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EUROPEAN SPACE AGENCY FUEL CELL ACTIVITIES

F. BARON*

European Space Agency, Postbus 299 2200 AG, Noordwiek (The Netherlands)

Hermes activity

At the Ministerial conference in the Hague in November 1987, the development of the Hermes winged-space vehicle solution was endorsed and the first step of the development programme was approved.

This paper describes the progress status concerning the Hermes fuel cell development programme (HFCP).

Two fuel cell power plants represent the main power sources for Hermes which will consume an average of about 4.6 kW and an energy around 1220 kW h for a twelve day mission (including safety margin). Figure 1 shows a schematic of the power architecture.

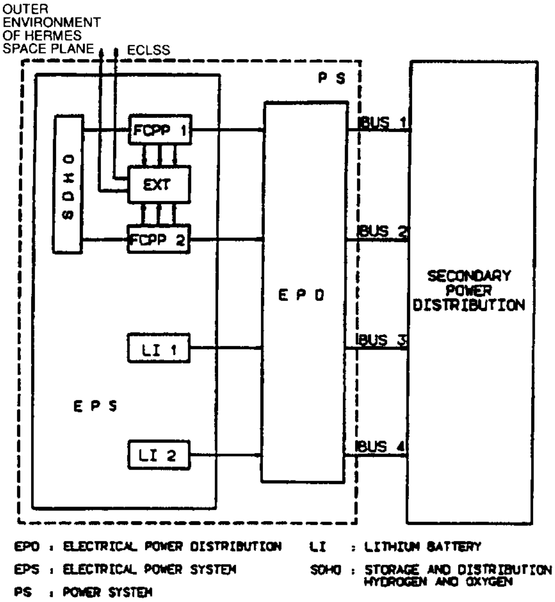

Fig. 1. Present architecture of the Hermes power system.

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*Present address: ESA Toulouse, HERMES Engineering Division, 18 Avenue Edouard-Belin, 31055 Toulouse Cédex, France.

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TABLE 1

Main HFCP requirements

Power	2 - 6.5 kW
Voltage	75 - 115 V d.c.
Power/weight ratio	50 W/kg
Power/volume ratio	40 W/l
Water production at 4 kW	1.545 kg/h
Accumulated operation time	4000 h
Accumulated storage time	26000 h

The main present Hermes requirements are summarised in Table 1.

Under ESA funding, an industrial team led by Dornier, under direct supervision of Aerospatiale (prime contractor of the spaceplane) is performing the development task. Up till now, no European company has experience of fuel cells for space applications. Therefore, and because European experience in the field of fuel cells was gained in an alkaline medium, several different technologies based on an alkaline electrolyte and which can meet in principle the Hermes requirements, have been evaluated during a selection phase performed by Dornier in 1988.

The Hermes fuel cell power plant (HFCP) consists mainly of seven sections as follows.

- Stack
- Water separation device
- Cooling components
- Gas management elements
- Product water management
- Controller
- Harness, structure and containment

Although all the HFCP components are important, it was decided to concentrate efforts on the stack and the main peripheral components in a first step. Following a formal selection procedure prepared by Dornier and based on analytical and testing investigations and analysis, four basic fuel cell configurations have been evaluated.

Three companies have been pre-selected as potential suppliers and have been requested to demonstrate the maturity of their own technology and state-of-the-art. Elenco (B) for recirculation technology, Siemens (D) for recirculation and static technologies and Varta (D) for recirculation and static technologies.

The following summarises the features of the different technologies:

- Recirculation system (1). The circulating electrolyte (KOH) moves through the stack and is used to remove both the product water and the heat dissipated by the stack. A schematic of this configuration is described, see Fig. 2.

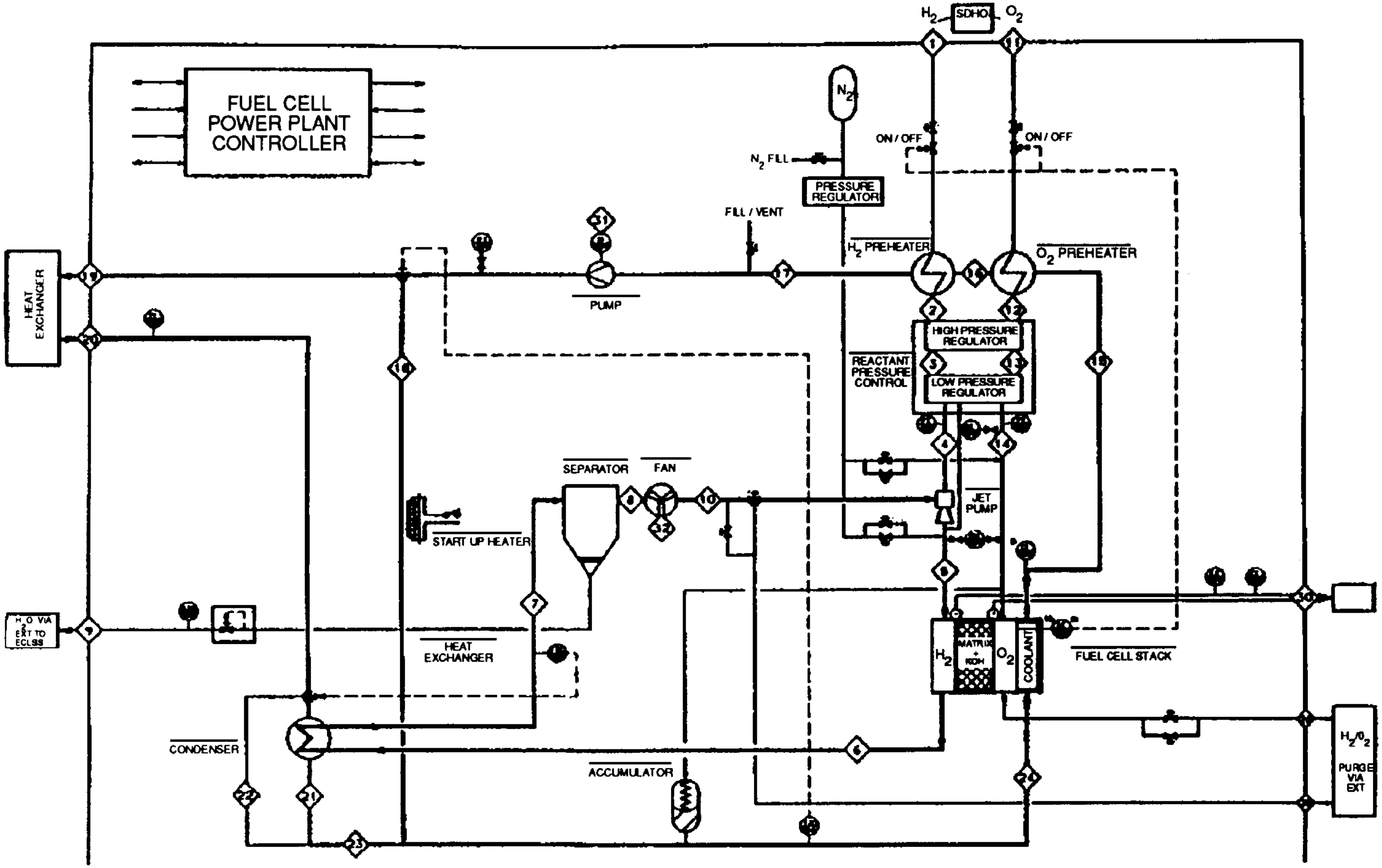

Fig. 2. Flow scheme of the recirculation system (1).

- Recirculation system (2). An alternative to the previous configuration where product water is now removed via the hydrogen gas loop, see Fig. 3.
- Static system. The electrolyte is retained in a matrix whereas a separate cooling loop removes the heat and the hydrogen loop removes the product water of the reaction as shown in Fig. 4.
- Static Eloflux system. The KOH is trapped inside the stack and an isotonic fluid cycle permits water removal and is used as cooling fluid (see (Fig. 5).

Several trade-offs related to the choice of sub-assembly dealing with the control of the HFCP (*e.g.* water management, gas management, thermal management) had to be investigated (still in progress) in order to optimise the scenarios/solutions with respect to the fulfilment of the Hermes requirements and the functionality of the overall power source. As a consequence, evaluation of non-electrochemical components has also been carried out with tests on ancillaries such as:

- Gas trap
- Jet pump, KOH pump
- Liquid/gas separator (hydrophilic membrane and cyclone)
- KOH regenerator
- Bubble separator (gas/liquid separation device)

All data collected from the different elements/components tested at Dornier (electrodes, stacks, peripherals/ancillaries) have formed the main input for the performance and functional engineering analysis of the system selection phase. With the help of a mathematical simulation model called SANFU, the modelling of system behaviour with respect to controlling aspect, evaluation of the operational functions, calculation of the overall performance data have been possible as well as the preliminary detection of critical areas.

Besides the ‘raw technical data’, other criteria have been taken into account for the selection. Table 2 describes the weighting factors which have been applied.

The compilation of the different results with the application of the criteria as listed in Table 2, showed that the static KOH system based on the Siemens technology was most advanced. After a critical analysis of weak points and safety aspects, it appeared that the static KOH technology proposed by Siemens has the best characteristics and presents the best growth potential regarding the space conditions/applications. Therefore, Dornier has recommended the development of this technology, a decision which has been supported by Aerospatiale. The customers (CNES and ESA) have requested Dornier to propose and form a strong and competent industrial team able to perform the next development phases.

At the time of writing this paper, important progress has been achieved and the necessary authorisations to proceed to the C1B phase should be given very soon.

The basic flow scheme configuration of the static KOH system is shown in Fig. 6 and the main functions can be summarised as follows.

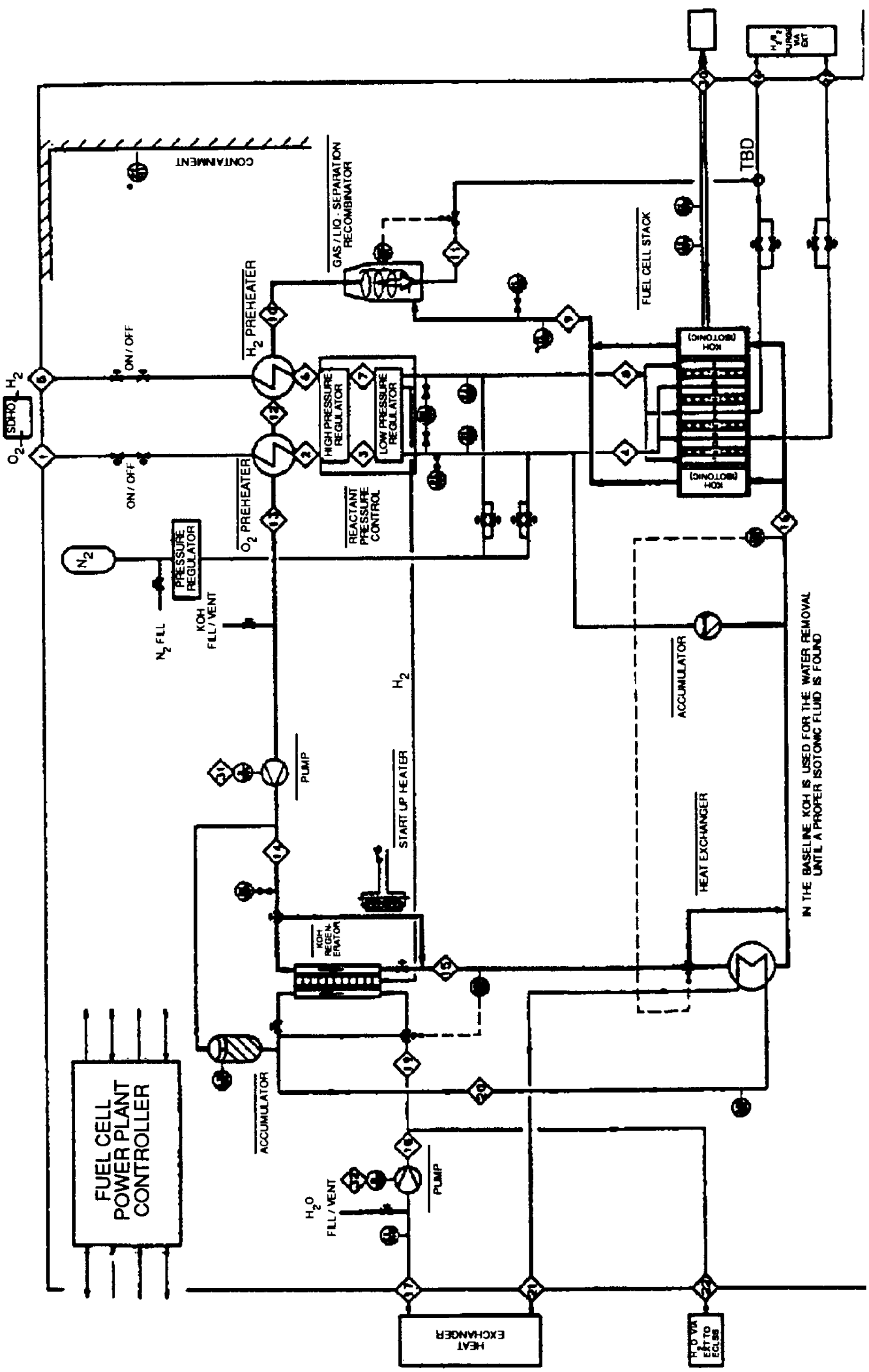

Fig. 3. Flow scheme of the recirculation system (2).

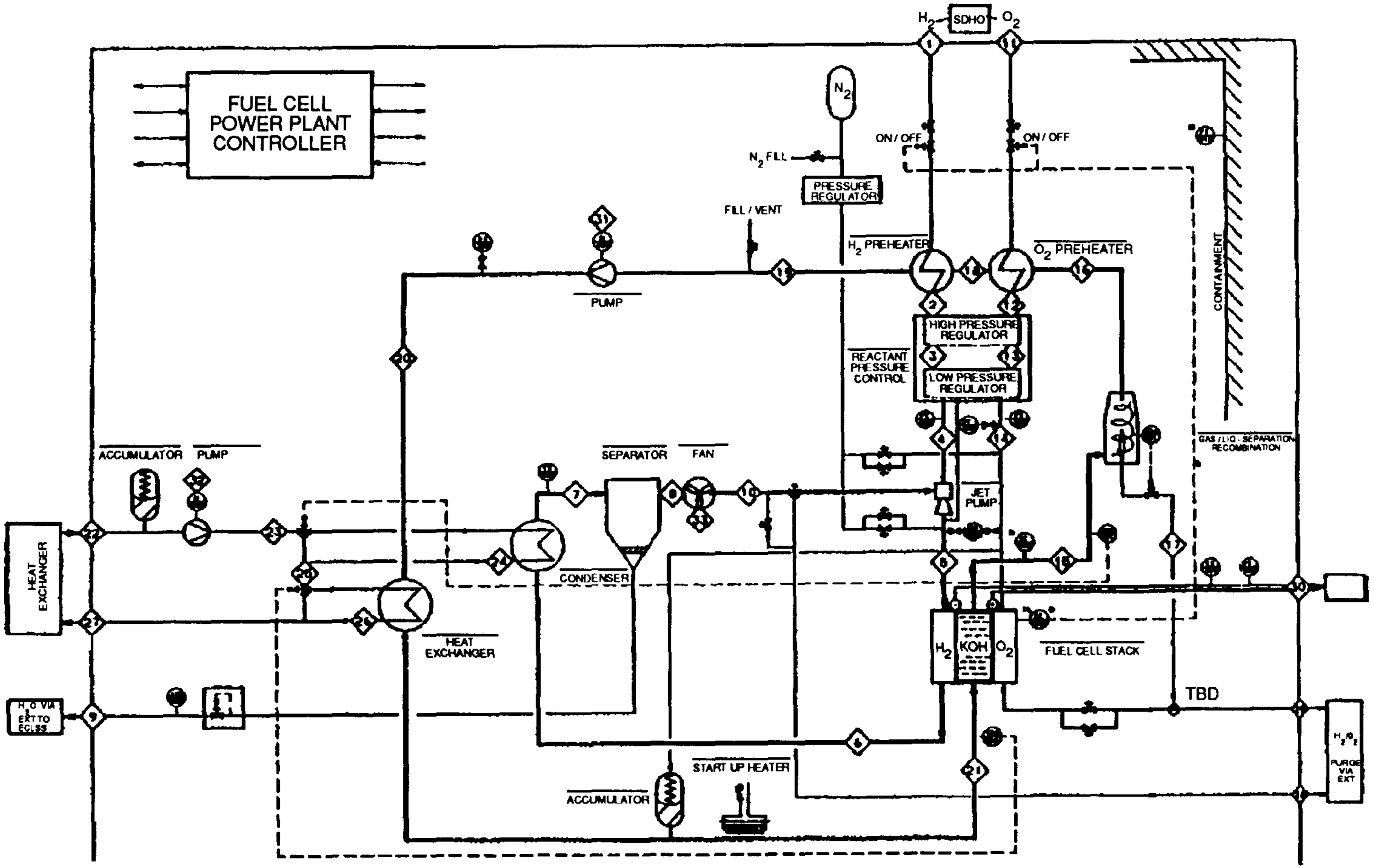

Fig. 4. Flow scheme of the atatic system.

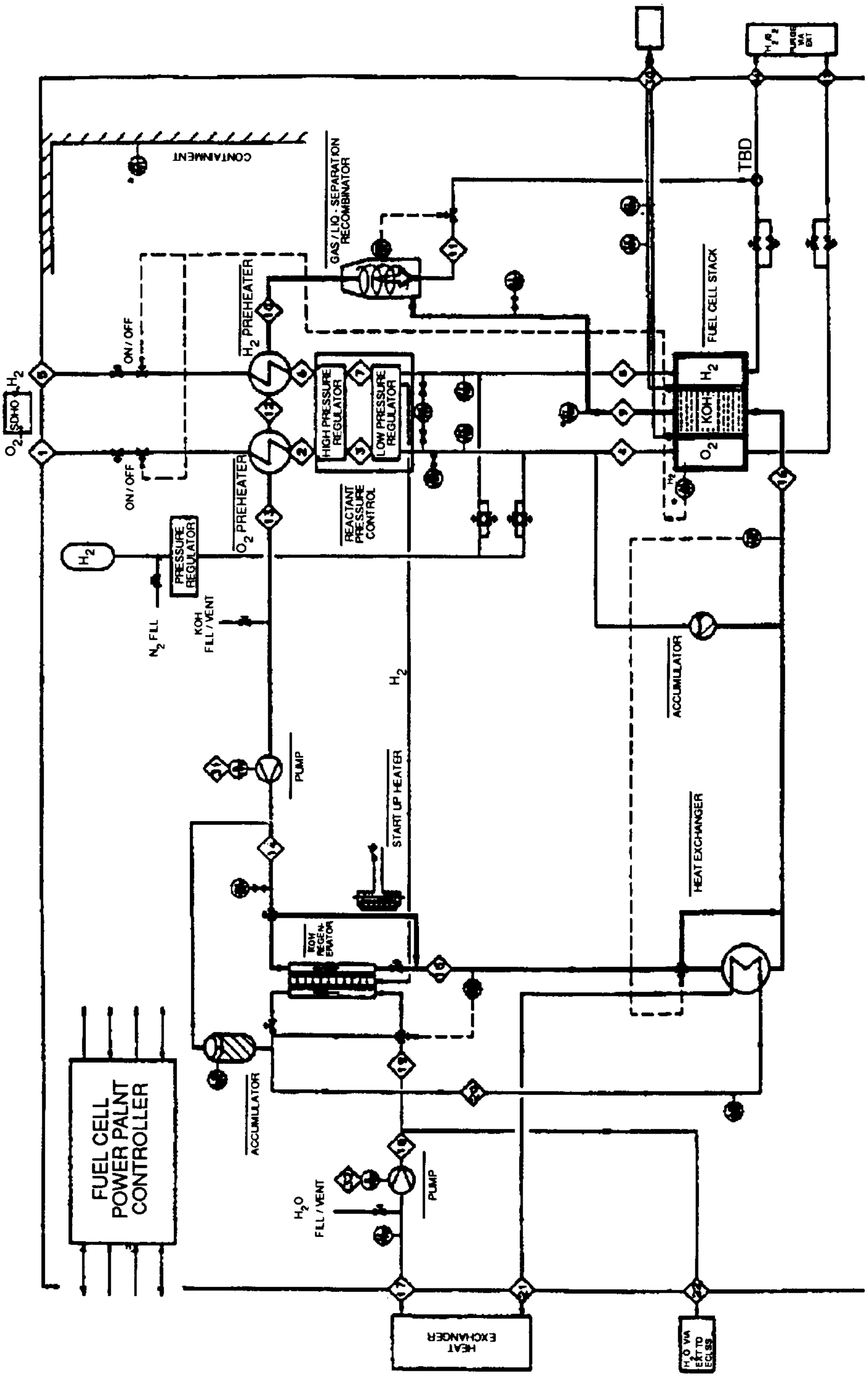

Fig. 5. Flow scheme of the static Eloflux system with isotonic fluid cycle.

TABLE 2

Selection criteria (%) with weighting factors

Safety	17
Performance	17
Reliability	15
Operational behaviour	15
Technological experience (including development risk)	10
Mass	10
Volume	7
European state-of-the-art	5
Cost	4

- The reactants coming from the gas distribution system (SDHO) are pre-heated above 0 °C and the pressure reduced from 65 (maximum) to 10 bar in a high pressure regulator device. Then, a low pressure regulator component finally reduces the reactant pressure in accordance with requirements and follows the pressure demand difference which is required for an optimum operation of the fuel cell stack.
- The hydrogen gas is transported with the help of a jet pump with an optional support of a fan in order to overcome the pressure drop across the peripherals where hydrogen is circulated. A significant excess of hydrogen is necessary to remove the product water. Humidified gas passes through a liquid/gas separator (either a membrane separator where water vapour diffuses or a pump separator combined with a condenser) where water is directed towards the product water management sub-equipment and the controlled and partially dried hydrogen is 're-injected' inside the H_2 compartments of the stack.
- A coolant fluid (*e.g.* water) is heated up when circulating inside the stack and is used to warm-up the reactants (with the pre-heaters) coming from the SDHO. Then a heat exchanger connected to the TCS (thermal control system) removes most of the heat dissipated by the fuel cell stack.
- A local controller will be in charge of all the functions of the fuel cells components: acquisition of data, sequence control and safety aspects. A multitude of sensors and actuators will be managed by the controller.

During phase C1B (ending in December 1990), the industrial development team led by Dornier and formed by Dornier, Siemens, Elenco and Drager is being requested to demonstrate the feasibility of the selected technology and to solve the main problems which are expected so far.

Considering the criticality of the fuel cells for space application, in particular for the limited time schedule of Hermes, it has been decided as a first priority that a full scale breadboard will be built and tested in order to perform a functional demonstration of the overall HFCP.

The main objectives being to have the first flight models (fully certified for the Hermes application) beginning of 1997, several development models

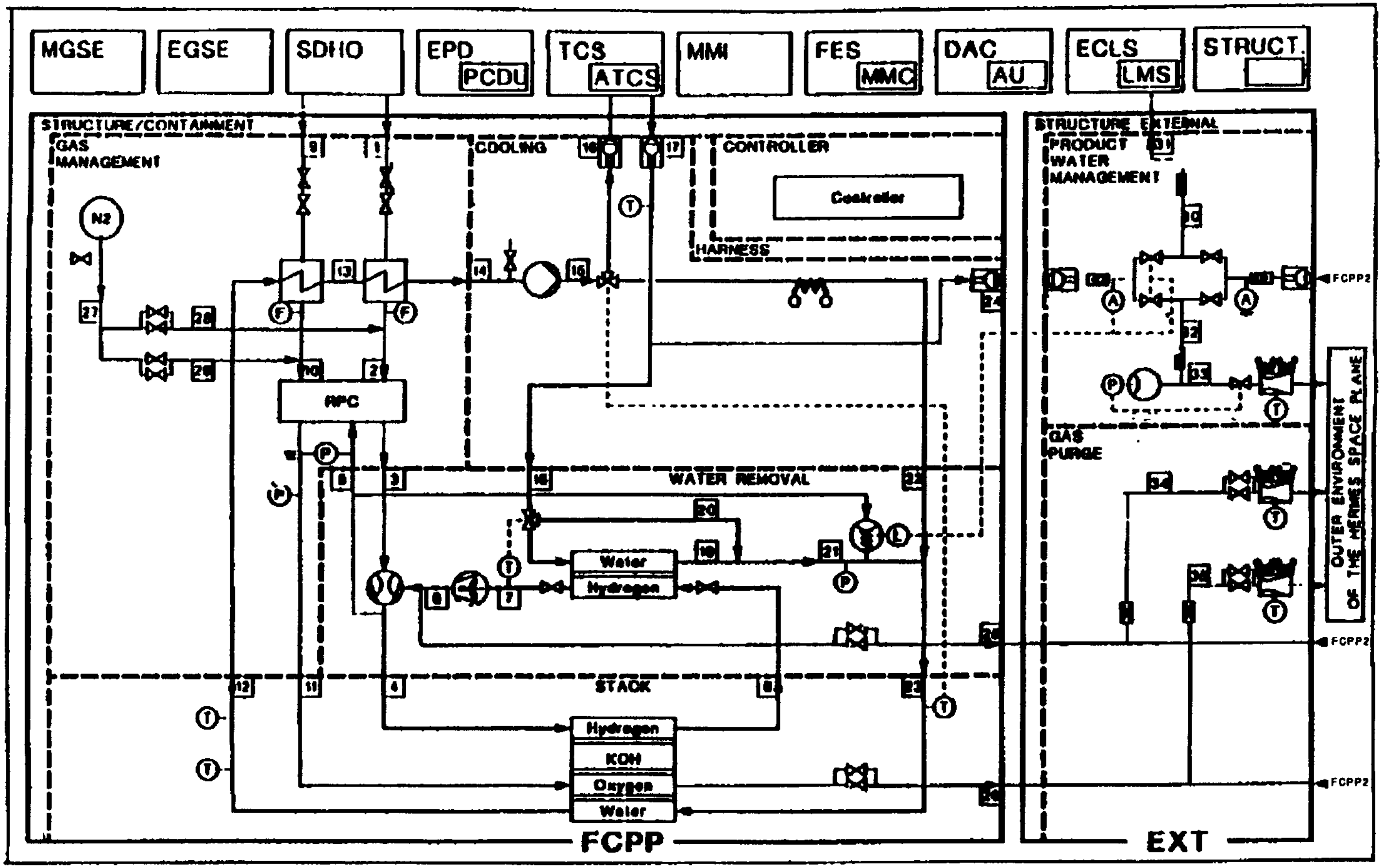

Fig. 6. Flow scheme of the technical baseline configuration of static KOH system.

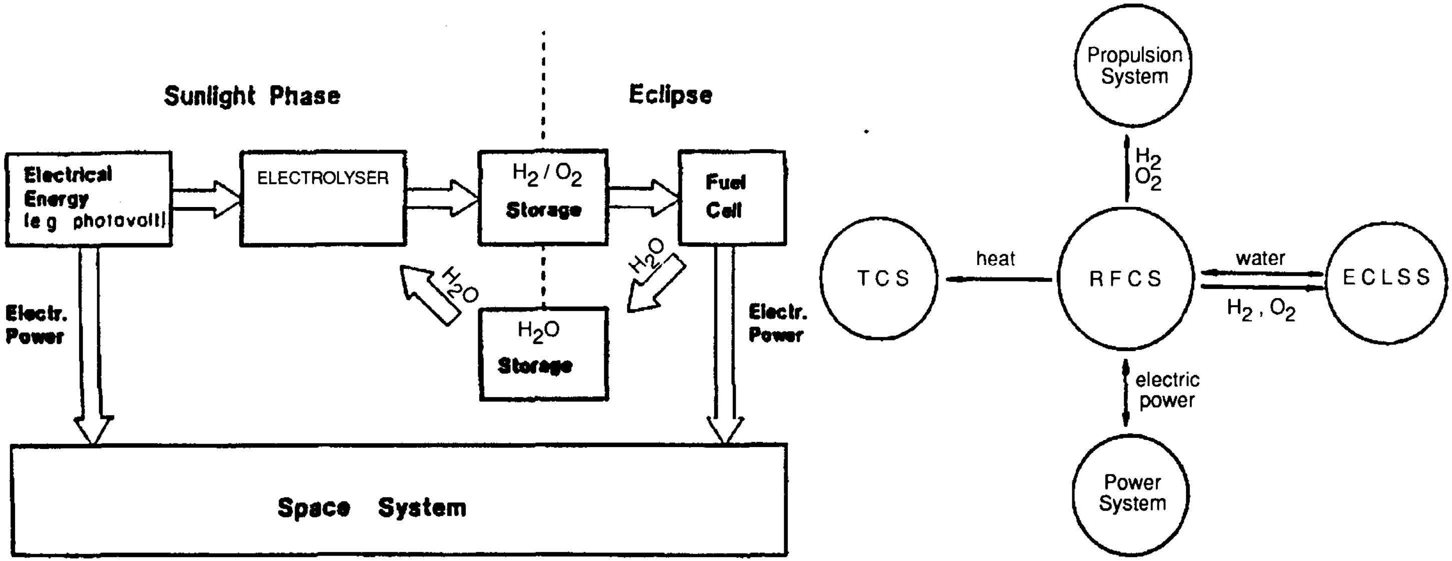

Fig. 7. Cyclic process of the RFCS and potential interfaces with other space systems.

TABLE 3

RFCS targets

Mean power	20 kW
Voltage level	120 V d.c.
Mission duration	5 years (30000 cycles)
Orbital replacement unit concept	
Reactant storage	30 bar (gas)
Overall mass	330 kg
Energy density	36 W h/kg

(engineering models and qualification models) will be tested within the C2/D phases.

RFCS activities

Since 1985, under the technology and research programme (TRP), ESA is funding preparatory activities related to the development of the RFCS as alternative to the conventional batteries (nickel–cadmium or nickel–hydrogen) commonly used as energy storage in combination with solar generators for European spacecraft and platforms. At power levels above 10 kW, the RFCS becomes attractive and lighter than other systems. Electrical power is provided by solar array during the sunlight phase to the electrolyser unit which regenerates from water, the hydrogen and oxygen reactants. These gas reactants are stored and supplied to the fuel cell which produces energy and water to the spacecraft during the eclipse phase.

The RFCS which works on a cyclic process mode could be combined with other space systems such as ECLS (where oxygen in excess can be provided to the life support, and hydrogen for the CO_2 reduction or propulsion system (supply of hydrogen and oxygen)). Figure 7 shows the operating principles of the RECS and its potential multi-functions with other space systems.

Two study phases have already been awarded to Dornier in order to review the feasibility of developing a European RFCS for space application, a third TRP phase is under negotiation (mid-1989 until end of 1991).

Although no short-term project has foreseen the use of RFCS, medium and long term ESA programmes for large low earth orbit platforms such as COLOMBUS-AOC (autonomous operational concept) are among the potential users. As a consequence, it is proposed to proceed later with the development of a 'breadboard' under project funding namely the European Manned Space Infrastructure (EMSI) budget.

Table 3 summarises the main requirements/targets of the RFCS.

During the first phase, four configurations were pre-selected.

- Static alkaline (KOH) electrolyte system

- Mixed system with KOH static fuel cell and PEM electrolyser
- Proton exchange membrane (PEM) system
- Recirculating alkaline (KOH) electrolyte system

During these two phases, a serious effort has been devoted to the study of alkaline and PEM potential electrolysers with European companies (CJBD (U.K.), Hydrogen System (Belgium), CGE (France)). Other tasks on main peripheral components such as the pumps, the gas and water storage tanks, the two-phase (G/L and L/G) separators have provided analytical data which have been used for system comparison with the help of a mathematical simulation model called SAREF.

A global comparison of the characteristics (performances, round trip efficiency etc.) has been performed by Dornier and its subcontractors during phase 2. Figures 8 to 11 summarize the results.

A review of advantages and disadvantages at system level of the different technologies/configurations has shown that the static KOH system and

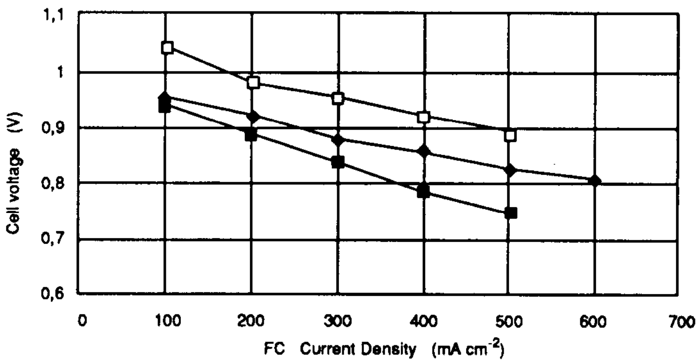

Fig. 8. Comparison of fuel cell system efficiencies, including thermal and current efficiency and auxiliary power demand. ■, Recirculation; □, static; ◆ PEM.

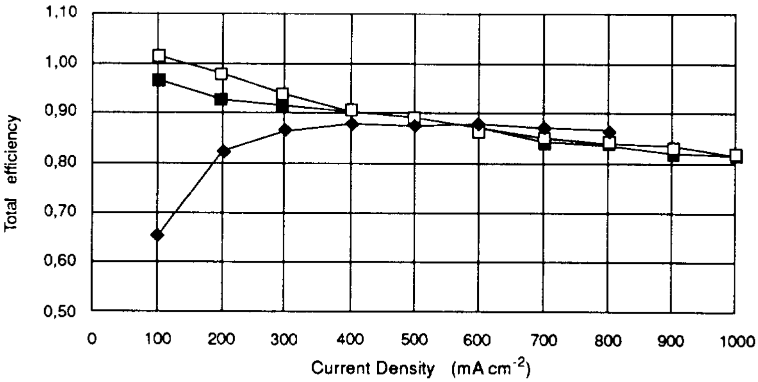

Fig. 9. Comparison of electrolyser system efficiencies, including thermal and current efficiency and auxiliary power. ■, Recirculation; □, static; ◆ PEM.

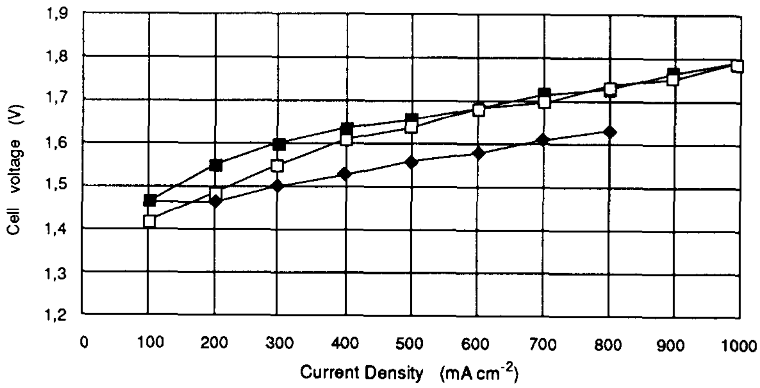

Fig. 10. Comparison of electrolyser performances (80 °C, 30 bar). ■, Recirculation; □, static; ◆, PEM.

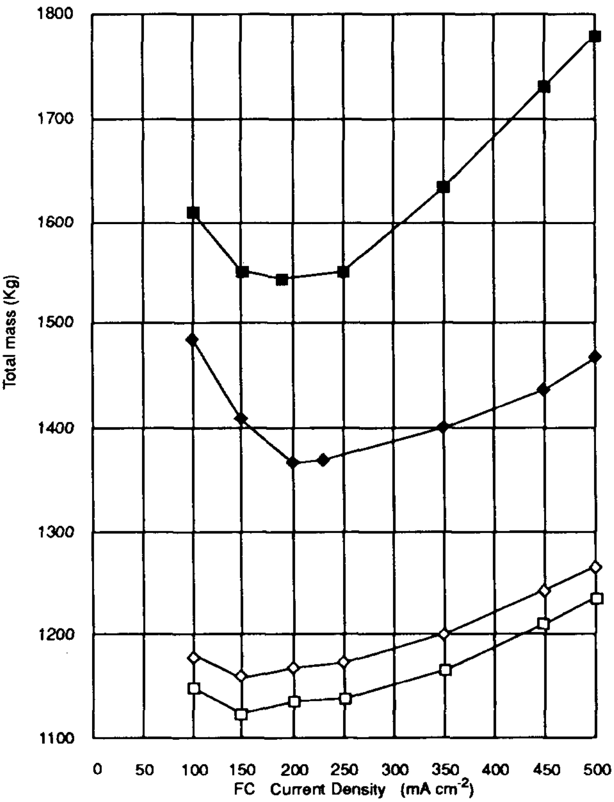

Fig. 11. RFCS mass comparison including solar arrays and radiators, power output 20 kW at 120 V, 0.6 h eclipse, 0.95 h sun. Optimum current densities of the electrolysers: static KOH 310 mA/cm^2, recirculating KOH 480 mA/cm^2, PEM 800 mA/cm^2. ■, Recirculation; □, static; ◆, PEM; ◇, mixture.

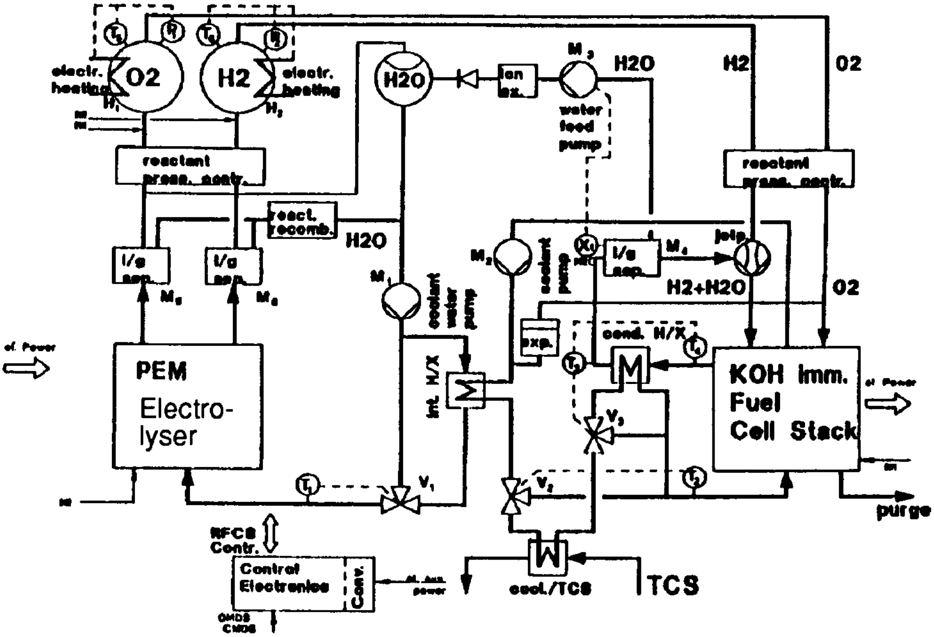

Fig. 12. 'Mixed' RFCS (static KOH fuel cell and PEM electrolyser).

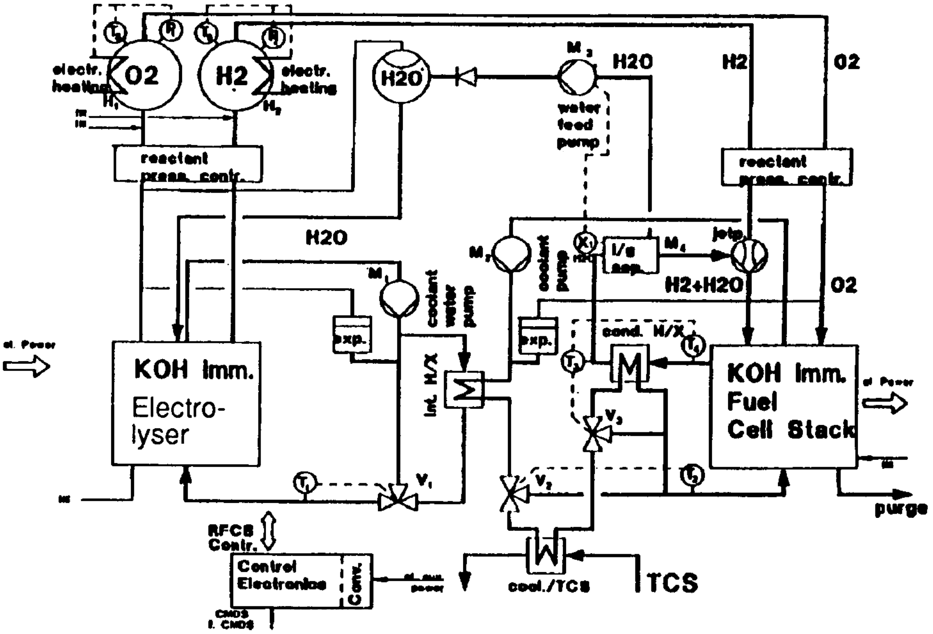

Fig. 13. Static KOH RFCS.

the mixed system stand out as most appropriate at this time for this specific space application.

Figure 12 describes the basic schematic configuration of the 'mixed' RFCS whereas Fig. 13 shows one of the complete static KOH RFCS. The main difference consists in the use of a PEM electrolyser instead of a static KOH electrolyser. The performances of these two different electrolysers are similar, the PEM electrolyser has the advantage at higher current densities (see Fig. 11). Nevertheless the main drawback of the PEM electrolyser is the relatively bad current efficiency due to the gas permeation of the ion exchange membrane at high pressure and temperature (a new membrane under development could minimise this problem).

Another concern which appears most critical for the mixed RFCS is the necessary quality of water produced by a static alkaline fuel cell and used by an acid electrolyser. The use of a cartridge deioniser bed seems mandatory at the present time which means additional maintenance or refurbishment. Furthermore, a water/gas separation is mandatory in the case of the PEM electrolyser with a similar volume of the two phases (not yet developed for working in micro-gravity).

However, European experience/background which pertains to recirculating KOH electrolysers has been abandoned for the RFCS application due to an unacceptable overall mass penalty, system complexity and bad estimated reliability. Only Dornier has begun (one year ago) preliminary laboratory research and development on static KOH electrolysers, whereas superior experience is available with PEM electrolysers used for submarine applications.

As a consequence, although technical preference is given to the static KOH RFCS, some additional activities with laboratory testing of hardware directed to a decision concerning the selection of the electrolyser should be necessary as a first step in the third study phase. Then the second part of this technology phase will be devoted to a detailed system engineering and optimisation of the selected configuration with, in addition, development work on the main components (electrolyser, pressure controller and storage units). A detailed 'breadboard' specification/requirement should complete this phase.

A three year phase of 'breadboarding' (January 1992 - end of 1994) will follow with the development, construction and tests of a complete RFCS at the laboratory level to demonstrate/confirm the feasibility of the RFCS.