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SOME DIRECT CONVERSION POSSIBILITIES FOR ADVANCED CTR SYSTEMS

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SOME DIRECT CONVERSION POSSIBILITIES FOR ADVANCED CTR SYSTEMS*

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ABSTRACT

Some of the means for directly converting fusion energy into electricity in various types of CTR systems are surveyed. It is concluded that relatively simple and efficient means exist for so converting essentially all forms of energy outputted from a thermonuclear reaction zone. It is noted that CTR power plants burning exotic fuels—neutron- and radionuclide-free nuclei combinations—maximally exploit the profound asymmetries between fission and fusion power sources, asymmetries that potentially strongly favor fusion-based means of electricity generation.

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Introduction

We wish to survey some of the more readily apparent means for directly converting to electricity the fusion energy produced in CTR power plants, such as might be employed in second-generation systems. Such direct conversion is potentially of interest not only in order to reduce the waste heat engendered per unit electrical power outputted, but also because quite substantial savings in power plant capital investment may be realized thereby. (Indeed, mundane economic considerations, not scientific/technological ones, may determine the advent of the fusion power age, due to the necessity of competing successfully in the marketplace against advanced fission power systems a few decades hence.) See Table I. Furthermore, such electricity generation approaches admit of a potentially far fuller exploitation of the asymmetries between power generation from fission and from fusion energies sources, asymmetries which profoundly favor fusion power production. See Table II.

In this discussion, we will be concerned with conversion systems which are seemingly well-suited to all types of CTR systems, pulsed or quasi-CW, such as the neutron-scattering electrostatic converter. We will also consider conversion means best-suited only for CW or pulsed fusion energy sources, such as ion electrostatic and AC plasma magnetohydrodynamic means, respectively. Emphasis will be placed on conversion systems which aptly exploit the characteristics of the exotic fuel systems[1], which output $99.9^{+}\%$ of their energy in x-rays and charged particles, i.e. are neutron- and radionuclide-free. See Table III.

Conversion Means Peculiar to Quasi-CW Systems

The quasi-CW CTR systems are those which have peak energy generation rates not greatly in excess of their time-average rate. The associated direct conversion system therefore need not have a high peak power rating or capability and, in particular, need not store a rapidly generated pulse of energy and release it relatively slowly to a transmission line, i.e. it need not act as an energy transformer in the frequency domain.

A clever exploitation of the highly anisotropic charged particle flux from "open" magnetic confinement geometries is the magnetic nozzle expansion--multiple electrode electrostatic conversion scheme proposed and experimentally studied by Moir and collaborators.[2] See Table IVa. However, since operation of such devices depends crucially on expanding an initially low density plasma into one so low that its Debye length is not negligible compared to the scale length of the converter electrode geometry, it does not seem practical for pulsed fusion systems, whose plasmas have relatively very great densities in both space and time.[3] Also, their use in conversion in "closed" magnetic geometries seems critically dependent on how well the plasma out of such systems can be collimated into a low divergence beam. Since such conversion means have been extensively discussed previously, they will not be further mentioned here. However, it should be noted in passing that the use of non-neutron-producing fusion fuels might greatly simplify the design and construction of such systems. See Table IVb.

Directing the plasma exhaust of a CW containment device into a suitable MHD duct,[4] perhaps after mixing with a buffer gas as a concession to materials limitations, is another rather attractive possibility, particularly with respect to power density. However, such an approach again demands that the plasma exciting the containment region do so in a rather decent beam, for practical reasons. Also, either gaseous or liquid conductor-driven MHD ducts have the character of heat engines, and are thus outside the scope of the present discussion; this is particularly so in view of the fact that the level of MHD duct technology at present is such that such relatively direct conversion techniques are likely to serve only as total efficiency-enhancing, "topping" units for conventional steam-thermal converters, rather than replacing them in toto.

Pulsed System-Specialized Conversion Means

One obvious means of converting the energy produced from a pulsed fusion source (such as a thermonuclear microexplosion) is to expand the associated fireball against an externally applied magnetic field.[5] This is an especially attractive option when fusion fuels are used which do not engender significant amounts of penetrating radiation (e.g. neutrons and gamma rays), so that the superconducting solenoid sources of magnetic flux can be located in close proximity to the fusion energy source, minimizing structural and superconductor mass and cost. (This is of course another example of how physics asymmetries between fission and fusion may be advantageously exploited by proper choice of CTR power plant parameters.) See Fig. 1.

The fireball-compressed magnetic field may be coupled to an external electrical load in a variety of rather obvious ways. It is worth noting, also, that this approach quite naturally frequency-shifts the microexplosion energy pulse from the picosecond time scales associated with fusion energy generation to the microsecond ones arising from fireball expansion to convenient (e.g. meter) scales, time scales which are much more technologically accessible.

Such means may also be employed to efficiently directly convert the relatively large fraction of hard x-radiation which use of exotic fuels will inevitably entail. Pulsed injection of small quantities of intermediate Z gas (e.g. Kr, Xe) into the combustion chamber just prior to microexplosion initiation will suffice to efficiently convert the fireball x-ray energy to low density plasma, which may be co-expanded with the fireball plasma itself, against the applied magnetic field. Such gas (or fog) injection may also be used to further lower the frequency (and thus also the magnitude) of the voltage pulse induced in pick-up coils, by slowing fireball expansion to nearly any desired extent (e.g. 1-2 orders of magnitude). A sketch of one of the possible types of CTR power plants is indicated in Fig. 2;[6] this somewhat ancient concept assumed use of neutronogenic fusion fuel employing AC MHD conversion.

MHD duct techniques may of course also be used to convert fireball energy directly to electricity. However, as in the quasi-CW case, consideration of duct materials limitations will probably require the buffering of the multi-keV plasma with a much larger quantity of normal fluid prior to duct imputting. This in turn again makes this approach distressingly similar to a conventional heat engine, with its relatively high capital cost and low thermal efficiency.

General Purpose Direct Conversion Means

In addition to MHD duct approaches, there are at least two other quite obvious, low technological risk techniques for directly converting fusion energy to electricity which function about equally well for pulsed or quasi-CW systems.

One of these employs the well-known Compton effect to convert a fraction of the x-ray energy emitted by a fusion plasma to quasi-directed (into the forward solid angle) electron beams, which then do work against an electric field in a fashion very similar in principle to the system of Moir et al., mentioned earlier. See Fig. 3. There are two "slight" complications to this scheme, however—both of fairly fundamental origin. First, electrons have a non-negligible mass, while photons do not; therefore, until photon energies become comparable to electron rest energies, it is kinematically impossible for them to transfer large fractions of their energy to electrons. Second, hard x-rays have large Compton scattering mean free paths in matter, while the electrons they scatter have much shorter ones. Therefore, Compton generators have relatively little promise for converting "soft" photons (of energy $\lesssim$ 30-50 kev) to electrical energy in a technologically interesting fashion; they seemingly have relatively little interest for most DT-burning systems, in which both the electron and ion temperatures would be kept relatively low, and x-radation production is relatively small in any event.

However, they may be of considerable interest in exotic fuel-burning CTR power plants, which are likely to be comparatively rich sources of hard x-radiation, due to the high electron and ion temperatures involved ($\gtrsim$ 100 kev), and the large nuclear charges. In a pB^{11}-burning system, for instance, early calculations indicate that a Compton generator converter bank might be able to directly convert $\sim$ 30% of the emitted x-radiation to electrical energy. Such a generator would incidentally have to be a relatively complex, multi-layer one, in order to accommodate the greatly different electron and photon mean free paths. Such a device is indicated in Fig. 4, with the forward face section removed. This system represents the basic features of a pB^{11}-burning pulsed-type CTR plant. Most of the microexplosion energy is directly converted to electricity via the AC MHD technique mentioned before; the x-ray fraction of it is partially converted in the surrounding Compton converter bank. A foot of high density shielding outside the Compton bank reduces the external radiation level[1] (due essentially completely to γ rays) to $\sim$ 10 mR/hour. Our present estimates are that such a system could produce electricity at 50-60% efficiency, with rejected heat at $\sim$ 500°C.

Referring back to Fig. 3, a mechanism for converting multi-Mev neutron energy directly to electricity is sketched in the other half of the figure. As far as direct conversion is concerned, this may be considered as a device for stripping the electron off a neutron, just as thin metal foils are used for removing electrons from atomic and ionic beams. The electron-stripped neutron—a proton—carrying, on the average, about half of incident neutron's energy, is then made to do work against an imposed electric field, a now-familar gambit.

This electrostatic generator differs from the type of Compton generator just mentioned, since multi-Mev protons have somewhat more respectable mean free paths than $\lesssim$ 100 kev electrons. In particular, it appears technologically feasible to put intermediate foils between the anode and the cathode to "catch" protons of initially intermediate energy, which have done all the work possible against the imposed electrostatic field and are about to turn around and fall back into an anode; these foils exploit the relatively high opacity of most materials for low energy protons and "pick them up" whenever their energy falls below 1-2 Mev, shown in Table V. One thus has an automatic means of dropping the protons into the energetically right "pocket", not nearly as elegant but almost as effective as the scheme of Moir et al.[2]

Unfortunately, multi-Mev-neutrons do have considerably longer mean free paths in cold matter than do multi-Mev-protons, so that it is necessary to operate such a converter as a stacked bank of individual sections, as in the Compton case. The conversion efficiency of such a bank will be fairly strongly dependent on the complexity of such a bank, increasing as the number of proton-catching foils in each section is increased, the total thickness of each section is decreased, and the number of sections in the bank increased. Ultimate overall conversion efficiencies of 80-90% presently appear attainable.

Taken into account in estimating such efficiencies are the losses associated with removing the $\lesssim$ 100 milliwatts cm^{-2} from the layers of each section via grids of small coolant tubes. If neutronic Compton generator sections are operated with their layers largely parallel to an imposed magnetic field (as might be the case for plasma energy direct conversion systems), total bank thicknesses of the order of a meter might be feasible, due to the possibility of exploiting the "magnetic insulation" effect.[7] In the absence of external magnetic fields, several-fold greater thicknesses would be required by vacuum dielectric strength considerations.

Some of the salient features of such converters are noted in Table VI. A sketch of such a system in cross-section is shown in Fig. 5.

Conclusions

One of the technologically most relevant asymmetries between fission and fusion electrical energy production is one very real possibity of efficiently and cheaply converting fusion energy directly to electricity. This is a particularly "live" option when the fusion energy is produced essentially free of gamma rays, neutrons and radionuclides--when the fusion power reactor may be validly viewed simply as a source of billion degree plasma, with virtually no radioactive "dirt" included. This seems to us to be the basic source of the free energy driving a serious second look at relatively exotic CTR fuels, which promise to deliver this type of performance.

We have attempted in the preceding to sketch some of the more obvious, low technological risk approaches for converting the various forms of fusion reactor energy output directly into electricity. It may well be that this discussion has overlooked some of the best current approaches, and it is virtually certain that much better approaches will be forthcoming, as more and more clever people begin to think about these problems.

What we have attempted to do here is to emulate the fabled butcher, who is reported to have so rendered and processed the pig that profitable use was found for everything except the squeal. Figure 6 indicates how we see the fusion power pig being partitioned, for both early and more advanced CTR reactors. The electrical energy production advantantages of early CTR over fission, and those of advanced CTR over early fusion systems, seem obvious.

REFERENCES

1. T. Weaver and L. Wood, Exotic CTR Fuels for Direct Conversion-Utilizing Fusion Reactors, UCID 16230 (1973); T. Weaver, G. Zimmerman and L. Wood, "Prospects for Exotic Fuel Usage in CTR Systems I. $B^{11}(p,2\alpha)He^4$: A Clean, High Performance CTR Fuel", UCRL 74191/UCRL 74352 (1972).

2. R. W. Moir, W. L. Barr, R. P. Freis and R. F. Post, Plasma and Controlled Nuclear Fusion Research (Proc. Conf. Madison, Wisc., 1971) V. 3, I.A.E.A., Vienna (1971); R. W. Moir and W. L. Barr, Nucl. Fusion 13, 35 (1973).

3. J. Nuckolls, L. Wood, A. Thiessen and G. Zimmerman, Laser Compression of Matter to Super-High Densities I. Thermonuclear (CTR) Applications, Nature 239, 139 (1972).

4. Richard J. Rosa, Magnetohydrodynamic Energy Conversion, (McGraw-Hill Book Company, New York, 1968).

5. A. F. Haught, D. H. Polk and W. J. Fadar, Phys. Fluids 13, 2842 (1970) and private communication.

6. B. Freeman, L. Wood and J. Nuckolls, Some General Design Considerations Regarding Laser-Fusion CTR Power Plants, UCRL 74486 (1971).

7. F. Winterberg, Phys. Rev. 174, 212 (1968); Rev. Sci. Instr. 41 1756 (1970).

EXOTIC FUEL/DIRECT CONVERSION POSSIBILITIES/IMPLICATIONS FOR ADVANCED CTR SYSTEMS

- More obvious possibilities considered
- Possible advantages
  - Less waste heat — lower thermal pollution
  - Lower capital cost
    - Necessity to successfully compete with advanced fission power plants in the marketplace in 1990-2010 period
  - Exploit asymmetries between fission and fusion energy sources

TABLE 1

ASYMMETRIES BETWEEN FISSION AND FUSION ENERGY SOURCES

	Fission	Problems Posed For Early CTR	Advanced CTR
Neutron criticality	Yes	No	No
Neutron budget stringencies	Yes	Doubtful	No
Copious, prompt, hard gamma production	Yes	Somewhat	No
Extensive generation of beta/gamma-active nuclei	Yes	Somewhat	No
Afterheat (ECCS) problems	Yes	Somewhat	No
Neutron activation of structure/coolant/moderator	Yes	Yes	No
Explosive yield problems	Yes	No	No
Fuel supply	Yes	No	No
$n\tau$ and ion heating requirements	No	Yes	Yes

TABLE 2

SOME NON-HEAT ENGINE MEANS OF FUSION-BASED ELECTRICITY GENERATION

- Quasi-CW Systems (Mirrors, Tokamaks, etc.)
  - Electrostatic (Post, et al) — electrostatic conversion of "exhaust" of magnetically confined plasma device
- Pulsed Systems (Laser- and Electron Beam-Induced Microexplosions)
  - MHD — fireball expansion against imposed magnetic field (Haught, et al)
  - MHD — exhausting (plasma + wall shielding layer) into MHD duct

SOME NON-HEAT ENGINE MEANS OF FUSION-BASED ELECTRICITY GENERATION, continued

- CW or Pulsed Systems
  - MHD — exhausting plasma (with buffer gas?) into MHD duct
  - Compton generator — conversion of x-ray energy to directed electron streams, w/electrostatic conversion
  - Neutronic Compton generator — generation of directed, high energy proton streams by neutron scattering, w/electrostatic conversion

TABLE 3

CW DIRECT CONVERSION SYSTEMS, continued

- Exploitation of non-neutron-producing, exotic fuels in magnet and shield design
- MHD Duct
  - High power density
  - Exhausted plasma beam buffered with cool fluid — liquid or gas — prior to duct input
  - Critically dependent on materials limitations
  - Standard duct technology
  - Basically heat engine
  - Probably "topping" unit on conventional steam-thermal cycle

(a)

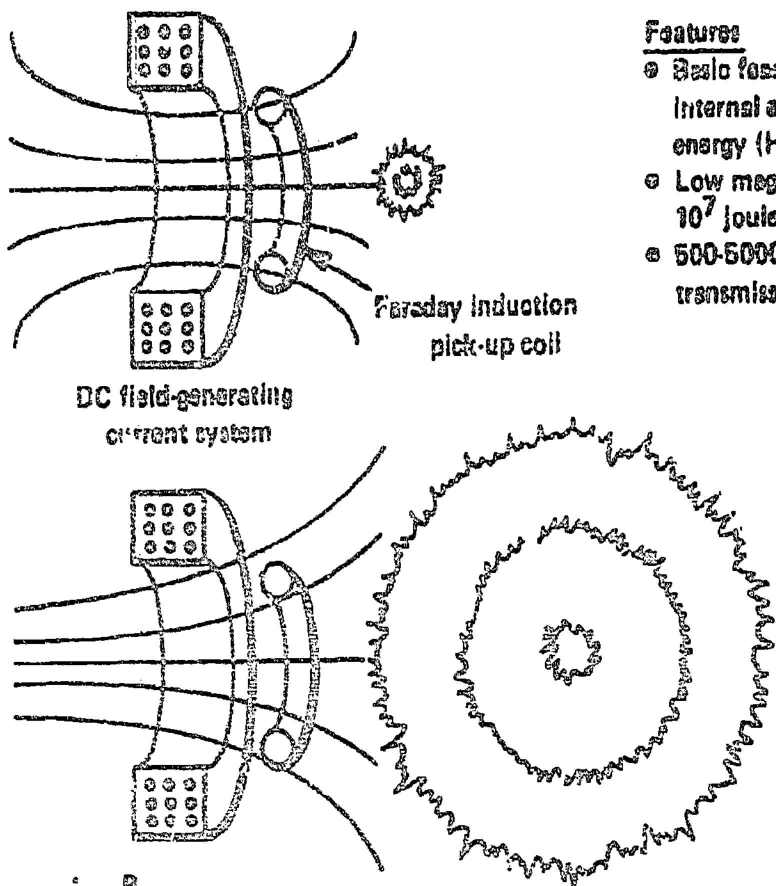
CW DIRECT CONVERSION SYSTEMS

- Electrostatic (Post, et al)
  - Magnetic nozzle expansion
  - Low power density
  - Disproportionation of energy into ions
  - e/m magnetic separation into charged plasmas
  - Energy extraction from ions via deceleration against auto-selected electric field-generating electrodes
  - Dependent on well-focussed ion beams exiting "open" magnetic geometries
  - Apparently not practical for high density ion "burst"
  - Calculationally and experimentally verified

(b)

TABLE 4

AC MHD CONVERSION FROM THERMONUCLEAR MICROEXPLOSIONS



Features

- Basic feasibility demonstrated — $\gtrsim$ 70% of KeV fireball internal energy converted to compressed magnetic field energy (Haught, et al, 1970)
- Low magnetic field intensities suitable — 2-4 Tesla for 10^7 joule microexplosions
- 500-5000 kv, $\simeq$ 1 μsec rise time pulses available for direct transmission line excitation, or for transformation

$$V \propto \frac{\dot{B}}{C} \simeq \frac{B_o}{C} (\nu_{plasma}/\ell_{scale})$$

$$P \propto \left(\frac{\dot{B}}{C}\right)^2 \frac{1}{Z} \lesssim 10^{13} \text{ watts}$$

$$(P_{TN} \simeq 10^{16} \text{ watts})$$

FIGURE 1

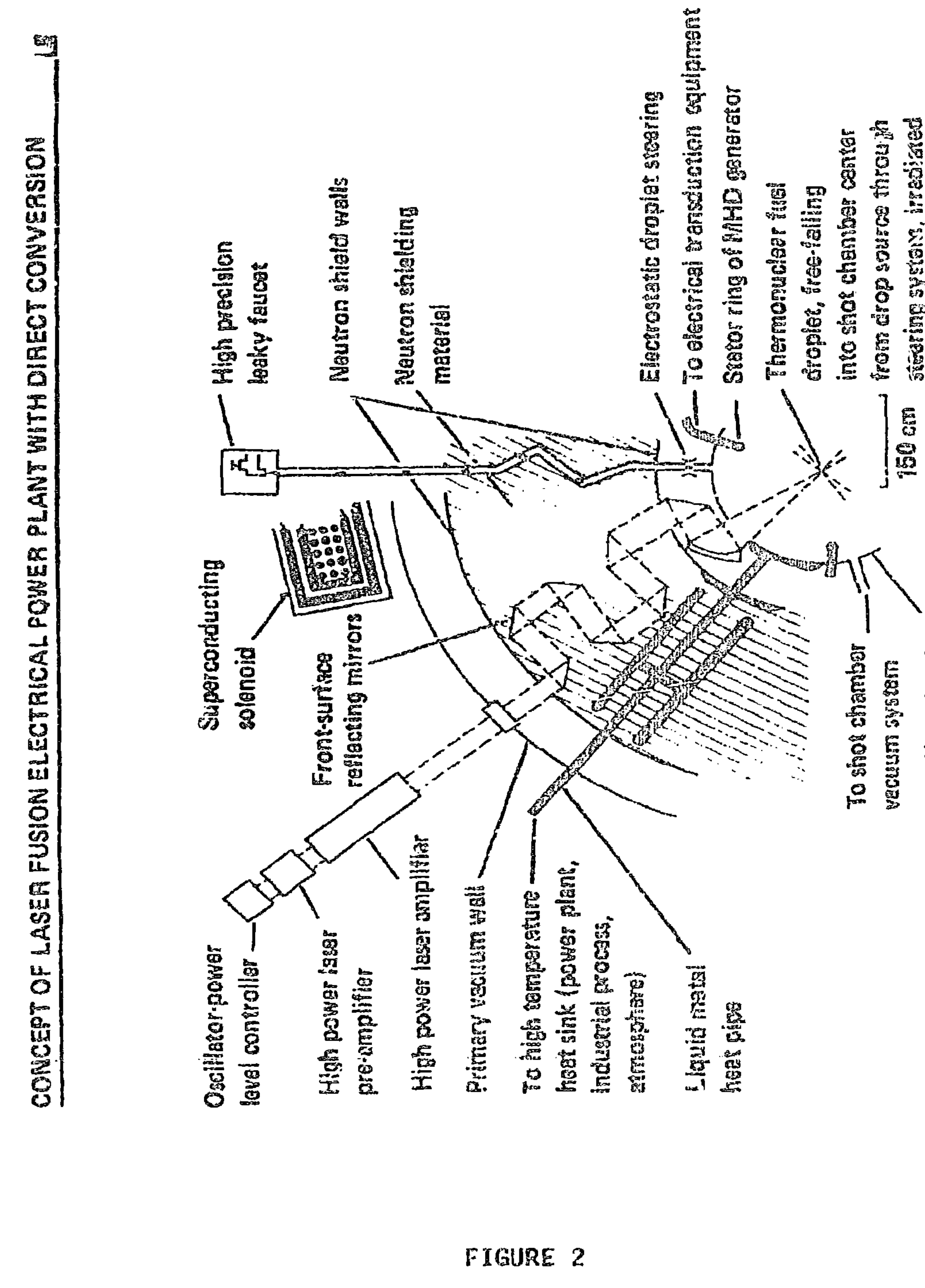

CONCEPT OF LASER FUSION ELECTRICAL POWER PLANT WITH DIRECT CONVERSION
Oscillator-power level controller
High power laser pre-amplifier
High power laser amplifier
Primary vacuum wall
To high temperature heat sink (power plant, industrial process, atmosphere)
Liquid metal heat pipe
Superconducting solenoid
Front-surface reflecting mirrors
High precision leaky faucet
Neutron shield walls
Neutron shielding material
Electrostatic droplet steering
To electrical transduction equipment
Stator ring of MHD generator
Thermonuclear fuel droplet, free-falling into shot chamber center from drop source through steering system, irradiated from several sides by high power lasers
150 cm
To shot chamber vacuum system
Shot chamber wall

FIGURE 2

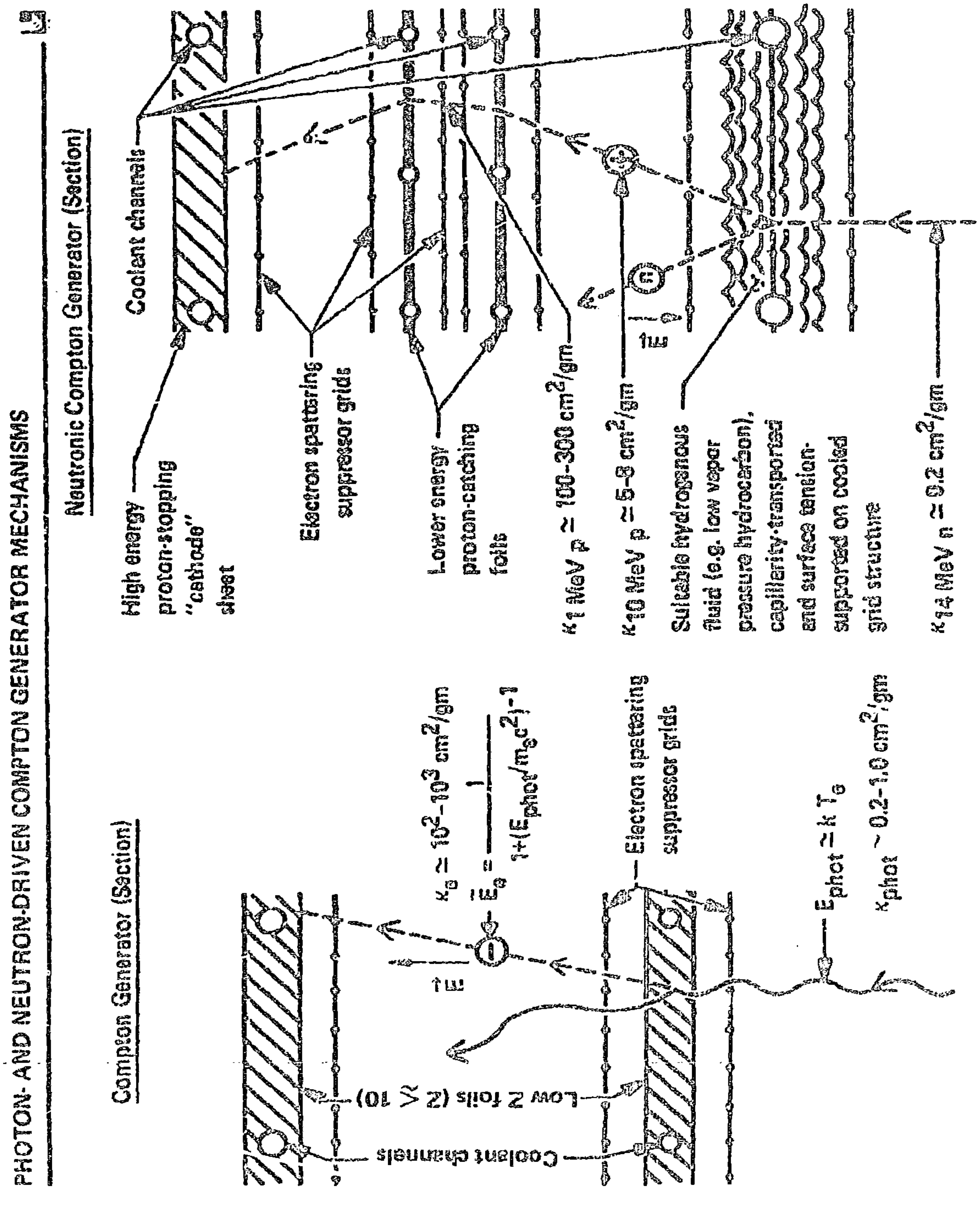

PHOTON- AND NEUTRON-DRIVEN COMPTON GENERATOR MECHANISMS
Compton Generator (Section)
Coolant channels
Low Z foils ($Z \lesssim 10$)
Electron spattering suppressor grids
$\kappa_e \simeq 10^2$-10^3 cm^2/gm
$\bar{E}_e = \frac{1}{1+(E_{phot}/m_e c^2)^{-1}}$
$E_{phot} \simeq k\, T_e$
$\kappa_{phot} \sim 0.2$-1.0 cm^2/gm
Neutronic Compton Generator (Section)
High energy proton-stopping "cathode" sheet
Coolant channels
Electron spattering suppressor grids
Lower energy proton-catching foils
$\kappa_{1\,MeV\,p} \simeq 100$-$300$ cm^2/gm
$\kappa_{10\,MeV\,p} \simeq 5$-$8$ cm^2/gm
Suitable hydrogenous fluid (e.g. low vapor pressure hydrocarbon), capillarity-transported and surface tension-supported on cooled grid structure
$\kappa_{14\,MeV\,n} \simeq 0.2$ cm^2/gm

FIGURE 3

RANGE AND STOPPING-POWER TABLES FOR HEAVY IONS

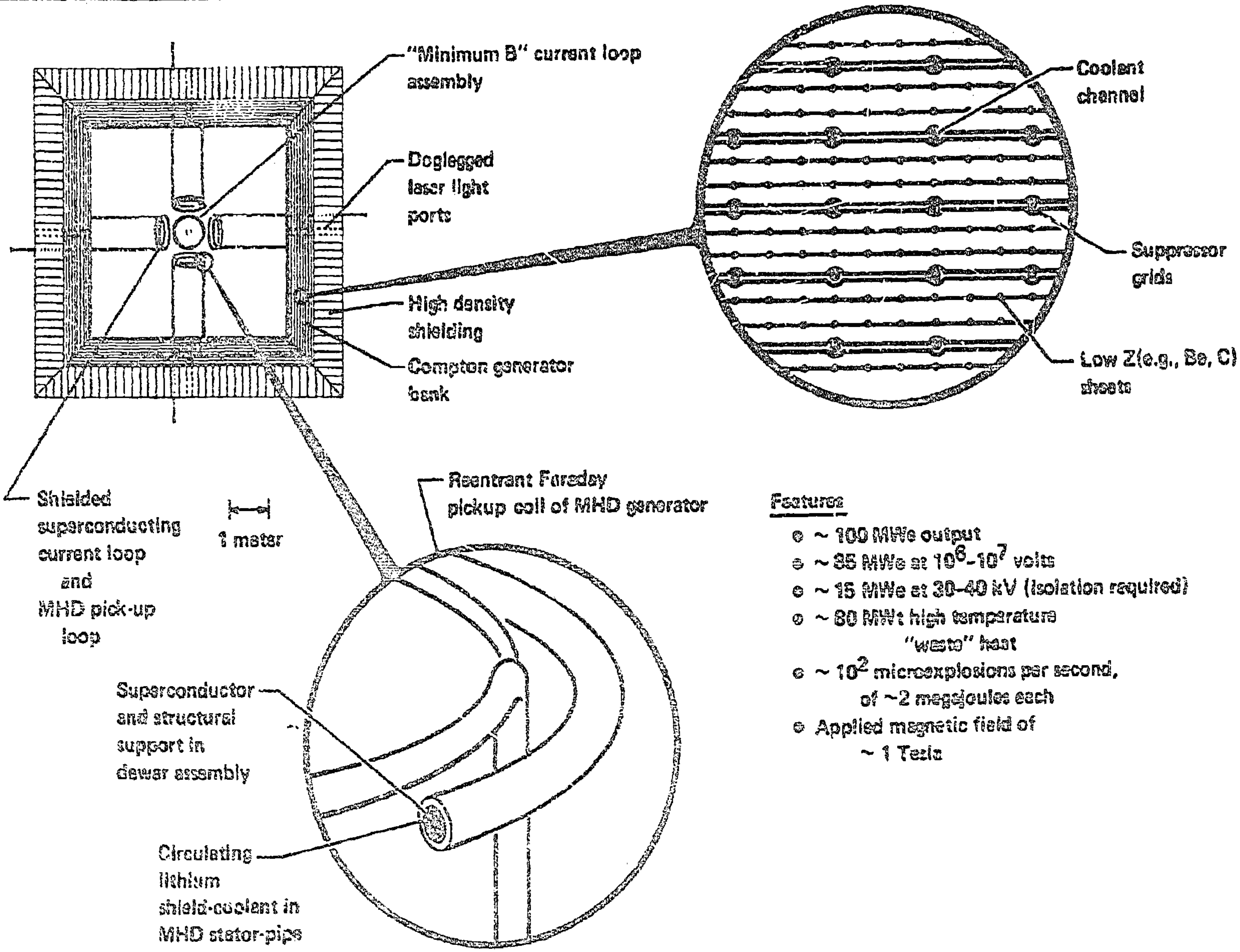
$^{1}_{1}$H IONS

ENERGY PER MASS UNIT	RANGE IN UNITS OF MG/SQ CM												ENERGY FOR A=1
MEV/AMU	BE	C	AL	TI	NI	GE	ZR	AG	SN	TA	AU	U	MEV
0.0125	0.059	0.070	0.102	0.150	0.193	0.216	0.251	0.266	0.378	0.421	0.469	0.491	0.0126
0.0160	0.068	0.082	0.118	0.181	0.222	0.247	0.285	0.283	0.430	0.488	0.521	0.575	0.0161
0.0200	0.078	0.093	0.136	0.205	0.251	0.279	0.320	0.320	0.489	0.556	0.595	0.651	0.0202
0.0250	0.089	0.106	0.151	0.231	0.283	0.315	0.358	0.367	0.554	0.632	0.678	0.737	0.0252
0.0320	0.102	0.122	0.173	0.264	0.321	0.360	0.406	0.414	0.635	0.727	0.781	0.847	0.0322
0.0400	0.116	0.137	0.196	0.298	0.365	0.405	0.456	0.460	0.719	0.824	0.885	0.959	0.0403
0.0500	0.132	0.158	0.222	0.337	0.411	0.455	0.491	0.529	0.803	0.929	1.006	1.139	0.0504
0.0600	0.147	0.179	0.246	0.374	0.458	0.507	0.546	0.586	0.905	1.018	1.117	1.260	0.0605
0.0700	0.161	0.195	0.270	0.409	0.500	0.556	0.597	0.641	0.990	1.196	1.223	1.391	0.0705
0.0800	0.175	0.209	0.293	0.443	0.541	0.600	0.646	0.694	1.072	1.240	1.326	1.509	0.0806
0.0900	0.190	0.226	0.316	0.476	0.582	0.644	0.694	0.746	1.152	1.321	1.423	1.623	0.0907
0.1000	0.204	0.242	0.339	0.510	0.622	0.683	0.742	0.797	1.230	1.410	1.519	1.734	0.1008
0.1250	0.240	0.281	0.397	0.592	0.721	0.790	0.861	0.924	1.428	1.629	1.796	2.005	0.1260
0.1600	0.293	0.327	0.480	0.709	0.861	0.952	1.029	1.103	1.684	1.931	2.077	2.378	0.1613
0.2000	0.357	0.402	0.580	0.840	1.025	1.133	1.227	1.316	1.993	2.280	2.440	2.806	0.2016
0.2500	0.444	0.486	0.714	1.031	1.241	1.371	1.485	1.591	2.309	2.778	2.926	3.351	0.2519
0.3200	0.580	0.614	0.919	1.306	1.554	1.726	1.874	2.006	2.873	3.307	3.628	4.151	0.3225
0.4000	0.756	0.774	1.179	1.649	1.964	2.164	2.355	2.520	3.685	4.100	4.401	5.122	0.4031
0.5000	1.007	0.998	1.542	2.122	2.511	2.761	3.010	3.222	4.662	5.262	5.626	6.422	0.5039
0.6000	1.291	1.253	1.947	2.662	3.110	3.412	3.727	3.992	5.676	6.421	6.855	7.814	0.6047
0.7000	1.615	1.539	2.394	3.210	3.761	4.119	4.506	4.820	6.739	7.636	8.176	9.301	0.7055
0.8000	1.971	1.857	2.881	3.826	4.461	4.877	5.364	5.726	7.876	8.970	9.577	10.808	0.8062
0.9000	2.359	2.207	3.405	4.480	5.207	5.682	6.235	6.686	9.230	10.395	11.056	12.541	0.9070
1.0000	2.780	2.589	3.967	5.177	5.997	6.533	7.178	7.697	10.546	11.848	12.602	14.275	1.0078
1.2500	3.967	3.685	5.326	7.088	8.193	8.851	9.766	10.481	14.095	15.789	16.769	18.935	1.2597
1.6000	5.946	5.552	8.056	10.140	11.586	12.529	13.827	14.860	19.647	21.931	23.269	26.189	1.6125
2.0000	8.443	8.132	11.435	14.165	16.030	17.317	19.155	20.620	26.795	29.798	31.580	35.463	2.0156
2.5000	12.461	11.975	16.361	19.938	22.471	24.137	26.772	28.863	35.865	40.830	43.256	48.349	2.5195
3.2000	19.455	18.433	24.518	29.375	32.867	35.196	39.120	42.149	52.940	58.680	61.830	68.810	3.2250
4.0000	28.827	27.268	35.569	42.008	46.706	49.893	55.479	59.875	74.010	81.494	86.070	95.420	4.0312
5.0000	42.846	40.387	51.855	60.461	66.796	71.210	78.126	85.676	104.075	114.385	120.447	133.199	5.0390
6.0000	59.307	55.720	70.767	81.732	89.870	95.609	106.176	114.726	138.207	151.568	159.272	175.591	6.0468
7.0000	78.125	73.180	92.199	105.704	115.830	122.961	136.444	147.441	176.200	192.816	202.100	222.177	7.0546
8.0000	99.236	92.701	116.062	132.276	144.562	153.185	169.769	183.483	217.769	237.961	249.315	273.414	8.0624
9.0000	122.562	114.237	142.202	161.361	175.962	186.185	206.058	222.734	262.856	286.881	303.174	328.479	9.0702
10.0000	147.989	137.754	170.795	192.064	209.966	221.810	249.277	265.037	311.387	339.290	354.659	387.461	10.078
11.0000	175.544	163.200	201.546	226.713	246.606	260.164	287.142	310.756	361.240	395.146	417.596	450.213	11.086
12.0000	205.152	190.514	234.483	267.068	285.442	300.978	332.155	358.306	418.272	456.277	473.072	516.605	12.094

TABLE 5

From L. C. Northcliffe and R. F. Schilling, Nuclear Data 7A, 233 (1970).

CONCEPTUAL DESIGN OF MHD CONVERTER-COMPTON GENERATOR MODULE (100 MWe) OF pB^{11}-BURNING PULSED FUSION POWER PLANT



Features

- ~ 100 MWe output
- ~ 85 MWe at 10^6-10^7 volts
- ~ 15 MWe at 30-40 kV (isolation required)
- ~ 80 MWt high temperature "waste" heat
- ~ 10^2 microexplosions per second, of ~2 megajoules each
- Applied magnetic field of ~ 1 Tesla

FIGURE 4

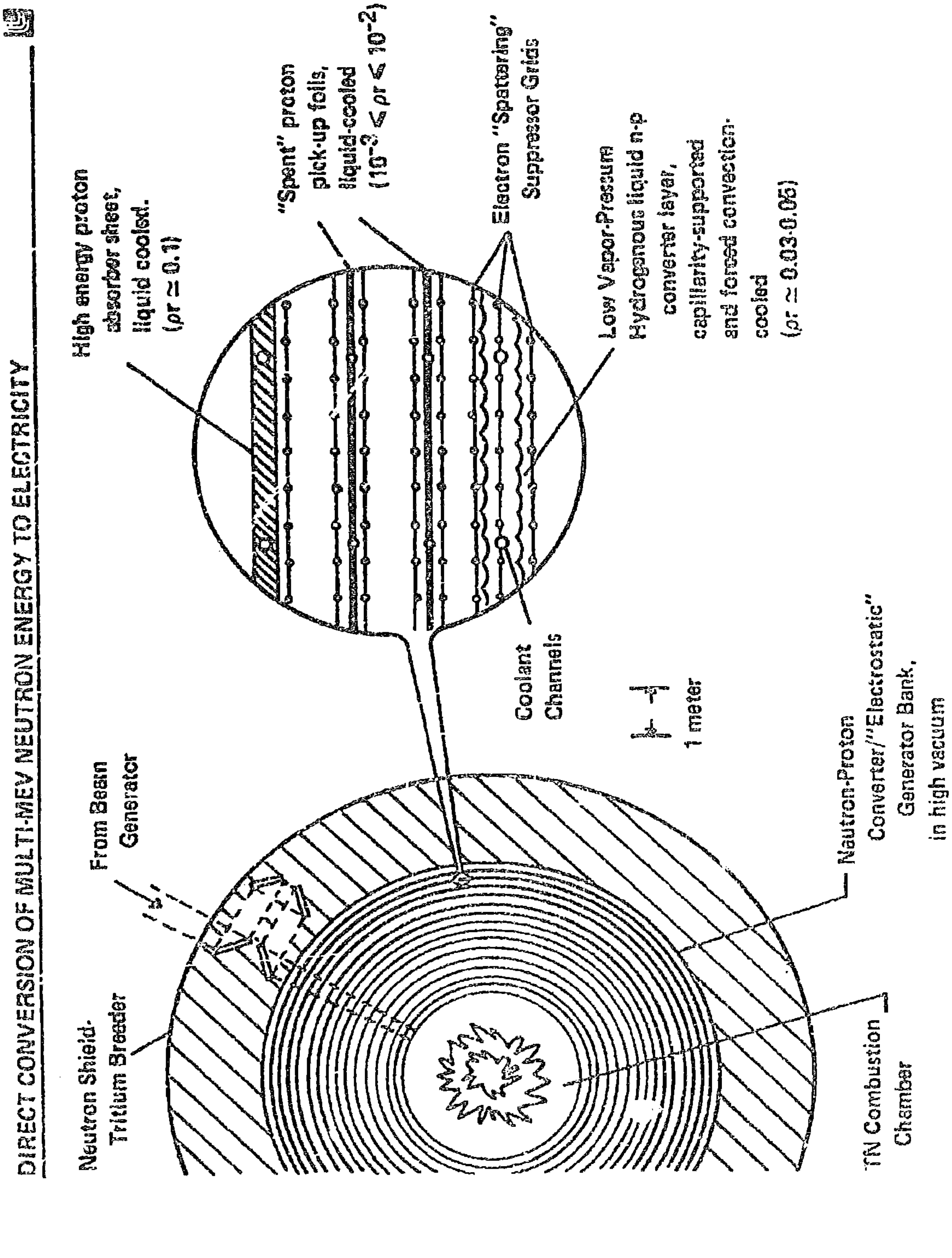

DIRECT CONVERSION OF MULTI-MEV NEUTRON ENERGY TO ELECTRICITY
Neutron Shield-
Tritium Breeder
From Beam
Generator
High energy proton
absorber sheet,
liquid cooled.
($\rho r \simeq 0.1$)
"Spent" proton
pick-up foils,
liquid-cooled
($10^{-3} \leqslant \rho r \leqslant 10^{-2}$)
Electron "Spattering"
Suppressor Grids
Low Vapor-Pressure
Hydrogenous liquid n-p
converter layer,
capillarity-supported
and forced convection-
cooled
($\rho r \simeq 0.03$-0.05)
Coolant
Channels
1 meter
Neutron-Proton
Converter/"Electrostatic"
Generator Bank,
in high vacuum
TN Combustion
Chamber

FIGURE 5

DIRECT CONVERSION OF MULTI-MEV NEUTRON ENERGY TO ELECTRICITY, continued

Features

- Potentially high (50-80%) efficiency of conversion of 14 MeV neutron energy to electricity
- Amenable to both pulsed and CW neutron source conversion
- Requires relatively large intra-shield volume (100-300 converter layers, high electric fields, even when layers are connected in parallel)
- Efficiency strongly complexity-dependent
- Capable of operation in high-magnetic fields ($\lesssim$ 10T); "magnetic insulation" exploitation
- Substantially lower tritium breeding capability
- Probably less capital-intensive than steam-thermal conversion — lower power cost

DIRECT CONVERSION OF MULTI-MEV NEUTRON ENERGY TO ELECTRICITY, continued

- Potentially less rejected heat — lower thermal pollution
- Subject to experimental evaluation in the near term

TABLE 6

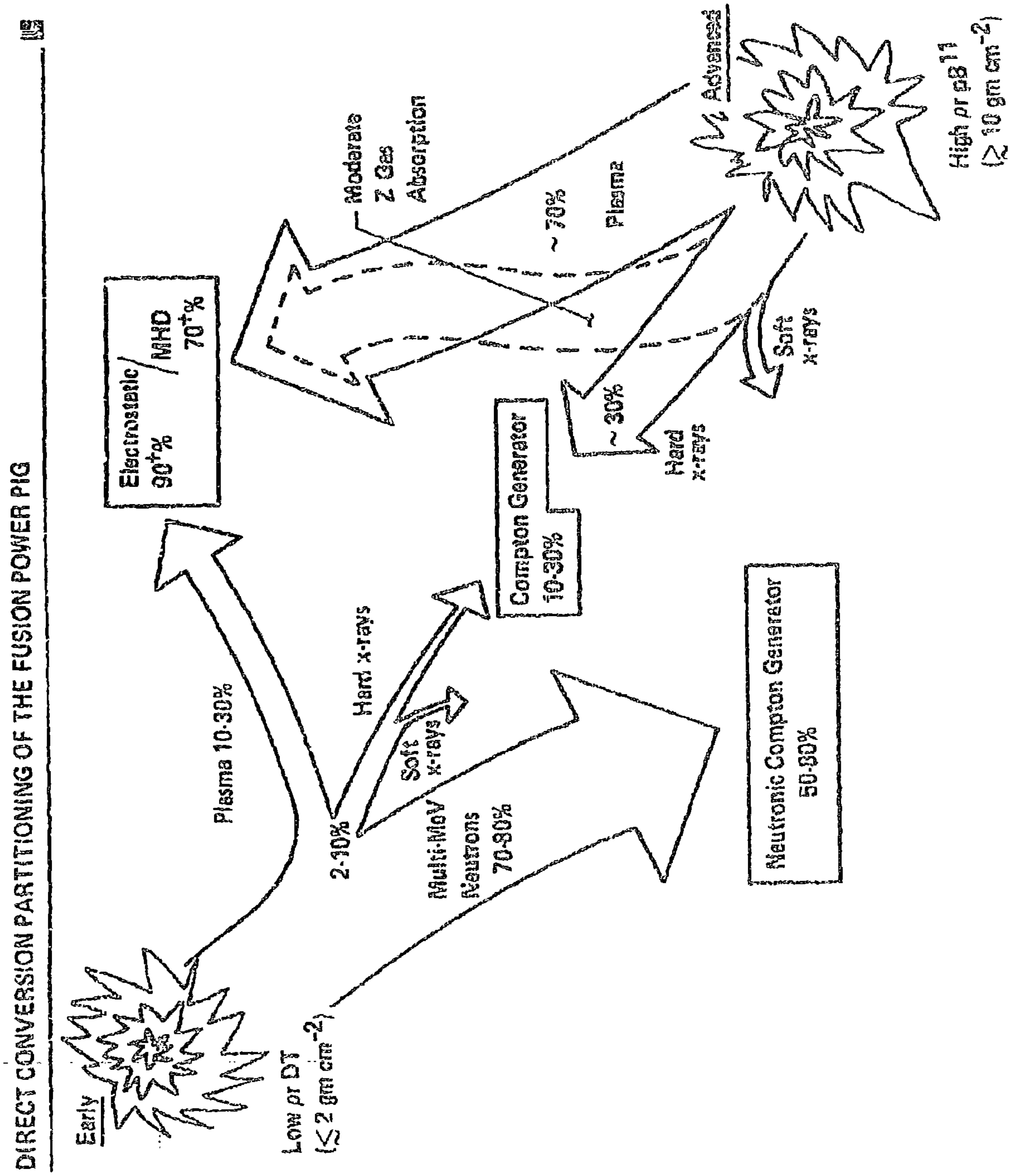

DIRECT CONVERSION PARTITIONING OF THE FUSION POWER PIG
Early
Low ρr DT
(≲ 2 gm cm^{-2})
Plasma 10-30%
2-10%
Hard x-rays
Soft x-rays
Multi-MeV Neutrons 70-80%
Electrostatic 90$^+$%
MHD 70$^+$%
Compton Generator 10-30%
Neutronic Compton Generator 50-60%
Moderate Z Gas Absorption
~ 70%
Plasma
~ 30%
Hard x-rays
Soft x-rays
Advanced
High ρr pB^{11}
(≳ 10 gm cm^{-2})

FIGURE 6