UCRL-ID-124781

Reactor Startup

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August 1, 1962

Lawrence
Livermore
National
Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

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NAVAL APPLICATIONS MEMO NO. 4 - August 1, 1962

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FROM: James W. Hadley

SUBJECT: Reactor Startup

This will outline some of the problems and requirements that appear to go with a submarine-based nuclear ramjet startup.

In general, the same problems will apply as in starting a Pluto land based engine. Additional ones are also brought in, however, by a pair of constraints having to do with safety of the submarine.

In the first place, the reactor on a submarine-based missile must be made safe against nuclear excursions caused by water. It should not be assumed that watertight integrity of the launch tube and missile can be guaranteed at all times. The reactor must therefore remain subcritical even when completely flooded with seawater. Since the normal control system will not have sufficient reactivity swing to accomplish this, auxiliary poison elements will have to be used. These might take the form of flexible tapes, bead strings, etc., threaded into tie tubes, and would be pulled out just prior to reactor startup. It appears that a large price in mechanical complexity would be paid to make these capable of re-insertion, once retracted. Therefore it will not be possible to make the reactor critical unless an actual launching and startup is imminent. Any routine reactor checkout would be limited to exercising the control elements and observing the resulting (small) change in neutron flux level.

Second, it appears very undesirable, in a missile launch, to bring the reactor to a critical condition on board the submarine. Probably the most sensitive period, with respect to the possibility of nuclear accidents, would be in just achieving criticality at a low but measurable power level. Going through this phase while still on board would

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emperil the entire submarine. Note also that the auxiliary safety system described above, if non-reversible, will make it necessary either to go ahead and launch or else to jettison the missile once the safety elements are retracted. Thus, any sort of tentative checkout aspects of going critical on board would not be available anyway. An additional point in favor of leaving the auxiliary poison in until the missile is in the air concerns underwater launching, if such a capability is to be provided. Without internal poisoning, some other means might have to be provided to prevent the reactor from going supercritical due to increased neutron reflection while passing through the water. Neutron poison material in the missile skin around the reactor is undesirable because of its heat load in high power operation. Conceivably sufficient negative reactivity could be provided in the control rods to take care of this problem; this will be investigated.

About one minute, at most, appears to be available, during boost, for bringing the reactor from subcritical up to full operating power and temperature. The principal problems involved in doing this lie in two areas, which are the period of initially reaching criticality and the period during which the reactor temperature is rising rapidly. Most of the range of transition from low to high power should be easy to get through in a hurry, since the only limitation on rate of power increase will be control system stability. The six or seven decades from 10 watts to 50 megawatts power could be traversed in one or two seconds if necessary.

The limiting rate of going from 50 MW to full power will have to be determined by a careful analysis of the thermal behavior of the reactor core. It is possible that mechanical interference problems would arise from different rates of thermal expansion of adjacent parts, but one would expect that careful design could eliminate this. The only restraint on the power program in the 50 MW-full power range would then be that it should produce a desired core temperature program with respect to proper engine startup conditions.

We can reasonably expect, then, that something like 30 seconds will be available for retracting the auxiliary poison system, going critical, and raising the power to around 10 watts, where enough neutron detector signal should be available to permit going on a very short period. With operating control rods fully inserted, the reactor will be perhaps \$3 to \$4 subcritical and will be running at a power level of a few milliwatts. The exact reactivity will not be known, and available information on the neutron level will have poor time resolution. As the rods are withdrawn, the control system at first will not be able quickly to appraise the reactor response, owing to statistical fluctuations in the available detector current. As the power level rises, the signal will become steadier, and it will be possible to evaluate within constantly decreasing time intervals what the rate of change of neutron flux is. If possible, the rate of rod withdrawal would be chosen so that the time interval needed at any stage to evaluate the reactor response is never as great as the interval in which the power level can go into a sharp rise and outrun the capacity of the control system to bring it back. Steady withdrawal of control rods in this manner, with the only information available being that "nothing has gone wrong yet" is of course, contrary to all conventional practice, but should be quite satisfactory for this application. A possible alternative scheme, if the preceeding proves unattainable, would be to make a quick rod bump, out and in, of \$1.00 or so, then stop and evaluate the detector current received. If the integrated current were less than a predetermined permissible amount, the rods would move out farther, say 50 cents worth, and make another \$1.00 bump. It is possible that a more rapid and safe approach to criticality could be made in this way than by a steady rod motion, since it eliminates the need to wait for a danger signal before initiating a rod insertion.

Means should be provided to ensure that the core is dry even though it is protected by auxiliary poison elements. Water gathered in incidental voids between fuel elements, perhaps from condensation, could raise the reactivity enough to interfere with normal startup operation: a Δk of the order of 1% is considered likely from this effect. The mechanical loads contributed by rapidly vaporizing water in startup should be looked at, but this seems unlikely to be a serious problem.

More specific information should be developed by the various technical groups in these problem areas. It should be assumed that the missile reactor is Tory II-C, although if definite advantages can be gained in the solution of these problems by modifying the design, this should be pointed out.

Neutronics

1) Find the quantity and configuration of poison (boron or other) required to make the flooded reactor subcritical.
2) What Δk results from outside water reflection of the missile as it is launched?
3) What Δk results from filling 1/2%, 2% of the reactor volume with water?

Controls

1) Develop a feasible startup scheme, going from subcritical to critical, to high power, and finally approaching flight operation.

Heat Transfer and Air Flow

1) Participate in development of suitably programmed power and temperature for startup.
2) Study reactor response to fast startup, with respect to interferences caused by thermal expansion as well as other possible effects.

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