(12) UK Patent Application (19) GB (11) 2 085 643 A

(21) Application No 8033444
(22) Date of filing 16 Oct 1980
(43) Application published
28 Apr 1982
(51) INT CL³
G21C 1/00
(52) Domestic classification
G6P 3X
(56) Documents cited
None
(58) Field of search
G6C
G6P
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(54) **Atomic hydrogen reactor**

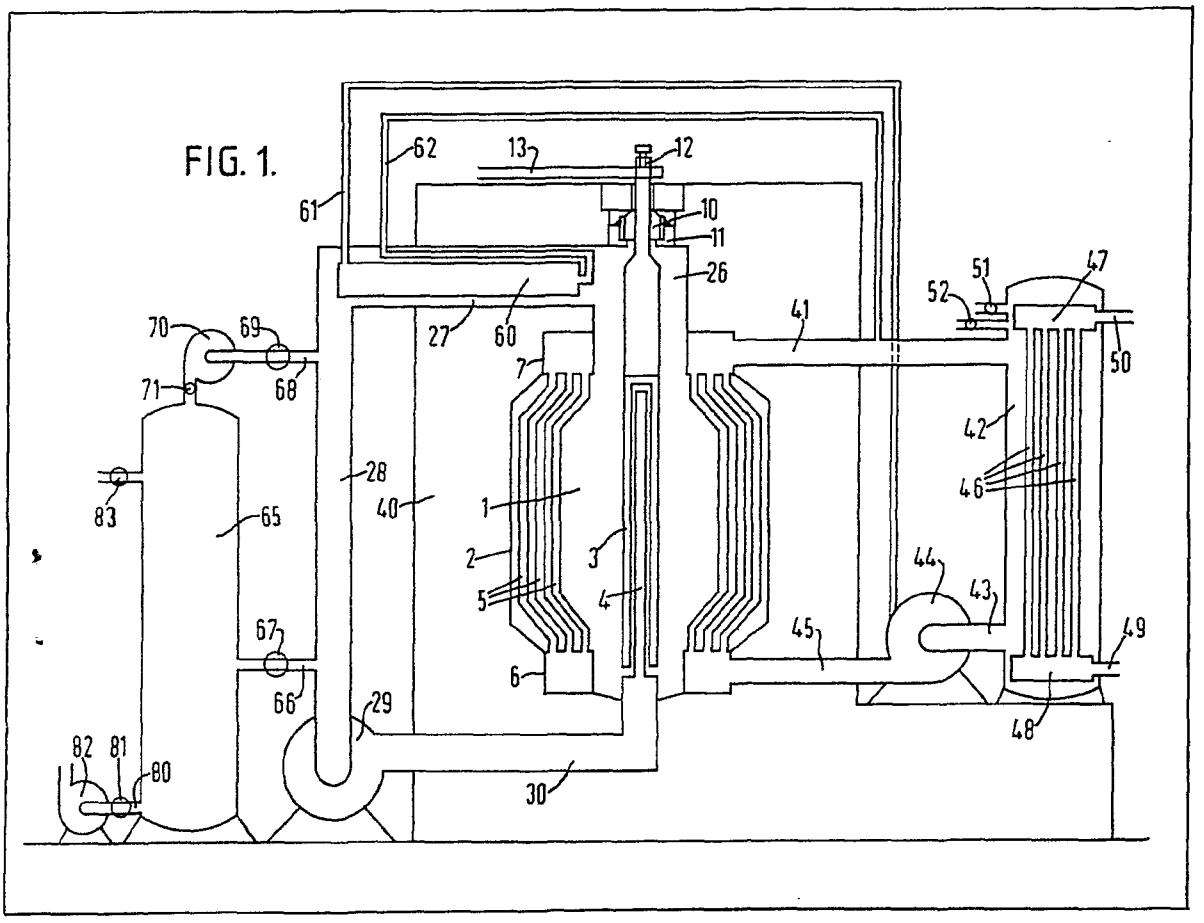
(57) In an atomic hydrogen reactor, heat is generated by: the production of atomic hydrogen from a hydrogen storage vessel (65) by an electrical discharge;

the capture of nascent neutrons from atomic hydrogen in a number of surrounding steel alloy tubes (5) having a high manganese content, to yield radioactive manganese 56 (Mn 56);

the irradiation of atomic hydrogen by the high energy antineutrinos from the beta decay of Mn 56, to yield nascent neutrons; and

the removal of heat generated by the capture of nascent neutrons by the Mn 55 and by the beta decay of Mn 56, using a circulating cooling fluid flowing through the steel tubes (5) to and from a heat exchanger (42). The heat is used for electrical power generation and/or in a process industry requiring a large input of heat.

FIG. 1.



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

FIG. 1.

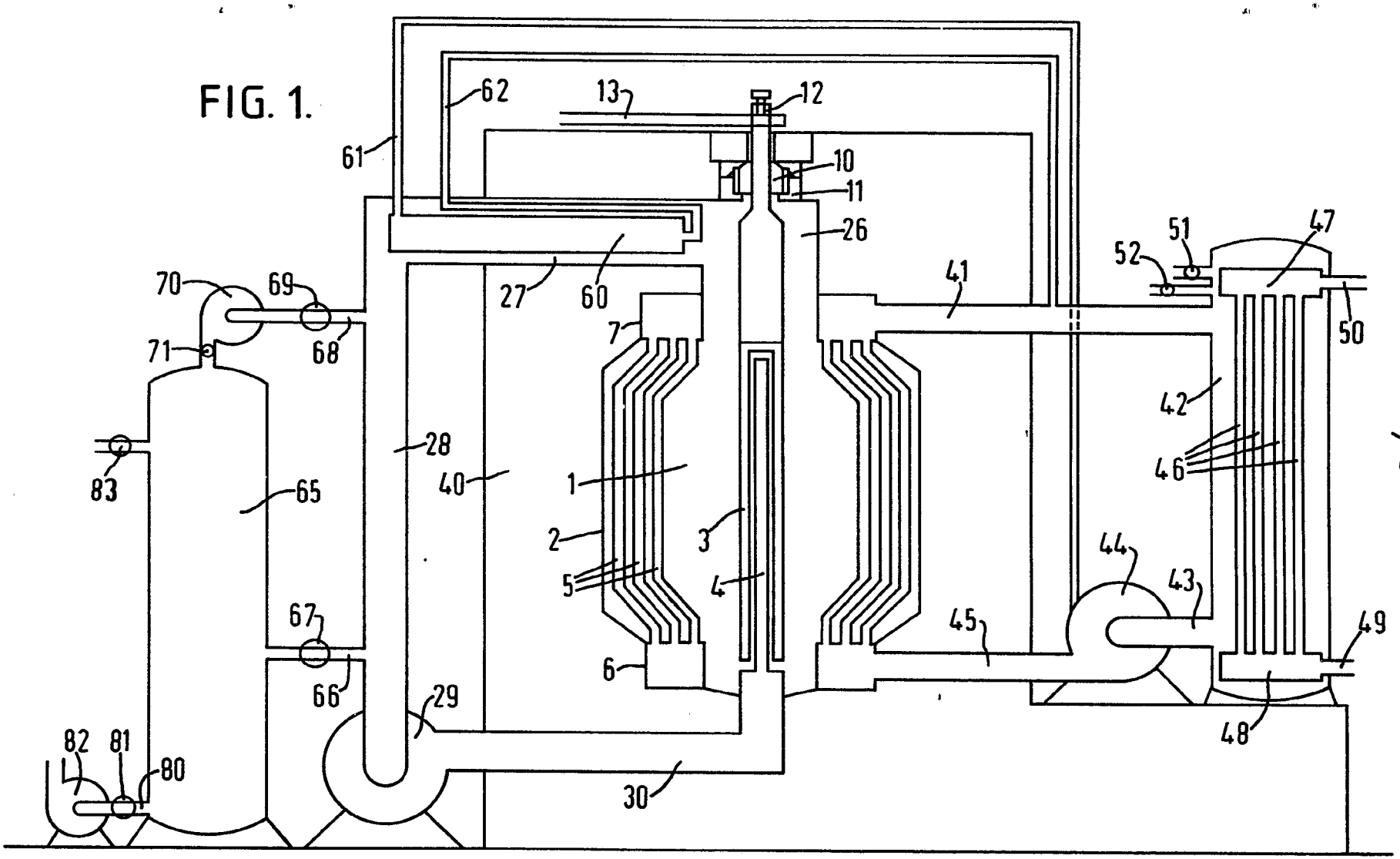

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FIG. 2.

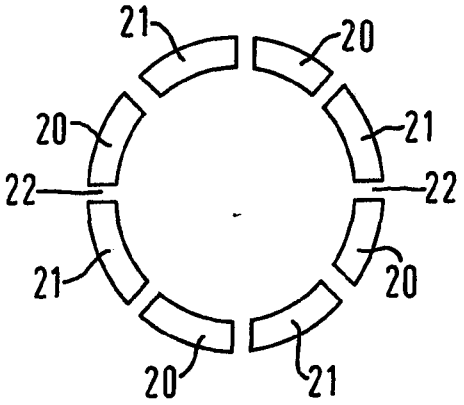
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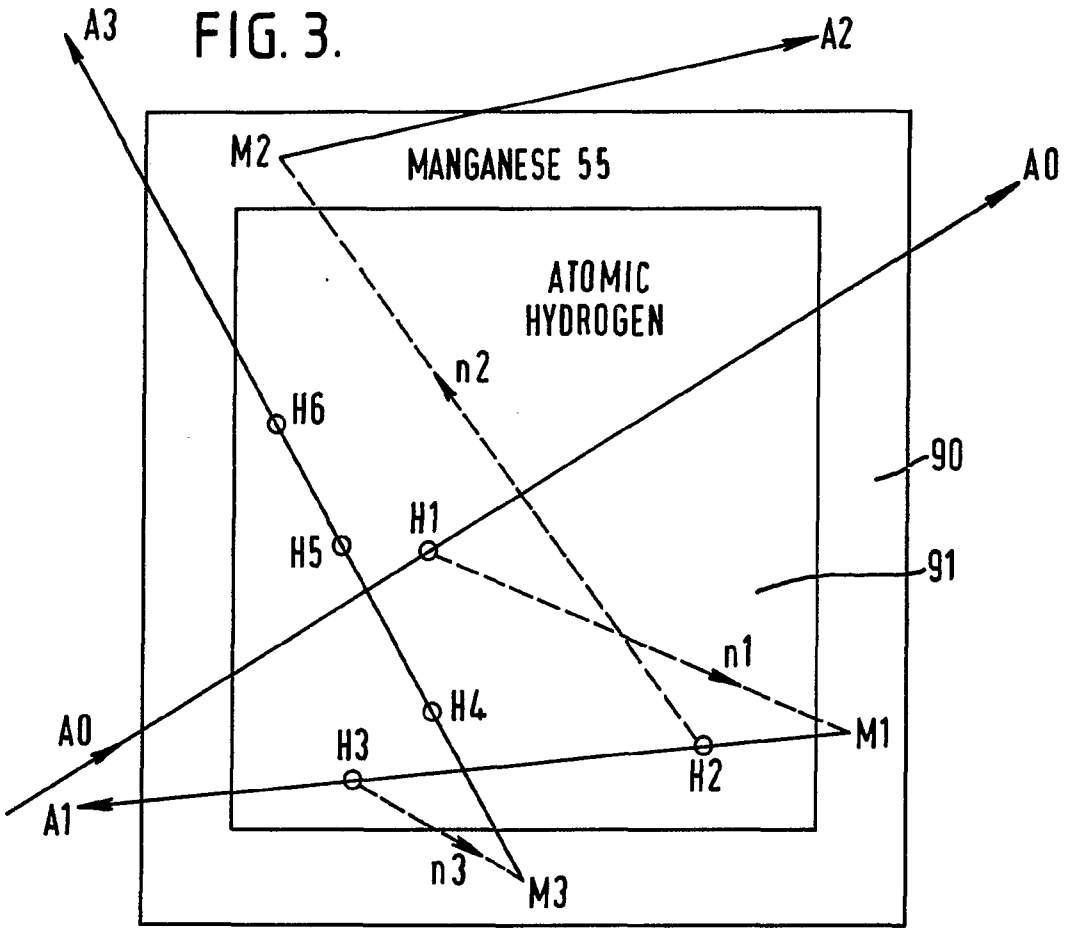
FIG. 3.


A3
A2
M2
MANGANESE 55
A0
ATOMIC
HYDROGEN
n2
H6
90
H1
H5
91
n1
H4
A0
M1
H3
H2
A1
n3
M3

SPECIFICATION

The nuclear generation of heat

This invention relates to the nuclear generation of heat.

Investigations conducted by the inventor lead him to the opinion that the universe is in a steady state, and the continuous creation of matter associated with steady state cosmology involves the following chain reaction:

(1) A neutron is created by interaction of an antineutrino with a neutral hydrogen atom in its ground state.

(2) At the low concentrations of matter which prevail in interstellar space and even in the outer atmosphere of many stars, such a created neutron decays prior to capture of ambient matter, with production of a proton, an electron and an antineutrino.

(3) Such a proton and electron ultimately undergo independent recombination, producing one new hydrogen atom, while the antineutrino from neutron decay becomes available to sustain the chain reaction, the net outcome of which is

1 H atom + 1 antineutrino →
2 H atoms + 2 antineutrinos

Process (1) was discovered by the inventor in experiments which showed that atomic hydrogen is a weak source of neutrons, with the earth itself supplying most of the antineutrinos through the beta decay of radioactive elements. Other workers have noted the emission of X-rays in energetic chemical reactions in which hydrogen is present, and it seems likely that these X-rays are a secondary product related to the emission of gamma rays when nascent neutrons from atomic hydrogen are captured by ambient matter.

Following this discovery, the inventor evolved a simpled theory which showed how the process of continuous creation was linked with the expansion of the universe in such a way as to ensure a constant cosmic density. This theory shows that the neutron creation cross-section of the hydrogen atom is of the order 30 barns when suitably averaged over the energy spectrum of the antineutrino from free neutron decay (0—783 kev).

Further investigations showed that neutron creation was quantitatively compatible with a wide variety of astrophysical data which need not be discussed in any detail here. In addition, the theory accounted for certain isotopic and elemental anomalies in stellar atmospheres which indicated an ample supply of free neutrons of otherwise unknown origin, including the presence of technicium 99 in the envelopes of some red giants, attributed to the capture of neutrons by molybdenum 98 nuclei. More recently, it has been proposed that the injection of neutrons from the sun's outer layers could account for the heating of the solar corona, and that the anomalously high carbon 14 content of lunar soil could be due to transport and implantation of C14 nuclei by the solar wind, these nuclei being produced by neutron capture by nitrogen in the solar atmosphere.

It appears now that the first step in the generation of nuclear energy by the sun is this interaction of antineutrinos with atomic hydrogen deep in the solar interior, where virtually all neutrons are captured prior to decay. Most of the created neutrons are captured by hydrogen, with production of deuterium (D) and 2.2 Mev gamma quanta, but without antineutrino emission. The H+D reaction then produces helium 3, which is probably converted to helium 4 and hydrogen in the central regions of the sun (fusion of two He3 nuclei). There is evidence that the neutron creation cross-section increases rapidly with the antineutrino energy. Thus although helium 3, at a solar concentration of 1 atom per 100000 H atoms, captures a significant proportion of neutrons by virtue of its very large capture cross-section, the tritium produced decays with the emission of low energy antineutrinos (maximum energy 18.6 kev) for which the neutron creation cross-section of atomic hydrogen is very low. When comparing the relative abundance, neutron capture cross-section and subsequent energy of emitted antineutrinos (where applicable) for all the elements in the sun, it is found that antineutrinos emission from the beta decay of manganese 56 nuclei plays a dominant role in relation to all other elements taken together, and accounts for about 96% of all neutron creation events. Although the overwhelming majority of neutron creation events do not produce an antineutrino of adequate energy to sustain the solar chain reaction, this is entirely compensated by the large number of neutrons (possibly of order 100000) created by the transit of a single antineutrino from Mn 56 through the sun. The local repulsion effect associated with neutron creation, which is the same process which drives the expansion of the universe, varies in phase with the oscillating population of Mn 56 nuclei (half life 2.576 hours) and accounts quantitatively both for the amplitude of the radial pulsations of the sun, and for their period of 2 hours 40 minutes.

Cepheid pulsations can be quantitatively explained in essentially the same way, though in that case the antineutrinos from free neutron decay are involved.

In addition to the considerable body of astrophysical evidence supporting the theory, there is now a most compelling new piece of evidence provided by recent satellite observations of stellar X-ray sources. It has been found that red dwarf stars, which have a low mass, small radius low surface temperatures and which far outnumber all other stars, emit on average nearly 10% of their total energy in the form of X-rays in the range 100 ev — 4 kev. This is a million times greater than expected from conventional astrophysics. A star whose mass is 0.1x solar mass has a luminosity of order 10^{-4}x solar luminosity, a surface temperature of about 3600°K and a surface gravity about 100 times

greater than that of the sun. Surface conditions favour the presence of atomic hydrogen, but the small scale height which would result from a high surface gravity is rapidly increased by a steeply rising internal temperature, which leads to almost total ionisation of the hydrogen within the top 100 km, which contains about 10^{23} H atoms per cm^2. Thus most of the neutron creation events are confined within this layer, whose column density is just sufficient to degrade much of the 2.2 Mev gamma radiation from H + n = D into a larger flux of soft X-rays. The exceptionally small energy dependence of the absorption coefficient of X-rays in hydrogen enables a substantial fraction of these X-rays to be emitted by the star prior to absorption. X-ray absorption, when it occurs, is followed by re-emission at optical and infrared wavelengths. Antineutrino emission in these stars is predominantly from free neutron decay in the top 100 km layer, which is just critical, with capture and decay occurring at similar rates. Thus, while no other theory or process can account for the observed flux of soft X-rays from red dwarfs, the neutron creation process can account quantitatively for this flux, which is also compatible with the emission of X-rays from energetic chemical reactions in which hydrogen is present, as previously noted by other observers (Z. Fonberg, Journal of Chemical Physics, 1951, Vol 19, p. 383).

The precise details of the process of neutron creation by interaction of an antineutrino with a neutral hydrogen atom in its ground state remains unknown. Presumably, the proton within a hydrogen atom has an internal structure which is influenced in some highly specific way by the ground state electron, and meets the physical requirements for neutron creation when an antineutrino interacts with it. Other protons, such as free protons, protons influenced by any other neighbouring electrons and protons bound to neutrons in atomic nuclei do not fulfil the necessary physical conditions for neutron creation. Other instances of highly specific processes abound in nuclear physics. For instance, the cadmium 113 nucleus contains 48 protons and 65 neutrons, and has a thermal neutron capture cross-section of 20000 barns. Cadmium 112, with just one neutron less, has a thermal neutron capture cross-section which is 400000 times smaller.

According to one aspect of the present invention, there is provided a method of generating heat in an atomic hydrogen reactor, which method comprises:—

producing atomic hydrogen by an electrical discharge;

capturing nascent neutrons from the atomic hydrogen in means comprising a material which thereby undergoes beta decay to yield antineutrinos;

irradiating the atomic hydrogen by the antineutrinos to yield further nascent neutrons;

removing heat generated by the capture of nascent neutrons by the said means and by the said beta decay; and

using this heat.

According to another aspect of the present invention, there is provided an atomic hydrogen reactor comprising:—

first means, for producing atomic hydrogen by an electrical discharge;

second means, for capturing nascent neutrons from the atomic hydrogen, the second means comprising a material which thereby undergoes beta deca to yield antineutrinos, the reactor being such that, in use, the atomic hydrogen is irradiated by the antineutrinos to yield further nascent neutrons; and

third means for removing and using heat generated by the capture of nascent neutrons by the said second means and by the said beta decay.

According to another aspect of the present invention, there is provided a method of generating heat in an atomic hydrogen reactor, which method comprises:—

the production of atomic hydrogen by an electrical discharge;

the capture of nascent neutrons from atomic hydrogen in a number of surrounding steel alloy tubes having a high manganese content, to yield radioactive manganese 56 (Mn 56);

the irradiation of atomic hydrogen by the high energy antineutrinos from the beta decay of Mn 56, to yield nascent neutrons;

the removal of heat generated by the capture of nascent neutrons by the Mn 55 and by the beta decay of Mn 56, using a circulating cooling fluid flowing through the steel tubes; and

the use of this heat for electrical power generation and/or in a process industry requiring a large input of heat.

Conveniently, to achieve a critical chain reaction in which the rate of antineutrino emission (or loss) from the reactor is balanced by the rate of antineutrino production by Mn 56 decay (following neutron creation by atomic hydrogen and neutron capture by the Mn 55 in the steel tubes) the atomic hydrogen may be generated in the central part of a chamber whose walls are lined by an array of manganese steel tubes. These tubes are the equivalent of the nuclear fuel elements commonly used in fission reactors, and their manganese content is gradually depleted by neutron capture events which convert the manganese into iron (Fe 56 produced by the beta decay of Mn 56).

According to another aspect of the present invention, there is provided a plant suitable for the generation of nuclear energy, which plant comprises:—

electrical means for the production of atomic hydrogen;

pumping means for the removal of the molecular hydrogen which is rapidly produced by recombination of hydrogen atoms in three-body collisions;

pumping means for the removal of the heat generated by nascent neutron capture and subsequent Mn 56 decay;

means for using this heat to generate electrical

power; and

control means for initiating and controlling the chain reaction.

According to yet another aspect of the present invention, there is provided a plant comprising:— a set of high voltage direct current electrodes for the electrical production of atomic hydrogen; a set of manganese steel tubes through which a cooling fluid such as carbon dioxide is passed; a pressure vessel in which the electrodes and tubes are mounted; a gas circulating circuit to remove heat continuously and transfer it to a steam boiler; another gas circulating circuit to recycle the hydrogen through the electrode assembly; a bio-shield; a hydrogen compressor; a hydrogen storage vessel; a vacuum pump to remove the air initially present in the reactor and adjacent pipework; and ancillary plant for the initiation and control of the electrical discharge through hydrogen.

For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a vertical section through an embodiment of a nuclear reactor and auxiliary plant;

Figure 2 is a horizontal section through an electrode assembly of the plant;

Figure 3 is a diagrammatic representation of the various nuclear processes involved in the chain reaction.

Referring firstly to Figure 1 of the accompanying drawings, this shows diagrammatically one embodiment of an atomic hydrogen reactor. A reactor core 1 is contained within a pressure vessel 2 which is filled with hydrogen. A positive electrode 3 and a negative electrode 4 are mounted along the vertical axis of the pressure vessel. A substantial number of manganese steel tubes 5 are mounted within the pressure vessel, with their lower ends welded to a lower annular head 6, and their upper ends welded to an upper annular head 7. In the upper part of the pressure vessel, the positive electrode is insulated by an insulating collar 10 from a metal flange 11 which caps the pressure vessel. An uppermost part of electrode 3 is connected at a terminal 12 to a positive electrical supply line or bus bar 13 maintained at a high voltage. The negative electrode 4 is welded directly to the pressure vessel and so is earthed.

Figure 2 shows a horizontal section through the two electrodes. This section is applicable to the central part of the vertical electrode assembly. The two electrodes comprise two separate cylindrical tubes 20 and 21, for example made of tungsten or other high melting point metal. Alternate sectors of both tubes have been removed by machining, so that the wall of the two tubes are received one within another, yielding effectively a longitudinally slotted tube, with alternate segments belonging alternately to tubes 20 and 21, which are insulated from each other by slots 22. Thus, the positive electrode 20 can be maintained at a high positive voltage with respect to the earthed negative electrode 21.

Reverting to Figure 1, the upper part of electrode 3 (which is electrode 20 of Figure 2) is mounted on the axis of a pressure vessel outlet 26 which is connected by pipes 27 and 28 to the inlet of a hydrogen pressurising pump 29, whose outlet is a pipe 30. This pipe 30 is joined to the base of electrode 4 (which is electrode 21 of Figure 2).

The pressure vessel 2 is surrounded by a biological radiation shield 40, typically made of reinforced concrete, whose function is to reduce by a very large factor the nuclear radiations emanating from the pressure vessel. These are mostly beta particles, nascent neutrons and gamma rays.

A pipe 41 connects upper annular header 7 to the upper part of a heat exchanger 42, the lower part of which is connected by a pipe 43 to the inlet of a carbon dioxide gas circulating pump 44. The outlet of pump 44 is connected by a pipe 45 to the lower annular header 6. Heat exchanger 42 contains a large number of heat exchanger tubes 46 which are welded to an upper header 47 and a lower header 48. Header 48 is connected to an inlet pipe 49, and header 47 to an outlet pipe 50. Heat exchanger 42 also carries a valve 51 which can be connected to a vacuum pump (not shown) for initial evacuation of a carbon dioxide circuit, and a valve 52, which can be connected to an external supply of compressed carbon dioxide.

Within pipe 27 there is mounted a heat exchange 60 whose inlet is connected by a pipe 61 to the carbon dioxide circulating pump 44, and whose outlet is connected by a pipe 62 to pipe 41. Pipe 28 is connected to a hydrogen storage vessel 65 by a pipe 66 and a valve 67. Pipe 28 is also connected to vessel 65 by a pipe 68, a valve 69, a compressor 70 and a valve 71. Vessel 65 can be evacuated through a pipe 80, a valve 81 and a vacuum pump 82, which vents to the atmosphere. A valve 83 can be connected to an external supply of compressed hydrogen.

The operation of the atomic hydrogen reactor will now be described. The plant must be initially evacuated to remove all air, using vacuum pumps 82 to pump out pressure vessel 2, storage vessel 65 and all connecting pipes and spaces via valve 81, which is then closed. The carbon dioxide circuit must also be evacuated via valve 51, using another vacuum pump (not shown). Valve 51 is then closed, and valve 52 is connected to an external supply of carbon dioxide to pressurise the carbon dioxide circuit. The hydrogen circuit is pressurised via valve 83, which is connected to an external supply of compressed hydrogen. At the end of these operations valves 52 and 83 are then closed.

Next the hydrogen pressurising pump 29 and the carbon dioxide circulating pump 44 are switched on, and water is passed through heat exchanger tubes 46. A high direct current voltage is next applied across electrodes 3 and 4 in the central part of the pressure vessel. The hydrogen

flowing through the longitudinal slots 22 between electrodes 3 and 4 (which are electrodes 20 and 21 in Figure 2) is then exposed to a high voltage electric discharge which raises its temperature to around 4000°K, producing about 25% dissociation of molecular hydrogen to atomic hydrogen. In spite of this elevated temperature, surrounding metal surfaces are not excessively heated, owing to the continuous removal of heat by the carbon dioxide gas which flows through the manganese steel tubes 5 and annular headers 6 and 7.

For a better understanding of the detailed processes leading to the establishment of an energy liberating chain reaction within the above system, reference will now be made to Figure 3, which shows diagrammatically the various nuclear processes involved in the chain reaction. For simplicity, the proposed plant arrangements may be replaced by an equivalent system consisting simply of an enclosure whose walls are made of manganese, and which is filled by an amount of atomic hydrogen whose column density, or number of atoms per unit area, is sufficient to initiate and sustain a controlled neutron creation chain reaction.

Figure 3 shows a thick-walled vessel 90 made of manganese (Mn 55) and enclosing a cavity 91 filled with atomic hydrogen. Antineutrino trajectories are shown as solid lines, hydrogen atoms as small circles and neutron trajectories as dashed lines. For simplicity, these dashed lines indicates the net displacement of the neutron between creation and capture, without showing the intermedidate zig-zags due to neutron scattering events. The diagram shows the sequence of events initiated by an externally supplied antineutrino A0, which passes through the manganese and atomic hydrogen, and interacts with hydrogen atom H1 before leaving the vessel. The created neutron n1 is captured at M1 by an Mn 55 nucleus which is converted to Mn 56 with gamma ray emission (not shown). This Mn 56 nucleus ultimately decays by emission of an antineutrino A1 and a beta particle (not shown). A1 creates neutrons n2 and n3 by interaction with hydrogen atoms H2 and H3. Neutron n2 is captured by manganese atom M2, but the subsequently emitted antineutrino A2 fails to pass through the atomic hydrogen and creates no neutrons. However, n3 is captured at M3 and the antineutrino from M3 creates three more neutrons at H4, H5 and H6. For clarity, these extra neutrons are not shown, but the chain reaction is already leading to a growing production of neutrons and antineutrinos. Energy is liberated primarily by gamma ray emission from neutron capture, and to a lesser extent by beta decay. For 47% of Mn 56 nuclei, the maximum energy of the beta particles is 2.84 Mev, and this is also the end point of the antineutrino energy spectrum. For the other 53% of Mn 56 nuclei, a substantial part of the excess energy is emitted as gamma radiation, and the end point of the antineutrino energy spectrum is correspondingly reduced.

Reverting to Figure 1, the supercritical amount of atomic hydrogen produced initially in reactor core 1 leads to an increasing rate of neutron creation. Most of these neutrons are captured by the manganese in tubes 5, and the heat of neutron capture and beta decay generated within these tubes is removed by the carbon dioxide which is circulated by pump 44. This travels along pipe 45, and after passing through annular header 6, moves upwards through tubes 5 and header 7 to heat exchanger 42, where the heat removed by the carbon dioxide is used to convert pressurised feed water entering the heat exchanger at 49 into high pressure, high temperature steam. This steam is generated inside tubes 46 and flows out from the upper header 47 through outlet pipe 50, which feeds a conventional turbo-alternator set for electric power generation, the condensed steam being returned by a boiler feed pump to inlet pipe 49.

The atomic hydrogen produced in reactor core 1 tends to recombine to molecular hydrogen by three-body interactions. To maintain a fairly high proportion of atomic hydrogen in reactor core 1, the hydrogen is driven in a closed loop by the hydrogen pressurising pump 29. On leaving the reactor core, the atomic hydrogen recombines in pipe 27, where it is cooled by heat exchanger 60. Molecular hydrogen is then recycled via pipe 28, pump 29 and pipe 30 through the slots between electrodes 3 and 4, where it is again converted to atomic hydrogen by the high voltage electric discharge.

Circulating carbon dioxide pump 44 transfers a fraction of its output of cooled gas to heat exchanger 60 via pipe 61, and the heat of recombination of atomic hydrogen evolved in pipe 27 is removed by the circulating carbon dioxide which is then transferred to heat exchanger 42 via pipes 62 and 41.

Although under starting conditions the atomic hydrogen concentration is held at a sufficiently high level to achieve a substantial degree of supercriticality, several days are required for the power generation to reach its design level, due to the relatively long half-life of Mn 56 (2.576 hours). As this level is approached, the concentration of atomic hydrogen is gradually reduced until the system is just critical. This may be achieved either by reducing the voltage applied across electrodes 3 and 4, or by reducing the hydrogen pressure, by opening valve 69 and using pump 70 to transfer some of the hydrogen from the reactor core 1 to the hydrogen storage vessel 65.

Adjustments in power level during protracted periods of operation can be similarly effected. It is impossible for the chain reaction to produce rapid and potentially explosive power excursions, as the rate of growth of neutron and antineutrino fluxes is limited by the long half-life of Mn 56. Sudden termination of the chain reaction may be achieved by switching off the electrical power supply to electrodes 3 and 4, but it is necessary to continue to remove heat through the sustained operation of the carbon dioxide coolant circuit, as the rate of

heat emission due to the beta decay of the Mn 56 only declines slowly.

Over a period of 20 to 30 years of power generation, a substantial fraction of the manganese in tubes 5 is converted into iron, and the life of the plant is then at an end. Little Mn 56 radioactivity persists after a few days, but parasitic neutron capture by other structural materials may lead to the formation of small quantities of longer-lived radioactive substances.

EXAMPLE

It is estimated that the available energy due to neutron capture by Mn 55, followed by beta decay of Mn 56 to Fe 56, will be about 9 Mev or 1.44×10^{-5} erg. Since the mass of an Mn 55 atom is 9.2×10^{-23} gm, the thermal energy obtained per gram of Mn 55 used up is

$$(1.44 \times 10^{-5}) / (9.2 \times 10^{-23}) = 1.565 \times 10^{17} \text{ erg g}^{-1} = 3.74 \times 10^{9} \text{ cal g}^{-1}$$

As the calorific value of coal is 8000 cal g^{-1} the total conversion of one tonne of Mn 55 to Fe 56 yield an energy equivalent to about 470000 tonnes of coal. However, if manganese steel is used, an appreciable amount of energy will also be liberated by neutron capture in iron, so that one tonne of manganese will yield altogether the energy of 600000 tonnes of coal. Assuming the reactor becomes unusable through radiation damage after one third of the manganese has been used up, it is anticipated that the energy output practically obtainable from one tonne of manganese will be equivalent to 200000 tonnes of coal.

A power station with a maximum net electrical output of 2000 MW and a mean load factor of 60% over a life of 8×10^8 seconds (about 25 years) generates 2×10^{16} erg $5^{-1} \times 0.6 \times 8 \times 10^8$ s $= 9.6 \times 10^{24}$ erg. If the net plant efficiency is 30%, the required thermal output is $(100/30) \times 9.6 \times 10^{24} = 3.2 \times 10^{25}$ erg, roughly equivalent to the combustion of 100 million tonnes of coal. Thus, the reactor must contain 500 tonnes of manganese, and the mass of manganese steel needed could be 2500 tonnes and occupy a volume of some 300 m^3. This would be compatible with a pressure vessel of volume 1000 m^3 and linear dimensions 10 m. These dimensions would allow the removal of heat at the maximum required rate of 7000—8000 MW, using pressurised carbon dioxide as the circulating cooling gas.

In such a reactor, the diameter D of the atomic hydrogen region would be about 5 metres. A rough criterion for criticality is $n_H \sigma_n D = 1$ where n_H is the number of neutral H atoms per unit volume, and σ_n the mean effective neutron creation cross-section of the neutral H atom for antineutrinos whose energy spectrum ranges from E = 0 to E = 2.84 Mev. For antineutrinos from free neutron decay, whose maximum energy is 0.783 Mev, σ_n is estimated from theory to be 30 barns. If, as seems likely, the value of σ_n increases at least as fast as E^3, then for Mn 56 antineutrinos, σ_n 3×10^{-23} cm^2 $\times$ $(2.84/0.783)^3 \times 0.47 = 7 \times 10^{-22}$ cm^2 since only 47% of Mn 56 decays are accompanied by the emission of a high energy antineutrino. Hence $n_H = 1/\sigma_n D = 2.8 \times 10^{18}$ H atoms cm^{-3}.

If the electrical discharge is adequate to maintain the hydrogen at a temperature of 4000°K and produces 25% thermal dissociation of the initial molecular hydrogen, then an initial 100 molecules of H_2 yield 75 H_2 molecules and 50 H atoms. There are thus produced 125 particles, and the 50 H atoms represent 40% of the new population. Hence the total number density or concentration of H + H_2 is $n = n_H 0.4 = 7 \times 10^{18}$ cm^{-3} and the gas pressure $p = nkT$ where k is the Boltzmann constant (1.38×10^{-16} erg $^0K^{-1}$). Thus $p = 7 \times 10^{18} \times 1.38 \times 10^{-16} \times 4000 = 3.86 \times 10^6$ dyne cm^{-2} = 3.8 atmospheres.

Such a pressure is consistent with the assumed 25% dissociation at 4000°K and is practically not excessive in relation to the size of the pressure vessel.

The electrical power consumption needed to sustain these conditions is approximately that required to compensate for energy losses from the atomic hydrogen reactor core by heat conduction, convection and radiation. It is expected that at these elevated temperatures radiation losses will be the most important. A very rough estimate of the gas luminosity L will be derived, using $L = A\varepsilon\sigma T^4$ where L is the radiation rate of energy loss, A the surface area, ε the emissivity of the gas, T its absolute temperature, and σ is the Stefan-Boltzmann constant (5.67×10^{-5} erg cm^{-2} s^{-1} $^0K^{-4}$). The emissivity of the gas is influenced by the presence of dust and free electrons and so is somewhat uncertain, but is unlikely to exceed 0.05. Considering a cylindrical reactor core region of diameter 5 m and height 10 m, its total surface area is about 200 m^2, or $A = 2 \times 10^6$ cm^2. Hence the luminosity $L = A\varepsilon\sigma T^4 = 2 \times 10^6 \times 0.05 \times 5.67 \times 10^{-5} (4000)^4 = 1.45 \times 10^{15}$ erg s^{-1} or 145 MW. This power requirement is only 7% of the electrical output at full load. However, it is independent of the electrical power output of the plant and for economic operation this should not be less than say 500 MW for the installation considered in this example.

As the ratio of power output to power input is insensitive to plant dimensions, atomic hydrogen reactors of substantially smaller or larger dimensions are technically realisable. For a given plant size, the power output may, if necessary, be increased by using more effective coolants, such as pressurised water or a liquid metal, in place of carbon dioxide. This would improve the ratio of power output to power input if desired.

For pilot plant investigations, the linear dimensions could be reduced by a factor 20. As both the power input and output vary approximately as the square of linear dimensions, both would be reduced by similar factors of order 400. Thus a pressure vessel of internal diameter 50 cm would be necessary to generate 5000 kW, while the electrical power input would be, to a first

approximation, 360 kW. To sustain criticality, the hydrogen pressure would need to be raised from 3.8 to 76 atmospheres. To compensate for the reduced degree of dissociation of hydrogen at higher pressure, the attainment of criticality might require raising the gas temperature to 5000°K, and the electrical power input to 1000 kW. Such a small plant would be ideal for test purposes, though too small to compete commercially with similar but larger plant.

Although it has been convenient to describe a reactor using manganese 55 as the neutron capturing medium, there are a number of other elements which could be used instead. In particular aluminium is even more abundant than manganese, yields an antineutrino of very similar mean energy, and its half-life (2.27 minutes) is more convenient than that of manganese. However, the neutron capture cross-section of aluminium is much smaller, and more importantly the metal has a relatively low melting point. Other elements of potential interest include vanadium and boron 11. Vanadium has a convenient half-life and melting point, while the sole merit of boron 11 is that the B12 formed by neutron capture emits an antineutrino of exceptional energy (Emax = 13 Mev).

The production of a sufficient amount of atomic hydrogen, and the dependable removal of heat by a cooling fluid, are the main technical problems presented by an atomic hydrogen reactor. The main advantages of this type of reactor, in relation to fission reactors, are the following:—

(1) Manganese, aluminium and vanadium are much more abundant and much cheaper than uranium.

(2) No isotope separation process is needed, except in the case of boron 11.

(3) No fuel reprocessing and no breeding of nuclear fuel is needed.

(4) The ease of control of the chain reaction secures greater safety, obviates the need for control rods, and results in a plant of much cheaper construction, in which no provision need be made for nuclear refuelling.

(5) The construction time should be correspondingly reduced.

(6) At the end of the plant life, the low residual radioactivity arises solely from parasitic neutron capture by secondary structural materials.

(7) No nuclear weapon materials are involved.

CLAIMS

1. A method of generating heat in an atomic hydrogen reactor, which method comprises:—

producing atomic hydrogen by an electrical discharge;

capturing nascent neutrons from the atomic hydrogen in means comprising a material which thereby undergoes beta decay to yield anti-neutrinos;

irradiating the atomic hydrogen by the antineutrinos to yield further nascent neutrons;

removing heat generated by the capture of nascent neutrons by the said means and by the said beta decay; and

using this heat.

2. An atomic hydrogen reactor comprising:—

first means, for producing atomic hydrogen by an electrical discharge;

second means, for capturing nascent neutrons from the atomic hydrogen, the second means comprising a material which thereby undergoes beta decay to yield antineutrinos, the reactor being such that, in use, the atomic hydrogen is irradiated by the antineutrinos to yield further nascent neutrons; and

third means, for removing and using heat generated by the capture of nascent neutrons by the said second means and by the said beta decay.

3. A method of generating heat in an atomic hydrogen reactor, which method comprises:—

the production of atomic hydrogen by an electrical discharge;

the capture of nascent neutrons from atomic hydrogen in a number of surrounding steel alloy tubes having a high manganese content, to yield radioactive manganese 56 (Mn 56);

the irradiation of atomic hydrogen by the high energy antineutrinos from the beta decay of Mn 56, to yield nascent neutrons;

the removal of heat generated by the capture of nascent neutrons by the Mn 55 and by the beta decay of Mn 56, using a circulatig cooling fluid flowing through the steel tubes; and

the use of this heat for electrical power generation and/or in a process industry requiring a large input of heat.

4. A method according to claim 3, wherein, to achieve a critical chain reaction in which the rate of antineutrino emission (or loss) from the reactor is balanced by the ratio of antineutrino production by Mn 56 decay (following neutron creation by atomic hydrogen and neutron capture by the Mn 55 in the steel tubes) the atomic hydrogen is generated in the central part of a chamber whose walls are lined by an array of manganese steel tubes.

5. A plant suitable for the generation of nuclear energy, which plant comprises:—

electrical means for the production of atomic hydrogen;

pumping means for the removal of the molecular hydrogen which is rapidly produced by recombination of hydrogen atoms in three-body collisions;

pumping means for the removal of the heat generated by nascent neutron capture and subsequent Mn 56 decay;

means for using this heat to generate electrical power; and

control means for initiating and controlling the chain reaction.

6. A plant comprising: a set of high voltage direct current electrodes for the electrical production of atomic hydrogen; a set of manganese steel tubes through which a cooling fluid is passed; a pressure vessel in which the electrodes and tubes are mounted; a gas circulating circuit to remove heat continuously and

transfer it to a steam boiler; another gas circulating circuit to recycle the hydrogen through the electrode assembly; a bio-shield; a hydrogen compressor; a hydrogen storage vessel; a vacuum pump to remove the air initially present in the reactor and adjacent pipework; and ancillary plant for the initiation and control of the electrical discharge through hydrogen.

7. A method of generating heating in an atomic hydrogen reactor, substantially as herein described with reference to the accompanying drawings.

8. An atomic hydrogen reactor, substantially as herein described with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1982. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.