SUPPLEMENT NO. 1

to

ADDENDUM NO. 4

to the

Safeguards Report for Phase 1 of the
Saxton Nuclear Experimental Corporation
Five-Year Research and Development Progra

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ADDITIONAL INFORMATION ON THE SAXTON CRUD TEST

REQUESTED BY AEC LETTER OF OCTOBER 2, 1964

1. Provide an estimate of the maximum amount of crud, in terms of both surface density and thickness, that could be deposited on the core heat transfer surfaces. State the bases of this estimate.

REPLY: The maximum crud thickness would occur if all of the ferrous hydroxide injected into the system deposited on only that fraction of the core heat transfer surface which is undergoing nucleate boiling at the start of the injection. In order to calculate the maximum crud thickness, t, therefore, use

$$t\left(\frac{mg\ Fe_3O_4}{dm^2}\right) = \frac{W_a}{fA}$$

where W_a = weight of ferrous hydroxide added, expressed as the equivalent Fe_3O_4 weight (6 pounds or 2.724×10^6 mg).

f = fraction of core surface area undergoing nucleate boiling (approximately 10% at 20 MW nominal operating condition).

A = heat transfer (fuel rod) surface area in the Saxton Core (4,620 dm^2).

Thus $t = 2.724 \times 10^6/(0.1 \times 4,620)$

$= 5,900$ mg Fe_3O_4/dm^2

The geometrical thickness, d, would be

$$d\ (\text{mils}) = 10\ t/(2.54\ \rho)$$

where t is the thickness in mg/dm^2 and ρ is the deposit density in mg/cm^3. The density, ρ, of pure magnetite (Fe_3O_4) is 5,180 mg/cm^3, however, due to its porous structure the apparent density of the deposit will be lower. Void fraction in deposits have been reported from 0.5 to 0.9; assuming the reasonably conservative void fraction of 0.81, the apparent density is 1,000 mg/cm^3 and the maximum geometrical thickness is 23.2 mils.

2. Evaluate the significance of this amount of crud on the reactor heat transfer characteristics. Provide calculations of cladding and fuel pellet center line temperature including, if applicable, effects of the crud on coolant flow characteristics.

REPLY: To answer this question, recourse must be taken to experimental data on the effect of local boiling on the apparent thermal conductivity of crud deposits. It has been found that when nucleate boiling occurs in a crud deposit, the apparent thermal conductivity, k, of the deposit under the worst Saxton heat flux conditions of 0.533×10^6 Btu/hr-ft^2 in the spiked element at 23.5 MWt for a crudded core is not less than 30. With the worst deposit case considered above, the temperature drop across the deposit would therefore be

$$\Delta T = \frac{q'd}{k} = \frac{(0.533 \times 10^6)(23.2 \times 10^{-3}/12)}{30}$$

$$= 34.4^\circ F$$

Thus in this extreme case, the clad temperature and fuel center line temperature would only be increased by less than 34°F over that of the normal operating conditions. The clad surface temperature would normally, in the hot spot with reactor pressure at 2000 psi, be about 650°F. The normal center line maximum temperature in the spiked element would be about 4,160°F.

Such deposits would cause significant increases in pressure drop or decreases in flow; however, reliable calculations cannot be made on this point. The Saxton instrumentation (flow probes and thermocouples on the fuel assemblies) will indicate any significant effect of this nature.

3. State the minimum crud thickness that could be detected by reactivity change.

REPLY: A parametric computer study of the effect of clad thickness on reactivity of the Saxton reactor, assuming increased clad thickness displaces the moderator-coolant water, has been carried out. These results are directly applicable to the problem of the reactivity worth of the crud with a simple correction for the difference in macroscopic cross-section between the 304 SS clad and the magnetite crud which we will be adding.

The study indicates that a 0.84 mil increase in cladding thickness would decrease the Saxton reactivity by 1/2% $\Delta\rho$. The macroscopic thermal neutron absorption cross-section of the 304 SS is 0.265 cm^{-1}, while for 5.18 gm/cm^3 Fe_3O_4 it is 0.102 cm^{-1}. Hence (0.84)(0.265/0.102) or 2.22 mils of 5.18 gm/cm^3 Fe_3O_4 would decrease reactivity by 1/2% $\Delta\rho$. Since 0.1% $\Delta\rho$ (and even lower) is readily measured at the Saxton reactor, 0.44 mils of theoretical density Fe_3O_4 could be detected. At an apparent density of 1.0 as assumed above, the geometrical thickness of the deposit would be 2.3 mils. This assumes uniform deposition. In the non-uniform deposit case, allowance must be made for the increased worth of the crud in the high flux regions. This increased worth is estimated to be a factor of two, hence the non-uniform deposit (on 10% of the core) would be detectable at a thickness of 2.3/(0.10)(2) or 12.5 mils.

The significance of this is that reactivity effects will be noted long before any undesirable thermal and hydraulic effects are noted. Also it should be noted that hideout effects can be expected in even thinner (geometrical) deposits $\sim$0.5 mil.