from the debris of underground nuclear explosions. This method should not be overlooked as a future practical source of these elements, since it has the distinct advantage of producing the higher, relatively short-lived isotopes in much greater proportion than can be accomplished by reactor irradiation, by means of the reactions shown in Figure 18. For example the largest quantity of the 95-day fermium-257 that has yet been produced and recovered was obtained from an underground explosion. A theoretical assessment of potential yields of heavy nuclides from underground explosions that has been made at Los Alamos shows that concentrations of fermium-257 of the order of nanograms per ton of debris can be anticipated. Figure 19 lists some of the nuclear reactions that could be studied in a laboratory environment if sufficient fermium-257 were to be recovered from the site of an underground explosion.

THE ACCELERATOR AS A NEUTRON SOURCE

Our Canadian colleagues have been speculating on the possibility of still another approach to large-scale heavy nuclide production. They propose the use of a proton accelerator to produce intense neutron fluxes in a massive target by spallation reactions. Called the Intense Neutron Generator (ING), this very large and expensive machine would produce a proton beam of 65 milliamperes at 1 GeV energy incident on a liquid metal target. The spallation neutrons would be moderated in a tank of heavy water and the thermalized neutrons would be withdrawn through a beam tube. The design objective of the machine is a thermal flux of 10^{16}. Some of you may recall the efforts of E. O. Lawrence along this line at Livermore almost 20 years ago.

ACTINIDES IN THE FUTURE

The future for the actinide elements appears to offer continuing excitement, with literally new worlds becoming available for their utilization.

Reliable and compact power supplies for manned space missions of perhaps several years duration could require many kilograms of actinide heat sources in their electrical power supplies, with the waste heat being gainfully employed to maintain the quality of the spacecraft's cabin atmosphere and to recycle water for drinking, cooking, and sanitary purposes.

(more)

Underwater laboratories - the "Sealabs" - could use similar or even larger power supplies and the waste heat generated by them, since providing heat and power several hundred feet below the surface of the ocean for months to years at a time is a true technological challenge.

Many new medical applications for the actinides will appear, I am certain, either in the form of power supplies for use in prosthetic devices of many different sorts or as radiation sources for diagnostic, therapeutic and reseach purposes.

The chemists of the years to come will be trained through the educational process to know the chemistry of the actinide elements in the same way that they now master the chemistry of the naturally occurring elements, and they will have available relatively stable isotopes of the actinides with which to perform their experimental research.

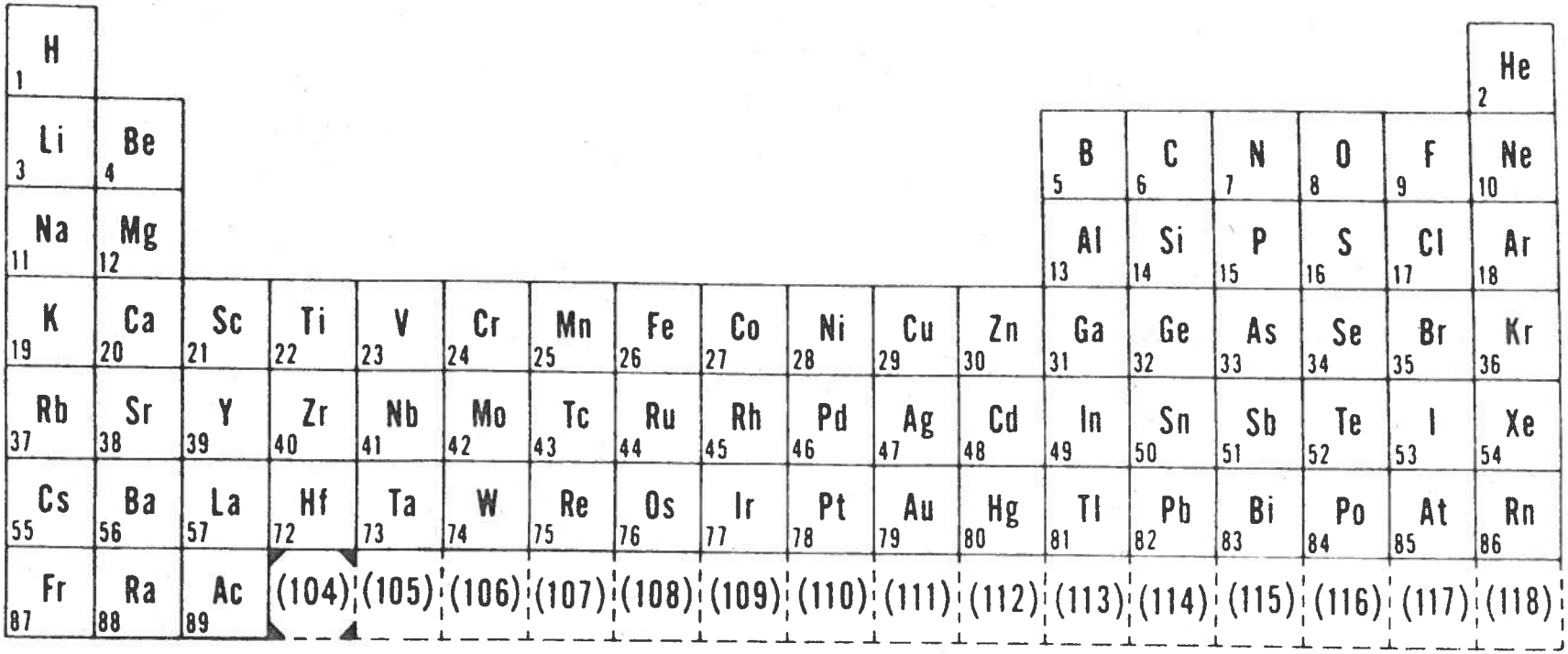
A scientific challenge still remaining - although many people have attempted to find a solution with but limited success - is the means for converting the kinetic energy of the emissions of radioisotopes directly into electricity without going through a degradation to thermal energy. Such a process could conceivably have a very high efficiency and would open up new vistas for applications which we probably can't even visualize now.

I end on this note because it is the duty of someone to sound the clarion for things yet to be done, rather than noting with smugness and satisfaction that everything important has been accomplished already. I wish you "good hunting."

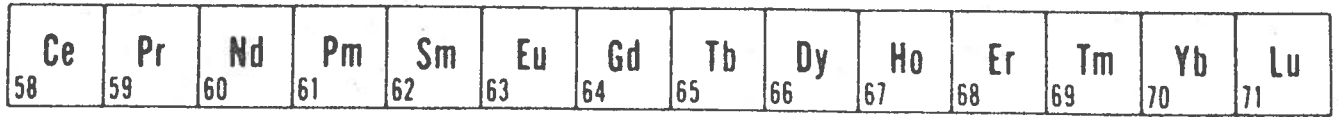
#

Fig. 1

PERIODIC TABLE OF THE ELEMENTS



LANTHANIDE SERIES



ACTINIDE SERIES

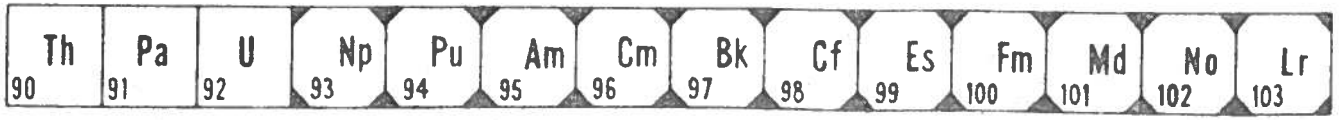


Fig. 2

NUCLEAR REACTIONS FOR THE PRODUCTION OF HEAVY ELEMENTS BY INTENSIVE SLOW NEUTRON IRRADIATION

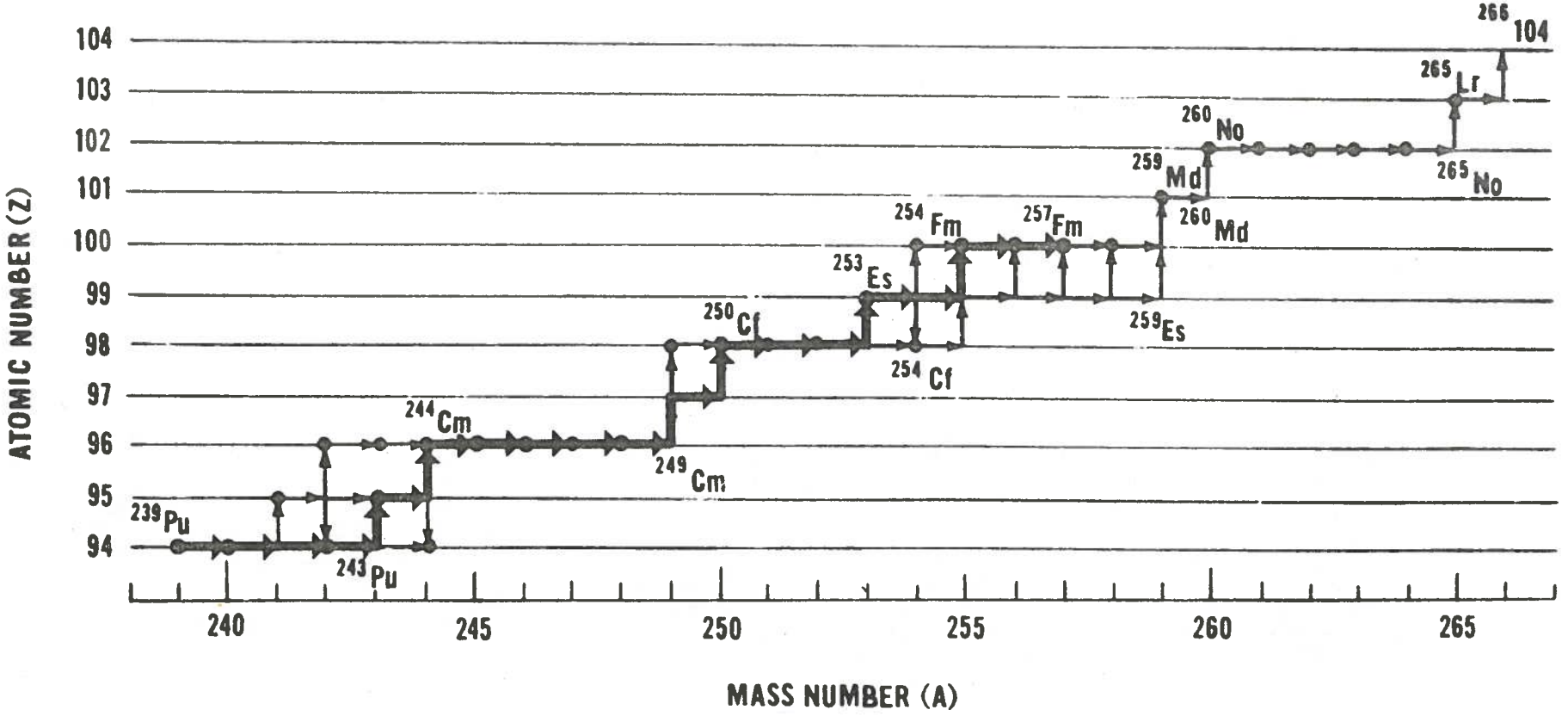


Fig. 3

ESTIMATED AVAILABILITY OF SEPARATED
TRANSURANIUM ELEMENTS IN THE UNITED STATES BY 1975 and 1980

Element	Atomic No.	Principal (Isotopes)	Annual Production Rate Grams	
			1975	1980
Neptunium[a]	93	^{237}Np	2×10^{5}	5×10^{5}
Plutonium[a]	94	^{239}Pu	1×10^{7}[b]	3×10^{7}[b]
Americium[a]	95	$^{241,243}Am$	7×10^{4}	2×10^{5}
Curium[a]	96	^{244}Cm	3×10^{3}[c]	3×10^{4}[c]
Berkelium[d]	97	^{249}Bk	10^{-1}	
Californium[d]	98	^{252}Cf	1[e]	
Einsteinium[d]	99	$^{253,254,255}Es$	10^{-2}	
Fermium[d]	100	^{257}Fm	10^{-5}	

[a] From U. S. civilian power reactors only.

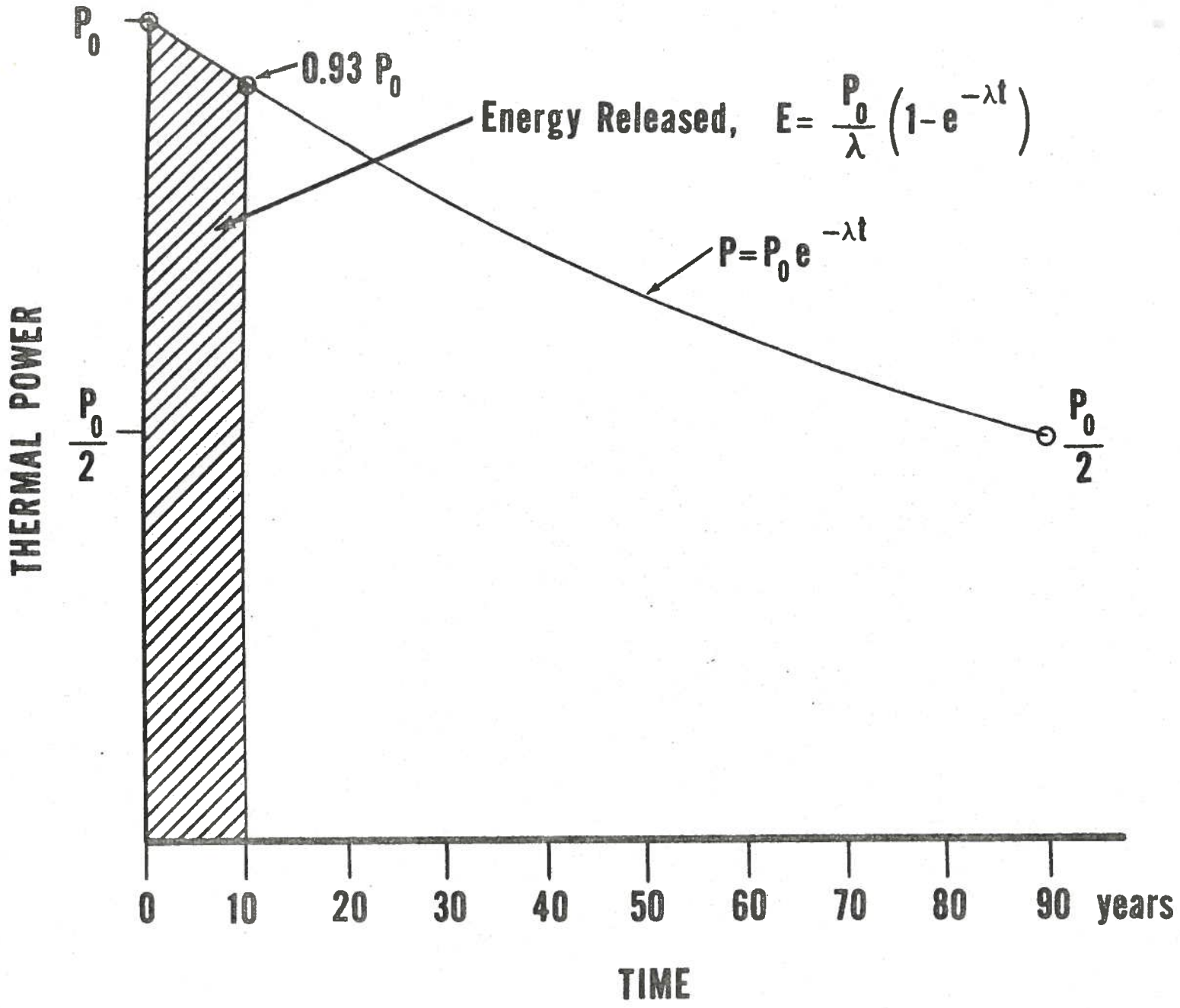
[b] Includes higher mass number isotopes.

[c] Includes small quantity of higher mass number isotopes.

[d] From HFIR only.

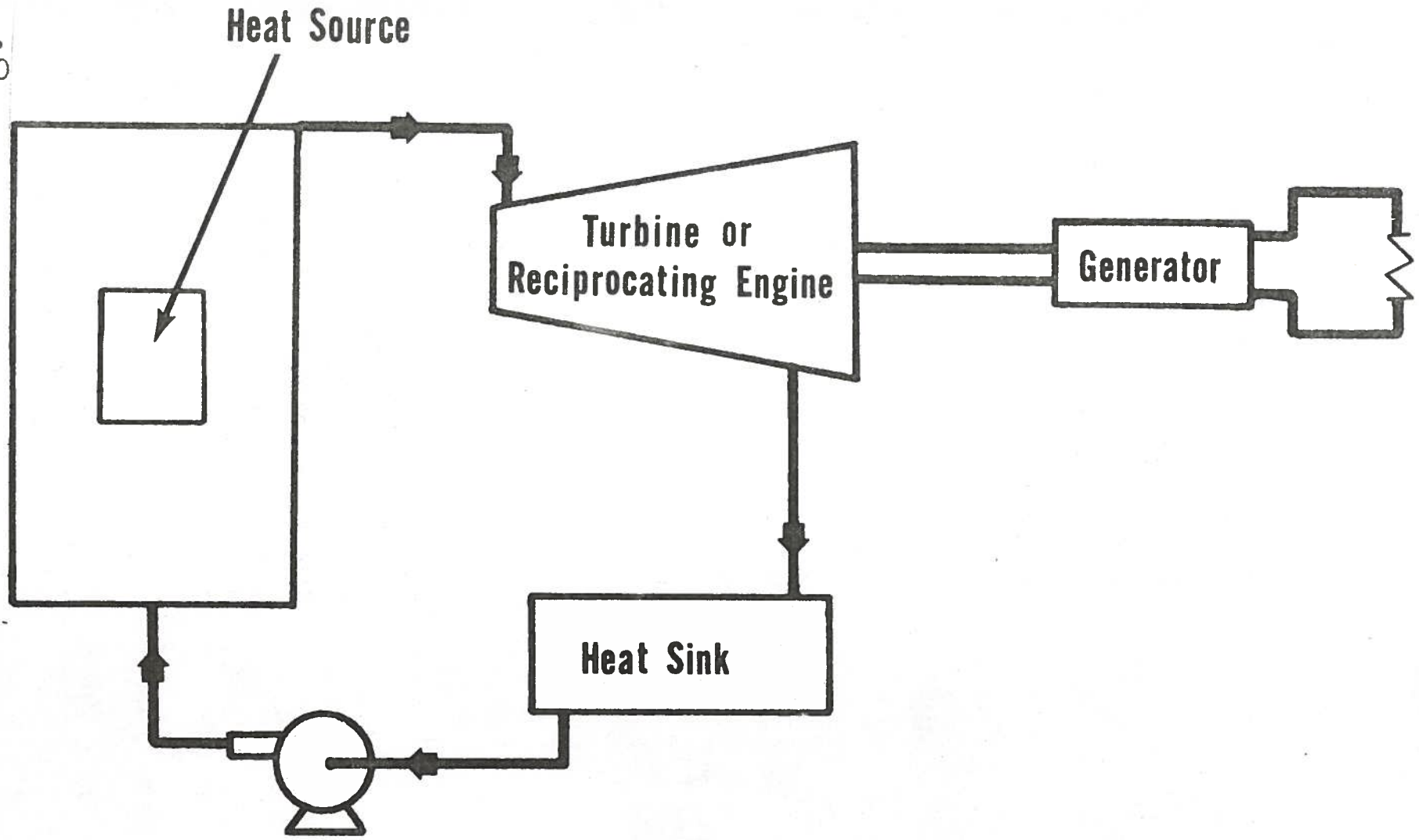
[e] Excludes lower mass number isotopes that are present.

Fig. 4



ENERGY RELEASE FROM PLUTONIUM 238

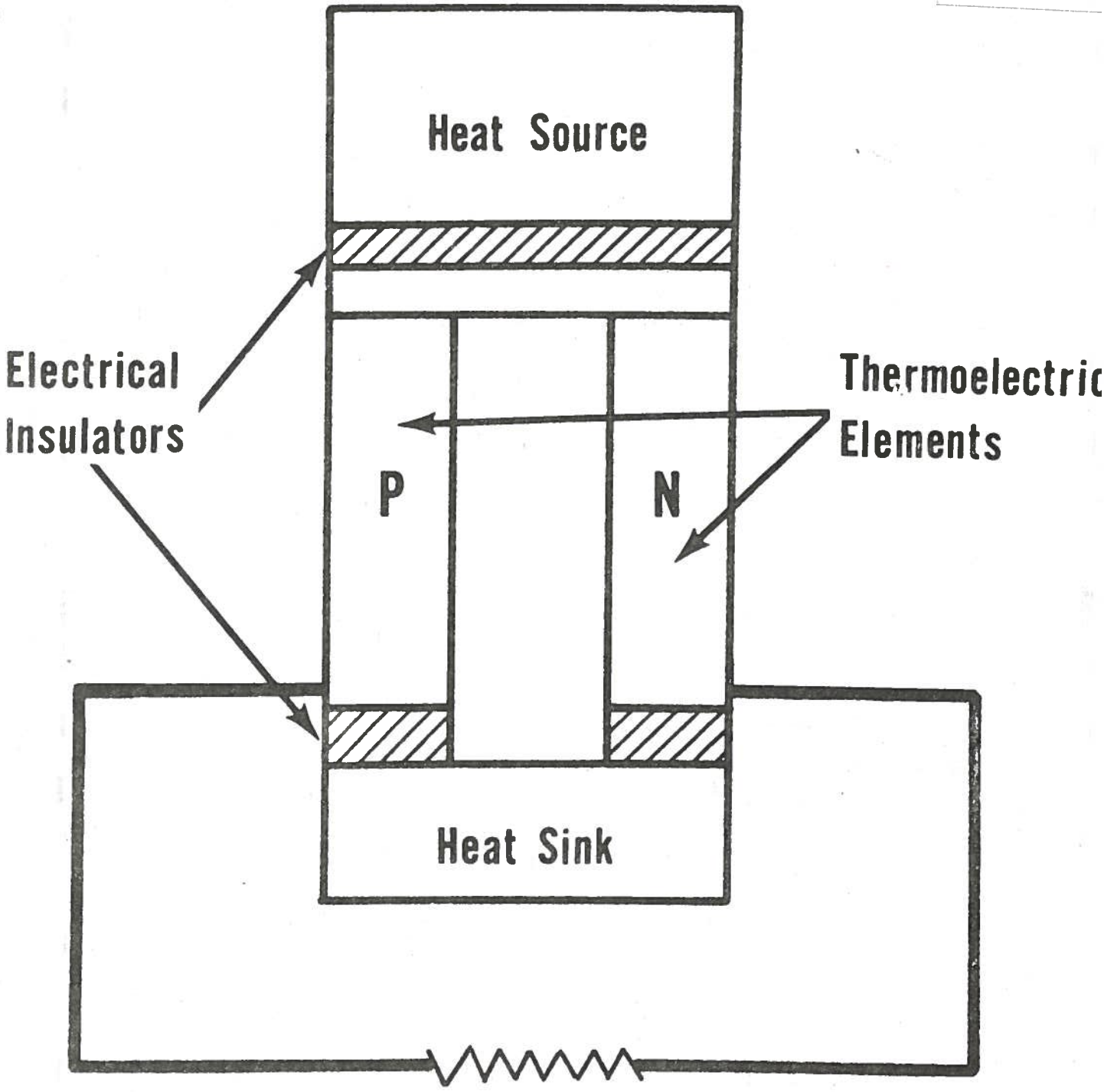
Fig.



ENERGY CONVERSION SYSTEMS

I. DYNAMIC

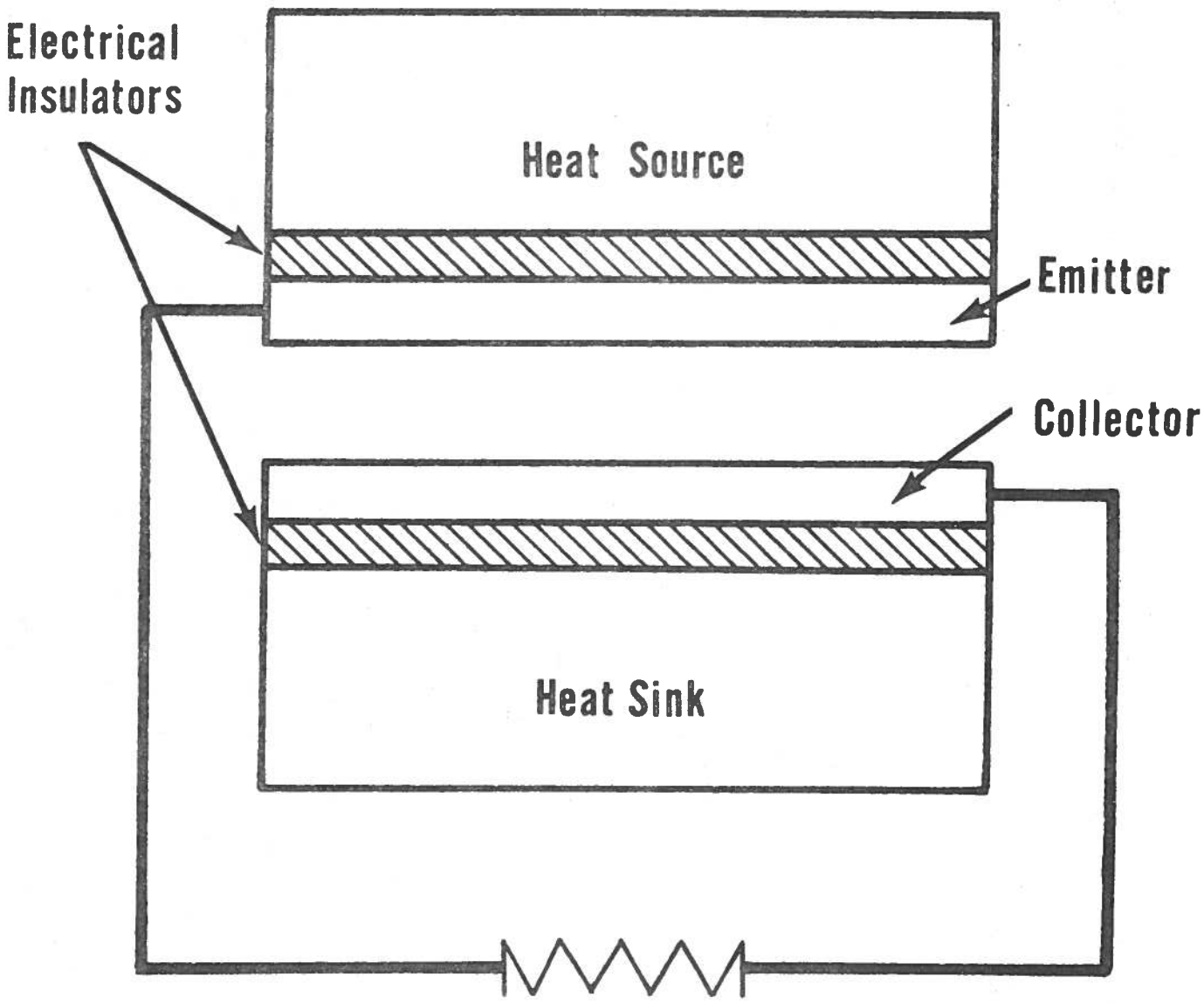
Fig. 6



ENERGY CONVERSION SYSTEMS

2. THERMOELECTRIC

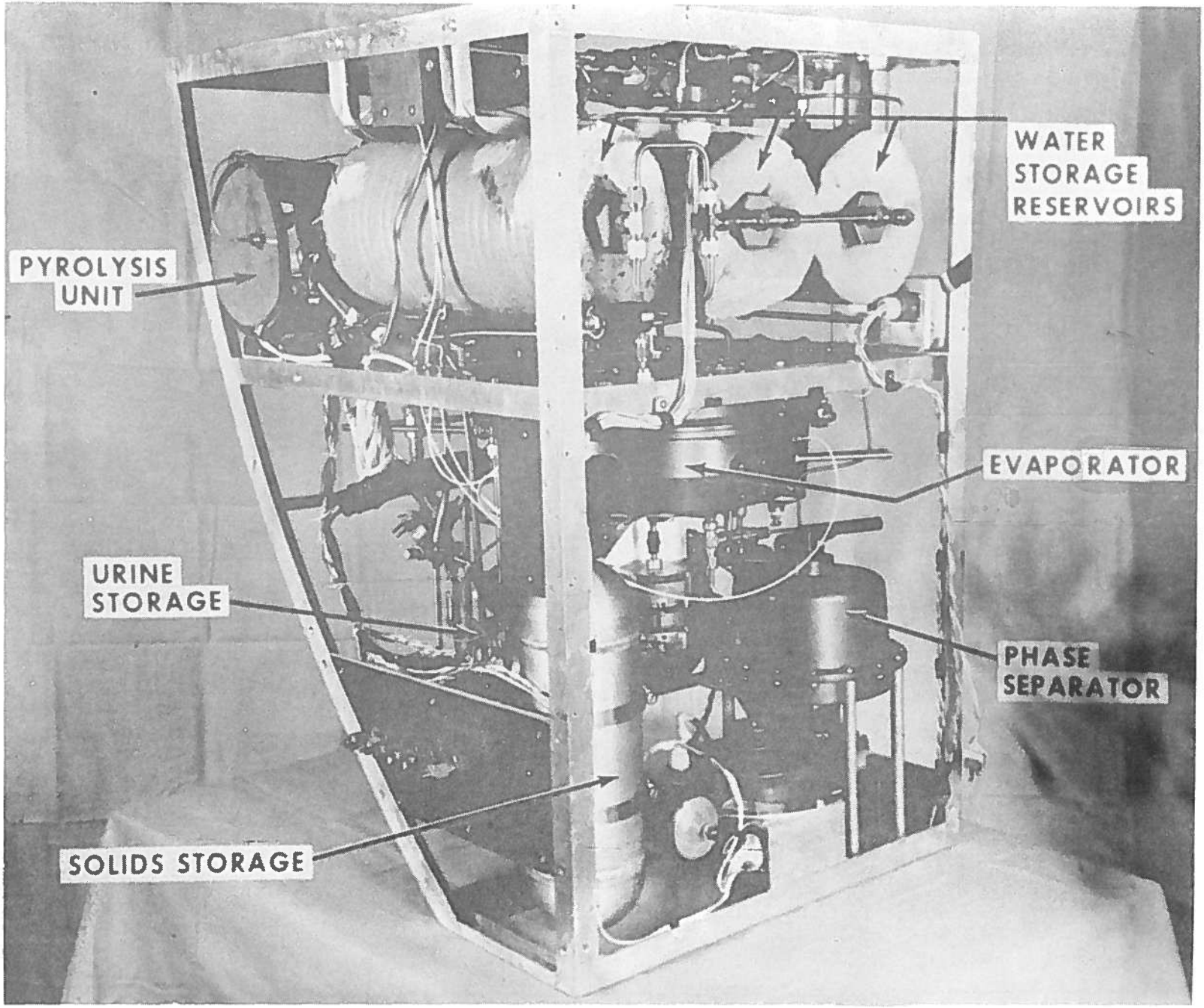
Fig. 7



ENERGY CONVERSION SYSTEMS

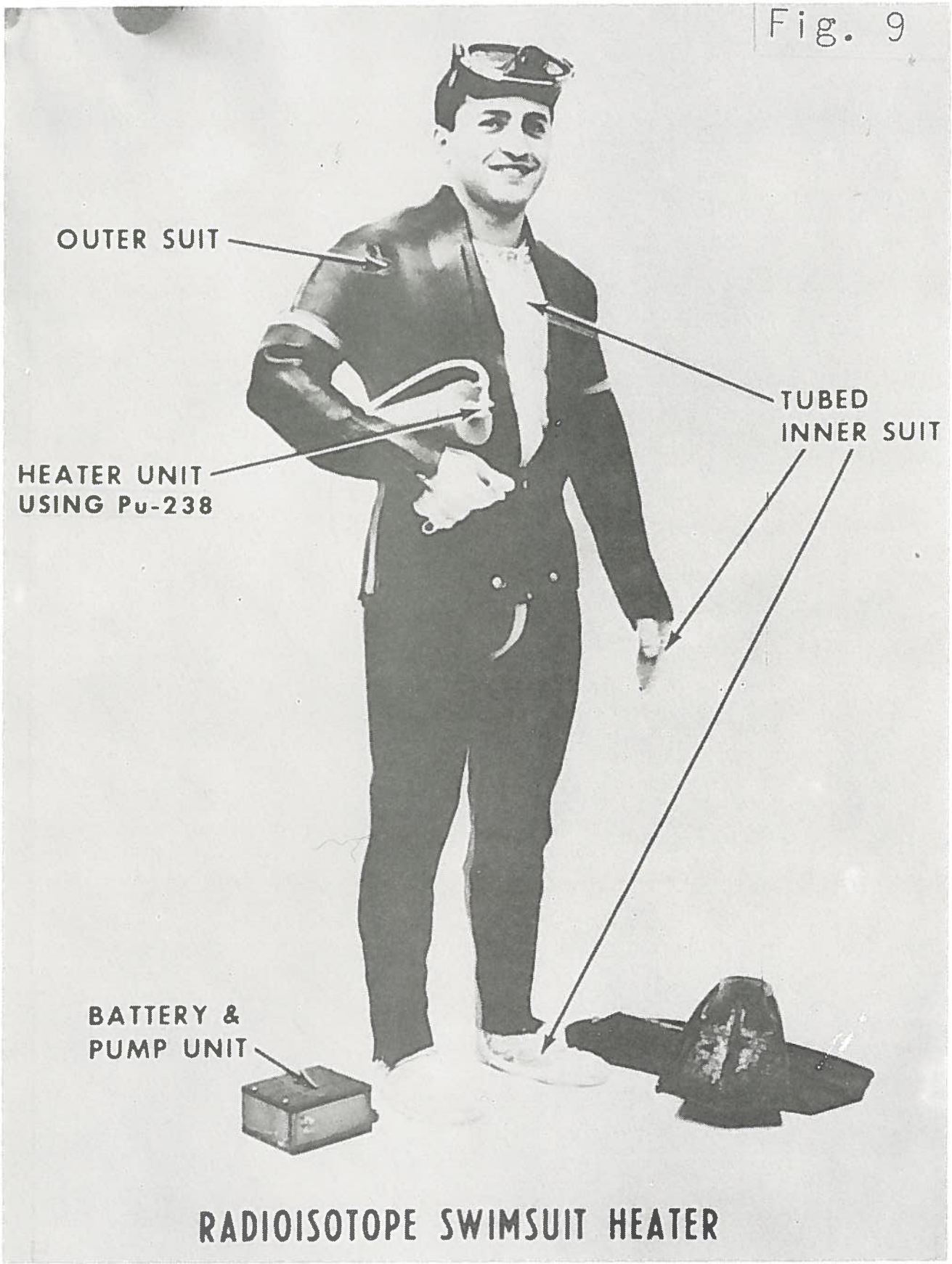
3. THERMIONIC

Fig. 8



WATER RECOVERY SYSTEM FOR ASTRONAUTS USING Pu-238

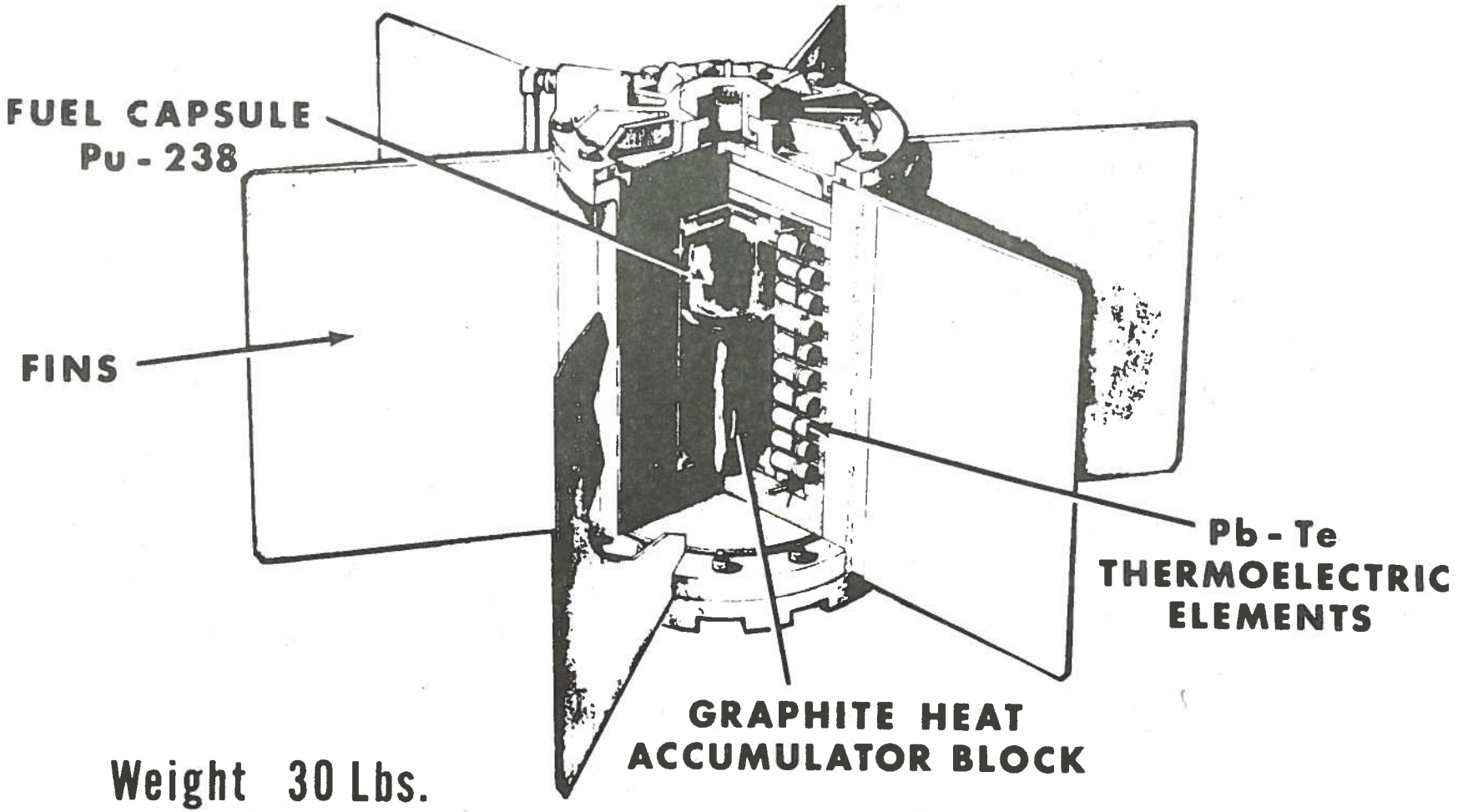
Fig. 9



RADIOISOTOPE SWIMSUIT HEATER

Fig. 10

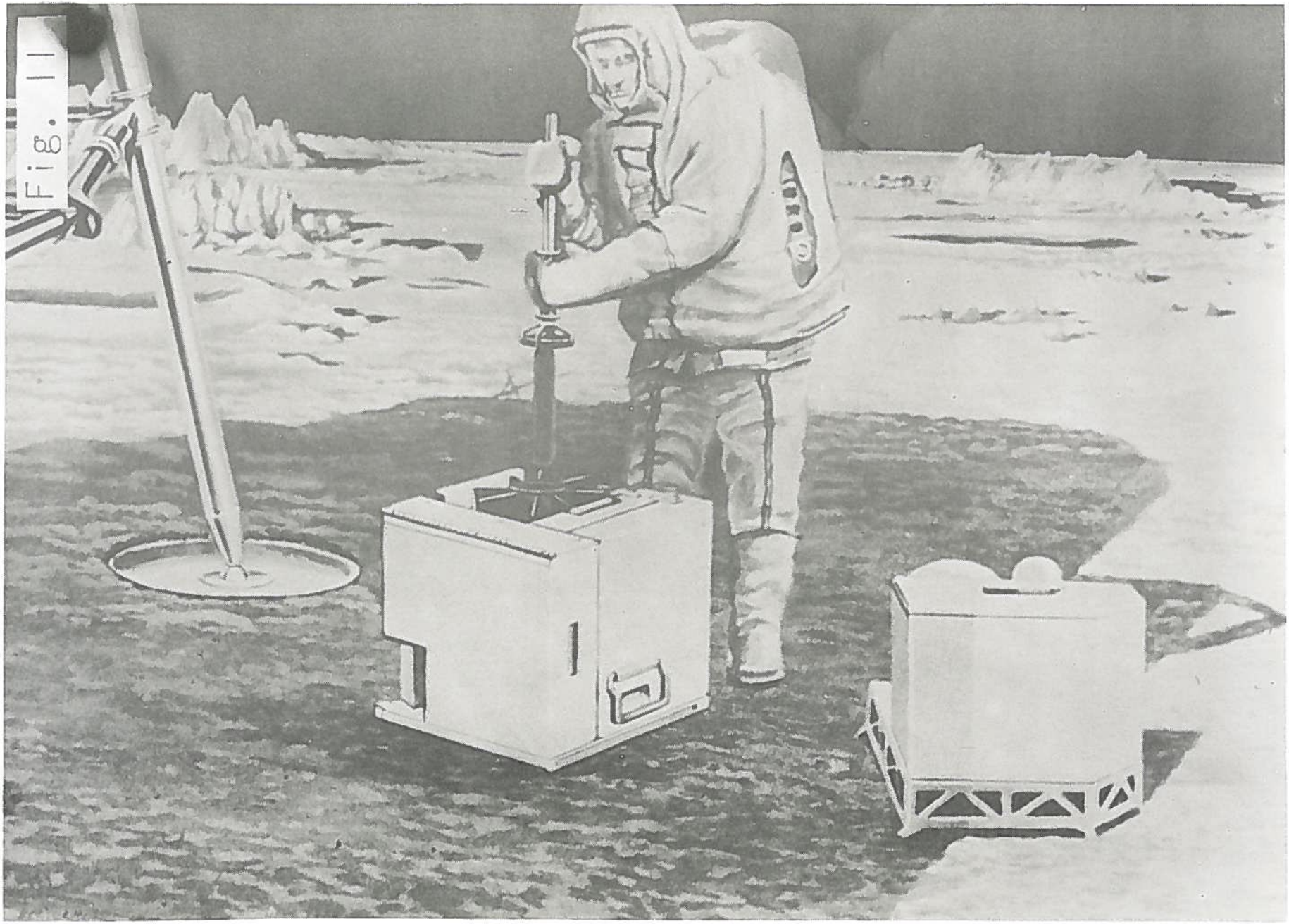
SNAP-19 POWER SUPPLY FOR NIMBUS B SATELLITE



Weight 30 Lbs.

Power Output 30 Watts

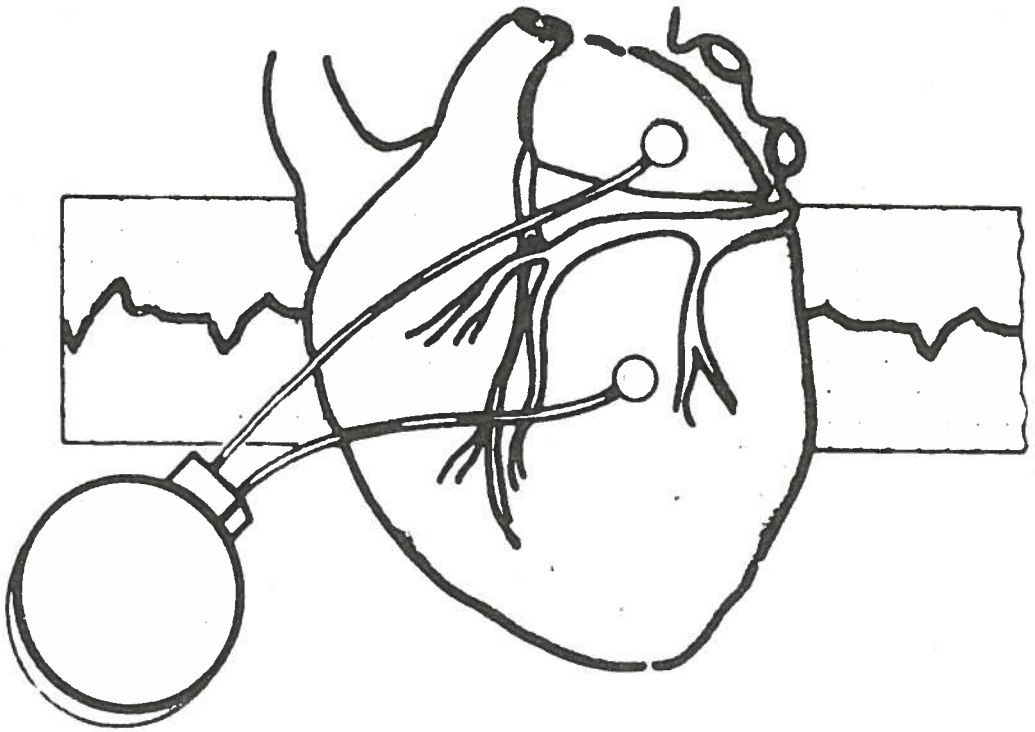
Fig. 11



SNAP-27 POWER SUPPLY USING Pu-238 FOR APOLLO SCIENTIFIC EXPERIMENTS

Fig. 12

RADIOISOTOPE - POWER CARDIAC PACEMAKER



POWERED
BY
Pu-238

Fig. 13

COMPONENTS OF ARTIFICIAL HEART

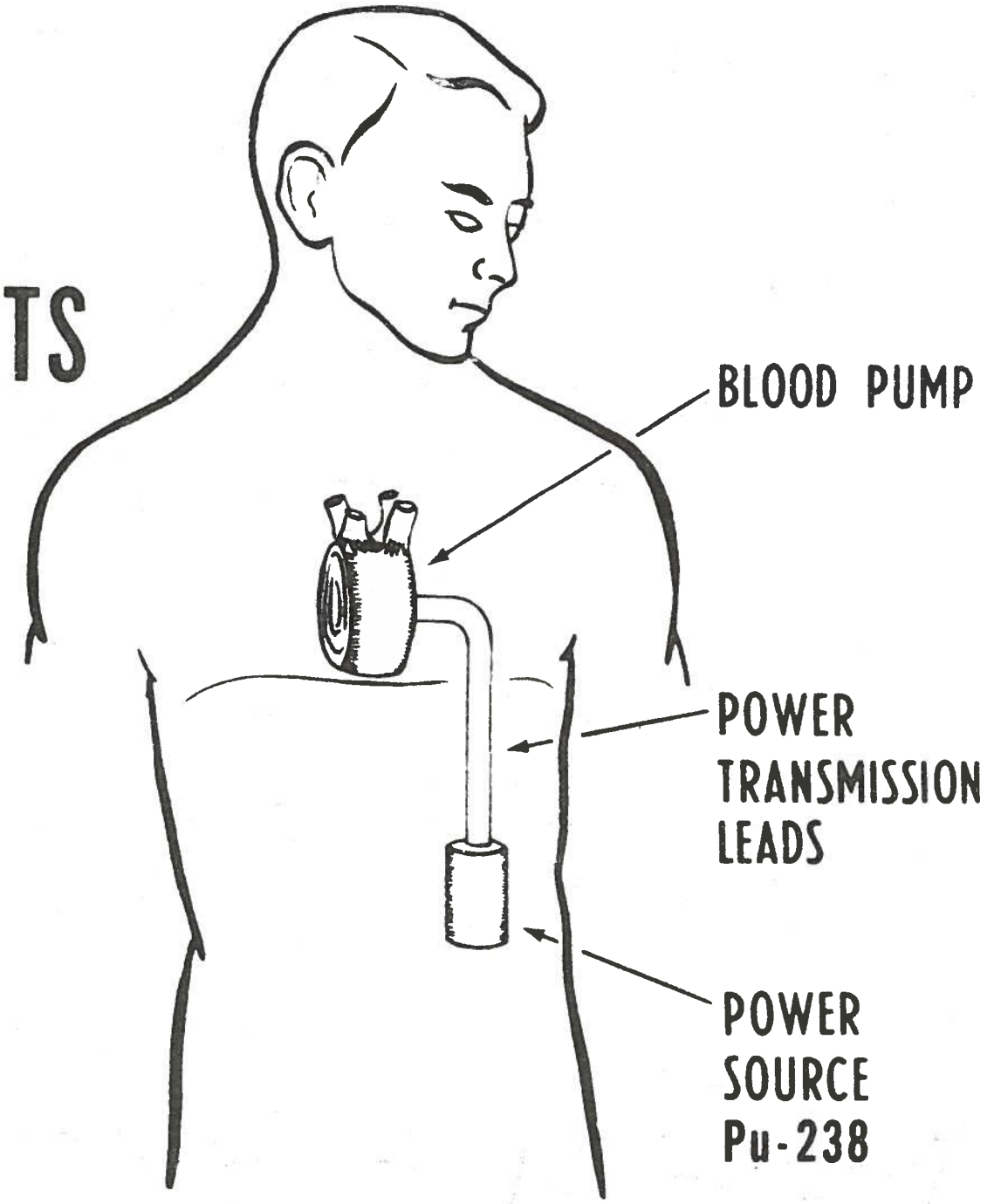
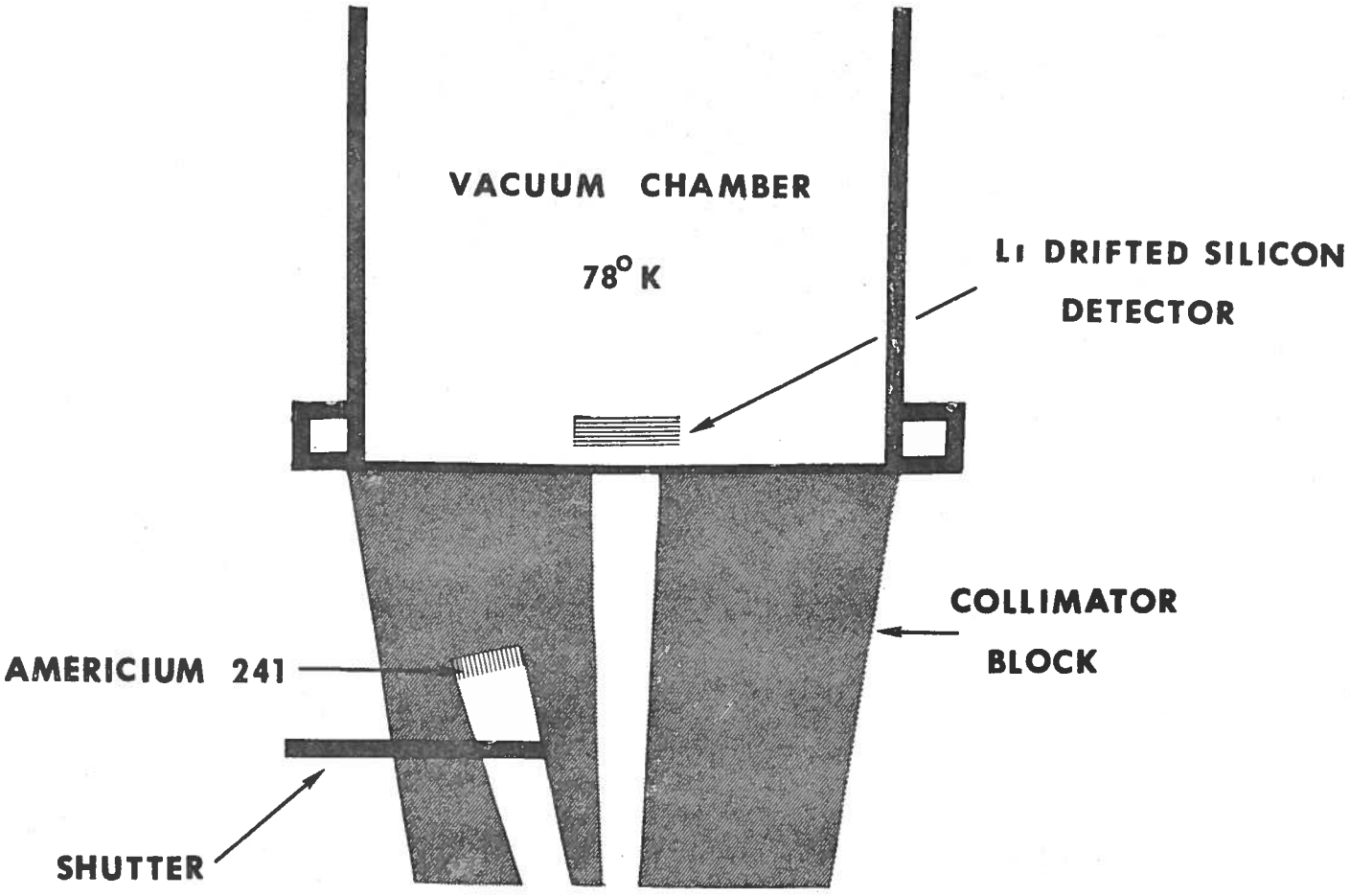
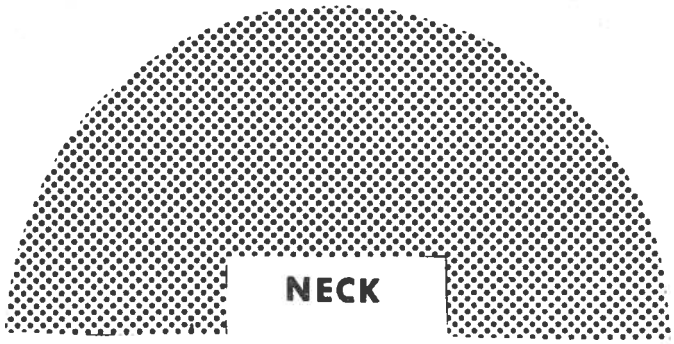


Fig. 14





APPARATUS FOR THYROID DIAGNOSIS

Fig. 15

PRODUCTION OF Pu-238 FROM U-235 AND U-238

Fig. 16

YIELD OF TRANS-CURIUM ISOTOPES RESULTING FROM HIGH FLUX NEUTRON IRRADIATION OF ^{242}Pu IN SAVANNAH RIVER REACTOR.

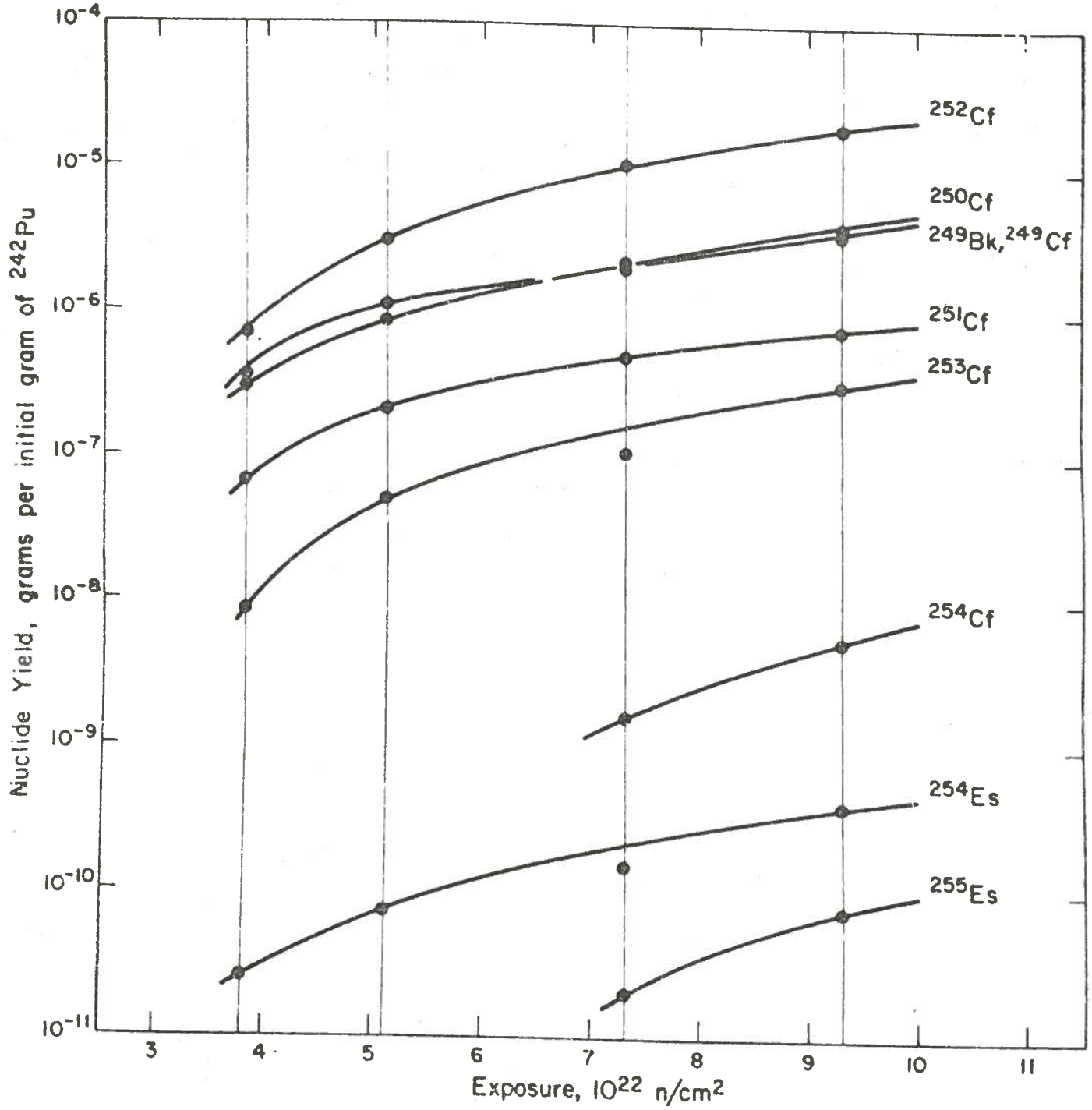


Fig. 17a

YIELD OF TRANSPLUTONIUM ISOTOPES RESULTING FROM HIGH-FLUX THERMAL NEUTRON IRRADIATION OF ^{242}Pu

FLUX = 5×10^{15} n / cm^2 / sec

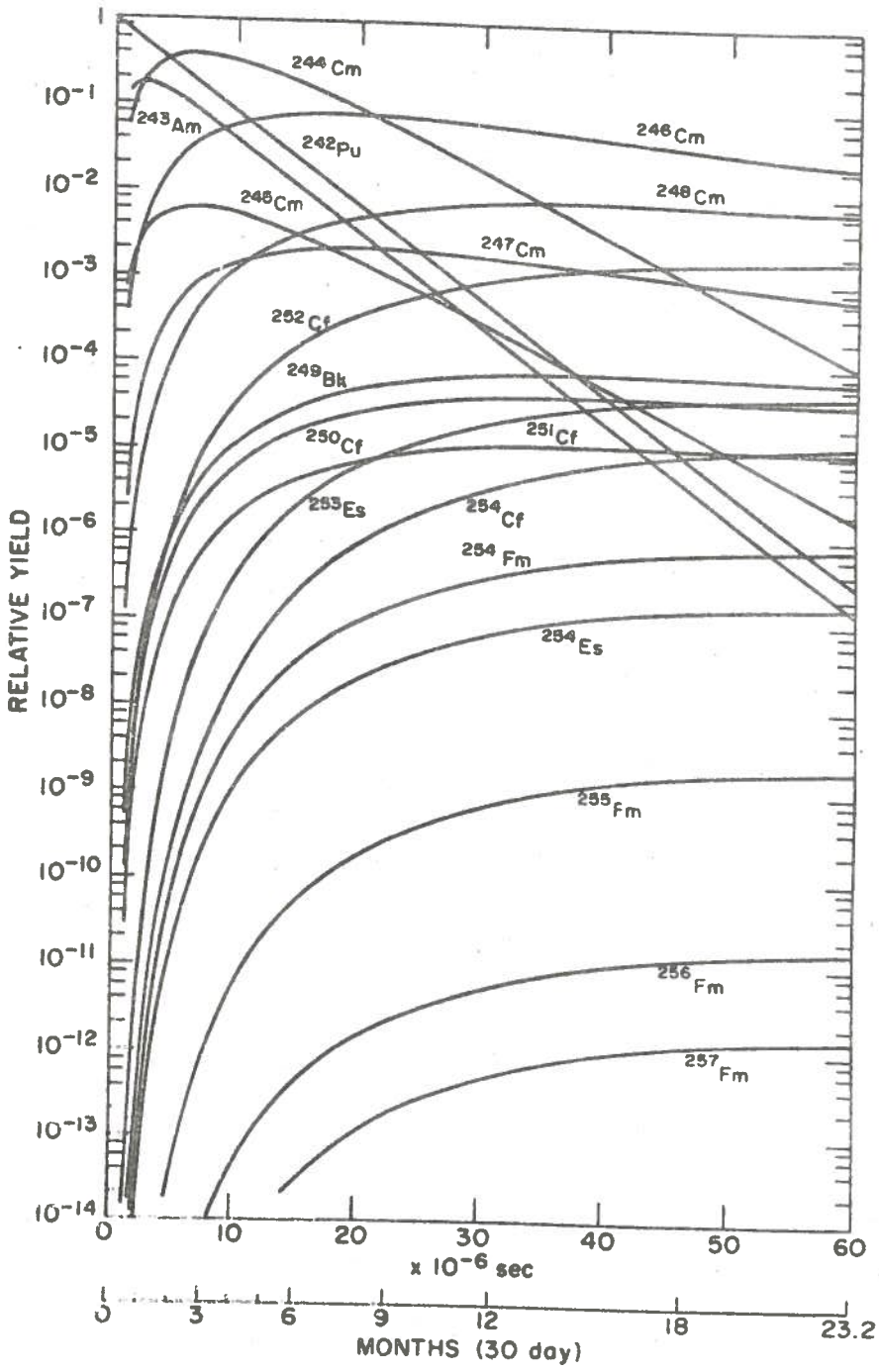


Fig. 17b

YIELD OF TRANSPLUTONIUM ISOTOPES RESULTING FROM HIGH-FLUX THERMAL NEUTRON IRRADIATION OF ^{244}Cm

FLUX: 5×10^{15} n / cm^2 / sec