STATUS of the REACTOR CORE BASED ON FISSION PRODUCT ANALYSIS

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Coolant water in the reactor coolant system and the reactor sump at TMI-2 contains large quantities of non-volatile and sparingly volatile fission products and fuel materials. This effluent from the reactor fuel can give some insights into the nature and the extent of damage ~~which occurred that were~~ sustained by the reactor core.

The mere presence of the fission products in the coolant water is evidence of fuel cladding failure. However, it is desireable to obtain indications of what regions of the reactor core sustained damage, how extensive was that damage, and what is the state of the reactor fuel following the accident. ~~The approach used for obtaining the results cited here was to compare~~

~~Some indications~~

The following analyses were attempted to answer these questions:

a) Isotopic ratios of plutonium and uranium in the sump were compared to the ratios expected for the TMI-2 fuel to determine the regions of ~~the~~ the core that were damaged

b) The time variations of ^{131}I, ^{134}Cs, ^{136}Cs, ^{137}Cs concentrations in the reactor coolant system were used to determine the rate of coolant leakage.

c) the inventories of fission products in the sump and the coolant system were used to determine the "prompt" losses of these species and thereby the extent of fuel damage.

d) The rates of leaching of ^{89}Sr and ^{90}Sr were used to derive the effect particle size of the damaged fuel in the core and to establish a bound on the fine particulate material in the core.

~~Comparison of the isotopic ratios of the Pu and uranium in the reactor core with ratios ex.~~

The fuel in the TMI-2 core is enriched to 3 with ^{235}U to three different levels - 2.96, 2.64, and 1.98 % ^{235}U. The assemblies containing fuel of these various enrichments are located in the core as shown in Figure 1. The isotopic ratios of Pu and U calculated for fuel assemblies of various enrichments are compared with the ratios found for Pu and U in the sump of the reactor.

The observed ratios compare favorably with an average of the expected ratios for fuel initially enriched with 2.64 and 1.98 % ^{235}U. If more error is tolerated between observed and calculated ratios, the observed ratios also compare well with a expected ratios for a uniformly damaged core.

~~The gradients of Pu and U concentration in the reactor sump are consistent with the presence of solids dissolving in the water rather than solids precipitating~~

This comparison of observed and calculated isotopic ratios suggest that the central region of the reactor core was certainly damaged. With less certainty the comparison is consistant with a ~~uniformly~~ core damaged across its entire cross-section.

The ~~Plasma~~ Pu and U gradients in the sump water are consistant with solid dissolving in the water rather than solids precipitating from the water. This indicates the Pu and U in the sump came either from solids ejected from the reactor coolant system or dissolved species that initially precipitated in the sump and subsequently began to redissolve.

The consistancy of the uranium isotopic ratios, with the exception of U^{236} which may be in error, with those expected of the fuel provides no evidence for the intrusion of river water into the reactor sump.

The concentrations of ^{131}I, ^{134}Cs, ^{136}Cs, and ^{137}Cs in the reactor coolant system decrease with time even when corrected for radioactive decay. This suggests that little leaching of these materials is occuring. Since they are among the most leachable species in the fuel, it appears that these species were volatilized nearly to completion from the damaged fuel during the accident.

The decreasing concentrations of these species in the reactor coolant system is consistant with leakage of coolant. Constant leak rates estimated from the concentrations of the species are:

Species	Leak rate (gal/min)
^{131}I	1.02
^{134}Cs	1.34
^{136}Cs	1.28
^{137}Cs	1.42
[illegible]	mean = 1.26
std. dev.	std. dev. = 0.13

These leak rates apply to the first 43 days after the accident. Concentration data taken from later times suggest that leakage may have slowed considerably.

The inventory of Cs and I in the sump and coolant system may be used to determine the extent of damage to the reactor core. Results of such calculations are shown below

Species	% of Core Inventory in Water	Expected Release Fraction	% of Core Damaged
^{131}I	>58	1.00-0.95	<61-58
^{137}Cs	43	0.89-.96	48-45
^{134}Cs	36	0.89-0.96	40-38

The ~~E~~ expected release fractions listed in the table above were taken from experimental data for melting fuel (G.W. Parker et al. ORNL-3981, July 1967) The computation of "% of core damage" was made under the presumption that the release of the species occurred only from the damaged fuel. Consequently the result for ^{131}I ~~would be~~ is an upper bound since iodine would be release from the fuel-clad gap even from relatively intact fuel. The results for cesium are lower bounds since ~~release~~ only the sump and coolant system inventories of cesium were considered. The computed extent of core damage based on

Comparison of Calculated and Observed
Isotopic Ratios

% of Isotope relative to total elemental abundance in

Species	1.98% enriched fuel	2.64% enriched fuel	2.96% enriched fuel	observed in sump	Average of 1.98 and 2.64% enriched fuel	Core Average
^{235}U	1.605	2.254	2.572	2.207	1.943	2.156
^{236}U	0.074	0.081	0.083	0.064	0.078	0.080
^{238}U	98.32	97.665	97.345	97.71	97.98	97.763
^{239}Pu	87.916	90.274	91.098	90.5	87.145 ~~[illegible]~~	89.807
^{240}Pu	9.684	7.97	7.341	7.84	8.790	8.299
^{241}Pu	2.292	1.697	1.497	1.46	1.982	1.818

these fission products are in remarkably good agreement with similar calculations based on the extent of hydrogen formation.

Attempts to calculate the extent of core damage using other isotopes were not fruitful. The range of uncertainty for the "Expected Release Fraction" was too great for other species to provide useful estimates of the % of core damage.

The concentrations of ^{89}Sr, ^{90}Sr and ^{140}Ba ~~increase with time~~ in the reactor coolant system increase with time. These species are leaching from the ~~fuel~~ damage fuel exposed to the coolant waters. Leaching data are available for ~~Sr~~ strontium which allow the time dependences of ^{89}Sr and ^{90}Sr to be used to compute the surface area of the fuel exposed to the water. The surface area to weight ratio so found can be used to derive an ~~mean~~ equivalent spherical particle radius for the damage fuel. Results are shown below.

~~Calculated results for~~

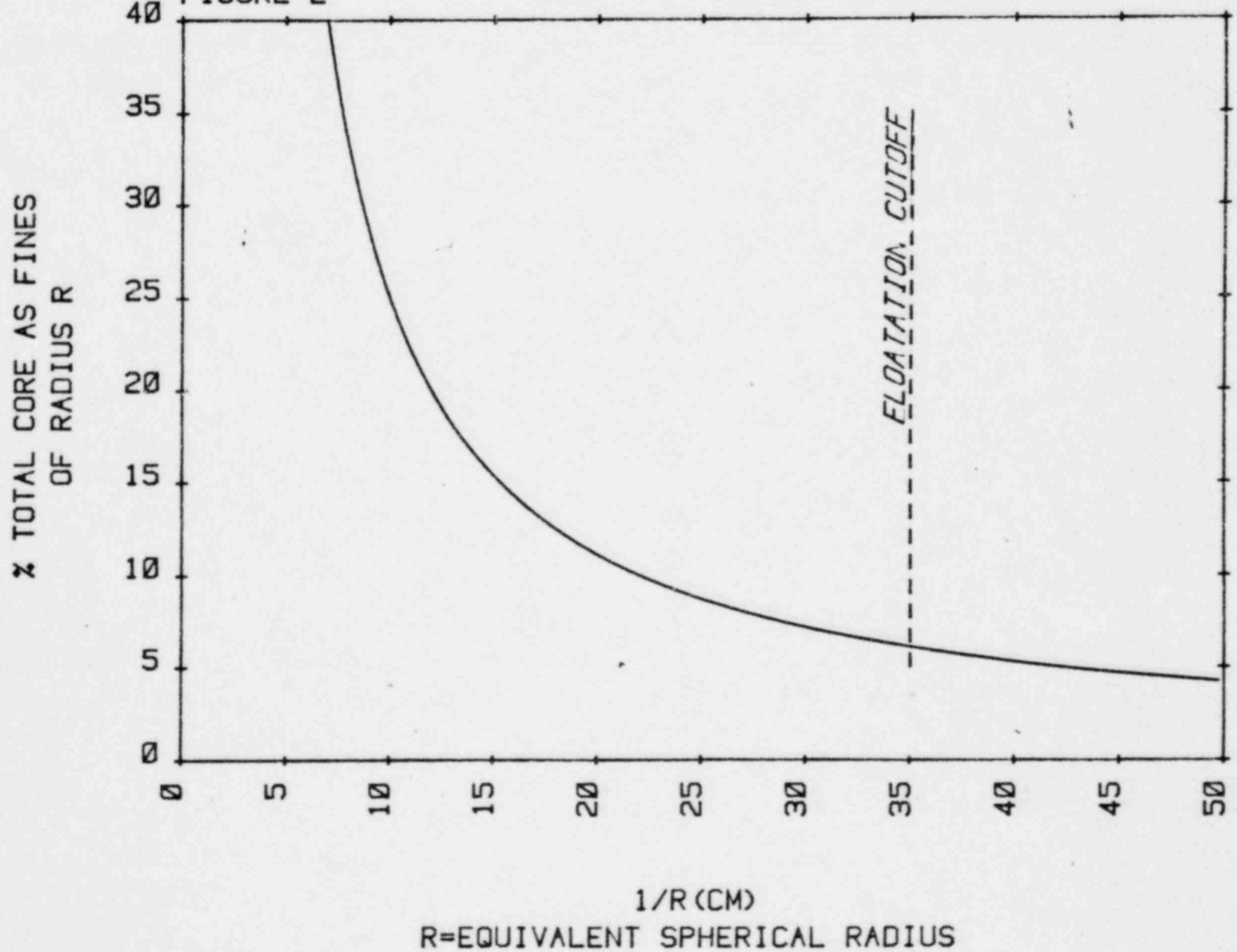
Species	Surface Area to Weight ratio† (cm^2/g)	equivalent spherical particle ~~mean particle~~ size* (cm)
^{89}Sr	3.0	0.1
^{90}Sr	2.0	0.15

† assumes that 40% of the core is exposed to coolant

* ~~assumes that particles are spheres~~ Spherical particle that has the same surface to weight ratio

If it is assumed the core debris is made up of intact pellets and fuel fragments of a particular size, an estimate of the volumetric fraction of fine fragments in the core may be made. The volume fraction of the core that could have a size r is plotted versus r in Figure 2. Very fine fragments are not likely to have developed. ~~since~~ ~~F~~ Fine materials would be levitated by the coolant flow and would have escaped the reactor coolant system to a much greater extent than observed. Consequently, ~~the~~ a cut-off in the possible size of the fines of about 0.03 cm is shown in Figure 2.

FIGURE 2


% TOTAL CORE AS FINES
OF RADIUS R
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
FLOATATION CUTOFF
1/R (CM)
R=EQUIVALENT SPHERICAL RADIUS