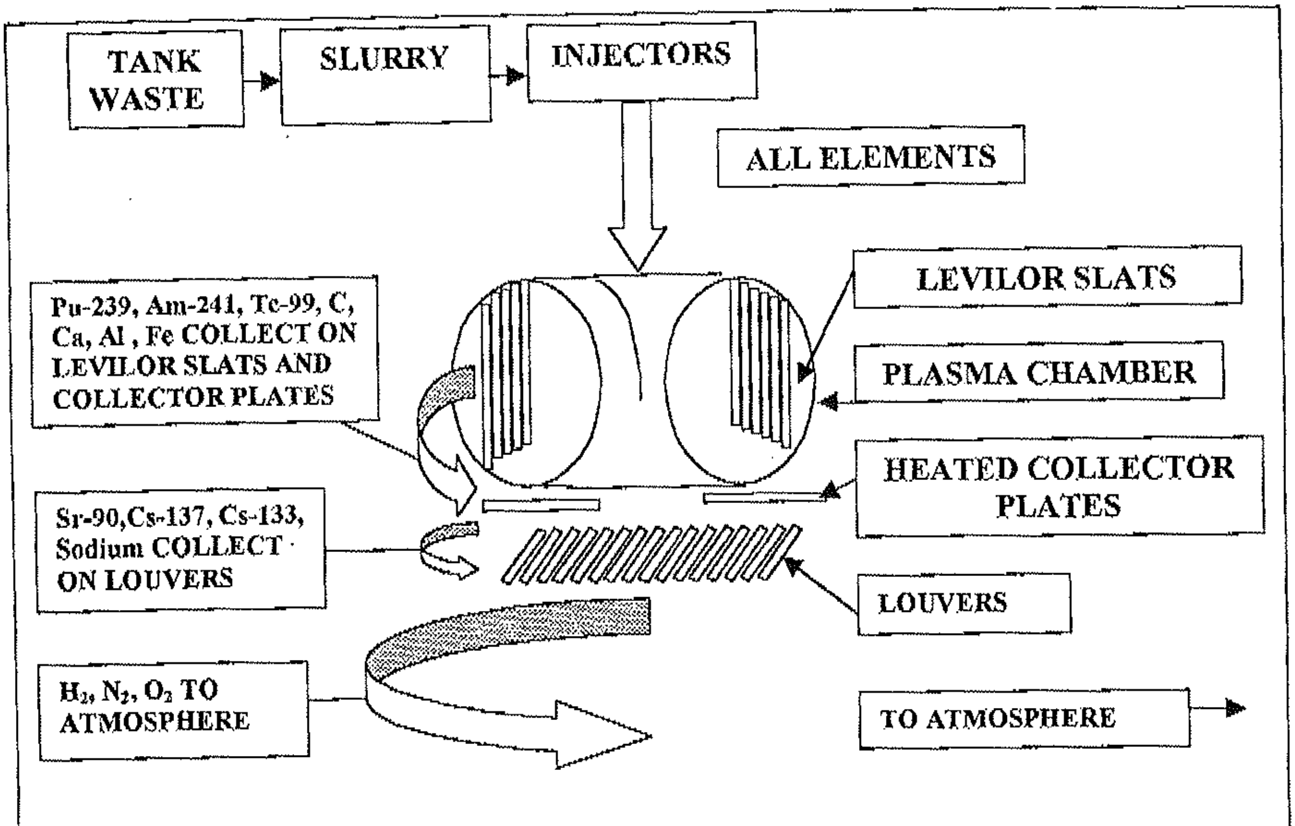

FIGURE 1
MATERIAL FLOW SCHEMATIC

The proposal is basically an outline of what would become a formal, unsolicited proposal, providing that there is sufficient interest on the part of the DOE. Our proposed subcontractors are: the University of Texas at Austin (Ken Gentle) and the Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University (John Plodinec).

II. Prototype Program Elements

A. The Prototype

The prototype device will include the plasma processor which, in a toroidal version, would be about 7 feet in diameter, with a height of about 3 feet.. The power supplies would be about the size of a 10 foot cube. The slurry injectors would occupy a space of about a 3 foot cube. Access for removal of separated species would be provided. (It is assumed the separated species are taken to a separate site for final disposition.) Options could include glass matrix isolation or commercial sale of some of the products. The TEXT Tokamak (valued at about $15,000,000) at the University of Texas would be dedicated to this project.

B. Validation Requirements - Operating Density

Plasmas with temperatures on the order of 5,000,000 degrees and electron heat flux of over 5,000,000 watts/cm^2 were developed in the early 1980's. This hot plasma represents a unique new medium, which can ionize any solid or liquid material within a few hundred millionths of a second after being injected in the plasma. Complete ionization of solid pellets and streams have been performed in such fusion research devices since 1982. In fact, pellets have been ionized to perform chores such as coating the inside walls of the devices with gettering materials such as silicon, boron, and carbon. Over 200 pellet ionization experiments have been performed world wide. It is this ability to ionize any substance that the Fusion Torch/LVPP uses for tank waste separation. The waste does not have to be characterized, just converted into a slurry.

The final maximum plasma density in solid ionization experiments is about $5 \times 10^{14}/cm^3$.

The pilot plant requires that the maximum plasma density be raised a factor of ten, to $5 \times 10^{15}/cm^3$. Stabilization techniques are included in the above mentioned patents to allow achievement of those conditions. Experiments are required to validate operation in this higher density regime as part of the prototype design effort. The Tokamak facility at the University of Texas would be used for these validation experiments.

C. Validation Requirements - Separation Efficiency

Theoretical analysis indicates a high degree of separation of species. Assuming the initial species concentration of Hanford Tank Waste is represented by the average chemical composition (see references 2 and 3) Experiments are required to validate separation at the maximum operating densities of $5 \times 10^{15}/cm^3$. For these experiments, "surrogate" (benign) isotopes of the targeted species will be used. The Tokamak facility at the University of Texas would be used for these separation experiments.

D. Validation Requirements - Thruput (Repetition Rate)

Each pellet or stream ionization event is for a relatively small pellet (about 1 mm in radius). The prototype will be designed to process at a 60 Hz rate. At 60 Hz, the throughput for a 2 MW system with the dimensions described above would be about 250 kg/day (assuming an average atomic weight of about 10.) Experiments at a repetition rate of 60 Hz will be performed in the Tokamak device at the University of Texas.

E. Validation Requirements-Energy Consumption

At 250 kg/day and for an electricity cost of .06/kWhr, the energy cost is between \$7 and \$10/kg. In comparison, the present DOE TWRS program estimates a cost of about \$77/kg over 25 years to eliminate the tank waste.[5] Validation of these cost estimates will be done with the above mentioned Tokamak.

F. Validation Requirements-Material Balance

Conversion of the waste to a plasma state inherently allows a complete determination of each of the separated species. When in the ionized plasma state, each species emits particular radiation lines that can be monitored to determine their inventory. This would be taken advantage of early in the experimental program to perform an initial material balance. DIAL has the instrumentation and the personnel necessary to carry out this task.

G. Conversion of Tank Waste to Slurry

The DOE already supports a number of programs for conversion of tank waste to slurry. DIAL is already modeling such processes, as well as developing basic thermodynamic data to support waste retrieval decisions. DIAL will perform modeling and experimental slurry stability studies to integrate the tank waste slurry operation with the prototype operation. Perhaps the most important result of this program will be confirmation that a slurry can be produced which is compatible with the rest of the process.

III. Prototype Design

In contrast to previous plasma device design, the point of departure for the FT/LVPP Prototype is Reliability, Availability, and Maintainability ("RAM"). This requirement is driven by:

1. The presence of large quantities of hazardous and volatile radioactive materials,
2. The need to continuously remove these materials in a continuous or repetitive batch mode,
3. The need to perform the material removal completely remotely,
4. The need to completely and remotely maintain the plasma system for very long periods (years) of time, and
5. The need to accomplish the mission of tank waste remediation.

While the prototype is not a production machine, its objective is to establish the basis for the design and fabrication of production machines. Thus, it will satisfy the requirements stated above.

The most stringent of these requirements is remote material handling. There are two components to this:

1. Machine system and subsystem maintenance (demonstrated to some degree for the very large International Thermonuclear Experimental Reactor design), and
2. Radioactive material handling, particularly those that are deposited as solids on the interior surfaces of the machine.

With few exceptions, machines and facilities built to handle radioactive materials are designed for vertical lifts (most fission reactors, reprocessing canyons, etc.) as the simplest and safest handling approach. Plasma devices, being either toroidal or linear, don't obviously lend themselves to this maintenance approach. These devices, having been experimental in the past and focused on low duty-cycle physics objectives, did not require significant remote maintenance. However, designs of "Engineering Test Reactors" over the past decade have addressed these issues and will be used as a significant resource for Prototype design. Additionally, recent private work in special magnet and plasma environment subsystem design ("first wall" and "divertor") will be incorporated in Pilot Plant design. Likewise, slurry feed systems developed at DIAL will be modified to be easily integrated with the Prototype. Finally, post-processing of the recovered material, a new requirement for a plasma device, will be similarly integrated into the Prototype design and RAM system. DIAL will be responsible for determining whether the products of the LVPP will satisfy DOE's waste form specifications.

Conceptual Design will be started immediately for the overall Prototype and the subsystems unrelated to the confirmation of physics objectives. This effort will intensify at the beginning of the second year and a Preliminary Design will be completed by mid-year. Engineering Design, a refinement of the Preliminary Design, will be completed at the end of the second year.

Fabrication and installation is planned to take three years with initial operations at the end of the fifth year.

IV. Program Elements And Estimated Costs <u>Exclusive of Containment</u>

Year 1 Validation Experimental Setup		
First 6 months - TEXT Restart Planning & Conceptual Design	UTA	600,000
Specification of control systems and other equipment	UTA	350,000
Control equipment, new vacuum pumps etc	DIAL	100,000
Sludge Modeling	ESEC/DIAL	50,000
Collection Technique Scoping	ESEC	125,000
Pilot Plant Conceptual Design	ESEC	250,000
Program Management and Systems Studies		
Second 6 months - ReCommissioning of UT Tokamak	UTA/DIAL	50,000
Diagnostic development for material balance	UTA	600,000
Initial Validation Experiments	ESEC	125,000
Pilot Plant Conceptual Design	ESEC	250,000
Program Management and Systems Studies		
YEAR ONE TOTAL		2,275,000
Year 2 Further validation experiments, intense prototype design activity.		
First 6 months – Preliminary Design & Initial Design Verification Tests	TEAM	5,000,000
Pilot Plant Preliminary Design		
Second 6 months – Engineering Design & Final Design Verification Tests	TEAM	7,000,000
Pilot Plant Engineering Design		
Year 3-5 Construction		
Construction	TEAM	60,000,000
TOTAL ESTIMATED COST		74,275,000

References:

1. U. S. Patent 5,868,909, Feb. 9, 1999.
2. U. S. Patent 5,682,434, Oct. 28, 1997.
3. U. S. Patent 5,630,880, May 20, 1997.
4. Boomer et al. 1993, Tank Waste Technical Options Report. WHC-EP-0616, Rev. 0. Westinghouse Hanford Company, Richland, Washington. March, 1993

Generation of Hydrogen by Ultra-Violet Light Produced by the Fusion Torch[*]

by

B. J. Eastlund and W. C. Gough

ABSTRACT

Present day production of hydrogen is based on processes that have been developed in response to economic factors. However, hydrogen is now being investigated for use in fuel cells that would use hydrogen plus air to generate pollution free electricity in an urban environment and for the production of portable fuels. Hydrogen would be produced at large, electrical generating stations and transported to the city via pipeline or tank car. In this paper, we present calculations on hydrogen production using ultra-violet light generated directly in plasmas extracted from future fusion reactors.

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[*] Presented at the 163rd National Meeting of the American Chemical Society, Boston, Massachusetts, April 9-14, 1972.

Introduction:

Studies of future energy systems indicate the need for a portable fuel supply in addition to large central station fission or fusion power plants. Hydrogen is receiving increasing study as a potential portable fuel which would be produced at such generating plants.

At the present time, the cheapest and most economic present process for production of hydrogen is based on the use of fossil fuels. However, as fossil fuel supplies of natural gas are depleted, hydrogen production processes which do not consume fossil fuels will be needed. Systems for hydrogen production which are based on the use of heat and or electrical energy generated by nuclear fission reactors are presently being studied. These techniques include: water-electrolysis, direct use of nuclear heat, and chemonuclear reactions (direct breaking of the chemical bonds of water by fission fragments).

We introduce a new possibility for hydrogen production based on the use of ultraviolet photons produced using a fusion reactor. This new concept is based on the Fusion Torch.[1] In brief, photons would be produced with high efficiency from leakage plasma from a fusion reactor and would then be used to photodissociate water to produce hydrogen.

Hydrogen from Photolysis

Hydrogen has been observed as the result of photolysis of water vapor.[2] The reactions shown in Table I are energetically possible. Reactions number 1 and 3 have not been observed. Ung and Back[2] have produced H_2 and H_2O_2 by phtolysis of water vapor (at temperatures of 200°C to 350°C and pressures from 1.3 to 28mm Hg) with ultraviolet radiation at 1849 Å. Their results for yield of H_2 as a function of

		ΔH, kcal.	ΔH, e.v.	λ, A.
(1)	$HOH \rightarrow H_2 + O(^3P)$	116.0	5.0	2468
(2)	$HOH \rightarrow H(^2S) + OH(X^2\Pi)$	117.5	5.1	2420
(3)	$HOH \rightarrow H_2 + O\ (^1D)$	161	7.0	1763
(4)	$HOH \rightarrow H(^2S + OH(\Lambda^2\Sigma^+)$	209.5	9.1	1356
(5)	$HOH \rightarrow 2H(^2S) + O(^3P)$	219.0	9.5	1299
(6)	$HOH \rightarrow 2H(^2S) + O(^1D)$	264.	11.5	1073
(7)	$HOH \rightarrow H(^2P) +)H(X^2\Pi)$	352.5	15.3	807

TABLE I

Threshold Energies in Water Decomposition irradiation time is shown in figure 1.

Ung et. al. found that the initial quantum yield of hydrogen in the photolysis of pure water vapor at 25°C was about 0.4. This assumed a primary quantum yield of 1 for reaction 2 of table 1.

In addition to the straightforward study and reactions described above, photolysis of water in the presence of third bodies has been studied. It thus is shown that hydrogen can be produced in the photolysis of water vapor -- at least in small scale laboratory experiments.

Photons from a Plasma

Photons can be produced with high efficiency when high Z elements are injected into the ultra-high temperature, low density hydrogen plasmas which are characteristic of controlled fusion experiments. Such optical and ultra-violet radiation from high temperature plasmas is referred to as "excitation radiation" and has been extensively studied.[4] R. C. Elton has observed production of photons at 1900 Å at power levels on the order of megawatts per square centimeter in experiments with a small experimental high temperature plasma.[5] Efficiencies as high as 87% of conversion of plasma energy to photon energy in resonance lines of ions have been observed.[11] Use of aluminum as the exclusive impurity element could produce UV radiation between 1800 and 1950 Å with up to 86% efficiency (based on the same physical principles as described in reference 11.) when injected into the proper high temperature plasma.[1] This is because the resonance lines of AIII lie between 1850 and 1935 Å. A high degree of control over the rate of photon production can be obtained by regulating either the influx of Al or by adjusting the parameters of the plasma.

Figure 2 illustrates the geometry of the photon producing system. High Z elements would be injected into the plasma, excitation radiation would result in the production of photons of proper wavelength. These photons would escape from the plasma because it is optically thin to ultra-violet photons, and be transmitted through ultraviolet windows into chambers containing water vapor at appropriate pressures. It appears that window materials capable of operating with high fluxes of radiation could be developed. G. A. Yale has described some recent work on the development of radiation resistant ultraviolet window materials.[6]

Plasma From a Fusion Reactor

Research on controlled fusion power is active in many countries.[7] Fusion reactors would produce power via the fusion reactions of light elements such as deuterium and tritium in plasmas at temperatures of 100,000,000°C -- 1,000,000,000°C. Production of power from fusion is not yet a reality with crucial tests of scientific feasibility still to be performed. Present estimates indicate that scientific feasibility could be proven about 1980 and the first significant contribution of fusion power to the nation's energy supply around the beginning of the 21st century.[8] However, some general features such reactors will have are known now, and some methods by which plasma could be extracted from a fusion reactor for the production of photons can be described.

The possibility exists for using plasma extracted from fusion reactors of both the mirror and toroidal type. An open system (mirror) reactor vessel is illustrated in figure 3. The basic reactor design is described in more detail in reference 9. A high temperature reactor plasma (T_e 100,000,000°C, number density $10^{14}/cm^3$ is contained by magnets (20-150 kilogauss) within a magnetic mirror region. Natural leakage of the mirror plasma is channeled by a magnetic field out of the main containment vessel. The leakage plasma is typically of high temperature (60,000,000°C) but low density (10^{10}-$10^{11}/cm^3$). These are not ideal conditions for generation of photons in the ultraviolet region via excitation radiation from high Z elements. Injection of cold hydrogen gas at a proper rate could provide a flow stream with much higher density (10^{13}-$10^{14}/cm^3$) and lower temperatures ideal for generation of ultraviolet photons. Such injection of H_2 into leakage plasma from a mirror reactor has been studied theoretically.[10]

Hydrogen from a Fusion Reactor via Photolysis

A conceptual block diagram of the process is shown in figure 4. A fusion reactor generates plasma energy. Plasma leaking out of the confining field is augmented with cold hydrogen to provide a medium suitable for production of photons in the ultraviolet range via excitation radiation. The photons are transmitted through a suitable window into a water vapor cell. The hydrogen gas is recovered from the cell while the thermal energy is converted into electricity or possibly used for production of hydrogen by thermal means.

Energy Considerations

The energy requirements for such a scheme can be estimated using the data of Ung et al.[2] If it is assumed that 80% of the plasma energy can be converted to photons of the right wavelength and that the quantum efficiency is 0.4 then 222,500 kilowatt hours of plasma energy would be required to produce one ton of H_2. If the thermal energy absorbed in the water vapor cell could be converted to electricity at 30% efficiency with a turbine, then 53,000 KW-HR of electricity could be produced as well as the one ton on H_2. This electricity could also be a product <u>or</u> it could also be used to produce H_2 via electrolysis. If that is done then only 123,000 KW-HR of plasma energy would be required to produce 1 ton of H_2. This energy flow diagram is illustrated in figure 5.

These figures can be compared in a similar manner to energy requirements for the production of hydrogen by electrolysis from electricity produced with a nuclear reactor. Electrolysis requires approximately 71,000 KW-HR of electricity per ton of H_2. Assuming a 40% efficient reactor this gives 177,000 KW-HR as the thermal energy requirement.

Conclusions:

Since the beginning of earth, water molecules (H_2O) have been splitting apart in the upper reaches of the atmosphere and producing hydrogen and oxygen. The energy necessary to split the water molecules has come from the ultra-violet rays of sunlight. Research aimed at the achievement of controlled fusion energy has developed technologies that make it possible to stimulate this solar process for hydrogen production. Eventually, when fusion energy sources become available, it may be possible to produce large quantities of hydrogen directly through the photolysis of water by using a specific application of the Fusion Torch concept. Our conclusions are:

1) the overall energy required to produce a ton of hydrogen via direct photolysis using a fusion reactor appears to be less than that required via electrolysis.

2) important questions concerning recovery of H_2, H_2O and heat energy from the photolysis cells remain to be answered.

3) the possibility of the direct conversion of energy from controlled fusion, an environmentally desirable prime energy source, to hydrogen, the basic element in non-polluting portable fuels, could be important to future energy considerations and deserves further study.

REFERENCES

1. B. J. Eastlund and W. C. Gough, Bull. of Am. Phys. Soc. 11, No. 13, 1564, November, 1968: B. J. Eastlund and W. C. Gough, "The Fusion Torch -- Closing the Cycle from Use to Reuse", WASH-1132, May 15, 1969.

2. A. Y. - M. Ung and R. A. Back, Canadian Journal of Chemistry, 42, 753 (1964).

3. J. R. McNesby and H. Okabe, in Advances in Photochemistry, Volume 3, John Wiley and Sons, 1964.

4. R. W. P. McWhirter, in Plasma Diagnostics, edited by R. H. Huddlestone and S. L. Leonard, Academic Press, New York (1965).

5. R. C. Elton, Plasma Physics (Journal of Nuclear Energy Part C) 6, 401, (1964).

6. G. A. Yale, Optical Spectra, 17, September/October 1968.

7. W. C. Gough and B. J. Eastlund, Scientific American, February, 1971.

8. Hearings of the Joint Committee on Atomic Energy on "The Current Status of the Thermonuclear Research Program in the United States, November 10 and 11, 1971, U.S. Government Printing Office Document 70-999-0, Washington, D. C. 20402.

9. D. J. Rose, Nuclear Fusion 9, 183 (1969).

10. G. W. Englert, NASA TND-3656, October, 1966.

11. H. J. Karr, E. A. Knapp, J. E. Osher, Phys. of Fluids 4, 424 (1961)

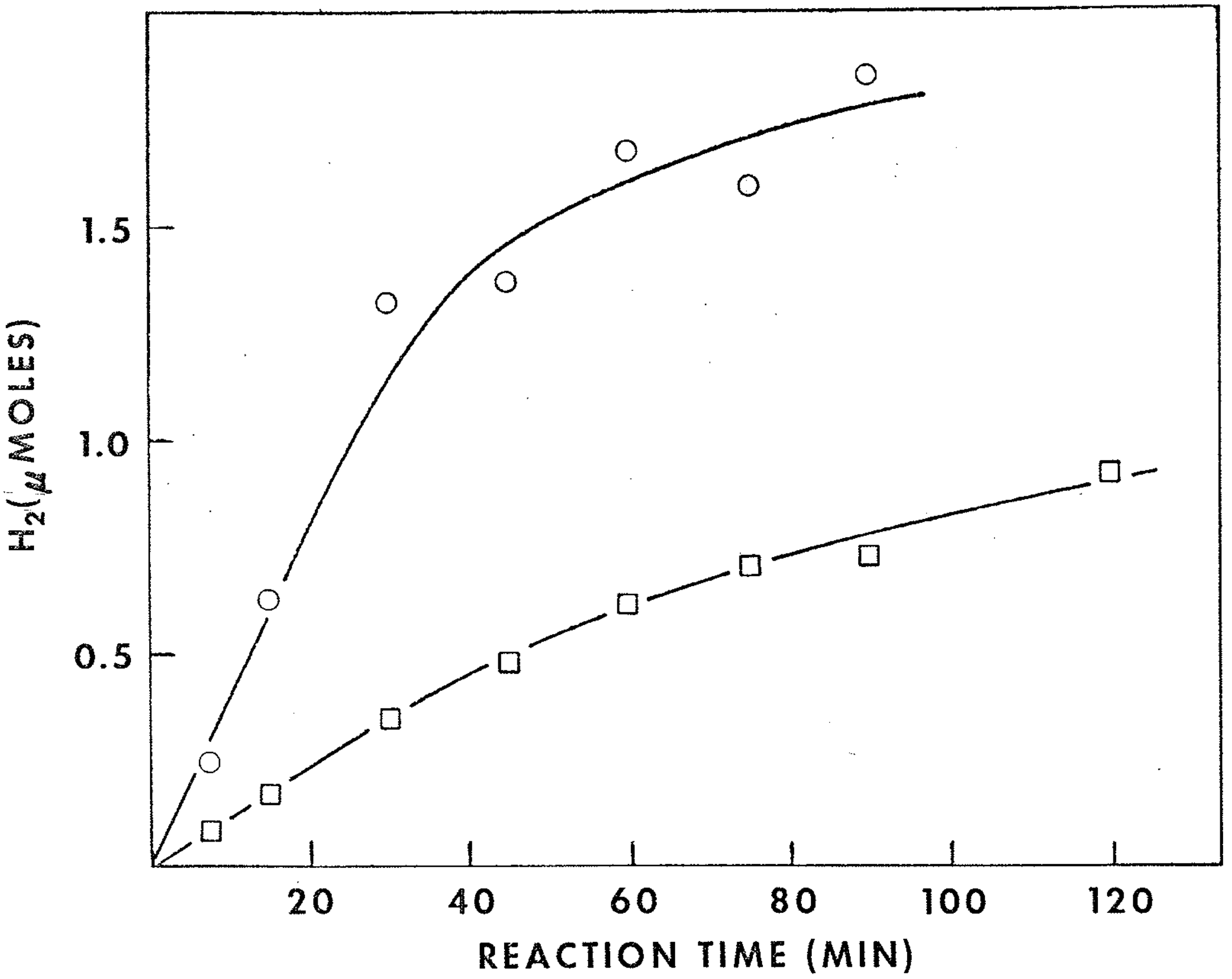

FIGURE 1

YIELD OF HYDROGEN FROM THE PHOTOLYSIS OF WATER VAPOR AT 25°C AT TWO DIFFERENT INTENSITIES.

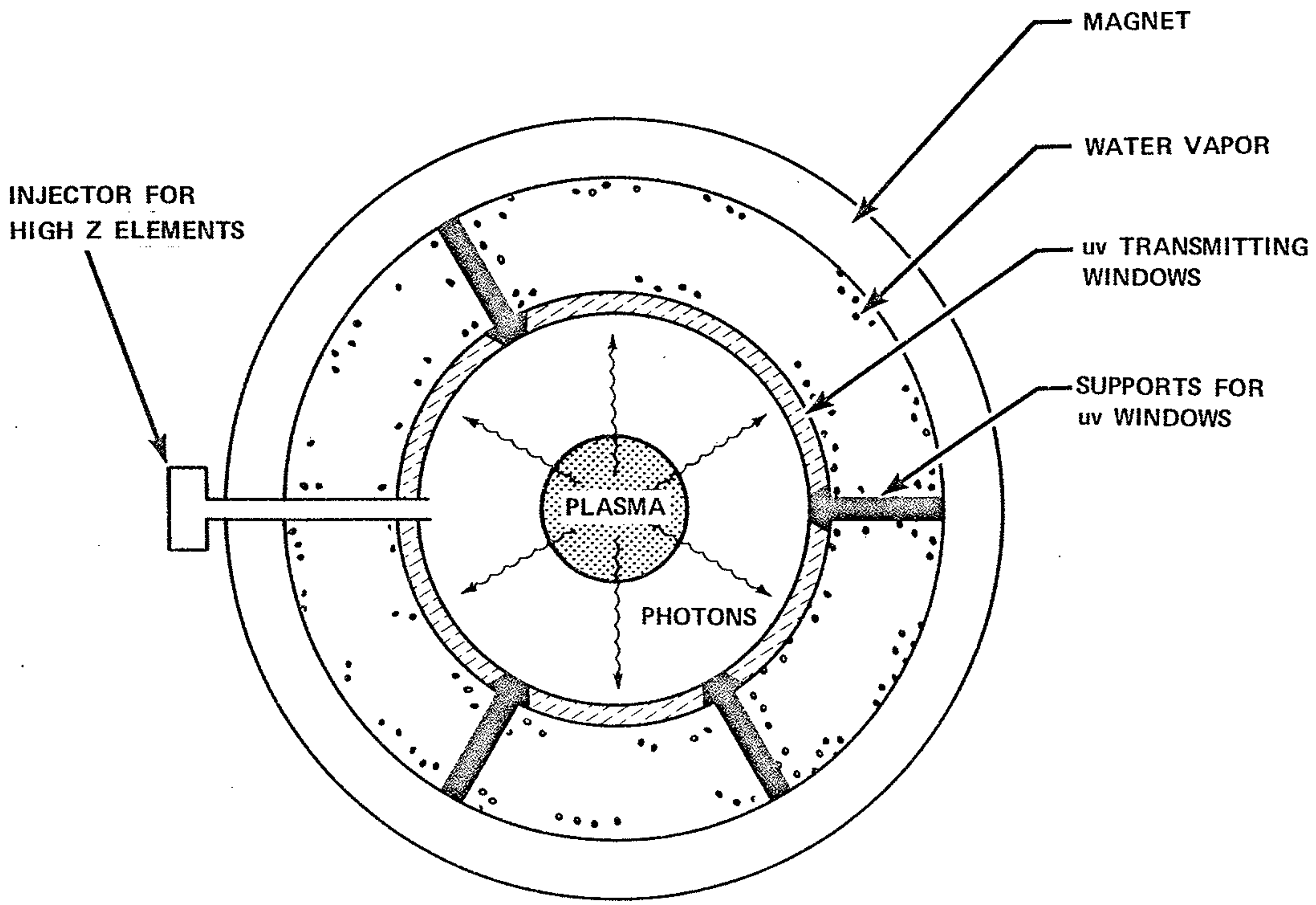

FIGURE 2

CROSS SECTION OF PHOTOLYSIS SECTION

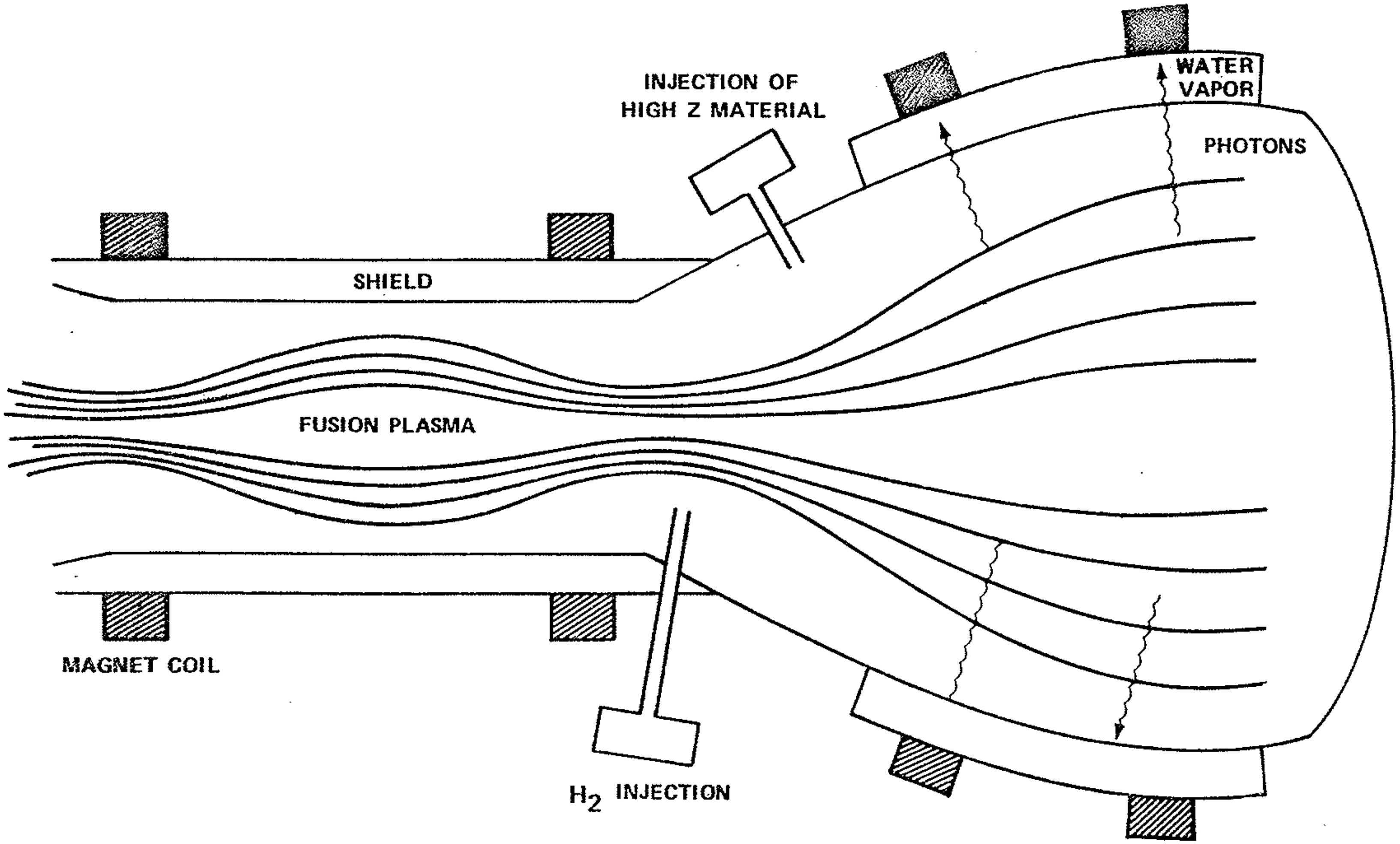

FIGURE 3

SCHEMATIC OF FUSION REACTOR WITH PHOTOLYSIS CONVERSION OF ENERGY

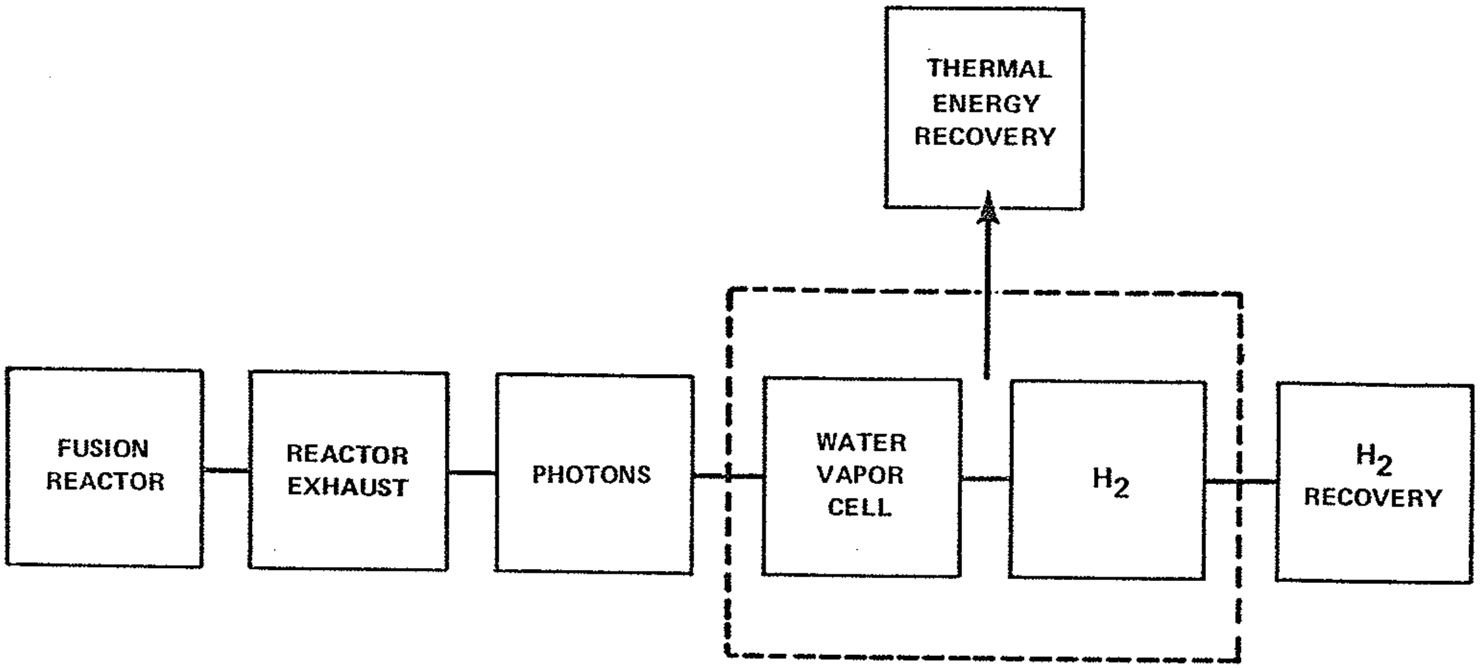

FIGURE 4

PHOTOLYSIS CONVERSION CHAIN

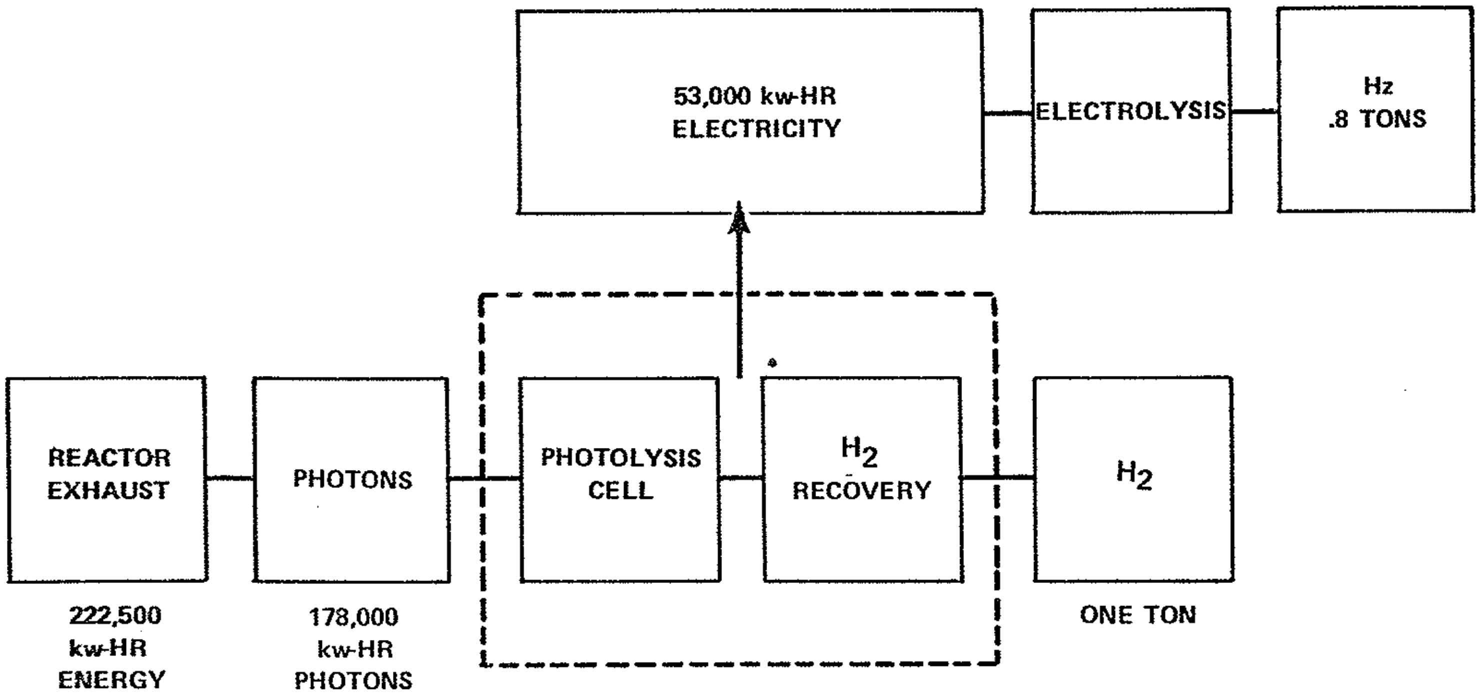

FIGURE 5

ENERGY BALANCE FOR PHOTOLYSIS CONVERSION