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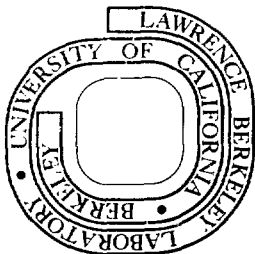
EXPLOSION POTENTIAL OF NEUTRAL-BEAM-SOURCE
CRYOPUMPS FOR TFTR

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Lawrence Ruby

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MEMORANDUM FOR THE DIRECTOR

Subject: Reactor Safety
Department of Energy
University of California
Berkeley, California

ABSTRACT

Work similar to the present effort for MSR, has been conducted to determine the effect of operating near instability and possible radiation trip on the ability to shut down with the latter objective, the process of securing approval of the design by the Government, brought to light two significant safety problems. The first concerns the possibility of fueling combustion during a leak-up/storain accident, the latter from data and test experiments conducted by us, we are convinced that there is a significant hazard. The second problem concerns the possibility of condensing significant amounts of liquid oxygen in such accidents, and we are presently unable to evaluate the relative hazard.

*Work performed under the auspices of the United States Department of Energy.

Large cryopumps have become an integral part of all neutral-beam injectors being developed for major fusion experiments. As a joint effort between LBL and LLL, a cryopump has been constructed¹ as a test of the design for TFTR. The design of our cryopump is similar to that for TFTR except that our liquid nitrogen and liquid helium systems are force fed from pressurized dewars. Further objectives were to investigate the compatibility of the pump and a nearby neutral beam, and to determine whether a pulse of neutrons and gamma rays, such as will be characteristic of TFTR, will cause desorption of the condensed gas. A somewhat similar radiation pulse can be obtained by placing the cryopump in the Exposure Room of the UC Berkeley TRIGA Mark III Research Reactor. The explosion potential of the test cryopump became a paramount issue in the safety analysis required for the reactor experiment. The LLL-suggested administrative limit for loading of a cryopump with normal hydrogen or deuterium is that amount of gas which will produce a partial pressure of 13 Torr at a total pressure of 1 atmosphere, i.e. a 1.7% mixture by volume. At atmospheric pressure, combustion can occur for mixtures in the range 4.0-5%. It is important to know whether, in a leak-up-to-air accident, when the partial pressure will range from 100% to 1.7%, an explosion can occur. For the test cryopump (225) loaded to the administrative limit, the energy of combustion would amount to about 4.1×10^4 J, or 10g of T.N.T. equivalent. The corresponding situation for TFTR will be discussed later.

Experiments by Eseff and Qinlan³ on the combustion limits of hydrogen in air at various pressures shown that the upper and lower dilution limits draw together as the pressure of the mixture gets lower. Figure 1 reproduces their data, which was taken at ambient temperature, as a dashed line. Everywhere above the line, the mixture is flammable; everywhere below the line, it is not. On the same figure is also shown the leak-up-to-air trajectory as given by the expression $P(\text{atma}) = 1.7\% \text{H}_2$. It can be seen that the trajectory is everywhere in the non-combustion range.

Wolfe and Yurezyk⁴ have done experiments on the limits of combustibility of $\text{H}_2\text{-O}_2$ mixtures. Figure 1 also shows their data, which was taken at 21°C and at -195°C . It can be seen that the trajectory is even further from the explosive area for gas mixtures at liquid-nitrogen temperatures than it is at ambient temperature.

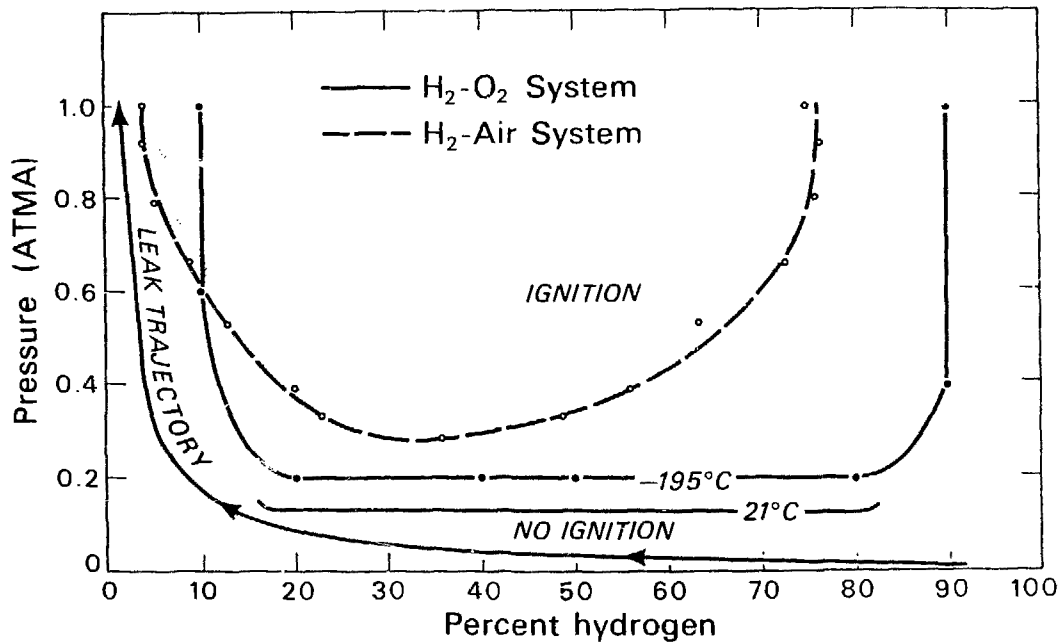
Although the experiments described above, indicate that the administrative limit suffices to insure that combustion will not take place at any subatmospheric pressure, the paucity of the data and the fact that the experiments were not done with deuterium, both argued for further corroboration of the safety. Hence, it was decided to stage 2 different leak-up-to-air accidents (with the experimenters behind a suitable barricade). In the first, air was admitted to the system with the cryopump loaded to the administrative limit for deuterium. A hot-filament ion gauge was arranged to burn throughout the leak-up-to-air cycle. The liquid nitrogen supply and the pressure to the helium dewar were then valved off and air admitted to the system. In a 20-minute leak cycle, followed by 10 minutes at atmospheric pressure, nothing occurred to indicate that combustion had taken place. Reassurance was thus obtained for the safety of the reactor experiment. Next, the experiment was repeated with, in addition, a spark gap firing in the vacuum system at approximately 1-second intervals. Again, no combustion

occurred during the leak cycle. While these experiments sufficed to satisfy the safety concerns for the reactor experiment, and indeed the cryopump has been pulsed several times in the Exposure Room at this writing, the leak-up-to-air accident which we staged, bears only a small resemblance to that envisioned for TFTR. The latter has been discussed by Valby⁵, who reports that because the individual beamlines cannot be isolated rapidly, all 4 will be affected as a result of a leak anywhere in the system. In a worst case analysis, i.e. large leak with maximum deuterium inventory, the total amount of deuterium which would be desorbed, has an energy of combustion amounting to 3.7×10^7 J, or 8.8 kg of T.N.T. equivalent. Nevertheless, no combustion can occur, according to our previous arguments, provided that at any subatmospheric pressure, only a gaseous mixture of deuterium and air is present in the vacuum system. Such, indeed, is not likely to be the case!

Contrary to our situation where the liquid-nitrogen feed was shut off at the start of the "accident", and where at most 50 liters of liquid helium was available to be vented subsequently through the system, TFTR will have a much greater potential for maintaining cooling in the vacuum system even if all liquid-nitrogen and liquid-helium feeds are shut off. Each beamline has a 750-litre dewar of liquid helium which must vent through the rupture disk to the atmosphere. Valby⁵ has calculated that the peak mass flow rate will be 7600 g/s. Thus, at this rate, it will require 12 s to exhaust the 90 kg of liquid helium from each beamline, and the actual time is bound to be longer. The liquid-nitrogen system has a reservoir in the form of a 20-cm pipe, 12-meters long, at each beamline. Thus, 377 liters of liquid nitrogen will be available for each beamline, in addition to the rather rapidly dwindling liquid helium, to condense liquid oxygen from the air rushing into the vacuum system. Experience has shown that liquid oxygen is an explosive hazard, even in the absence of hydrogen. Explosions have occurred at 3 nuclear reactors, Grenoble⁶, the Oak Ridge Graphite Reactor⁷, and the Sandia Annular Core Pulsed Reactor⁸, resulting from oxygen condensed in the presence of liquid nitrogen. In each case, radiation is believed to have catalysed the explosive reaction, but the quantity required, if any, is not known. Because of the possible deleterious effect on safety of condensed liquid oxygen, oxygen, we have proposed that our cryopump be devoted to an additional set of explosive experiments, once the reactor tests are completed. In the further experiments, we will attempt to maintain conditions during the leak-up-to-air accident as they would actually be in TFTR, and study whether conditions prevail which would permit the condensation of oxygen.

References

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Fig. 1