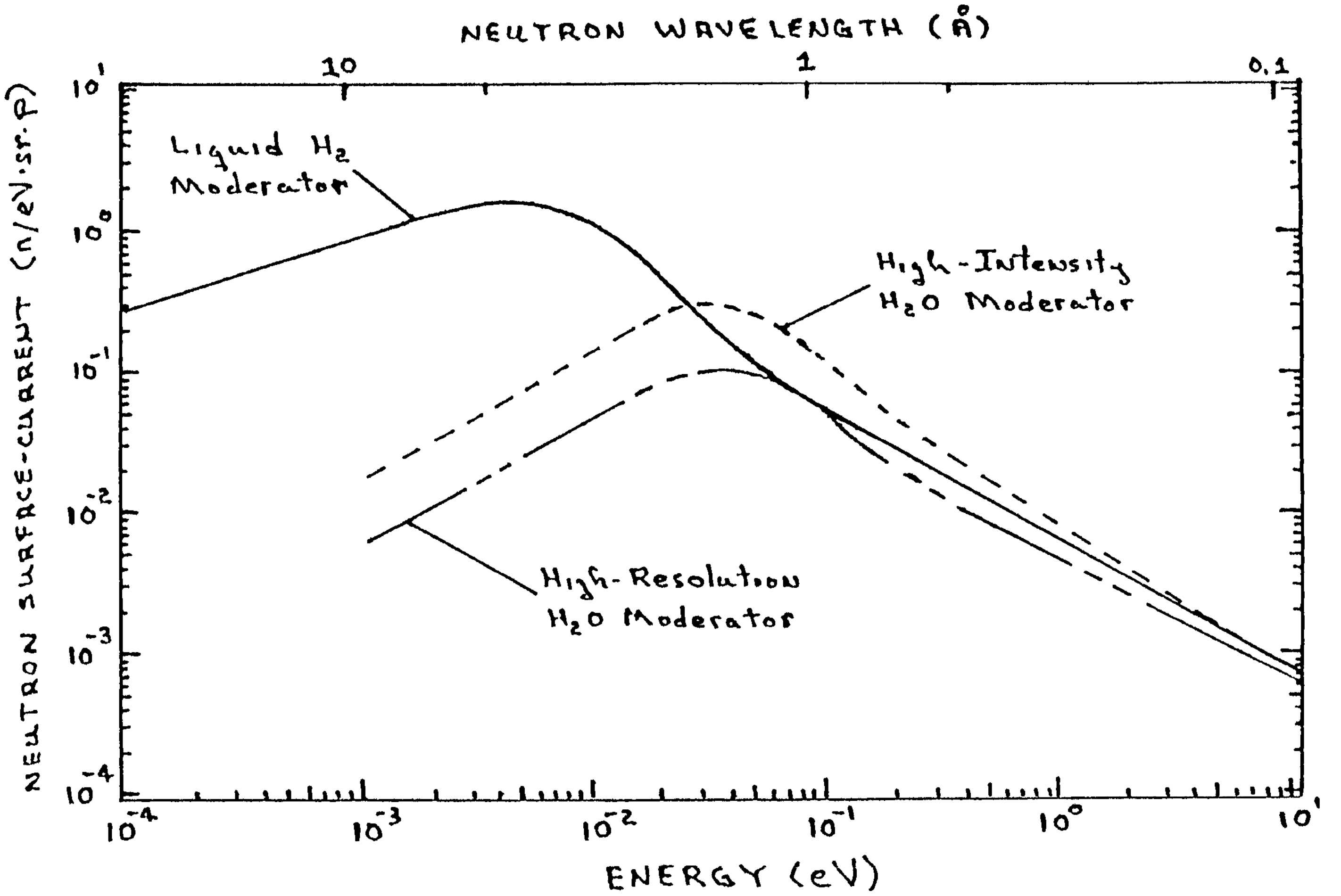


Fig. 7. Calculated neutron surface-current for various flux-trap moderators with a 10-cm-diam tungsten split-target. The moderator field-of-view was 100 cm^2.

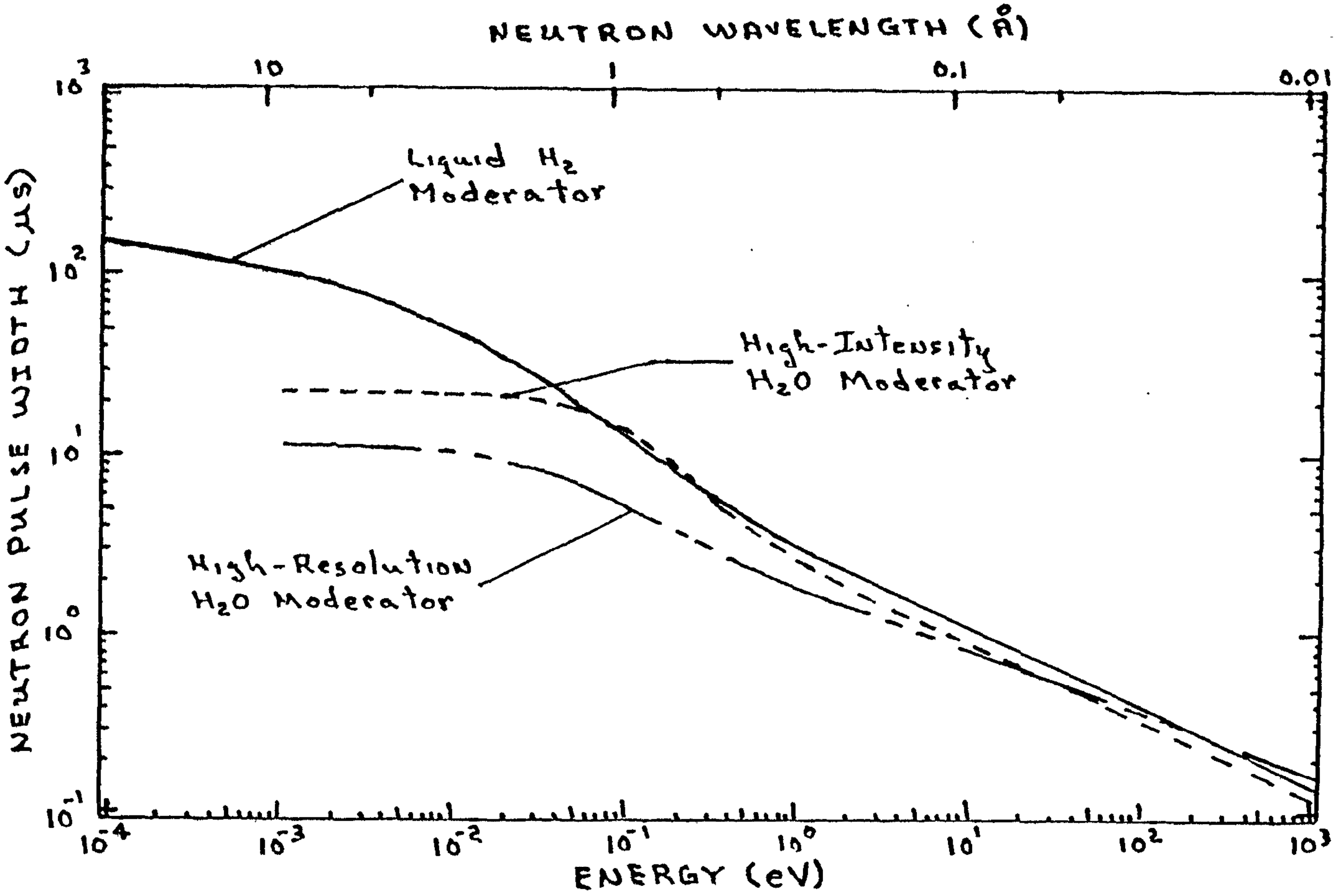


Fig. 8. Calculated standard deviation of neutron pulse for various flux-trap moderators with a 10-cm-diam tungsten target. The moderator field-of-view was 100 cm^2.

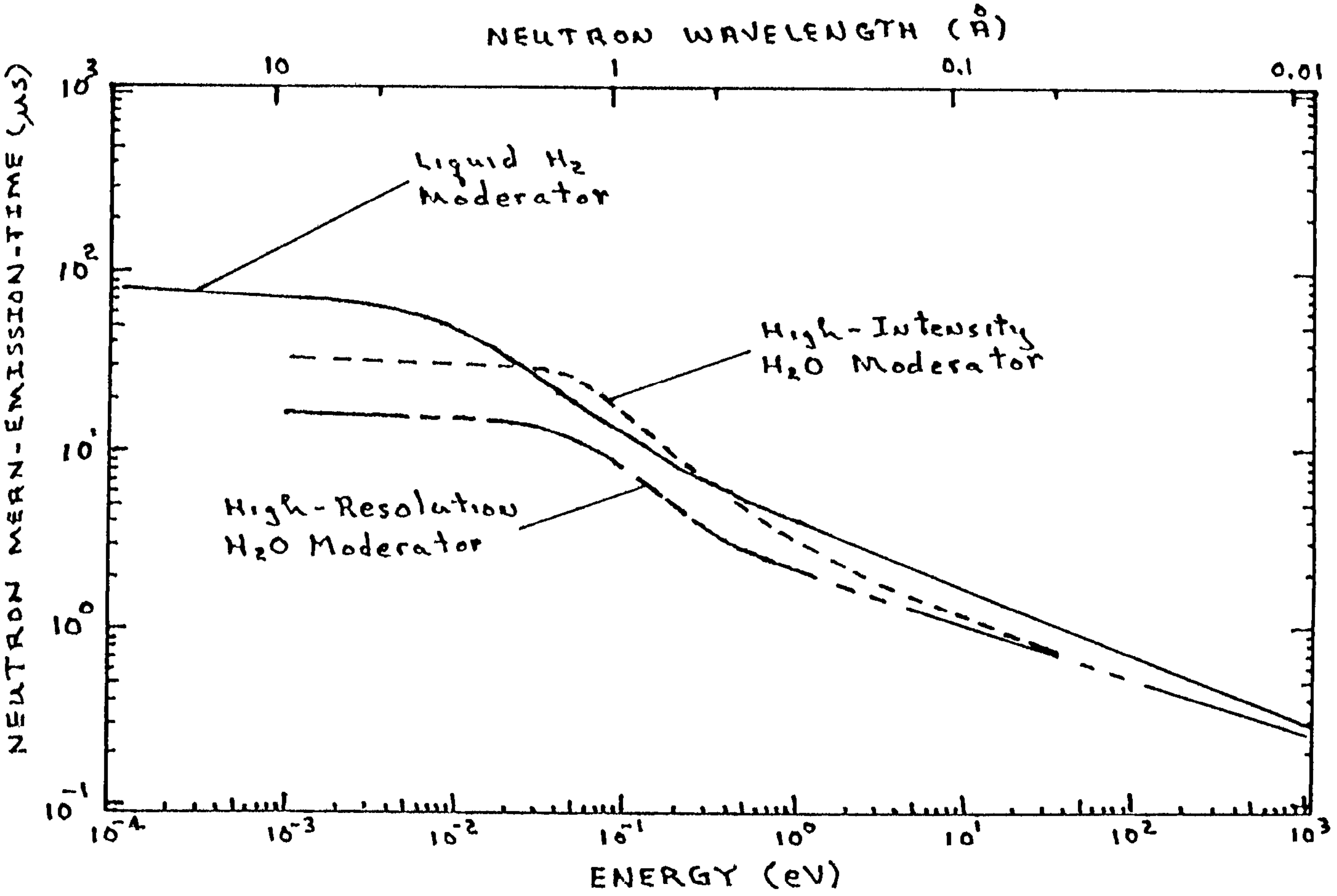


Fig. 9. Calculated neutron mean-emission-time for various flux-trap moderators with a 10-cm-diam tungsten split-target. The moderator field-of-view was 100 cm^2.

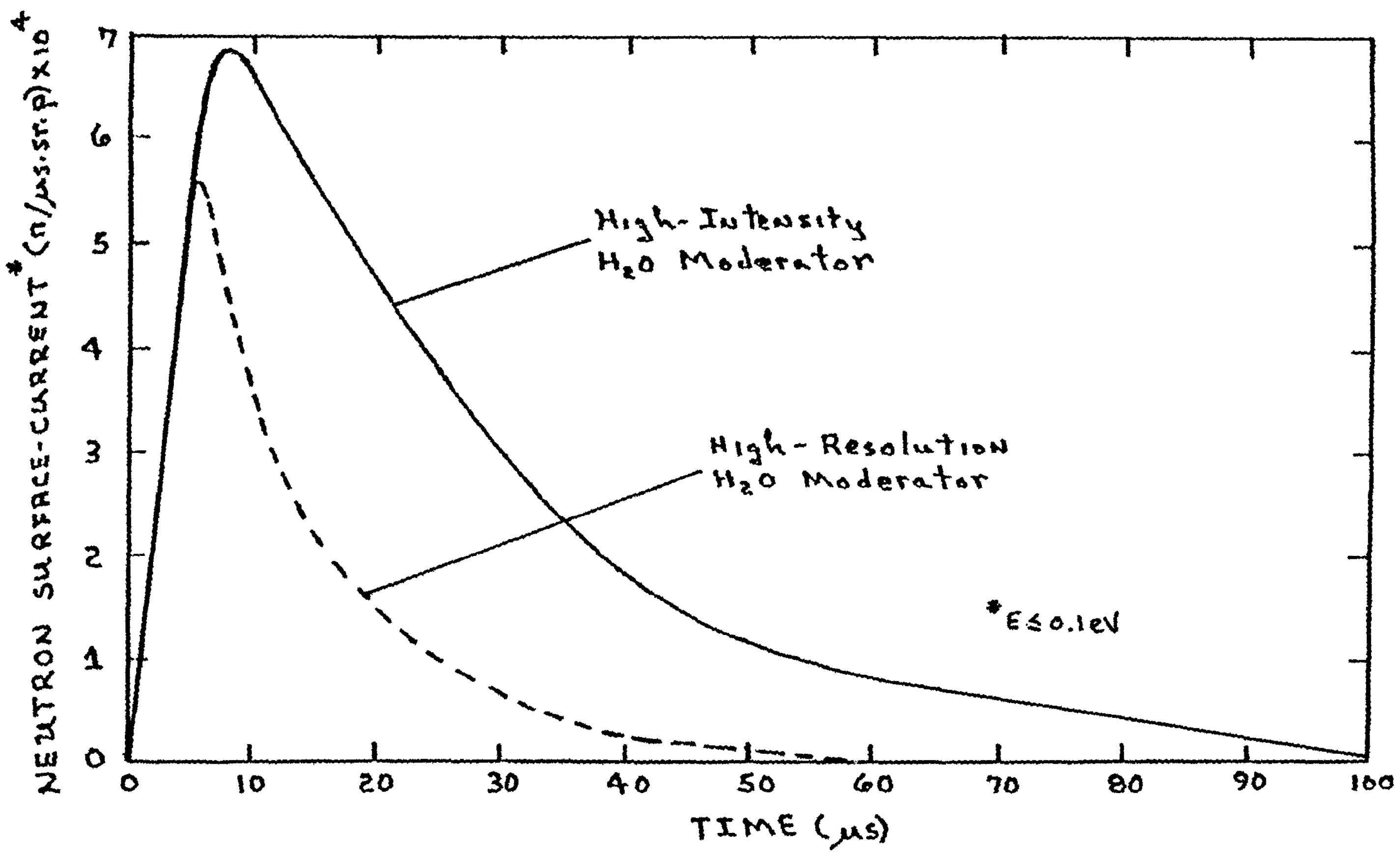


Fig. 10. Calculated neutron time distribution for high-intensity and high-resolution water flux-trap moderators with a 10-cm-diam tungsten target. The moderator field-of-view was 100 cm^2.

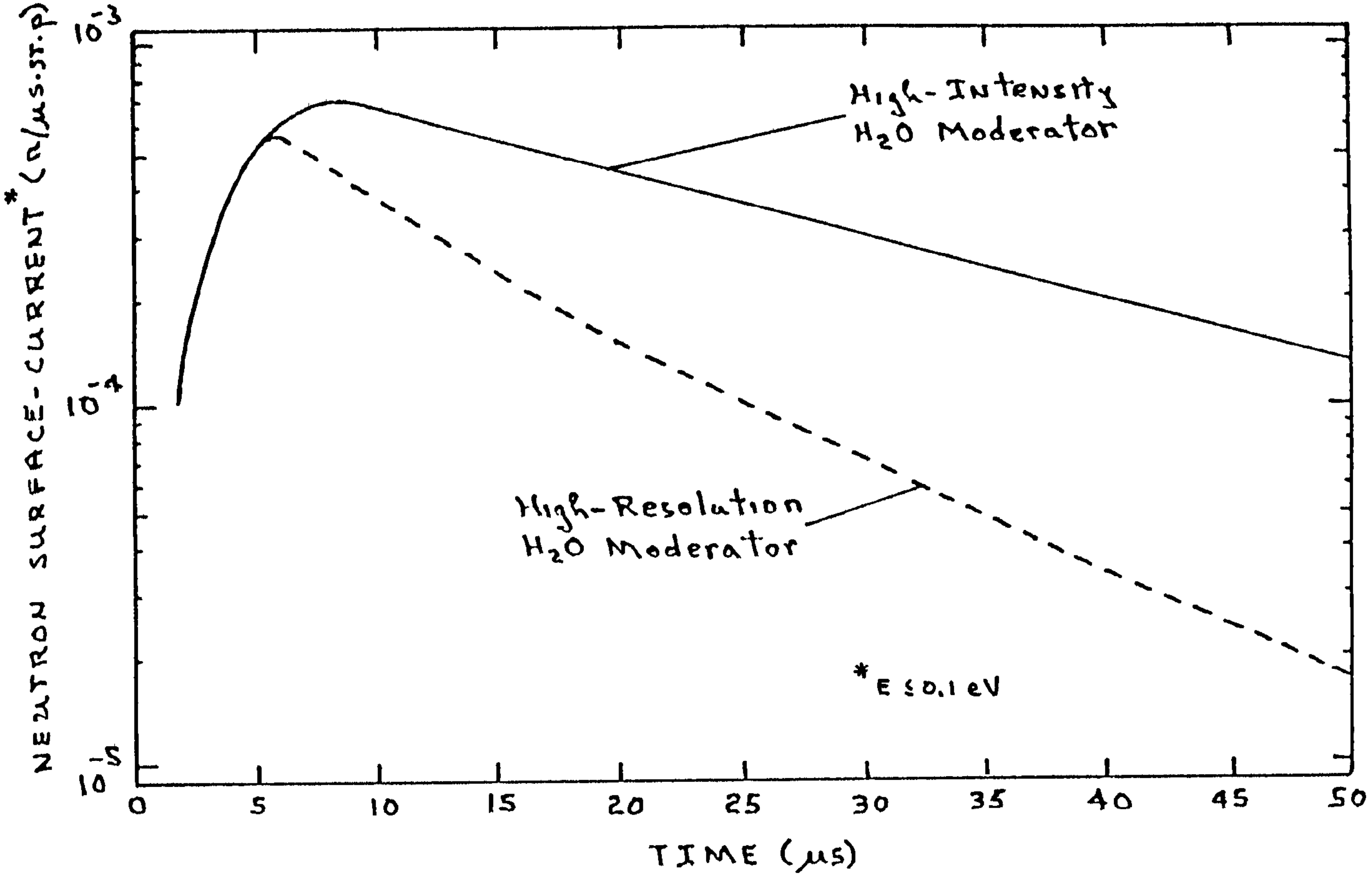


Fig. 11. Calculated neutron time distribution for high-intensity and high-resolution water flux-trap moderators with a 10-cm-diam tungsten target. The moderator field-of-view was 100 cm^2.

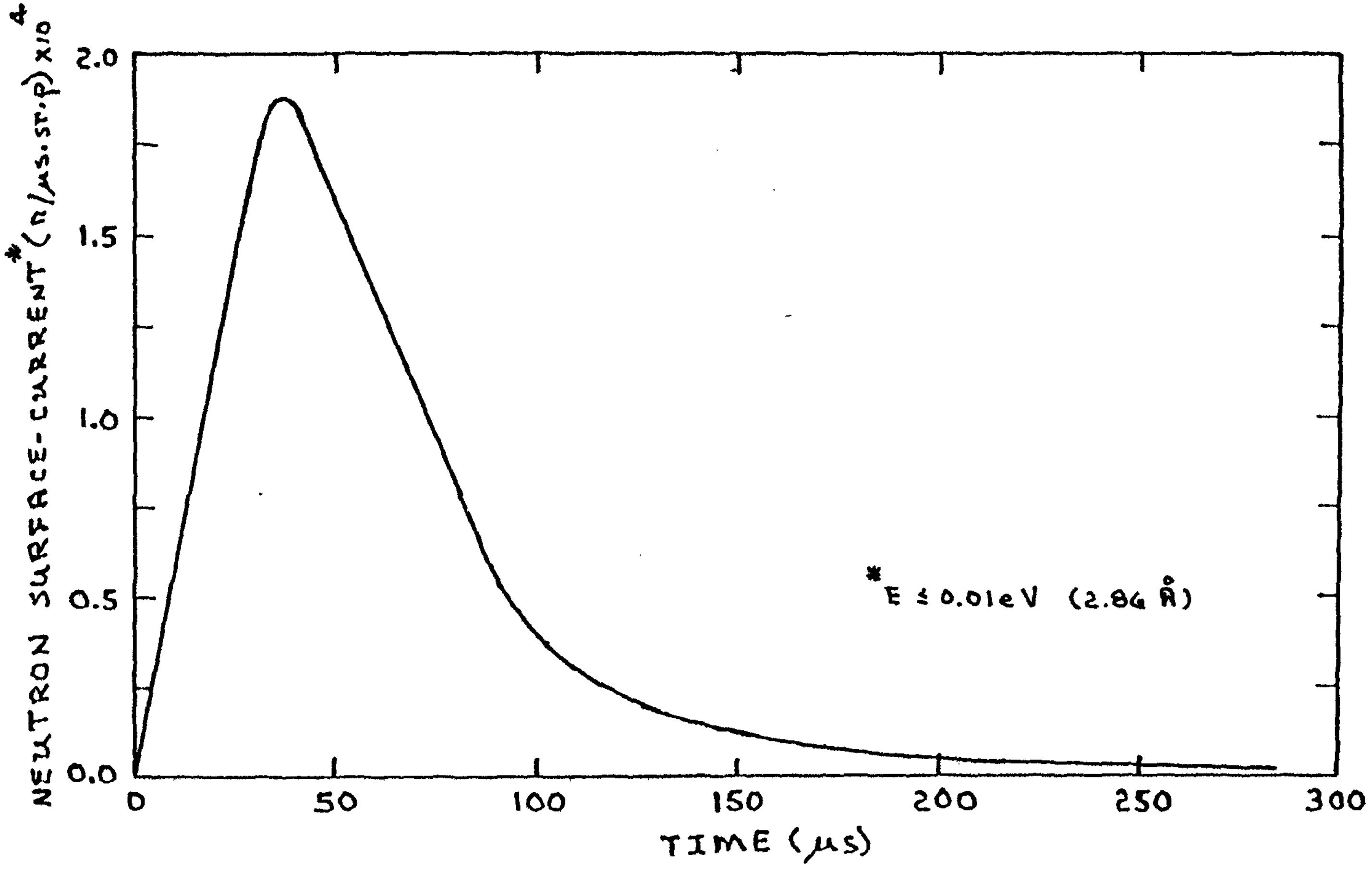


Fig. 12. Calculated neutron time distribution from the liquid hydrogen moderator with a 10-cm-diam tungsten target. The moderator field-of-view was 100 cm^2.

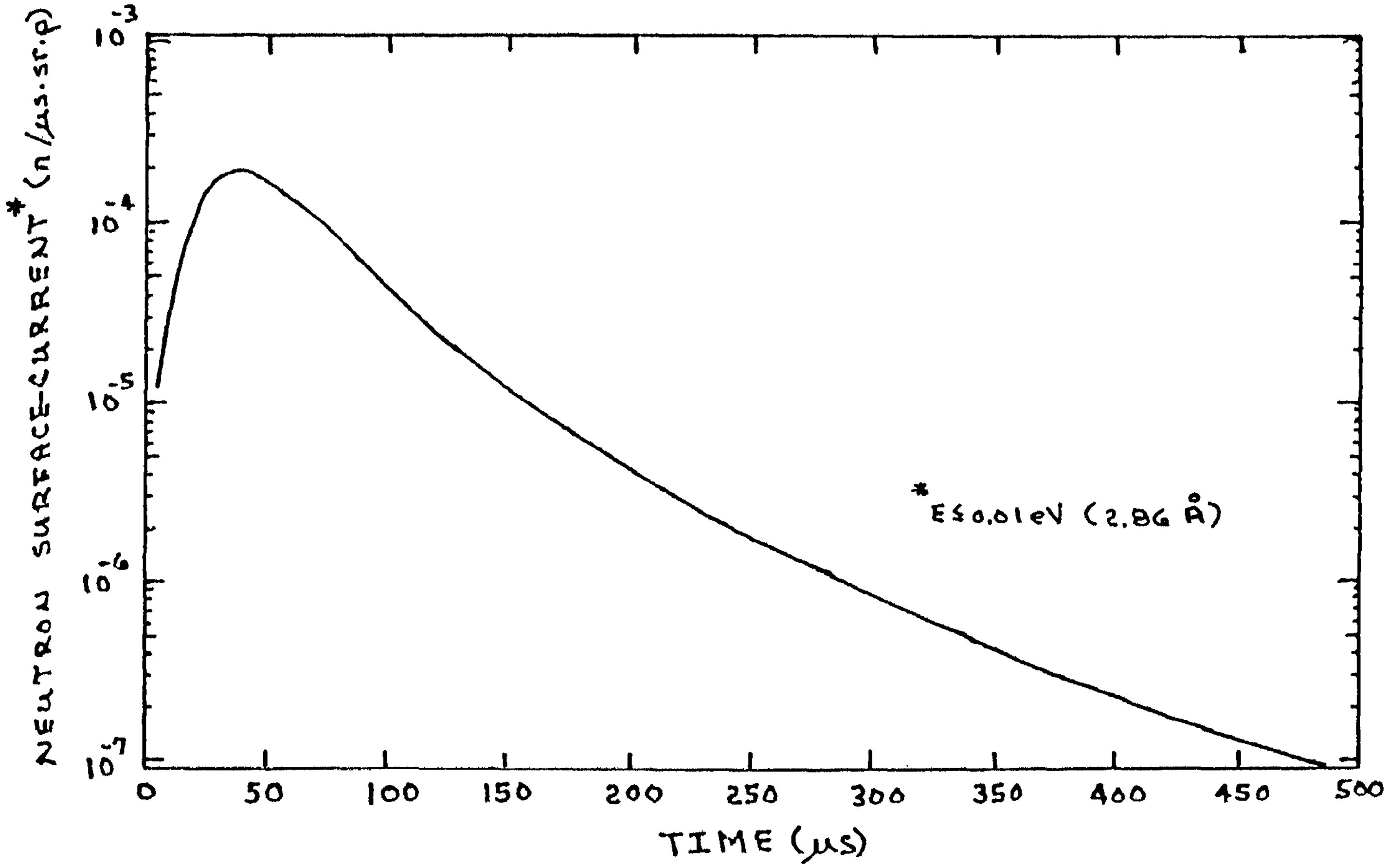


Fig. 13. Calculated neutron time distribution from the liquid hydrogen moderator with a 10-cm-diam tungsten target. The moderator field-of-view was 100 cm^2.

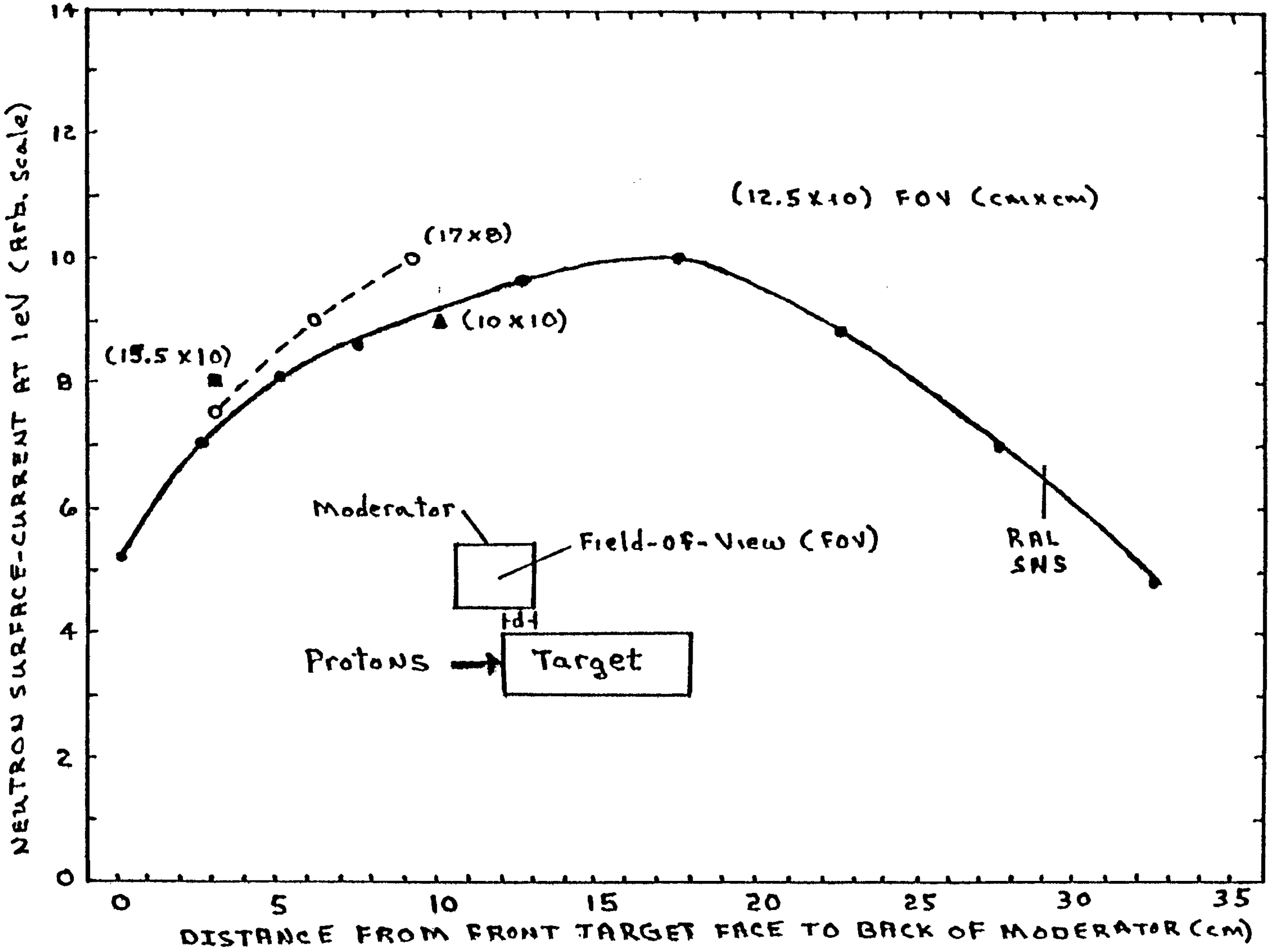


Fig. 14. Neutron surface-current versus location of moderator relative to target in reflected single-wing geometry.

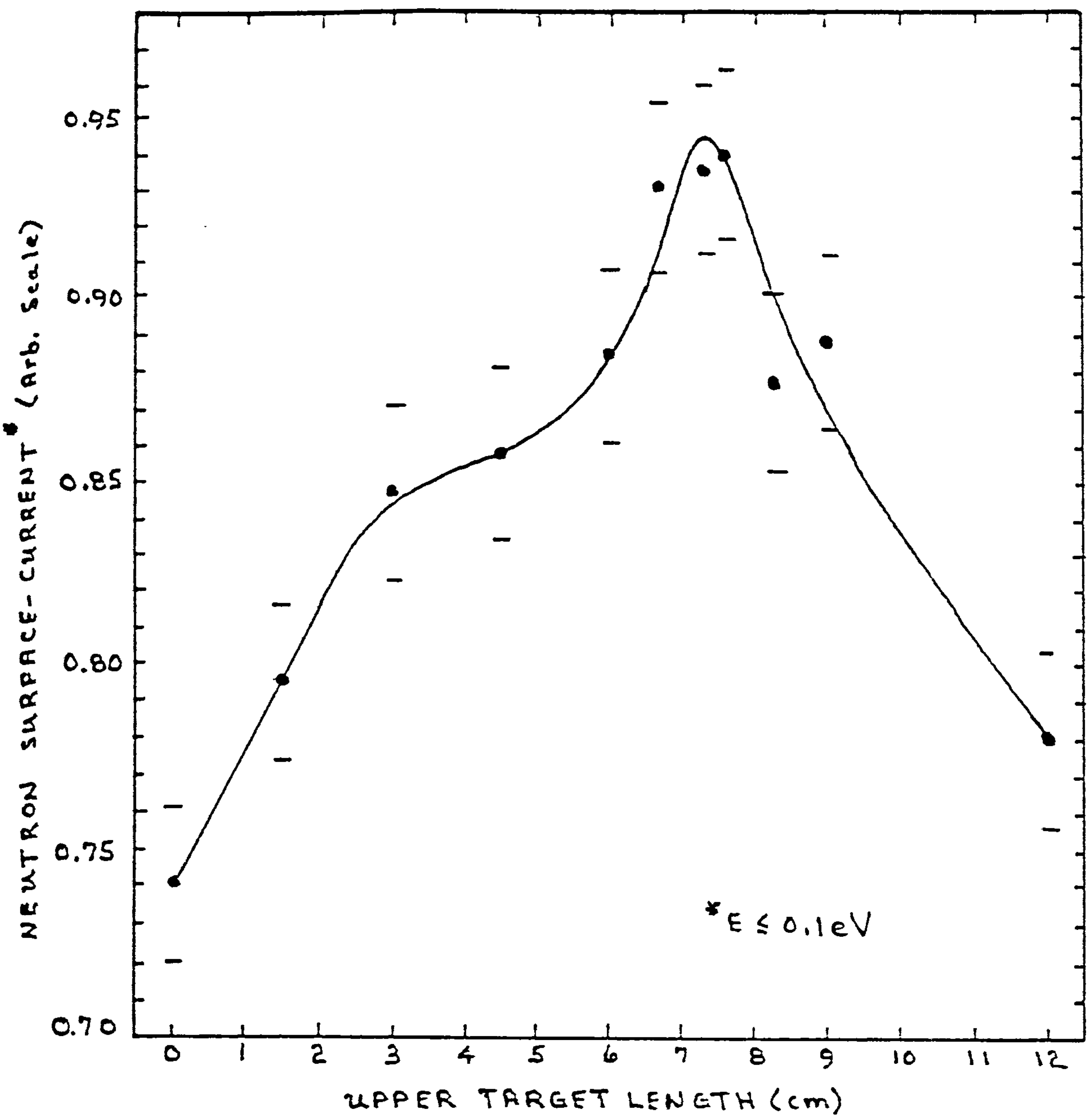


Fig. 15. Neutron surface-current from a high-intensity water moderator as a function of the length of the upper tungsten (10-cm-diam) target. The moderator field-of-view was 11.5-cm from proton beam center.

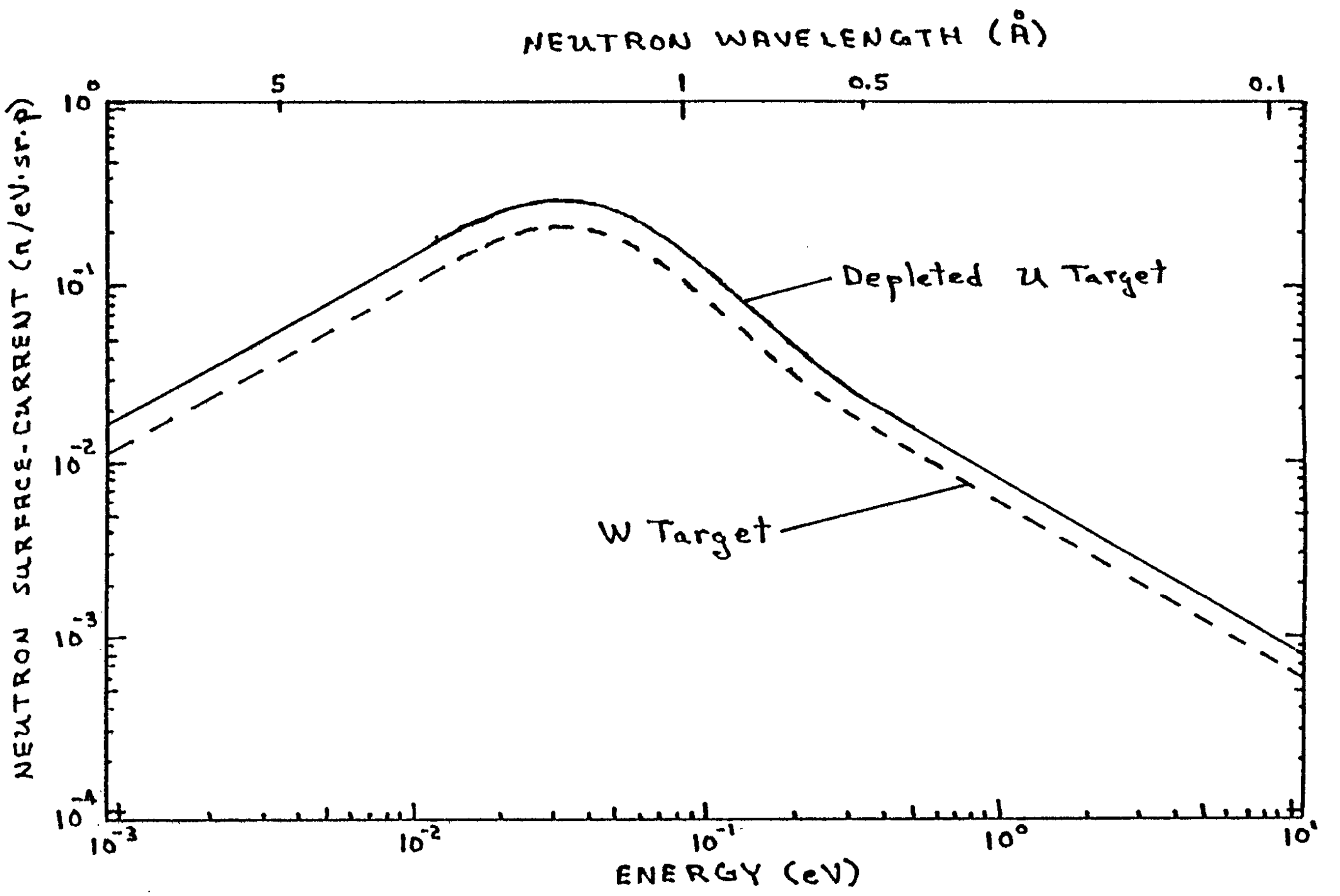


Fig. 16. Neutron surface-current from a high-intensity water moderator for split-targets. The 100 cm^2 moderator field-of-view was 11-cm from proton beam center.