2/28/85

Static Reactivity Worth - The static reactivity worth of an experiment is the absolute value of the reactivity change which is measurable by calibrated control rod comparison methods between two defined terminal positions or configurations of the experiment. For moveable experiments, the terminal positions are fully removed from the reactor and fully inserted or installed in the normal functioning or intended position.

Time Intervals

Annually - 12 to 15 months.

Biannually - 24 to 30 months.

Daily - 24 to 32 hours.

Monthly - 30 to 40 days.

Quarterly - 3 to 4 months.

Semiannually - 6 to 8 months.

Weekly - 7 to 10 days.

True Value - The true value of a process variable is its actual value at any instant.

Unscheduled Shutdown - An unscheduled shutdown is defined as any unplanned shutdown of the reactor caused by actuation of the reactor safety system, operator error, equipment malfunction, or a manual shutdown in response to conditions which could adversely affect safe operation, not to include shutdowns which occur during testing or checkout operations.

3.0 LIMITING CONDITIONS FOR OPERATION

3.1 Reactivity Limits

Applicability:

This specification applies to the reactivity of the reactor core and to the reactivity worths of control rods and experiments. When the reactor is operated with the heavy water reflector tank in place, the limits will not include the static reactivity worth of the tank.

Objective:

To assure that the reactor can be controlled and shutdown at all times and that the safety limits will not be exceeded.

Specification:

(1) The shutdown margin relative to the cold, xenon free critical condition shall be at least .025 delta K/K with all three shim safety rods fully inserted and the regulating rod fully withdrawn and 0.0045 delta K/K with the most reactive shim safety rod and the regulating rod fully withdrawn.

(2) The overall core excess reactivity including moveable experiments shall not exceed 0.038 delta K/K.

(3) The total reactivity worth of all experiments shall not exceed 0.012 delta K/K.

(4) The reactivity worth of each experiment shall be limited as follows:

Experiment	Maximum Reactivity Worth
Moveable	0.0012 delta K/K
Secured	0.012 delta K/K

(5) The reactor shall be subcritical by at least 0.03 delta K/K during fuel loading changes.

(6) Shim safety rods shall not be removed from the core for inspection if the shutdown margin is less than 0.01 delta K/K with the most reactive remaining shim safety rod fully withdrawn.

(7) The reactivity worth of the regulating rod shall not exceed 0.006 delta K/K.

exposure, inside a blast proof enclosure. The enclosure will not be coupled to the beamtube or beamport and will be constructed to fully contain any blast effects or missiles which might be generated by an accidental detonation.

Specifications 3.8.(5) and 3.8.(6) conform to the regulatory position put forth in Regulatory Guide 2.2 issued November, 1973. The calculations for experiment radioactivity limits are provided in section 14.3 of the SAFETY ANALYSIS.

3.9 Fission Density Limit

Applicability:

This specification applies to fission density limits in FNR fuel.

Objective:

To prevent fuel plate swelling which could result in clad rupture and release of radioactive fission products.

Specification:

(1) The FNR fission density limit shall be 1.5×10^{21} fission/cc.

Bases:

The fission density limit is below operational fission densities reached in other operating reactors using the same kind of fuel without failures attributed to the fuel.

An experimental data base which supports the safe use of UAl_x and U_3O_8 fuel in the FNR up to the fission density was derived from irradiation tests performed in the Materials Test Reactor (MTR), the Engineering Test Reactor (ETR), and the Advance Test Reactor (ATR) at the Idaho National Engineering Laboratory, the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory, and the German Karlsruhe FR2 reactor.

14.2.4 Beamports

There are eight six-inch diameter and two eight-inch diameter aluminum beamports labeled A -J. The beamports penetrate the pool wall in a staggered arrangement at four different heights and terminate on the reactor's heavy water tank as shown in Figure 9.1. The four heights at beamport centerlines when referenced to the bottom of active fuel in the core are 0.38, 1.0, 1.61, and 2.28 feet. If the pool level reached the lowest elevation in the lowest beamport, active fuel would remain immersed in approximately two inches of water and the bottom of the core would be immersed in approximately three and one-half inches.

Beamports are configured as in Figure 14.1. Four barriers to loss of coolant can be provided; not all beamports have all four barriers. The first barrier is the beamtube itself. A collimator is sealed into the beamtube for the purpose of reducing an extracted neutron beam to a desired cross sectional area. The collimator can have watertight barriers at the pool end and the outer end. The beamport shield door serves as the fourth barrier, but the door is raised when a beamport is in use which eliminates its utility.

At the Ford Nuclear Reactor, every beamport is configured with at least two of the barriers labeled one, two, and three in Figure 14.1, except I beamport. I beamport has a twenty-nine inch long collimator which is open at both ends. The outer aperture is a one-half inch by one and one-fourth inch rectangle.

In all of the beamports, the collimators do not extend beyond the concrete pool wall. Even if the beamtube were sheared off, the collimator would remain intact to prohibit loss of coolant, with the exception of I beamport.

I beamport is shown diagramatically in Figure 14.2. The centerline of the beamport is 1.61 feet above the bottom of active fuel in the core. If the pool level drained to just below this centerline, active fuel would remain immersed in approximately eighteen inches of water.

14.2.5 Pneumatic Tubes

A bundle of eight, one and 7/16 inch diameter, pneumatically operated, aluminum, sample irradiation tubes penetrate the pool floor and terminate adjacent to the west face of the reactor core. A typical set of two tubes can be seem in Figure 9.1 on the left side of the core.

Flow rate through a rupture equals the rate at which the pool level drops times the surface area of the pool.

$$w = -A_a \, dh/dt \tag{14.5}$$

where:

A_a = Pool surface area, 210 ft^2.

Substitute w from equation (14.3) into equation (14.5) and separate variables.

$$dt = -(A_a/A \sqrt{2 gh}) \, dh \tag{14.6}$$

To calculate the drain time from an initial pool water level down to a lower level, integrate equation (14.6) between the two levels.

$$t = (\sqrt{2} A_a/A \sqrt{g}) (\sqrt{h_o} - \sqrt{h}) \tag{14.7}$$

where:

t = Drain time, sec;

h_o = Initial pool level above rupture, ft;

h = Final pool level above rupture, ft;

Convert drain time to hours.

$$t = (.0145/A) (\sqrt{h_o} - \sqrt{h}) \tag{14.8}$$

Calculations for flow rate, equation (14.4), and drain time, equation (14.8), for I beamport and one pneumatic tube are summarized in Table 14.1. These two parameters are calculated: (1) shortly after rupture has occurred when the pool level has decreased one foot below normal to the level scram setpoint; (2) when the pool level reaches the top of the core; and, (3) when the pool level reaches the bottom of the core. In the case of I beamport, level will not recede below the beamport which is 1.61 feet above the bottom of active fuel and 1.78 feet above the bottom of the core as can be seen in Figure 14.2.

The maximum flow rate as the result of the rupture of a 1-7/16 inch diameter pneumatic tube with the pool level 27.94 feet above the opening where the draining occurs is 209 gpm. In this most severe case, with no emergency makeup flow, the core remains completely covered for 3.03 hours and partially covered for 3.58 hours following an automatic low pool level scram. By the time the core begins to uncover, fission product decay heat

Table 14.1 Flow Rates and Drain Times Corresponding to Various Reactor Pool Levels for Ruptures at I Beamport and One Pneumatic Tube

	Pool Level (ft above rupture)	Flow Rate (gpm)	Drain Time (hr)
I Beamport			
Pool Level Scram	19.56	69	0
Level at Top of Core	0.56	12	12.39
Level at Beamport Centerline	0	0	14.91
Pneumatic Tube			
Pool Level Scram	27.94	209	0
Level at Top of Core	8.94	119	3.03
Level at Bottom of Core	6.60	102	3.58

will have decreased form about seven percent of full power at shutdown to less than one percent of full power.

14.2.7 Emergency Makeup Water

Emergency makeup for the reactor pool is provided by a four inch water main that enters the reactor building. The four inch line reduces to three inches and eventually branches to three three-inch lines that supply emergency pool water. Calculations using the fire protection handbook and accounting for valves, elbows, and tees in the lines show the emergency makeup flow rate to be approximately 600 gpm. This flow rate is almost four times greater than the maximum loss of coolant flow rate in Table 14.1.

14.2.8 Conclusions

Abnormal loss of coolant from the Ford Nuclear Reactor pool that could result in partial or total uncovering of the core can be caused by a rupture in or damage to I beamtube or the pneumatic tube system. The maximum loss of coolant flow rate, from a pneumatic tube failure, is 162 gpm. The emergency makeup water system, with a flow rate of approximately 600 gpm, exceeds the loss of coolant flow rate by almost a factor of four. If emergency makeup water were not utilized, the reactor core would remain completely covered for 3.92 hours subsequent to a pool level scram at which time fission product heat would have decayed to less than one percent of the two megawatt normal operating power level. Based upon this analysis, the most severe abnormal loss of coolant event at the Ford Nuclear Reactor would not cause core damage.

14.3 Failed Experiment

Limits are placed on the radioactivity content of gaseous, particulate, and volatile reactor experiments to ensure that the exposure of workers in the restricted area and the general public will result in doses below 10CFR20 limits in the event of an experiment failure.

14.3.1 Experiment Radioactivity Limits Based Upon Exposure to Personnel Within the Restricted Area of the FNR Building

14.3.1.1 Assumptions

a. Restricted area MPC (MPC_R) produces a dose of 5 rem/year for the isotope involved based upon 2000 hours/year exposure.

b. Volatile or dispersible activity in a pool experiment is uniformly dispersed in the lower 1/4 of the pool floor volume.

c. Pool floor volume, V, is approximately 58,000 cubic feet or 1.6×10^{9} cc.

d. Personnel require no more than 0.1 hour or 6 minutes to diagnose the experiment failure, initiate building evacuation, and evacuate the reactor building.

e. Calculations are based upon single encapsulation of experiments. The allowable dose fraction for single encapsulation based upon Technical Specifications is 0.1 MPC_w.

14.3.1.2 Calculations

The concentration of radioactivity, C, permitted in the reactor building air is:

$$C = (T/t)(0.1\ MPC_w)\ \mu Ci/cc \qquad (14.9)$$

$$= 2000\ MPC_w$$

where:

T = 2000 working hours per year;

t = Exposure time, 0.1 hr.

The total activity, A, of an experiment based upon the concentration and volume into which it is dispersed is:

$$A = CV/4 \qquad (14.10)$$

$$= 8.0 \times 10^{11}\ MPC_w\ \mu Ci$$

14.3.2 Experiment Radioactivity Limits Based Upon Exposure to Personnel in Unrestricted Areas

14.3.2.1 Assumptions

a. Unrestricted area MPC (MPC_u) produces a dose of 0.5 rem/year based upon continuous exposure.

b. Stack dilution is 400.

c. The maximum rate at which air can be exhausted from the FNR following initiation of building evacuation is 300 cfm based upon opening the exhaust duct for the hood in Room 3103.

d. The PML exhaust fan flow rate is 11,000 cfm. Room 3103 hood airflow is diluted by this flow.

e. Calculations are based upon single encapsulation of experiments. The allowable dose fraction for single encapsulation based upon Technical Specifications is 0.1 MPC_u.

f. The unrestricted area is continuously occupied for 2 hours following the experiment failure.

g. Volatile or dispersible activity in a pool experiment is uniformly dispersed in the lower 1/4 of the pool floor volume.

36' h x 38' NS x 42' EW

h. Pool floor volume, V, is approximately 58,000 cubic feet or 1.6×10^9 cc.

i. MPC_w is approximately 40 MPC_u.

14.3.2.2 Calculations

The allowable ground level concentration of radioactivity, C_g, is:

$$C_g = [(365)(24)/2](0.1\ MPC_u)\ \mu Ci/cc \qquad (14.12)$$

The allowable stack concentration, C_s, based upon a 400 dilution factor is:

$$C_s = 400\ C_g \qquad (14.13)$$

$$= 400\ [(365)(24)/2]\ (0.1\ MPC_u)\ \mu Ci/cc$$

The allowable exhaust hood concentration, C, based upon mixing with the remainder of the PML exhaust in the stack is:

$$C = (11{,}000/300) C_s \qquad (14.14)$$

$$= (11{,}000/300) 400 [(365)(24)/2]\ (0.1\ MPC_u)$$

$= 6.42 \times 10^{6}\ MPC_{w}\ \mu Ci/cc$

Assuming no fresh air is introduced into the pool floor and that the radioactivity undergoes no decay, the total experiment activity, A, allowed would be:

$$A = CV/4 \qquad (14.15)$$

$$= 2.57 \times 10^{15}\ MPC_{w}$$

$$= 6.42 \times 10^{13}\ MPC_{a}\ \mu Ci$$

14.3.3 Limits on Single and Double Encapsulation Experiments

Comparison of equations (14.10) and (14.15) shows that the total radioactivity for an experiment with single encapsulation is limited by exposure to personnel within the restricted area of the reactor building. The microcurie content of any experiment is calculated using equation (14.10) and MPC_{a} values from 10CFR20 for the isotope involved.

For double encapsulation experiments, the dose fraction is increased from 0.1 MPC_{a} to MPC_{a} because the double barrier decreases the probability of experiment failure. Therefore, the total radioactivity content of an experiment with double encapsualtion is limited to ten times the content of an experiment with single encapsulation.

In the event that an experiment contains more than one releasable isotope,

$$\Sigma[A_{i}/(A_{i})_{limit}] \leq 1 \qquad (14.16)$$

where:

A_{i} = Actual isotope radioactivity, μCi;

$(A_{i})_{limit}$ = Equation (14.10) radioactivity limit, μCi.

14.3.4 Fissile Material Experiment Activity Limit

A review of 10CFR20 limits of fissile materials and their fission products shows that iodine-133 has the most restrictive limit due to its biological impact. In placing activity limits on fissile material or fueled experiments, the assumption is made that the entire fission yield is iodine-133.

A calculation follows to determine the combination of fissile material weight, neutron flux, and irradiation time that will produce an amount of iodine-133 activity equal to the limit in equation (14.10). Specific values for U235 are provided as an example.

14.3.4.1 Calculations

The fission reaction rate, R, is given by:

$$R = N\sigma\emptyset \quad (14.17)$$

$$= 1.48\times10^{-3}\ W\emptyset \quad \text{U235 fissions/sec}$$

where:

N = Atoms of fissile material;

= WA_o/M;

W = Sample weight, mg;

A_o = Avogadro's number, 6.02×10^{23} atom/mole;

M = Molecular weight, mg;

= 235,000 mg for uranium-235;

σ = Microscopic fission cross section, cm^2;

= 577×10^{-24} cm^2 for uranium-235;

$\emptyset$ = Thermal neutron flux, $n/cm^2/sec$.

The total number of fissions, F, in a given irradiation time is:

$$F = Rt \quad (14.18)$$

$$= 1.48\times10^{-3}\ W\emptyset t \quad \text{U235 fissions}$$

where:

t = Irradiation time, sec.

Two fission products result per fission, so the total number of fission products produced, FP, is:

$$FP = 2F \quad (14.19)$$

$$= 2.96\times10^{-3}\ W\emptyset t \quad \text{U235 fission products}$$

The decay rate, D, of radioactive fission products is proportional to the half-life, $T_{1/2}$, of the isotope involved. Since it was assumed that all fission products are I133, the I133 half-life of 20 hours is used. The value of 20 hours is reasonably representative of the average half-life of all fission products.

$$D = L\ FP \qquad (14.19)$$

$$= (\ln 2/T_{1/2})\ FP$$

$$= 2.85\times10^{-8}\ W\emptyset t \quad \text{U235 disintegrations/sec}$$

where:

L = Fissile material decay constant, sec^{-1};

$= \ln 2/T_{1/2}$;

$T_{1/2}$ = Fissile material half-life, sec;

$= 7.2\times10^{4}$ sec for I133.

Experiment radioactivity, A, is obtained by converting the decay rate to microcuries.

$$A = D/3.7\times10^{4} \quad \mu Ci \qquad (14.20)$$

$$= 7.7\times10^{-13}\ W\emptyset t \quad \mu Ci \text{ I133}$$

The combination of fissile material weight, neutron flux, and irradiation time permitted is determined by setting equations (14.10) and (14.20) equal. For the specific example of U235 and its fission product, I133,

$$7.7\times10^{-13}\ W\emptyset t = 8.0\times10^{11}\ MPC_a$$

$$W\emptyset t = 1.04\times10^{24}\ MPC_a$$

$$= \cancel{2.08\times10^{17}}\ 3.12\ 10^{16} \text{ (single encapsulation)}$$

$$= \cancel{2.08\times10^{18}}\ 3.12\ 10^{17} \text{ (double encapsulation)}$$

where:

MPC_a = $\cancel{2\times10^{-7}}$ 3×10^{-8} μCi/cc for I133.