

## 50 YEARS WITH NUCLEAR FISSION

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FEASIBILITY OF BREEDING U-233 USING (D+D) "EXYDER" FUSION NEUTRON SOURCE

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### ABSTRACT

The Indian Nuclear Power Programme plans for Th-233 to be converted into U-233 in LMFBRs for use in Th/U-233 reactors. We examine a near-term solution of using an alternate fusion system as the neutron source: a newly invented self-colliding beam device known as EXYDER (strong focusing migma), operating at Q < 5 and consuming net electrical energy; since it can store MeV ions, the D-D reaction will be used, circumventing tritium problems. A simulation with deuterons of 1.5 MeV, 1.6 A (beam power 2.4 MW), and stored ion density of  $5 \times 10^{14}$  cm<sup>-3</sup> shows an n production rate of  $1.1 \times 10^{19}$  s<sup>-1</sup> (in  $4\pi$ ) and energy cost of neutron production of 5 MeV per n. The net U-233 production rate from one 10 m<sup>3</sup> EXYDER is estimated to be 100 g/day of U-233 (35 kg/year).



"India has 360,000 tons of recoverable thorium against only 45,000 tons of natural uranium."

"Installing one or two exyder type mini breeders to serve each nuclear power plant operating on Thorium/U-233 cycle would eventually render the power station

self sufficient as far as its fissile fuel requirement is concerned."



# Computer simulation Exyder module could economically produce 100 gram/day, 35 kg/year of U-233 electric energy cost \$50/Kg vs \$300/Kg for U-238. CANDU type reactor of 235 MWe burns 10 Kg of U-233/ year.

"Even 'sub-engineering' energy breakeven fusion systems

$$Q_{sci} = 4$$

$$Q_{eng} = 0.05$$



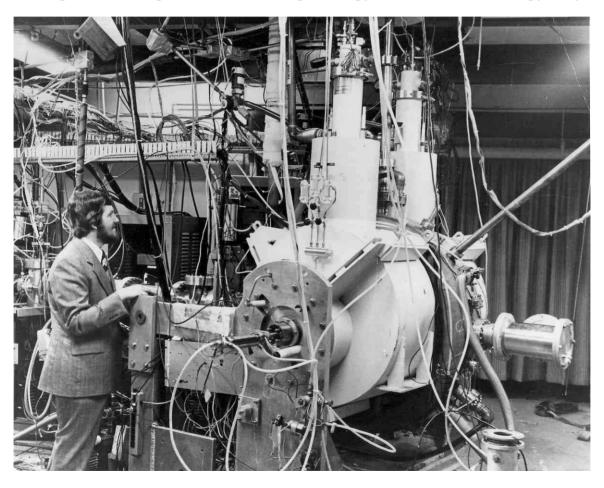
### WORLD'S STRONGEST MAGNET in its class 1975-1990

6 Tesla on coil, 3.2 Tesla midplane 5,000 cc volume
MIGMA-CELL 4 SUPERCONDUCTING Niobium-Titanium MAGNET

WORLD'S HIGHEST VACUU M in its class 1975 TO DATE

vacuum 10-11 Torr (static); 10<sup>-9</sup> (beam in) **200 liter volume** chamber is baked to 450°C 24 hours before injection

James Nering, Chief Engineer at Migma Institute of High Energy Fusion, Fusion Energy Corp., Princeton 1975.

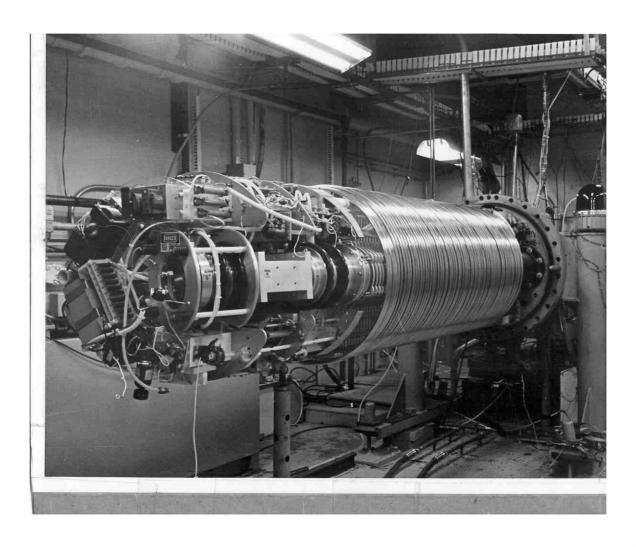


CALSEC
California Science & Engineering Corporation

•B. Maglich, Nucl. Instr. Meth. A271, 15 (1988); ibid., A271, 157 (1988).

### MIGMA-CELL 4 ACCELERATOR - INJECTOR

# WORLD'S HIGHEST FUSION CHAMBER INJECTION ENERGY: D<sub>2</sub>+ions of 1.45 MeV, 2mA





### MIGMA-CELL 4 AUTO-COLLIDER

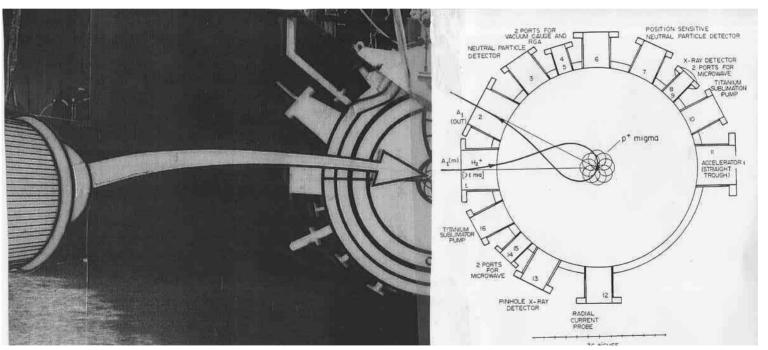
### **WORLD'S HIGHEST KINETIC TEMPERATURE**

D<sub>2</sub><sup>+</sup>ions of 1.45 MeV are injected, dissociated in center to create self- colliding 725 KeV D<sup>+</sup> + D<sup>+</sup> migma corresponding to

T = 10 Billion Degrees Centigrade

T = <u>10 Billion</u> Degrees Centigrade 10,000 times higher than in any fusion device

D. Al Salameh et al., Phys. Rev. LeU. 54,796 (1985).



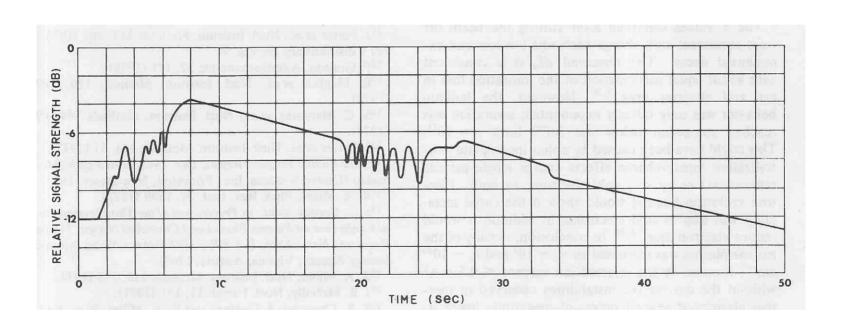


### MIGMA-CELL 4 confinement

### WORLD'S LONGEST ION ENERGY CONFINEMENT

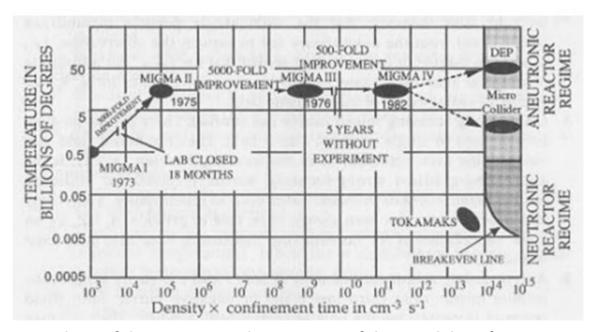
 $\tau_{1/e}$  = 34±4 sec Stable confinement was achieved by (1) the new process of electron oscillations through the circulating ions, where the ions acted like a grid in a triode oscillator, and (2) ultrahigh vacuum of 10<sup>-11</sup> Torr (no load), 10<sup>-9</sup> Torr with in.

Non-linear stabilization technique: "Stabilization by electron oscillations of stored ions at densities in excess of space-charge limit" Phys. Rev. Lett. 70,299 (1993) US Patent. B. Maglich and S. Menasian.





# Progress of migma system (black dots) from 1973 through 1982. Temperatures in $10^9$ °C (abscissa) vs. product n $\tau$ (cm<sup>-3</sup>s).



From proceedings of the International Symposium of the Feasibility of Aneutronic Power: Review of Searches for Nonradioactive Non Proliferating Nuclear Energy held at the Institute for Advanced Study, Princeton, 1987

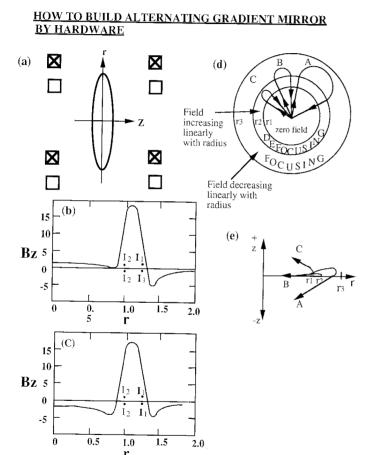
NUCLEAR INSTRUMENTS AND METHODS IN PHYSICS RESEARCH A 271, Volume 1
ENTIRE VOLUME DEDICATED TO COLLIDING BEAM FUSION

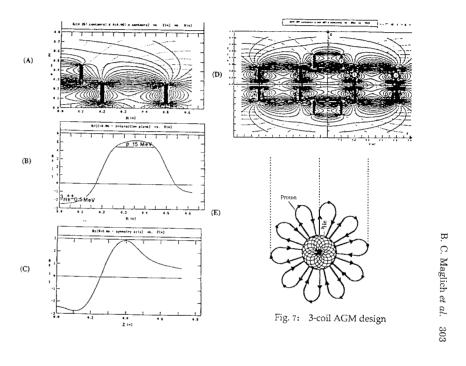
•B. Maglich, Nucl. Instr. Meth. A271, 15 (1988); ibid., A271, 157 (1988).



### SUPERCONDUCTING MAGNETIC FIELD for EXYDER

302 Modern Magnetic Fusion



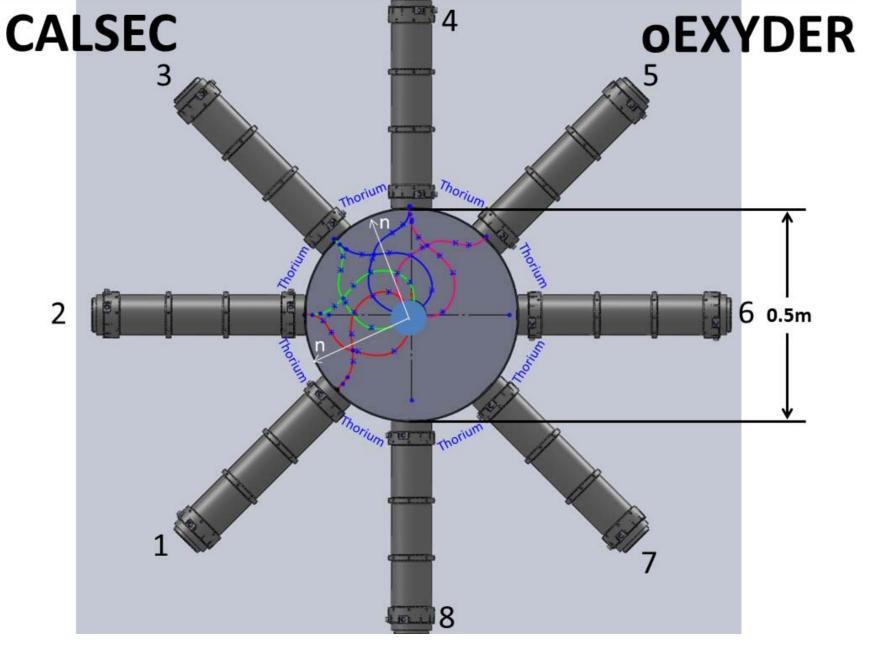


From B.C. Maglich, Modern Magnetic Fusion, AIP Conf. Proc. <u>311</u> pp.292 – 319 (1993)

J. P. Blewett, Nucl. Instr. and Meth. A271, 214 (1988); Part. Accel. 34, 13 (1990).

Fig. 6. Making of AGM field with two pair of coils: (a) Geometry of the AGM coil configuration in the (r,z) plane. (b)  $B_z(r)$  for  $-I_2=0.6I_1$ . (c)  $B_z(r)$  for  $I_2=-I_1$ . (d) Orbit in x-y plane. Orbits (a) and (b) would be stable while (c) is axially ejected. (e) orbits in r-z plane.





Ion sources not shown

US & International Patent pending 2011





Glen T. Seaborg (standing) and Bogdan Maglich (at Board) presenting Exyder Irvine, California, 1993



Cost & Gain Parameters for Production of U-233, Helium-3 and Tritium

**TABLE** 

EXYDER   10,000 Liter = 30 units 330Liter   ea.			•
ea.			EXYDER
2. Electric Power Input, Pin         6MWe (0.65)=9.2MWe           3. Charged Particle, Electric Power Input         3.32MWe           4. Neutron Production Rate         1.1 x 10 <sup>18</sup> s <sup>-1</sup> =66mg/h           5. Gross Energy Cost per Neutron         3.48MeV/ (0.65)/n= 5.36 MeV/n           6. Gross Energy Cost / Dollar Cost per Gram of Neutrons         140 MWh/g 58,360/g           7. Energy generated in fusion per Neutron         0.86MeV/n           8. Net Cost of Energy N / Per g of N (#5 - #7)         4.5MeV/n=119MWh/g 57,140g           9. Overall Scientific Power Gain Q = Ptot/Pin HELIUM-3	1. Vol	ume	10,000 Liter = 30 units 330Liter
3. Charged Particle, Electric Power Input  4. Neutron Production Rate  5. Gross Energy Cost per Neutron  6. Gross Energy Cost / Dollar Cost per Gram of Neutrons  7. Energy generated in fusion per Neutron  8. Net Cost of Energy N / Per g of N (#5 - #7)  9. Overall Scientific Power Gain Q = Ptot / Pin HELIUM-3  10. Net Energy Cost per Helium - 3 per g of Helium - 3 Liter / g Cost per liter of He-3 S2,380/g T46L/g S319/L  TRITIUM  11. per Tritium A.5 MeV/n S2,380/g T.46L/g S319/L  TRITIUM  12. Gross Energy Cost per gram S8,360  13. Value of 1 g n S14,000  14. Value of 3g He-3 S7,140  15. Value of 3g T S7,140  17. Gain (316 - #12) S19,920 / g			ea.
3.32MWe  4. Neutron Production Rate 5. Gross Energy Cost per Neutron 6. Gross Energy Cost / Dollar Cost per Gram of Neutrons 7. Energy generated in fusion per Neutron 8. Net Cost of Energy N / Per g of N (#5 - #7) 9. Overall Scientific Power Gain Q = Ptot / Pin At SUMPAN A	Electric Power Input, Pin		6MWe (0.65)=9.2MWe
4. Neutron Production Rate       1.1 x 101951=66mg/h         5. Gross Energy Cost per Neutron       3.48MeV/ (0.65)/n=5.36 MeV/n         6. Gross Energy Cost / Dollar Cost per Gram of Neutrons       140 MWh/g         7. Energy generated in fusion per Neutron       0.86MeV/n         8. Net Cost of Energy N / Per g of N (#5 - #7)       4.5MeV/n=119MWh/g         9. Overall Scientific Power Gain Q = Ptot/Pin       4.8         HELIUM-3       4.5 MeV/n         10. Net Energy Cost per Helium-3 per g of Helium-3 per g of Helium-3 \$2,380/g       52,380/g         Liter / g Cost per liter of He-3       \$319/L         TRITIUM       4.5 MeV/n         11. per Tritium per g of Tritium \$2,380/g       \$2,380/g         Liter / g Cost per Liter of Tritium \$319 / L       \$2,380/g         SUMMARY       \$319 / L         12. Gross Energy Cost per gram \$8,360       \$3,400         13. Value of 1g n \$14,000       \$7,140         14. Value of 3g He-3 \$7,140       \$7,140         15. Value of 3g T \$7,140       \$19,920 / g	3. Cha	rged Particle, Electric Power Input	
5. Gross Energy Cost per Neutron  6. Gross Energy Cost / Dollar Cost per Gram of Neutrons  7. Energy generated in fusion per Neutron  8. Net Cost of Energy N / Per g of N (#5 - #7)  9. Overall Scientific Power Gain Q = Ptot / Pin 4.8  HELIUM-3  10. Net Energy Cost per Helium-3 per g of Helium-3 S2,380/g Cost per liter of He-3 S319/L  TRITIUM  11. per Tritium per g of Tritium S2,380/g T.46L/g Cost per Liter of Tritium S2,380/g T.46l/g Cost per Liter of Tritium S319 / L  SUMMARY  12. Gross Energy Cost per gram \$8,360  13. Value of 1g n \$14,000  14. Value of 3g He-3 \$7,140  15. Value of 3g T \$7,140  16. (#13 - #15) \$38,200  17. Gain (316 - #12) \$19,920 / g			3.32MWe
5.36 MeV/n  6. Gross Energy Cost / Dollar Cost per Gram of Neutrons  7. Energy generated in fusion per Neutron  8. Net Cost of Energy N / Per g of N (#5 - #7)  9. Overall Scientific Power Gain Q = Ptot/Pin 4.8  HELIUM-3  10. Net Energy Cost per Helium-3 per g of Helium -3 S2,380/g T.46L/g Cost per liter of He-3  TRITIUM  11. per Tritium per g of Tritium S2,380/g T.46l/g Cost per Liter / g T.46l/g T.46l/	Neutron Production Rate		1.1 x 10 <sup>19</sup> 5 <sup>-1</sup> =66mg/h
6. Gross Energy Cost / Dollar Cost per Gram of Neutrons \$8,360/g  7. Energy generated in fusion per Neutron 0.86MeV/n  8. Net Cost of Energy N / Per g of N (#5 - #7) 4.5MeV/n=119MWh/g  9. Overall Scientific Power Gain Q= Ptot/Pin 4.8  HELIUM-3  10. Net Energy Cost per Helium-3 52,380/g Cost per liter of He-3 5319/L  TRITIUM  11. per Tritium 4.5 MeV/n per g of Tritium 52,380/g Liter / g 7.46L/g Cost per Liter of Tritium 52,380/g Liter / g 7.46l/g Cost per Liter of Tritium 5319 / L  SUMMARY  12. Gross Energy Cost per gram \$8,360 13. Value of 1 g n \$14,000 14. Value of 3g He-3 \$7,140 15. Value of 3g T \$7,140 16. (#13 - #15) \$38,200 17. Gain (316 - #12) \$19,920 / g	5. Gro	ss Energy Cost per Neutron	3.48MeV/ (0.65)/n=
of Neutrons       \$8,360/g         7. Energy generated in fusion per Neutron       0.86MeV/n         8. Net Cost of Energy N / Per g of N (#5 - #7)       4.5MeV/n=119MWh/g \$7,140g         9. Overall Scientific Power Gain Q = Ptot/Pin HELIUM-3       4.8         HELIUM-3       4.5 MeV/n         10. Net Energy Cost per Helium-3 per g of Helium -3 Liter / g Cost per liter of He-3       \$2,380/g 7.46L/g \$319/L         TRITIUM       4.5 MeV/n \$2,380/g 7.46l/g \$7.46l/g \$7.46l			5.36 MeV/n
7. Energy generated in fusion per Neutron  8. Net Cost of Energy N / Per g of N (#5 - #7)  9. Overall Scientific Power Gain Q = Ptot/Pin HELIUM-3  10. Net Energy Cost per Helium-3 per g of Helium -3 Liter / g Cost per liter of He-3  TRITIUM  11. per Tritium per g of Tritium per g of Tritium S2,380/g Liter / g Cost per Liter of Tritium SUMMARY  12. Gross Energy Cost per gram S8,360  13. Value of 1 g n S14,000  14. Value of 3g T S7,140 S18,200 S19,920 / g	6. Gro	ss Energy Cost / Dollar Cost per Gram	140 MWh/g
0.86MeV/n	of N	leutrons	\$8,360/g
8. Net Cost of Energy N / Per g of N (#5 - #7) 9. Overall Scientific Power Gain Q = Ptot/Pin HELIUM-3 10. Net Energy Cost per Helium-3 per g of Helium -3 Liter / g Cost per liter of He-3  TRITIUM 11. per Tritium per g of Tritium per g of Tritium S2,380/g Liter / g Cost per Liter of Tritium S2,380/g 1,461/g 2,380/g 7,461/g 7,461/g 7,461/g 8319 / L  SUMMARY 12. Gross Energy Cost per gram \$8,360 13. Value of 1 g n \$14,000 14. Value of 3g He-3 57,140 15. Value of 3g T \$7,140 16. (#13 - #15) \$38,200 17. Gain (316 - #12) \$19,920 / g	7. Ene	rgy generated in fusion per Neutron	
(#5 - #7)       \$7,140g         9. Overall Scientific Power Gain Q = Ptot/Pin       4.8         HELIUM-3       4.5 MeV/n         10. Net Energy Cost per Helium-3 per g of Helium -3 Liter / g Cost per liter of He-3       \$2,380/g         Liter / g Cost per liter of He-3       \$319/L         TRITIUM       4.5 MeV/n per g of Tritium \$2,380/g         Liter / g Cost per Liter of Tritium \$319 / L       \$319 / L         SUMMARY       \$319 / L         12. Gross Energy Cost per gram \$8,360       \$13. Value of 1 g n         13. Value of 3g He-3 \$7,140       \$7,140         15. Value of 3g T \$7,140       \$38,200         17. Gain (316 - #12) \$19,920 / g			0.86MeV/n
9. Overall Scientific Power Gain Q = Ptot/Pin HELIUM-3  10. Net Energy Cost per Helium-3 per g of Helium -3 Liter / g Cost per liter of He-3  TRITIUM  11. per Tritium per g of Tritium per g of Tritium S2,380/g Liter / g Cost per Liter of Tritium \$52,380/g Liter / g 7.461/g Cost per Liter of Tritium \$319 / L  SUMMARY  12. Gross Energy Cost per gram \$8,360 13. Value of 1 g n \$14,000 14. Value of 3g He-3 \$7,140 15. Value of 3g T \$7,140 16. (#13 - #15) \$38,200 17. Gain (316 - #12) \$19,920 / g	8. Net	Cost of Energy N / Per g of N	4.5MeV/n=119MWh/g
Q = Ptot/Pin       4.8         HELIUM-3       4.5 MeV/n         10. Net Energy Cost per Helium-3 per g of Helium -3 S2,380/g 7.46L/g 7.46L/g S319/L       52,380/g 7.46L/g S319/L         TRITIUM       4.5 MeV/n Per Gof Tritium S2,380/g 7.46l/g 7.46l/g 7.46l/g 7.46l/g S319/L         SUMMARY       5319/L         12. Gross Energy Cost per gram S8,360       513, Value of 1 g n S14,000         14. Value of 3g He-3 S7,140       57,140         15. Value of 3g T S7,140       538,200         17. Gain (316 - #12) S19,920 / g       \$19,920 / g	(#5	- #7)	\$7,140g
HELIUM-3  10. Net Energy Cost per Helium-3	9. Ove	erall Scientific Power Gain	
10. Net Energy Cost per Helium-3	Q=	P <sub>tot</sub> /P <sub>in</sub>	4.8
per g of Helium -3 Liter / g Cost per liter of He-3 TRITIUM  11. per Tritium per g of Tritium per g of Tritium Liter / g Cost per Liter of Tritium S2,380/g Liter / g T,461/g Cost per Liter of Tritium S319 / L SUMMARY  12. Gross Energy Cost per gram S8,360 13. Value of 1 g n S14,000 14. Value of 3g He-3 S7,140 15. Value of 3g T S7,140 16. (#13 - #15) S38,200 17. Gain (316 - #12) S19,920 / g	HELIUM-3		
Liter / g Cost per liter of He-3  TRITIUM  11. per Tritium per g of Tritium Liter / g Cost per Liter of Tritium S2,380/g Liter / g Cost per Liter of Tritium S319 / L  SUMMARY  12. Gross Energy Cost per gram S8,360 13. Value of 1 g n S14,000 14. Value of 3g He-3 S7,140 15. Value of 3g T S38,200 17. Gain (316 - #12) S19,920 / g	10. Net	Energy Cost per Helium-3	4.5 MeV/n
Cost per liter of He-3 \$319/L  TRITIUM  11. per Tritium \$2,380/g Liter / g 7.461/g Cost per Liter of Tritium \$319 / L  SUMMARY  12. Gross Energy Cost per gram \$8,360 13. Value of 1 g n \$14,000 14. Value of 3g He-3 \$7,140 15. Value of 3g T \$7,140 16. (#13 - #15) \$38,200 17. Gain (316 - #12) \$19,920 / g		per g of Helium -3	\$2,380/g
TRITIUM  11. per Tritium		Liter / g	7.46L/g
11. per Tritium			\$319/L
per g of Tritium \$2,380/g 7.461/g 7.461/g Summary \$319 / L \$2,380/g 7.461/g \$319 / L \$2,380/g \$319 / L \$2,380/g \$319 / L \$2,380/g \$319 / L \$2,380/g \$319 / L \$31	TRITIUM		
Liter / g 7.461/g \$319 / L \$UMMARY  12. Gross Energy Cost per gram \$8,360 \$13. Value of 1 g n \$14,000 \$14. Value of 3g He-3 \$7,140 \$15. Value of 3g T \$7,140 \$16. (#13 - #15) \$38,200 \$17. Gain (316 - #12) \$19,920 / g	11.	per Tritium	4.5 MeV/n
Cost per Liter of Tritium \$319 / L  SUMMARY  12. Gross Energy Cost per gram \$8,360  13. Value of 1 g n \$14,000  14. Value of 3g He-3 \$7,140  15. Value of 3g T \$7,140  16. (#13 - #15) \$38,200  17. Gain (316 - #12) \$19,920 / g		per g of Tritium	\$2,380/g
SUMMARY         12. Gross Energy Cost per gram       \$8,360         13. Value of 1 g n       \$14,000         14. Value of 3g He-3       \$7,140         15. Value of 3g T       \$7,140         16. (#13 - #15)       \$38,200         17. Gain (316 - #12)       \$19,920 / g			
12. Gross Energy Cost per gram \$8,360  13. Value of 1 g n \$14,000  14. Value of 3g He-3 \$7,140  15. Value of 3g T \$7,140  16. (#13 - #15) \$38,200  17. Gain (316 - #12) \$19,920 / g			\$319 / L
13. Value of 1 g n       \$14,000         14. Value of 3g He-3       \$7,140         15. Value of 3g T       \$7,140         16. (#13 - #15)       \$38,200         17. Gain (316 - #12)       \$19,920 / g			
14. Value of 3g He-3       \$7,140         15. Value of 3g T       \$7,140         16. (#13 - #15)       \$38,200         17. Gain (316 - #12)       \$19,920 / g			
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16. (#13 - #15) \$38,200 17. Gain (316 - #12) \$19,920 / g	_		
17. Gain (316 - #12) \$19,920 / g	15. Value of 3g T		\$7,140
, , ,	16. (#13 - #15)		\$38,200
18. Net gain / day (#17x100) \$1,992,000 / 100g		,	
	18. Net	gain/day (#17x100)	\$1,992,000 / 100g

