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C3Or3D-04: Analysis of a cryogenic refrigerator solution for the ITER Isotope Separation System

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The ITER project aims to build a fusion device with the goal of demonstrating the scientific and technical feasibility of fusion power. It is a joint project between the European Union, China, India, Japan, South Korea, the Russian Federation, and the USA. ITER is being built in Europe, at Cadarache in the south of France.
The ITER tokamak will be fuelled by streams of deuterium and tritium. The ratios of these injections will be varied to optimize the performance, and they will be injected by different systems. Additional gases for operation or by outgassing add to the fuelling gases and a gas mixture is exhausted from the tokamak. To reuse again the hydrogen isotopes in the fuel cycle of the ITER machine the exhaust gases need to be separated and purified.
After the separation of the hydrogen isotopes from any other gas species the hydrogens are transferred to the Isotope Separation System (ISS). To achieve the required purification rates the ISS uses cryogenic distillation to separate the hydrogen isotopes. The cryogenic distillation relies on the slight differences in boiling points (within 20 −25 K range at atmospheric pressure) for the hydrogen isotopologues. Overall, six interconnected cryogenic distillation columns are needed to fulfil the functional requirements of the ISS.
The gas feeds to the cryogenic columns require cooling, prior entering the distillation columns at 20-25 K. Overall five actively cooled heat exchangers are needed in addition to the six condenser units of the distillation columns. Each of these eleven actively cooled components have quite different heat loads varying between a few 10ths of Watt to several 100s of Watt.
A further complexity for the cryogenic supply is that for the distillation of protium a supply temperature of 18 K is required but as this temperature is below the triple point temperature of D_2, DT and T_2 a solidification of these gases could occur in the process piping and lead to a blockage of the systems. Therefore, two supply temperatures need to be delivered by the refrigerator: One at 18 K with a power of ˜600 W and one at 20 K with a power of ˜900 W. For these reasons, in between the refrigerator and the components a cryogenic distribution valve box needs to be integrated to supply the required cooling flows at the right supply temperatures to the different clients of the Isotope Separation System.
This contribution will outline the required cryogenic cooling needs of the ITER ISS and compare a conventional helium refrigeration system with a Turbo Brayton Cycle based refrigerator. The conventional system is based on screw Helium Compressors with their required oil and heat removal systems followed by the expansion turbines with the counterflow heat exchangers. These systems are optimized for achieving high efficiency at 4 K and are therefore not ideal for the ISS, operating at different conditions. The conventional refrigerators are also very elaborate and require complex maintenance efforts. The Turbo Brayton Cycle refrigerators can be optimized to the supply cooling power at ISS temperature needs and is an oil free system. The development of high frequency sealed compressors and expansion turbines in the last years have made this technology attractive as it could be much more compact and needing much less maintenance as the conventional refrigerators.
The current available Turbo Brayton based refrigerators on the market do not achieve the required cooling powers in the available space of the ISS. Studies with industrial partners have been launched to compare the two refrigerator solutions and to determine the advantages and disadvantages of each solution for a future procurement decision.

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