Safety Analysis Report for the Neutron Multiplier Facility, 329 Building

H. G. Rieck

September 1978

**Prepared for the U.S. Department of Energy
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**Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

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SAFETY ANALYSIS REPORT FOR THE NEUTRON
MULTIPLIER FACILITY, 329 BUILDING

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August, 1978

1.0 INTRODUCTION AND SUMMARY

Neutron multiplication is a process wherein the flux of a neutron source such as ^{252}Cf is enhanced by fission reactions that occur in a subcritical assemblage of fissile material. The multiplication factor of the device depends upon the consequences of neutron reactions with matter and is independent of the initial number of neutrons present. Safe utilization of such a device demands that the fissile material assemblage be maintained in a subcritical state throughout all normal and credibly abnormal conditions. Examples of things that can alter the multiplication factor (and degree of subcriticality) are temperature fluctuations, changes in moderator material such as voiding or composition, addition of fissile materials, and change in assembly configuration.

The Neutron Multiplier Facility (NMF) utilizes a multiplier- ^{252}Cf assembly to produce neutrons for activation analysis of organic and inorganic environmental samples and for on-line mass spectrometry analysis of fission products which diffuse from a stationary fissile target (≤ 4 g fissile material) located in the Neutron Multiplier. The NMF annex to the 329 Building provides close proximity to related counting equipment, and delay between sample irradiation and counting is minimized.

The Neutron Multiplier (NM) is a subcritical assembly of enriched uranium (93.2 wt% ^{235}U)-aluminum fuel rods having a neutron multiplication factor (k_{eff}) ≤ 0.993 . A thermal neutron flux of about 10^{10} n/cm² cm-sec is

produced from a 100 mg ^{252}Cf source. As a result of the following design features and operational procedures, the NM is maintained in a subcritical state.

- The fuel rod arrangement was designed from experimental measurements to optimize k_{eff} such that the assembly will remain subcritical under abnormal temperature fluctuations or water density changes (flooding or voiding).
- The NM is located at the bottom of a 20-ft deep pool of water. The water limits physical access to the NM and provides necessary radiation shielding.
- Physical constraints prevent unauthorized rearrangement of the fuel rods. The primary constraint is an aluminum cover plate fitted over the top of the lattice plate, securing the fuel rods in place. This cover plate is attached to the holding plate by locking nuts that can only be removed by a special tool made for this purpose. The tool will be kept and controlled by the Manager, Safety and Nuclear Materials Management.
- The maximum amount of fissile material allowed in the facility in excess of the NM fuel loading is 4 g in the form of irradiation samples. Extra fuel rods for the NM shall be stored in the 303-C fissionable material storage facility under the control of Safety and Nuclear Materials Management personnel.
- Irradiation samples that may cause an increase in k_{eff} of the NM will be regulated by approved Criticality Safety Specifications.
- Physical security of the facility will be maintained by roof and door penetration and motion detectors that alarm at the 300 Area patrol headquarters. The steel grating which covers the top of the NM pool is equipped with an intrusion alarm that also signals at the patrol headquarters.
- Initial fuel loading and any subsequent modification to the fuel loading will be regulated by a Criticality Safety Specification. Fuel loadings and modifications shall be conducted under the direct supervision of the Manager, Critical Mass Laboratory, or his authorized delegate.

- Any maintenance on the NM assembly shall be reviewed and approved by the Manager, Safety and Nuclear Materials Management. Maintenance requiring rearrangement of the fuel loading shall be conducted under the direct supervision of the Manager, Critical Mass Laboratory, or his authorized delegate.
- Operations of the facility shall be limited to personnel qualified to handle fissionable material in the NM facility. Qualification requirements shall be in accordance with the training requirements given in Procedure No. 7, Criticality Safety Procedures, BNWL-MA-25.

A high degree of radiation safety is maintained by the following design features and administrative controls:

- Shielding by the pool water and other external shields or barriers is adequate for personnel to remain in accessible pool room areas during NM operation.
- Physical restrictions or external shielding are used to limit personnel exposure when voided center tube experiments are in progress.
- The fuel rods and ^{252}Cf sources are adequately encapsulated to prevent contamination spread.
- All irradiated sample and ^{252}Cf source handling is performed under an approved Radiation Work Procedure.

It is concluded that the NMF will operate without creating an unacceptable risk to the public or to the operating personnel.

2.0 NUCLEAR SAFETY LIMITS

The Nuclear Safety Limits stated in this section are binding. Material presented elsewhere is intended to be descriptive of, or justification for, the Nuclear Safety Limits. Other restrictions given in this report are examples of those set forth in Criticality Safety Specifications and Radiation Work Procedures, presented for description purposes, and subject to change within the boundaries of the limits stated here. Any change in operations or equipment that introduces an unreviewed safety question, or significantly increases the probability or consequences of an accident discussed herein, shall require an addendum to the Safety Analysis Report.

The operation of the NM and handling of fissionable material in the NM facility shall be controlled by Criticality Safety Specifications. Criticality Safety Specifications covering the operation, fuel loadings and modifications, and fuel handling in the NM facility, shall be reviewed and approved by the Manager, Critical Mass Laboratory. This review and approval replaces that normally performed by the Criticality Safety and Shielding Analysis Section.

2.1 LIMITS

- 1) Fissionable material within the NM facility is limited to the NM fuel loading, sealed sources to drive the NM, and a maximum of 4 g fissile material in excess of the fuel loading in the form of irradiation samples.
- 2) The NM shall be limited to a maximum k_{eff} of 0.993.
- 3) The amount of beryllium shall be limited to 5 g and D_2O shall not be permitted within the facility.
- 4) The total amount of carbon (in the form of organics or otherwise) loaded into the NM shall be limited to 715 g.
- 5) Fuel loadings and modifications shall be conducted under the direct supervision of the Manager, Critical Mass Laboratory, or his authorized delegate.
- 6) The total amount of ^{252}Cf in the driver source shall be limited to 100 milligrams.

2.2 BASES

- 1) Limit #1 limits the amount of fissionable material in the NMF to that determined experimentally to cause no greater hazard than that assumed for the Final Safety Analysis Report.
- 2) Limit #2 is the maximum k_{eff} of the fuel loading determined experimentally under credible conditions of samples, irradiation tubes and moderator-reflector conditions.
- 3) Beryllium and D_2O are more effective moderators than water or carbon.
- 4) When carbon is loaded into irradiation tubes, the center tube has the maximum effect on k_{eff} where 715 g increases k_{eff} 0.0024.
- 5) Since the mode of operation for the NM is slightly subcritical, any fuel loading or modification requires the direct supervision of an individual highly knowledgeable and experienced with critical and near critical systems.
- 6) Radiation potentials evaluated for this SAR are based upon 100 milligrams of ^{252}Cf as the driver source

3.0 DESCRIPTION

3.1 SITE

The NM is housed in an annex attached to the 329 Building near the southeast corner. The 329 Building is located in the 300 Area of the Hanford Reservation. A 300 Area site description is given in BNWL-CC-1693. A view of the facility is shown in Figure 3-1.

3.2 FACILITY

The NMF is a 26-ft long x 20-ft wide x 16-ft high one-room structure attached to the 329 Building. The NM is installed near the bottom of a 5-ft diameter x 20-ft deep water filled pool which is located in the southeast corner of the floor area. The NM support equipment includes a neutron source drive assembly, a water treatment system (circulating pump, filter, ion exchange, and auxiliary controls), an electric hoist, a standard and laminar flow hood, and standard laboratory benches. Supporting services in the facility include air conditioning, ventilation system with HEPA filter, heat, light, sanitary water, electric power, penetration alarms, and fire protection. A floor plan is shown in Figure 3-2.

3.2.1 Building

The NMF is constructed of insulated metal siding that provides a dustproof interior. Equipment access to the room is provided from the loading dock through a 12-ft high double door at the southeast corner of the room. Main access to the NMF is through an entry door from the 329 Building at the southwest corner. A 4-ft square hatch is located in the ceiling over the pool to facilitate transfer of the ^{252}Cf sources into and from the facility. All outside accesses are weather-stripped to provide adequate dust proofing. Ventilation is a "once-through" system with a single stage HEPA filter in the exhaust. Security of the room is provided by penetration and motion detectors with alarms at 300 Area patrol headquarters. The doors, roof hatch and pool cover are equipped with penetration switches. Two motion detectors provide surveillance over 75% of the room volume.

FIGURE 3-1. Neutron Multiplier Facility

FIGURE 3-2. Floor Plan--Neutron Multiplier Facility

3.2.2 Pool

The wall of the pool is a 9-in. thick layer of 300 psi reinforced concrete poured inside a 6-1/2 ft diameter circular liner plate. The liner plate is attached to the surrounding soil column with a grouting procedure. The construction provides resistance to earthquake motions with peak horizontal accelerations of 8.05 ft/sec^2 , and simultaneous peak vertical accelerations of 5.37 ft/sec^2 . A 6-in. high curb around the top of the pool will prevent entry of floor surface water into the pool. The interior surfaces of the pool are coated with plastic sealer to prevent leaching of concrete into the pool water. A four-section 500 psf steel grating covers the top of the pool and is equipped with a penetration switch.

3.2.3 Pool Water System

A 50 gpm pump circulates the water from the pool through a particulate filter and an ion exchange resin bed. Inlet to the pump is 18 in. below the pool surface and the discharge is 9 in. above the bottom of the pool. Flow, temperature, and conductivity sensors monitor the system operation and water quality. No drain connections are provided in the pool construction; therefore, the pool water is isolated from all sewer systems. Water cannot be drained from the pool except through an accidental breach of the pool wall or by use of a portable pumping system. Water level in the pool is maintained by a manually operated valve in series with a float valve. When the manual valve is periodically opened, the float valve controls the level of the pool water.

3.2.4 Neutron Multiplier System

The system is a water shielded annular assembly of fuel rods, a ^{252}Cf source(s), and an array of sample irradiation tubes. The fuel assembly is rigidly supported on a structure which is attached to the pool floor. The ^{252}Cf source is attached to a source drive arm located below the fuel assembly. The NM is turned "on" by remotely raising the source into the fuel assembly, where neutrons from ^{252}Cf interact with the fuel. A neutron proportional counter filled with ^3He is located in a polyvinyl chloride thimble on the side of the pool and monitors the proper operation of the NMA. The multiplier is turned "off" by lowering the source out of the fuel assembly. Irradiations may be done in one 2-in. diameter aluminum tube in the

center, four 2-in. diameter, or two 4-in. diameter aluminum tubes located on the outer periphery of the fuel region.

3.2.4.1 Fuel Assembly

The fuel region is the shape of an annular hexagon 9-3/4 in. across the external sides, 3-3/4 in. across the internal sides, and 23 in. long. The ^{235}U (93.2 wt%) fuel rods are held in fixed configuration by top and bottom lattice plates. Holes are drilled in a hexagonal pattern of 0.600 in. centers through the top plate and partially through the bottom plate to hold the fuel rods in the fixed configuration. The holes in the top plate are 0.5 in. diameter to provide for an aluminum sleeve around the fuel rod. This sleeve will allow easy removal of the fuel rods in event that corrosion occurs. The two lattice plates are held 22-5/8 in. apart by three aluminum angle structural members in a welded construction. Eyes in the top end of the structural members provide means for raising or lowering the loaded fuel assembly. An aluminum cover plate fits over the top lattice plate and holds the fuel rods in place. The lattice assembly is shown in Figures 3-3 and 3-4.

The lattice assembly with fuel rods is positioned in a support structure which is attached to the floor of the pool. A bottom or mounting plate is bolted to a tubular aluminum framework which is bolted to the pool floor. The upper or holding plate is attached to the bottom plate with three tie rods which are attached by locknuts on the bottom plate and by specially designed locknuts on the top plate. The fuel-lattice assembly is secured in position by three element retainers and locking nuts attached to the holding plate. The locknuts can only be removed by a special tool for this purpose. The source drive and irradiation tubes are attached to the mounting and/or holding plate with bolts and suitable brackets. The holding and mounting plates are shown in Figures 3-5 and 3-6.

The fuel rods are 93.2% ^{235}U enriched uranium-aluminum alloy (28 wt% U) canned in 0.040-in. wall 1100 aluminum seamless tubing with welded top and bottom closure. The fuel element is 0.3 in. diameter and 20.6 in. long. Each rod contains 22.224 grams of ^{235}U . A drawing of a fuel rod is shown in Figure 3-7. The heat generated by the fission reaction in the NMA is estimated to be 103 W. This calculation is shown in Appendix C.

FIGURE 3-3. Fuel Pin Lattice Assembly

FIGURE 3-4. Lattice and Cover Plate Details

FIGURE 3-5. Neutron Multiplier System

FIGURE 3-6. Support Structure and Plates

3.2.4.2 ^{252}Cf Source

The neutron sources which "activate" the neutron multiplier are 100 mg of ^{252}Cf . Neutrons are produced by spontaneous fission. Six sources (100 mg total or less) are attached to the holder which is installed in the source drive arm. The sources are doubly encapsulated in 304L stainless steel containers. The total weight of steel is 0.438 lb. The total source yield is 2.34×10^{11} neutrons/sec, and the heat output is 3.9 W. The ^{252}Cf source holder is shown in Figure 3-8.

The ^{252}Cf is moved into and out of the fuel region by a source positioning mechanism. An electric motor-driven screw assembly above the pool surface is attached to a long rod which extends down into the pool below the fuel assembly. An arm extends horizontally from the bottom of the rod to the center line of the fuel assembly; then vertically 15-in. The sources are attached to the vertical section of the arm and are held on the centerline of the fuel assembly by a mechanical guide. The source drive is shown in Figure 3-9.

Limit switches on the screw assembly stop the source travel at the lower or "off" location and at the upper or "on" location. A clutch in the motor drive provides for slippage in case resistance to movement is encountered. Speed of travel is 10 in./min.

Source loading is done by lowering the positioner to the pool floor and manually rotating the arm from under the fuel assembly. Bypass of the lower limit switch is required. The source drive can be manually operated with a hand wheel.

3.2.4.3 Irradiation Tubes

An aluminum tube 2-in. outside diameter and 0.035-in. wall thickness extends from 5 in. above the steel grating down the fuel assembly center line to the bottom of the fuel assembly. The tube bottom is open and a perforated aluminum disk is welded in place about 1/4 in. above the horizontal center line of the fuel region. This allows placement of the source in the position of maximum effectiveness.

CLAD MATERIAL: ALUMINUM, 1100

LOAD MATERIAL: 28 w/o U IN AI, 93.2 w/o ^{235}U IN U, 1 gm U (93.2) / cm^3 . 3 FUEL PIECES PER ROD. 22.224 gm ^{235}U PER ROD

FIGURE 3-7. Fuel Rod (or fuel pin)

SECTION A-A

FIGURE 3-8. ^{252}Cf Sources and Holder

FIGURE 3-9. Source Drive Details

Two dry tubes are located around the periphery of the fuel assembly. One tube is 2-in. outside diameter and the other is 4-in. outside diameter. Wall thickness is 0.035 in. These tubes have bends that provide a 9 in. offset between top and bottom to limit radiation beams. Lead shot in the bottom of the dry tubes provides neutral buoyancy. Slots in the top of the holding plate are provided so that the dry tubes can be moved away from the fuel assembly when not in use. The tubes extend from 5 in. above the grating down below the bottom or mounting plate.

One 4-in. diameter and three 2-in. diameter aluminum wet tubes are located around the periphery of the fuel assembly. These tubes are held in place by clamps bolted to the bottom or mounting plate. These tubes have an opening in the bottom and are not intended to be moved from position. The irradiation tubes are shown in Figure 3-10.

A 2-in. outside diameter dry tube may be substituted for the wet center tube when pneumatic sample transfer or on-line mass spectrometer irradiation experiments are conducted.

FIGURE 3-10. Irradiation Tube Details

4.0 ORGANIZATION AND ADMINISTRATIVE CONTROLS

Nuclear safety was a predominant factor in the design and fabrication of the neutron multiplier system. The nuclear parameters of the fabricated assembly were established by an extensive and complete testing phase in the Critical Mass Laboratory. Certain operating restrictions evolved during the testing phase and responsible administrative controls insure that these requirements are met.

4.1 ORGANIZATION AND ASSIGNMENT OF NUCLEAR SAFETY RESPONSIBILITY

The Physical Sciences Department, Battelle Northwest, is responsible for the nuclear safety of the NMF. A Facility Supervisor who reports to the Manager of Physical Sciences Department is responsible for the operation of the facility. His responsibilities (referenced in Criticality Safety Procedures, BNWL-MA-25) include personnel training, security, radiation, nuclear and industrial safety, and proper operation of the facility.

4.2 ADMINISTRATIVE CONTROLS

Administrative controls prescribed for the operation and use of the NMF insure a high degree of safety to personnel, equipment, and the public. These administrative controls are formulated in accordance with the BNW Management Guide and Criticality Safety Procedures, BNWL-MA-25. The controls are considered effective requirements that will provide a safe operation based upon the nuclear parameters determined by mock-up experiments at the Critical Mass Laboratory.

4.2.1 Nuclear Safety Procedures

Safety in the startup and operation of the NMF is insured by the following operational requirements:

- The loading of the neutron multiplier assembly (NMA) in the water pool and subsequent startup is in compliance with an approved Criticality Safety Specification. Any fuel loading or modification shall be under the direct supervision of the Manager, Critical Mass Laboratory, or his authorized delegate.

- Operation of the facility and conduct of experiments shall be by qualified personnel as specified in the training program guidelines (Procedure No. 7, Criticality Safety Procedures, BNWL-MA-25).
- All experiments and operations conducted in the NMF are in compliance with the Criticality Safety Specification and the Final Safety Analysis Report.
- A high degree of physical security for the NMF is maintained.
- Periodic inspections and testing of the NM and supporting equipment is done to verify normal operation and discover and identify any abnormal conditions.

4.2.2 Mandatory Nuclear Safety Specifications

The Criticality Safety Specifications for the NMF conform with the requirements specified in Criticality Safety Procedures, BNWL-MA-25, for a Non-Reactor Nuclear Facility. An exception to these requirements is that the Manager, Critical Mass Laboratory shall review and approve Criticality Safety Procedures for the NM facility in place of that normally conducted by the Criticality Safety and Shielding Analysis Section.

4.2.3 Criticality Safety Audits

All procedures that affect the Criticality Safety of the NMF are periodically audited by prescribed Operating and Nuclear Safety personnel to insure compliance with the requirements of the Criticality Safety Specification and the Final Safety Analysis Report. The audit program will comply with the requirements specified in Criticality Safety Procedures, BNWL-MA-25.

4.2.4 Training Program

The training program for personnel who are involved with the operation and use of the NMF complies with the requirements of Procedure No. 7, Criticality Safety Procedures, BNWL-MA-25.

4.2.5 Labeling and Posting

The labeling and posting program in the NMF complies with the procedures prescribed in Criticality Safety Procedures, BNWL-MA-25.

4.2.6 Radiation Generating Devices

The Neutron Multiplier is a radiation generating machine and where applicable meets the requirements of Radiation Protection Procedures, BNWL-MA-6.

4.2.7 Emergency Procedures

Emergency procedures will be prepared prior to the operation of the facility.

5.0 SAFETY ANALYSIS

The analysis of environmental samples frequently requires the measurement of very low concentrations of the element of interest. The lower limit of detection depends upon the neutron flux available when the analysis is done by neutron activation techniques. The operating parameters of the NM must therefore provide the maximum neutron flux commensurate with absolute criticality safety.

5.1 CRITICALITY POTENTIAL AND CONTROL

Following a calculational design, a detailed, fueled mockup of the neutron multiplier was extensively tested at the Critical Mass Facility. Operating parameters were experimentally optimized and the safety of the assembly was verified.⁽¹⁾ The NM uses the same lattice plates and fuel rods that were tested in the mockup.

5.1.1 Fissionable Material Description

The fissile material in the neutron multiplier is approximately 5.6 kg of ^{235}U contained in about 252 fuel rods 0.4-in. diameter and 23.75-in. long. The fuel is a 28 wt% uranium (93.2% ^{235}U enriched) - aluminum alloy.

5.1.2 Criticality Potential

The NM is arranged in an annular hexagon configuration of fuel rods and moderator that can result in a maximum credible k_{eff} of 0.993. Criticality could be caused by one or more of the following actions:

- an additional specified amount of fissile material is inserted within the assembly
- the water is replaced by a material that increases the reactivity of the NM, or if
- a specified number of fuel rods are removed from the midsection of the annular fuel rod assembly.

5.1.3 Criticality Controls and Limits

Criticality control of the neutron multiplier is accomplished by arranging a specified number of fuel rods in a fixed configuration in water at a

near optimum moderation. The specified number is experimentally determined under conditions of maximum sample interactions. Engineered safety features are incorporated in the NM design and administrative controls are established to insure that these criticality controls are met.

The final mass and configuration of the fissile fuel region was determined experimentally at the Critical Mass Laboratory for slightly undermoderated conditions. This corresponds to 1) flooded external irradiation tubes, 2) moderator temperature at the highest temperature coefficient of reactivity, and 3) voided central volume equal to the maximum voiding coefficient of reactivity.

5.1.3.1 NM Characteristics

The fuel region of the NM is an array of fuel rods arranged in a configuration that is slightly undermoderated and consequently if selected fuel rods are removed from the midsection of the annular assembly, reactivity will increase. If a removed fuel rod is transferred into its center test location, reactivity will increase. If any other change in fuel rod location is made, the reactivity will decrease. The fuel region is annular in shape with an interior water moderated region known as a "flux trap".

5.1.3.2 Temperature Effects

The effects of surrounding water temperature fluctuations on the reactivity of the NMA was determined experimentally at the Critical Mass Laboratory. The results of these critical approach measurements are shown in Figure 5-1. The critical number of rods decreases with increase in temperature initially but reverses at about 48°C. This decrease in the critical number of rods (2.62) corresponds to an increase in k_{eff} of 0.0021. These tests verify that no ambient temperature can cause the assembly to become critical.

5.1.3.3 Voiding Effects

When the flux trap region is voided, the reactivity of the NM increases. The effects of voiding were measured at the Critical Mass Laboratory and the results are shown in Figure 5-2. As the flux trap is voided, the critical number of rods decreases until 30% voiding is reached. At this point the voiding effect reverses and increased voiding causes an increase in the critical number of rods. The maximum effect at 30% voiding corresponds to a

FIGURE 5-1. Temperature Change Effect on Neutron Multiplier Criticality

FIGURE 5-2. Center Void Effect on Neutron Multiplier Criticality

decrease of 10.5 rods or an increase in k_{eff} of 0.0093. These tests verify that voiding of the center flux trap region cannot cause the assembly to become critical.

Voiding effects external to the fuel lattice were measured at the Critical Mass Laboratory. Voiding was found to have a considerable negative effect on criticality; the critical number of rods increased 2.4 rods for a 2-in. diameter and 6 for a 5-in. diameter void external to the assembly. This corresponds to a decrease in k_{eff} of 0.0022 for the 2 in. void and 0.0053 for the 5 in. void.

5.1.3.4 Sample Effects on Reactivity

The change in reactivity caused by various materials in the irradiation position of the NMA was determined at the Critical Mass Laboratory. The changes in k_{eff} are shown in Table 5-1 for various materials tested in the center tube. The changes in k_{eff} for various materials tested in the external tubes is shown in Table 5-2.

Since the addition of graphite to the irradiation tubes increases the reactivity above that for water, the presence of graphite and other low absorption scatterers in the facility is regulated by administrative control. The insertion of 1/3 of a fuel rod or about 7.4 g of ^{235}U increases the k_{eff} 0.0038 and consequently the 4 g limit imposed by the Criticality Safety Specification and administrative control is a very conservative limit.

If the NMA is assumed to be in a typical operating mode with external test tube in positions of least reactivity, the consequences of credible changes in the operation are shown in Table 5-3. Data is presented for two fuel loadings; one is the initial fuel loading of 252 fuel rods, and the other is the maximum possible loading of 258 fuel rods. The initial fuel loading is approximately 252 fuel rods having a maximum credible operating k_{eff} of 0.9872. The fuel loading could be increased, however, to about 258 fuel rods maintaining a maximum credible k_{eff} of 0.9924; less than the allowable value of 0.993.

The pneumatic sample transfer operation is a means for rapidly inserting or withdrawing a neutron capturing sample from the NMA. Insertion reduces the value of k_{eff} . Withdrawal of the sample increases k_{eff} to the preinsertion

TABLE 5-1. Effect of Material in Center Tube*
(Center Tube 1/2-Filled with H₂O)

Material	Position	k_{eff}^{**}
Water	Flooded Center Tube	-0.0050
1/3 Fuel Rod (~7.4 g ²³⁵ U)	In Void - Above Center	+0.0038
1 Fuel Rod	Centered Vertically	+0.0100***
Graphite (1-3/4 in. OD)	In Void in Top Half	+0.0028
Source Mockup (200 g SS)	In Water in Bottom Half	-0.0017
Bismuth (1.34-in. Tube)	In Void in Top Half	+0.0007
Mineral Oil (1.34-in. Tube)	In Void in Top Half	-0.0022
Boric Acid (6 g/l), Filled 2-in. Void Tube	Centered Vertically	-0.0258***

* See Appendix D for calculations.

** Based upon $k_{eff} = 0.9799$ with 252 fuel rods on a 0.6" lattice spacing.

***Center tube completely void of water.

TABLE 5-2. Effect of Outside Lattice Void Tubes and Material*

Diameter	Placement Description	k_{eff}^{**}
2 in.	Void (flush to lattice plate)***	-0.0022
5 in.	Void (flush to lattice plate)	-0.0053
2 in.	1.75-in. D Graphite Rod in Void (flush to lattice plate)	+0.0032
2 in.	Graphite Rod in Void Compared to Water (flush to lattice plate)	+0.0010
2 in.	1.75-in. D Tube Mineral Oil in Void (flush to lattice plate)	-0.0009

TABLE 5-2. (contd)

2 in	1.34-in. D Tube Bismuth in Void (flush to lattice plate)	-0.0012
2 in.	1.25-in. D Wood in Void (flush to lattice plate)	-0.0012
2 in.	1.25-in. D Plexiglas in Void (flush to lattice plate)	-0.0009
2 in.	Tube Mineral Oil in Void Compared to Water (flush to lattice plate)	+0.00005

* See Appendix D for calculations.

** Based upon $k_{eff} = 0.9799$ with 252 fuel rods on a 0.6" lattice spacing.

***Center tube completely void of water

TABLE 5-3. Effect of Operating Changes on k_{eff}

Initial Operating Conditions

1. 2 in. and 4 in. external irradiation tubes voided.
2. Top 1/2 of center irradiation tube voided.*
3. Ambient temperature of 21°C.
4. No irradiation sample in center tube.

<u>Action Taken</u>	<u>Δk_{eff}</u>	<u>k_{eff}</u>	
		<u>252 rods</u>	<u>258 rods</u>
Initial Operating Mode		0.9717	0.9769
Source Removal	+0.0017	0.9734	0.9786
Move 2 in. tube away	+0.0022	0.9756	0.9808
Move 4 in. tube away	+0.0043	0.9799	0.9851
Insert graphite (715g)	+0.0032	0.9831	0.9883
Increase temp to 48°C	+0.0021	0.9852	0.9904
Insert 4 g fissile sample	+0.0020	0.9872**	0.9924

* Complete flooding of center tube decreases k_{eff} by 0.0050.

**Maximum k_{eff} under credible operating conditions.

value. The NM is a subcritical water moderation system having neutron lifetimes on the order of a few milliseconds. The sample withdrawal is approximately 50 milliseconds and should, therefore, not result in a flux increase greater than the equilibrium value obtained by a slow withdrawal of the sample. Rabbit operations have been used in critical reactor experiments ($k_{\text{eff}} \geq 1.0$) for many years and have not presented any unforeseen safety problems.

5.1.3.5 Rod Removal Effect on Reactivity

In order to obtain a negative temperature effect on reactivity, the lattice configuration of the NMA was designed to be undermoderated. This characteristic can be explained as follows. In an undermoderated lattice, the pathlengths in the moderator are not sufficient to completely thermalize the fast neutrons. This reduces the number of fission producing neutron reactions within the fuel. If the temperature of the lattice is increased, these path lengths become less effective in moderating fast neutrons: 1) the hydrogen atom concentration per unit volume decreases (because of density decrease) and 2) equilibrium neutron spectrum with the hydrogen moderator is at a higher temperature. The assembly becomes further undermoderated and k_{eff} decreases. If a single fuel rod is removed from within a cluster of fuel rods, water replaces the rod and the path length in water is significantly increased. The additional thermal neutrons produced increase the probability of fission, resulting in a higher k_{eff} . In experiments conducted at the Critical Mass Laboratory, the removal of a rod from within the lattice increased k_{eff} by 0.00048. Removal of adjacent fuel rods in the 0.6 in. lattice leads to an overmoderating situation that reduces the value of k_{eff} and maintains subcriticality. Criticality could not result except by removal of specific fuel rods from their location within the lattice. If the operating conditions of the NMA correspond to those for 258 fuel rods in Table 5-3, the removal of 16 specifically selected fuel rods could cause criticality.

5.1.3.6 Normal Operating Conditions

The neutron multiplier has two normal states, "on" and "off". During sample irradiation the neutron multiplier will be "on" (i.e., the ^{252}Cf

source will be at the symmetrical center of the neutron multiplier). When no irradiation is in progress the neutron multiplier is normally "off" (i.e., the ^{252}Cf source is in the lowered position below the neutron multiplier).

Since many samples require long irradiation intervals, the multiplier is "on" most of the time.

The center tube is a wet tube except in cases of mass spectrometer or pneumatic sample transfer experiments. Three 2-in. and one 4-in. diameter external tubes are wet tubes and are in a fixed location. One 2-in. diameter and one 4-in. diameter external tube are dry and both are moved out of the irradiation position when they are not being used for irradiations. These tubes are not moved during sample irradiation or with samples in the tubes.

Samples are only irradiated in the sample irradiation tubes that are located in their design positions. A sample may be inserted and/or removed with the neutron multiplier either "on" or "off". There is no restriction on the number of samples that may be irradiated at any one time. There is a restriction, however, on the composition of the samples. The amount of fissile material which can be irradiated in the NMA is 4 g. A gamma monitor with a portable probe is located near the pool and is utilized to indicate excessive radiation exposure to personnel during sample removal and subsequent handling. When radiation levels exceed values set by Radiation Work Procedures, audible and visual alarms are energized.

A neutron proportional counter is positioned adjacent to the pool wall near the same level of the NMA in a submerged polyvinyl chloride (PVC) thimble. The PVC thimble and detector cause no significant effect on reactivity because of their distance from the NMA. This detector serves to monitor the operation of the NMA, and is used primarily to calibrate the flux levels at the irradiation tubes. The neutron detector also indicates the "on" and "off" state of the NMA.

The mass spectrometer experiment, which may be periodically performed, involves irradiation of 4 g of ^{235}U . In this experiment, the ^{235}U metal sample is located in an evacuated (2-in. diameter) drift tube which replaces

the normal central irradiation tube. The experiment is designed to obtain on-line mass spectrometry information on fission products.

Normal operating conditions include a 20-ft depth of water in the pool. The water level is maintained by a manually operated valve in series with a float controlled valve fill system. Pool water circulation through the filter and ion exchange column will be at a rate required to maintain water quality. Water quality is monitored by a standard conductivity probe.

5.1.3.7 Engineered Safety Feature

Certain safety features have been incorporated into the design of the NM to help insure that the criticality controls and limits are met during the operation. Rearrangement of the fuel rods in the NMA can cause criticality; therefore, design features must control this possibility. Accessibility to the NM is an important factor to consider in evaluating the possibility of fuel region alteration. A major barrier against direct access to the NMA is provided by the 15-ft water column over the unit. When the lattice-fuel assembly is in place in the pool, three element retainers and special nuts lock the assembly and cover plate to the holding plate of the support structure. The assembly or cover plate cannot be removed without use of a special tool to remove the locking nuts. The special tool will be kept and controlled by the Manager, Safety and Nuclear Materials Management. The lattice plate locking assembly improves the procedural control for preventing an unplanned lattice loading change. When the cover plate is in place, the fuel rods are covered and cannot be removed or altered. The cover plate also protects the fuel rods from damage by objects falling into the pool. A steel grate equipped with an intrusion detector is located over the top of the pool and serves to further limit access to the NMA. The intrusion detector alarm is located at 300 Area patrol headquarters and is energized on all off shift hours.

The only moving part of the NM is the motor driven source positioner mechanism. In case of misalignment or jamming, a slip clutch in the motor drive assembly will prevent damage from being done to the source, lattice plates, or fuel rods.

Irradiations are done in one central and six external tubes extending from the pool surface to the NM. The 2-in. diameter center tube is flooded except in cases of pneumatic sample transfer or mass spectrometer experiments. The external tubes are flooded except for one 2-in. and one 4-in. diameter tube. The dry tubes will be moved adjacent to the fuel assembly during sample irradiations and are held in this position by slots in the top plate. The wet tubes are held in position by plates bolted in a fixed location on the bottom plate. The irradiation tubes can therefore cause no displacement or damage to the fuel rods in the assembly.

Criticality cannot be caused by changes in position, flooding or voiding of any combination of tubes because the maximum number of fuel rods allowable to maintain subcriticality was experimentally determined for slightly under moderated conditions with flooded external tubes and a partially voided center tube.

5.2 RADIATION POTENTIAL AND CONTROL

Operating personnel can receive radiation exposures from several sources during routine operation of the NMA. Although the water column above the NMA provides adequate shielding to neutrons and gamma radiation from the fission reaction and ^{252}Cf sources, dry irradiation tubes are potential sources for personnel exposures. Manipulation of the ^{252}Cf sources and handling irradiated samples are also potential exposure sources. The radiation hazard potential of each source is evaluated and control measures are identified.

5.2.1 Radiation from Neutron Multiplier

The maximum heat output of the neutron multiplier is estimated to be 103 watts. The maximum thermal neutron flux in the central irradiation tube is on the order of 10^{10} n/cm²-sec. The 15-ft water column above the fuel region of the neutron multiplier acts as an excellent radiation shield. From comparison with Bulk Shielding Reactor Experimental data⁽²⁾ on radiation attenuation in water, it is estimated that with the sample irradiation tubes removed or flooded, the radiation level at the top of the pool due to neutron multiplier operation is less than 0.01 mR/hr. The radiation is essentially all gamma rays.

5.2.1.1 Radiation from Irradiation Tubes

The two external dry irradiation tubes are constructed with an offset to prevent direct radiation streaming. The radiation field in the top section of the tubes reported in The Preliminary Safety Analysis Report for the BNW Neutron Multiplier Facility,⁽³⁾ BNWL-B-341, is 10 mR/hr. This value is based on conservative assumptions. The field is a highly collimated gamma radiation.

Except for special experiments involving irradiation of a 4 g uranium sample at the bottom of an evacuated drift tube, or for pneumatic sample transfer irradiations, the central irradiation tube is water-filled. Anticipated radiation levels above a dry central irradiation tube were reported in BNWL-B-341 to be 150 mrem/hr. This radiation field is primarily due to thermal neutrons and is a highly collimated 2-in. diameter beam directly above the tube. Access to the roof area will be controlled with radiation zones established by Radiation Work Procedures.

5.2.1.2 ⁴¹Ar Production - External Irradiation Tubes

When the external dry irradiation tubes are used for sample irradiations or if the center tube is used for pneumatic sample transfer irradiations, ⁴¹Ar is produced by interaction of neutrons with the natural argon in air. In the worst case situation, if both dry external tubes are used for irradiations, the maximum ⁴¹Ar activity produced at saturation is approximately 80 μ Ci. The maximum permissible concentration in air is 2×10^{-6} μ Ci/cc for a 40-hr week.⁽⁸⁾ This concentration would be obtained by diluting the ⁴¹Ar in 4×10^7 cc of air or 1471 ft³. Transfer of the entire amount of ⁴¹Ar from the irradiation tubes could only be accomplished by a specially designed effort such as displacement of the entire air volume of the external dry tubes at one time. A possible way for this to occur is by a simultaneous failure of these external tubes allowing the air volume to be displaced with pool water. A metal failure or a mechanical breaching of the tube walls to cause this to happen is unlikely and engineered features prevent accidental submergence of the tubes during operation. Operating procedures will minimize the ⁴¹Ar problem. When dry external tubes are not being used, they will be

moved away from the irradiation position and flux in the external tubes will be reduced to zero. When the tubes are in the irradiate position the active volume is partially displaced by the sample. If large sealed containers are used for long irradiation of samples, Radiation Work Procedures require these containers to be opened in the hood if there is a potential hazard from ^{41}Ar .

5.2.1.3 ^{41}Ar Production - Pneumatic Sample Transfer System

When the pneumatic sample transfer system is installed in the center tube location and air is used as the transfer gas, ^{41}Ar will be formed. The maximum credible ^{41}Ar release is from the first pneumatic transfer cycle following a long period with the NM "on". For example, if the NM is "on" for an overnight irradiation of samples in the external tubes, the first pneumatic transfer cycle will move the saturated ^{41}Ar out of the center tube. The maximum credible amount is 8 μCi . The exhaust of the pneumatic sample transfer system is vented to the hood. Release for the worst case situation of 8 μCi is into a 1900 CFM air stream. Turbulence from air flow through the duct will provide good mixing and therefore adequate dilution to insure that the limit of 2×10^{-6} $\mu\text{Ci/cc air}^{(8)}$ will not be exceeded at the building exhaust. A volume of 143 CF air or 4.5 sec of flow will accomplish this required dilution. Calculations of the ^{41}Ar productions are shown in Appendix A.

5.2.2 Radiation from Sample Manipulation

Personnel radiation exposure is a potential hazard that can result during removal of irradiated samples from the NM and from the isotope collections at the detector location of the on-line mass spectrometer experiments. Control of this hazard is accomplished by use of approved Radiation Work Procedures and appropriate radiation monitoring. Shielding and remote handling techniques are utilized to control exposures to personnel so that the limit of 1 rem/yr is not exceeded. A gamma monitor located in the vicinity of the pool provides visual and audible alarm in case of high radiation fields.

In on-line mass spectrometer and pneumatic sample transfer system experiments, radiation exposure from the voided center tube is a potential hazard. Control of this hazard is accomplished by shielding and by physical

restraint. Access to the roof above the pool will be controlled by established Radiation Work Procedures. In the on-line mass spectrometer experiment, radiation exposure is possible from the mixed radiations from the isotopes at the collector or detector location on the mass spectrometer. Similar experiments being conducted at Washington State University indicate that radiation levels at the collector may approach 20 mR/hr, and lead shielding is adequate protection from this source. Operating experience will dictate the final requirements for adequate radiation protection to personnel.

Samples will be prepared for activation in the neutron multiplier by appropriate encapsulation to prevent spread of contamination. It is imperative that a low level of contamination be maintained to avoid adversely affecting low-level counting operations conducted in the 329 Building. Encapsulation techniques which have been developed for successful use in other irradiation facilities will be adapted for use in the NMF.

5.2.3 Radiation from ^{252}Cf Source Manipulation

Six ^{252}Cf sources will be delivered to the NMF in two separate shipments of three sources each. Shipment will be made in a large transportation cask mounted on a trailer. Following arrival, the sources will be physically transferred out of the transport cask into the NM pool. This phase of the operation will present a radiation exposure hazard to personnel involved in the source transfer. Exposure to the neutron field will be minimized by use of shielding or by operating at a distance which affords the necessary reduction in exposure level consistent with the required dexterity and maneuverability to accomplish the transfer rapidly and without malfunction.

Three methods of source transfer are evaluated in Appendix E: 1) manipulator, 2) track and trolley, and 3) auxiliary transfer cask systems. Although source transfers could be accomplished by all three methods, the track and trolley method will provide the least radiation exposure to personnel. Using this system, the six sources can be transferred with an estimated maximum exposure accumulation of 50 mrem (n + γ). An additional advantage of this system is that it uses the manipulator that accompanies the

shipment. This manipulator is specifically designed for the transfer operation. The possibility of accidental release of a source by this manipulator has been evaluated and found acceptably low.

The disadvantage of the manipulator transfer system is the higher exposure levels encountered in the operation. Using this method, the six sources could be transferred with an estimated maximum exposure accumulation of 450 mrem (n + γ).

A transfer cask would reduce exposure levels to 1/3; however, this level would not permit close approach to the cask. Remote moving would be required. The transfer would be further complicated by additional source handling; i.e., transfer from transport cask to transfer cask and from transfer cask to the NM pool.

No exposure hazards are encountered during assembly or disassembly of the sources into the source holder since this operation is done under water. Manipulators are used in this operation to remove the shipping adapter from each source and to attach the source into the source holder. A long-handled manipulator will be used to lower the source holder into the source drive assembly.

5.2.4 Radiation from Ion Exchange Unit

During normal operation of the NMA, the ion exchange unit will remove ^{24}Na which is in the pool water as a result of aluminum corrosion of the fuel rod cladding. The ^{24}Na is formed by the (n, α) reaction of fast neutrons on ^{27}Al . At equilibrium operating conditions, the NMA contributes about 0.1 μCi of ^{24}Na . The gamma radiation from this source is less than 0.1 mR/hr. Calculation of ^{24}Na production is shown in Appendix B.

A fuel rod cladding or source container failure could cause a potential radiation hazard from the ion exchange unit. Buildup of long-lived isotopes on the resin bed from such a failure could cause much higher exposure levels than result from normal operation. The unit is located in a pit below floor level and is covered by a steel grate that will support lead shielding over the resin bed. Lead shielding can also be stacked around the unit below the steel grate if desired.

Standard operating procedures require routine periodic measurements of the radiation exposure rate from the ion exchange unit. Increases in the exposure rate will indicate that a failure is in progress.

5.3 CONTINGENCIES FROM OPERATION

Operating procedures for the NMA are established to provide a safe, reliable system for sample irradiation. Careless, accidental or intentional disregard for these procedures can cause abnormal conditions in the NMF which are hazardous to personnel conducting irradiation experiments. Unnecessary radiation exposure to personnel is the most likely consequences of these abnormal conditions.

5.3.1 Fissile Material in Excess of Allowable Quantity

The possibility of accidental or intentional introduction of an additional amount of fissile material to the NM must be considered in the safety analysis. The Nuclear Safety Limits for the NM facility restrict the amount of fissile material in the facility to be the fuel loading of the neutron multiplier, sealed sources to drive the NM, and an additional 4 g of fissile material. NMF operating procedures require verification of the fissile material content of all samples prior to entry to the facility. The facility manager shall approve the introduction of any fissile material into the facility.

5.3.2 Improper Irradiation Sample Handling

The most credible abnormal occurrence in the NMF is improper handling of an irradiated sample which causes an unplanned radiation exposure to personnel. The chemical makeup of the many environmental samples which are irradiated is not completely defined; therefore expected activities of irradiated samples cannot always be estimated with certainty. To control such exposure, a radiation monitor equipped with audible and visual annunciation is located in the vicinity of the pool. All sample removal and handling will be done in accordance with an approved Radiation Work Procedure which will specify proper radiation monitoring procedures. It is concluded that the probability and consequence of this occurrence is acceptably low.

5.3.3 Flooding of External Irradiation Tubes

Damage from carelessness or accidents in handling irradiation tubes or sample containers could result in flooding of an external irradiation tube. Flooding of the external tubes cannot cause criticality since the final design of the fuel region was experimentally determined with the external irradiation tubes flooded. The main hazard potential from this accident would be unplanned radiation exposure from a highly radioactive sample being irradiated in a positive buoyancy sample container which floats to the surface. Warning of this hazard is provided by the gamma monitor which is equipped with audible and visible annunciation. Radiation Work Procedures and standard NMF operating procedures detail actions to be taken in the event of such annunciation. It is concluded that the probability and consequence of this occurrence is acceptably low.

5.3.4 Failure to Maintain Proper Water Level

The water level in the pool gradually drops because of evaporation from the pool surface. A low water level alarm will sound when the level has dropped to a preset level. If water is needed, it may be added by opening a normally closed manual valve in the water make-up line. The person adding the water is required to remain in the room until the proper water level is attained and the manual valve is closed. As a backup, a float control in the pool operates a valve in series with the manual valve to shut off the make-up water when the proper water level is attained. A very liberal calculation of evaporation from the pool under credible conditions indicates that the level would drop less than 4 in. per day. If the condition went undetected for a week the loss of water shielding would increase radiation levels at the top of the pool approximately a factor of 10 to 0.1 mrem/hr. Standard NMF operating procedures require checking the pool water level on a frequency found to detect a drop in water level before it can create a hazard. It is concluded that the probability and consequence of this misoperation is acceptably low.

The walls of the neutron multiplier pool are designed to withstand the earthquake described in Section 3.2.2. The inside of the pool is coated with several layers of a resin sealant to prevent leaching of materials from the

concrete into the pool water. If a crack should occur in the wall and the plastic was breached or a pinhole flaw was located in that vicinity, pool water could flow out into the concrete and surrounding soil. Particulate matter (radioactive or nonradioactive) in the water would encounter a high degree of holdup and entrapment in the concrete. Further holdup and entrapment would occur in the soil. The half-life of ^{24}Na is 15 hr and decay to 1% of the initial value occurs in 100 hr. The hazard from ^{24}Na from a possible pool leak is therefore acceptably low because of holdup and decay.

A discussion of the ^{24}Na activity which may be present in trace amounts (10^{-5} $\mu\text{Ci}/\ell$) in the pool water is given in Appendix B.

5.4 CONTINGENCIES FROM ENVIRONMENTAL CONDITIONS

Catastrophic events such as fire, flood and tornado will have little effect on safety of the NMA. An earthquake could cause serious damage such as a breach in the pool wall, disarrangement of the fuel rod assembly and a rupture of the fuel pins. A specific fuel disarrangement could result in a criticality incident. During normal operation of the NMA, safety of the system does not depend on continued operation of the support equipment.

5.4.1 Equipment Failure

Safety of the NMF is not dependent upon continued operation of supporting equipment. Circulation of water in the pool is not required for cooling purposes; only to provide necessary water quality. If the pump fails, the heat output from the NMA will cause a local temperature increase in the pool water surrounding the assembly; however, natural convection cooling will limit the temperature rise. This is not a critical situation because the temperature coefficient of the NMA is negative above 48°C .

The ^{252}Cf source positioner mechanism serves to turn the NMA "on" or "off". An operational failure would have no effect on the safety of the NMA since the source position does not significantly affect criticality. Manual override operation of the source positioner is available during a motor failure. The stainless steel of the sample containers lowers k_{eff} 0.0017.

A failure of the air handling equipment would not cause a significant hazard. The amount of airborne particulate material in the room will be

negligible because of the location of the NMA. Particulate materials which may be formed by leaching or corrosion will remain in the water column until they are removed on the filter and ion exchange column section of the water process system. Particulate radioactive materials could be present in certain types of irradiated samples; however, handling these types of samples is in accordance with an approved Radiation Work Procedure designed to reduce the risk of contamination spread to an acceptably low level.

5.4.2 Fuel and Source Cladding Failure

The purity of the water (conductivity should be in the range 3-30 μ mhos) should result in extremely long life (of the order of 10's of years) for the fuel cladding. The ^{252}Cf is contained in a pelletized aluminum powder matrix which is doubly encapsulated in stainless steel. If the cladding should in some way be penetrated, the leak would be of the slow pinhole variety. The filter and ion exchange column in the water process system will very efficiently remove any material from the water. Administrative controls require periodic checking of the radiation emanating from the filter and ion exchange column. If fissionable material or fission products are detected, action will be taken to find and eliminate their source.

5.4.3 Fire

The neutron multiplier is housed in a mineral fiber-insulated, metal structure constructed on a reinforced concrete foundation and floor. The building is constructed of noncombustible materials in accordance with the Uniform Building Code and is fully protected by a wet sprinkler system. A fire alarm system is provided which is tied into the 300 Area fire station. The building contents are selected to minimize the combustible loading within the NMF. The facility mission requires the presence of only minimal quantities of combustible materials. Fire, or fire fighting, will not result in an environmental hazard. The neutron multiplier is located near the bottom of a 20-ft deep pool of water and its safety does not depend on equipment or facilities which could be affected by fire or fire fighting.

5.4.4 Tornado

The probability of a tornado striking the NMF is extremely small. However, if the building were to be destroyed by a tornado, no nuclear radiation, or radioactive material hazard to personnel or the environment would result. Since the neutron multiplier is located below ground near the bottom of a 20-ft deep pool and its safety does not depend on above ground equipment or facilities, it would be virtually unaffected by complete destruction of the building. Irradiated samples will not be stored in the NMF.

5.4.5 Flood

The NMF is located at an elevation of 398 ft which is higher than the estimated 100-year maximum Columbia River flood stage of 386 ft. Flooding from natural Columbia River floods is therefore unlikely during the history of the NMF. If flooding from natural or other causes should occur, the safety of the NMA would not be affected since it operates in a flooded condition and is not dependent on above ground facilities.

5.4.6 Earthquake

Although the pool wall is designed to satisfy the Hanford Standard Category II Criteria for Earthquakes, the NMA is not specifically designed to this standard. If ground motion caused a breach in the pool wall with subsequent loss of water, operation of the NMA would be greatly affected. Depending upon the level of water above the NMA, the radiation levels above the pool could increase significantly. If the water is lost completely, the NMA will become far subcritical due to the absence of moderator. In either case, a radiation field would be present above the pool. This field is difficult to estimate because the level of water in the pool has a great influence on the value. If complete water loss occurs, the field is caused by delayed gamma radiation from fission product decay and by gamma radiation and neutron emission from the ^{252}Cf sources. The gamma radiation from fission product decay depends on the length of operation. The radiation field from the ^{252}Cf sources is estimated at 18 rem/hr at the top of the pool. If water is lost to the height of the top lattice plate, a leakage of neutrons occurs,

reactivity decreases and the NM operates at a lower fission rate. The remaining water reduces radiation from ^{252}Cf source to about 6 rem/hr. The radiation field is composed of the source dose rate, neutron leakage and prompt gamma ray dose rate from the NM operation.

If high radiation fields are caused by complete or partial loss of the water column, shielding could be placed over the pool by remote operation of the jib crane located adjacent to the pool. Additional support members could be placed over the pool grates and shielding materials could then be installed. If enough water remained in the pool to sustain the chain reaction, a hose could be lowered into the pool and the remaining water pumped out. The ^{252}Cf sources could then be manipulated from the top of the pool using a shadow shield over the sources. The sources could be separated from the source holder and moved to an alternate storage location.

The NMA support structure is rigidly mounted on the floor of the pool by use of anchor bolts into the concrete bottom. The four support legs are 40 in. high and the bottom mounting plate is securely attached with bolts. The top holding plate is bolted to the mounting plate with three 3/4-in. diameter tie rods. The 60 lb (fuel weight - 47.5 lbs) fuel-lattice assembly is held in place between the two plates. The center of mass of the fuel-lattice assembly is 52 in. above the pool floor and an earthquake-induced horizontal floor displacement would cause considerable upsetting force on the NMA. Three stabilizing or centering rods, 120° apart, are attached to the top holding plate and extended out to the pool wall. The holding plate is solidly held at the pool center line by these three rods. Motions induced in the pool floor would therefore have minimal effect on the NMA.

The risk of an earthquake induced criticality should be evaluated. Since the NM assembly is slightly undermoderated, criticality can possibly but not likely occur if the fuel rod configuration is rearranged in a specific manner. In the 0.6 in. lattice assembly, criticality can be induced by removal of certain specific fuel rods from the midsection of the annular assembly. Fuel rod removal could not be a random or accidental choice. For example, if two adjacent fuel rods are removed, reactivity would decrease because removal

of the adjacent fuel rods would result in overmoderation. For an accidental criticality to occur, the following sequence of events would be required:

- The fuel pins are held in place by the cover plate which is locked to the top holding plate. Either the cover plate or the holding plate would need to be separated from the assembly. This action would require shearing the locking bolts or retaining clips which hold the cover in place or the 3/4-in. diameter tie bolts which connect the top holding plate to the bottom mounting plate.
- Specific rods would then require removal from the assembly without disturbing the remaining fuel elements. Since the fuel rods are held in fixed configuration by close tolerance holes in the lattice plate, it is unlikely that single specific rods could be displaced by mechanical motions unrelated specifically to fuel rod removal. For example, if the top lattice plate was bounced off, the fuel rods would fall against each other and reactivity would decrease because of further undermoderation.
- The outer and inner rings of fuel elements would need to be maintained in their respective positions and orientations. If the top plate twisted with respect to the bottom plate, the fuel elements would be forced closer together in the center and the reactivity would decrease because of further undermoderation.

The most likely result of a severe, damaging earthquake event would be a collapse of the assembly which would cause loss in reactivity because of undermoderation. Earthquake caused forces are not likely to reproduce the specific rearrangement of fuel pins which can result in criticality.

5.5 CONSEQUENCES OF A CRITICALITY ACCIDENT

If the assumption is made that a specific number of designated fuel elements was incredibly removed from the fuel assembly, criticality would result. The analysis of such a hypothetical event is presented to demonstrate that the consequences are certainly not intolerable.

If criticality occurred, no physical damage to the facility or dangerous direct radiation exposure to personnel would result because the assembly is

in the pool under 15 ft of water. Loss of noble gases, iodine, and volatile fission products to the environment could occur after percolation up through the water column. Loss of particulate materials to the environment would be limited by percolation up through the water column and by the HEPA filter exhaust system.

Evaluation of the criticality consequences was based upon the following assumptions:

- The facility was operated continuously for 2 years prior to the event at 1.3×10^{-4} MW.
- The event was 10 MW for 1 second followed by steady state 1 kW for 24 hours.
- Three release periods were used; the first from 0-30 min, the second from 1/2-8 hr, and the third from 8-24 hr.
- Each release was 100% of noble gases, 10% of iodine isotopes and 1% of the volatile fission products.
- Doses were calculated for Hanford moderately stable and very stable meteorological conditions.

Thompson and Beckerley⁽⁴⁾ summarize a number of criticality accidents for heterogeneous assemblies and homogeneous solutions. The energy release from several of these events is shown in Table 5-4.

An accidental criticality event^(a) at the Oak Ridge Y-12 plant involving an enriched uranium solution in a 55 gal. drum yielded approximately 1.3×10^{18} total fissions in several bursts. The burst size was estimated to be 10^{17} fissions. The Recuplex criticality incident^(c) at Hanford in 1962 yielded 8.2×10^{17} fissions over a 37-hr period. Approximately 20% of the total energy release occurred in the first 1/2 hour of the incident.

Criticality accidents have not been experienced with systems equivalent to the NMA and the initial burst energy release cannot be predicted with accuracy. The 10 MW-sec assumption is equivalent to 3.12×10^{17} fissions

TABLE 5-4. Energy Release from Prompt Critical
Excursions for Various Systems

<u>System</u>	<u>Energy Release</u> (fissions)
^{235}U metal - water reflected	3×10^{16}
^{235}U oxide-plastic-water reflected	1.22×10^{17}
^{235}U metal foil - graphite	3.2×10^{16}
U-metal (4000 kg) - D_2O moderated	2.5×10^{18}
Partially enriched U - H_2O moderated	3×10^{18}
^{235}U - paraffin moderator and reflector	$10^{15} - 10^{16}$
$\text{PuO}_2(\text{NO}_3)_2 - \text{H}_2\text{O}$	$8 \times 10^{16}, 1.5 \times 10^{17}$
$^{235}\text{UO}_2\text{F}_2 - \text{H}_2\text{O}$	$10^{17}, 1.6 \times 10^{17}$
$^{235}\text{UO}_2(\text{NO}_3)_2 - \text{H}_2\text{O}$	$\sim 6 \times 10^{17}, 1.3 \times 10^{18(a)}$
$^{235}\text{UO}_2(\text{NO}_3)_2$, 34 kg in 800 l water	$4 \times 10^{19(b)}$
$\text{Pu-H}_2\text{O}$	$\sim 8.2 \times 10^{17(c)}$
^{235}U metal - beryllium, plastic	4×10^{17}

-
- a) several oscillations
b) repeated excursions
c) 37 hr of criticality

which is a factor of three greater than the generally accepted value of 10^{17} fissions for a first burst energy release. The assumed equilibrium energy release rate of 1 kW cannot be justified by experimental data. The equilibrium rate is established by the physical-chemical parameters of the system. The parameters may be greatly influenced by the initial burst event. If the steady state energy release is assumed to be 1 kW-day, the ratio of the initial burst energy to the steady state energy is about the same as for the Recuplex incident.

Calculations were made using ORIGEN and SUBDOSA computer codes.⁽⁵⁾
Dose predictions for the noble gas fraction are shown in Figures 5-3 through 5-6 for stable and moderately stable conditions at 1,000, 2,000, 5,000 and 10,000 meters. Dose predictions from the iodine fraction are shown in

FIGURE 5-3. Inhalation Dose Prediction, Rem-Noble Gases
(assumes 100% release of Noble Gases)
Stable Meteorological Conditions

FIGURE 5-4. Inhalation Dose Prediction, Rem - Noble Gases
(assumes 100% release of noble gases)
Moderately Stable Meteorological Conditions

FIGURE 5-5. External Dose Prediction, Rem - Noble Gases
(assumes 100% release of Noble Gases)
Stable Meteorological Conditions

FIGURE 5-6. External Dose Prediction, Rem - Noble Gases
 (assumes 100% release of Noble Gases)
 Moderately Stable Meteorological Conditions

FIGURE 5-7. Inhalation Dose Prediction, Rem - Soluble I_2
(assumes 10% release of I_2)
Stable Meteorological Conditions

FIGURE 5-8. Inhalation Dose Prediction, Rem - Soluble I_2
 (assumes 10% release of I_2)
 Moderately Stable Meteorological Conditions

FIGURE 5-9. Inhalation Dose Prediction, Rem - Insoluble I_2
(assumes 10% release of I_2)
Stable Meteorological Conditions

FIGURE 5-10. Inhalation Dose Prediction, Rem - Insoluble I_2
 (assumes 10% release of I_2)
 Moderately Stable Meteorological Conditions

FIGURE 5-11. Inhalation Dose Prediction, Rem
Soluble Volatile Fission Products
(assumes 1% release of Volatile Fission Products)
Stable Meteorological Conditions

FIGURE 5-12. Inhalation Dose Prediction, Rem
Soluble Volatile Fission Products
(assumes 1% release of Volatile Fission Product)
Moderately Stable Meteorological Conditions

FIGURE 5-13. Inhalation Dose Prediction, Rem
 Insoluble Volatile Fission Products
 (assumes 1% release of Volatile Fission Products)
 Stable Meteorological Conditions

FIGURE 5-14. Inhalation Dose Prediction, Rem
 Insoluble Volatile Fission Products
 (assumes 1% release of Volatile Fission Products)
 Moderately Stable Meteorological Conditions

*ASSUMES 100% RELEASE OF NOBLE GASES, 10% RELEASE OF IODINE ISOTOPES, AND 1% RELEASE OF VOLATILE FISSION PRODUCTS

FIGURE 5-15. Total External Dose Prediction, Rem
Stable Meteorological Conditions

*ASSUMES 100% RELEASE OF NOBLE GASES, 10% RELEASE OF IODINE ISOTOPES AND 1% RELEASE OF VOLATILE FISSION PRODUCTS.

FIGURE 5-16. Total External Dose Prediction, Rem
Moderately Stable Meteorological Conditions

Figures 5-7 through 5-10. Dose predictions for the volatile fission products (Cs, Se, Te) are shown in Figure 5-11 through 5-14. Total external dose predictions for body and skin are shown in Figures 5-15 and 5-16.

Visual detection of a criticality might be difficult because visual contact is obscured by the 15-ft water column and the NMA top holding plate and cover. Visual evidence would be limited to bubble formation on the fuel rods and the bluish glow from the Cerenkov radiation during the short lived initial burst. The top holding plate and cover would prevent observation of these symptoms. The subsequent stages of criticality would possibly not appear different from routine operation.

A criticality condition would, however, be detected by the neutron calibration monitor located in the pool adjacent to the NMA. Although the detector might saturate during the initial burst, subsequent stages of criticality would indicate abnormally high readings on the calibration monitor. An alarm system signals this condition locally. The calibration monitor will be in continuous service with emergency power backup. For those periods in which the calibration monitor is not in service (equipment failure and maintenance service) insertion of samples for irradiation will be prohibited.

In the extremely unlikely situation that an accidental criticality did occur and caused a failure of the fuel cladding, radioactive gases released within the operating area of the NMF would be detected by the gamma detector giving both visual and audible alarms. This detector, like the calibration monitor, will be in continuous service with emergency power backup. A significant inhalation dose is not likely to be received from the radioactive gases because the room air is rapidly exchanged by the pass-through ventilation system in the NMF.

An actual or suspect occurrence of a criticality situation will require specific action on procedures designed to protect personnel and equipment from the consequences of such an incident. The severity of the incident will dictate the course of action to be taken. For example, if the pool wall is breached by the action causing the criticality, high radiation fields might be present in the room and the action taken would be different than in the case

of an intact water column. Minimum accomplishments following an actual or suspected criticality will include the following:

- Establish that a criticality event is in progress. Verification can be made by use of the neutron calibration detector. Evacuate facility until potential hazard from radioactive gases has been evaluated. Access to the room and subsequent actions will be governed by the radiation levels.
- Notify organizations who have a responsibility in this matter.
Assess the probable danger involved and evacuate the necessary areas.
- Quench the reaction by introduction of boron materials into appropriate irradiation tubes. Boron materials will be stored in an appropriate location within easy access to the NMA.
- Install appropriate shielding and/or restrict entry if high radiation fields exist.
- Determine cause of criticality and make necessary re-evaluations and revisions of procedures and/or equipment to prevent recurrence.
- A written recovery plan will be used if possible.

5.6 PLANS FOR EVENTUAL SHUTDOWN AND DISPOSAL OF THE NMF

If at some future time the need for the neutron multiplier no longer exists, the facility may be shut down and disposed of with minimal expenditure of time or funds. The exact steps required for shutdown and disposal will be developed when the decision is made to shut down the facility. A possible shutdown and disposal plan is given below:

- 1) Remove the fuel elements and ship them to a processing plant for recovery of the uranium
- 2) Remove and transfer the ^{252}Cf source
- 3) Process the pool water through the filter and ion exchanger for a sufficient length of time to reduce the amount of dissolved or particulate radioactive material in the water to such a level that the water may be disposed of in the cold process sewer system

- 4) Make required modifications to water process system and pump into cold process sewer system
- 5) Dispose of hardware which was situated in or close to the neutron multiplier unit as low level radioactive waste
- 6) The remainder of the facility should contain only trace amounts of radioactivity. Smear and monitor the remainder of the facility to detect any concentrations of smearable or fixed radioactivity. Any contaminated material or equipment should be selectively disposed of as radioactive waste. Disposal of all other material and equipment should follow the procedures used for non-contaminated materials.
- 7) Fill in or install a permanent cover over the neutron multiplier pit.

REFERENCES

1. R. C. Lloyd et al., Criticality Studies of a Neutron Multiplier Lattice, BNWL-2031, Battelle, Pacific Northwest Laboratories, Richland, WA. 99352, 1976.
2. Reactor Handbook, 2nd Edition, Vol. 1 Materials, C. R. Tipton, Jr. Editor, 1960. Interscience Publishers, Inc.
3. Ron Hall and George Rieck, Preliminary Safety Analysis Report for the Battelle Northwest Multiplier Facility, BNWL-B-341, Battelle, Pacific Northwest Laboratories, Richland, WA, 99352, October 1973.
4. T. J. Thompson and J. G. Beckerley (editors), The Technology of Nuclear Reactor Safety - Vol. I, MIT Press, Cambridge, Mass., 1964.
5. W. E. Kennedy, Jr. "Release Exposures from a Neutron Multiplied Facility Criticality Incident," May 10, 1976. Appendix F.
6. R. B. Richmond and C. W. Pollock, Corrosion and Wear Surveillance in Plutonium Recycle Test Reactor Through December, 1967, BNWL-726, Battelle, Pacific Northwest Laboratories, Richland, WA, 99352, July 1968.
7. Samuel Glasstone and Alexander Sesonske, Nuclear Reactor Engineering, D. Van Nostrand Company, Inc. Princeton, New Jersey, 1963.
8. Rules and Regulations of the United States Nuclear Regulatory Commission. Title 10, Chapter 1, Code of Federal Regulation, Part 20, Standards for Protection against Radiation. April 30, 1975

APPENDIX A

^{41}Ar PRODUCTION

⁴¹Ar PRODUCTION

Air contains approximately 0.93% (by volume) of the inert gas argon which is 99.6% ⁴⁰Ar. The (n,γ) reaction with ⁴⁰Ar yields ⁴¹Ar, a beta emitter with a 1.83 hr half life.

The following assumptions were made in calculating ⁴¹Ar production in a capped external irradiation tube:

- 1) ⁴¹Ar is produced during a long term irradiation at an average flux of 3×10^9 neutrons/cm²-sec assumed to exist in the approximately 2-ft long portion of a 4-in. diameter irradiation tube which is adjacent to the fuel region of the neutron multiplier.
- 2) The ⁴¹Ar will remain in the capped irradiation tube until physical action by facility personnel disturbs the condition in the tube.

The flux of 3×10^9 neutrons/cm²-sec is a conservative estimate of the average flux in the 2-ft long section of a 4-in. diameter external irradiation tube. ⁴¹Ar production in the irradiation tube outside the 2-ft long section adjacent to the core will be negligible compared to production in this section. There will be no mechanism for ⁴¹Ar transport except for normal slow diffusion in stagnant uniform temperature air.

Data

⁴⁰Ar Target

Composition in air	-	0.934% (by volume)
Molecular weight	-	39.94
Cross section, σ	-	0.64×10^{-24} cm ²
Density, g/l	-	1.784

⁴¹Ar

Decay constant, λ,	-	1.052×10^{-4} /sec
--------------------	---	-----------------------------

For External Irradiation Tubes

Volume

$$4 \text{ in. diameter tube} = \frac{(4)^2}{4} (24) (\pi) (16.387) = 4942 \text{ cm}^3$$

$$2 \text{ in. diameter tube} = \frac{(2)^2}{4} (24) (\pi) (16.387) = \frac{1235}{\text{TOTAL}} \text{ in.}^3$$

6177 cm³

Target ⁴⁰Ar

$$\text{Atoms} = \frac{(6.177)(0.00934)(1.784)(6.023 \times 10^{23})}{39.94} = 1.55 \times 10^{21}$$

⁴¹Ar Production (at saturation)

$$\frac{dN}{dt} = \text{Production-Decay} = \phi \sigma n - \lambda n$$

or
$$N = \frac{\phi \sigma n}{\lambda} (1 - e^{-\lambda t}) + N_0 e^{-\lambda t}$$

if $N_0 = 0$ and $t = \text{long compared to } t_{1/2}$

then $N_{\text{sat}} = \frac{\phi \sigma n}{\lambda}$ or $\text{Activity}_{\text{sat}} = \phi \sigma n$

or $\text{Activity}_{\text{sat}} = (3 \times 10^9)(0.64 \times 10^{-24})(1.55 \times 10^{21}) = 2.98 \times 10^6 \text{ d/s.}$

$$= 81 \mu\text{Ci } ^{41}\text{Ar}$$

For Pneumatic Sample Transfer System in Central Irradiation Tube

Assume that the pneumatic system replaces the center tube so that the active volume is 12 in. long and that air is used to drive the samples.

Volume

$$= \frac{(2)^2}{4} (\pi)(12)(16.387) = 617.28 \text{ cm}^3$$

Target Ar ⁴⁰

$$= (0.617)(0.00934) \frac{(1.784)}{39.94} (6.023 \times 10^{23}) = 1.55 \times 10^{20} \text{ atoms}$$

^{41}Ar Production at Saturation

$$\begin{aligned}\text{Activity}_{\text{sat}} &= (3 \times 10^9)(0.64 \times 10^{-24})(1.55 \times 10^{20}) = 2.98 \times 10^5 \text{ d/s} \\ &= 8.06 \text{ } \mu\text{Ci } ^{41}\text{Ar}\end{aligned}$$

^{41}Ar Production for a 10 Minute Sample Irradiation

$$\begin{aligned}A &= A_{\text{sat}}(1 - e^{-\lambda t}); \quad \lambda t = \frac{(.693)(10)}{(1.83)(60)} = 0.0631 \\ &= (8.06)(1 - e^{-0.0631}) = 0.5 \text{ } \mu\text{Ci } ^{41}\text{Ar}\end{aligned}$$

APPENDIX B

CALCULATION OF ^{24}Na ACTIVITY IN POOL WATER⁽³⁾

CALCULATION OF ^{24}Na ACTIVITY IN POOL WATER⁽³⁾

The pool water will contain trace amounts of ^{24}Na . A beta emitter with a 15-hr half life, ^{24}Na is produced by the (n,α) reaction of fast neutrons with ^{27}Al . The decay product of ^{24}Na is stable. The ^{24}Na activity will remain in the pool water until it decays or is retained in the ion exchange column. The maximum concentration of ^{24}Na in the pool water will be less than 10^{-5} $\mu\text{Ci}/\ell$ (as shown in this appendix). Normally, with proper cleanup of the pool water, the concentration would be significantly lower, since a large portion of the ^{24}Na would be collected on the ion exchange cartridge.

The $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ reaction is a threshold reaction occurring at approximately 3.25 MeV. The cross-section is initially quite small, not reaching 1 millibarn until 5 to 6 MeV. From 6 MeV it increases monotonically, reaching a value of approximately 90 millibarns at 10 MeV. The maximum thermal neutron flux in the neutron multiplier will be approximately 10^{10} neutrons/ $\text{cm}^2\text{-sec}$. The maximum flux above the $^{27}\text{Al}(n,\alpha)$ threshold is found from diffusion theory calculations to be approximately 2×10^8 neutrons/ $\text{cm}^2\text{-sec}$. The average above threshold flux is about 3/4 of this value.

Essentially any collision of a neutron in water will degrade its energy to below the threshold; therefore, the $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ reaction is only important in the fuel rod cladding. The ^{24}Na formed in the reaction will remain in the aluminum cladding until it decays or is leached into the water. Because of low porosity, there is no leaching from the aluminum metal. The ^{24}Na in the water comes from the thin oxide layer on the external surface of the fuel rod and is leached out at a corrosion rate which permits decay prior to entry into the water. Corrosion rates observed in the PRTR,⁽⁶⁾ under conditions which were more favorable for corrosion than those that will exist in the neutron multiplier pool, were less than 0.0001 in. per year.

The following calculations give an estimate of the ^{24}Na activity in the water:

$$R = \text{Reaction Rate/cm}^3 = \phi N_{\text{Al}} \bar{\sigma}$$

The flux above the $^{27}\text{Al}(n, \alpha)$ threshold is assumed to be 2×10^8 neutrons/cm²-sec.

The spectrum weighted average cross section is assumed to be 10 millibarns.

$$N_{\text{Al}} = \frac{(2.69)(6.023 \times 10^{23})}{26.99}$$

$$= 6.0 \times 10^{22} \text{ atoms/cm}^3$$

$$R = (2 \times 10^8)(6.0 \times 10^{22})(0.01 \times 10^{-24})(3.6 \times 10^3)$$

$$= 4.32 \times 10^8 \text{ atoms of } ^{24}\text{Na produced/cm}^3\text{-hr}$$

At equilibrium in the aluminum

$$\frac{d N_{24}}{dt} = 4.32 \times 10^8 - \lambda N_{24} = 0$$

$$N_{24} = \text{atoms of } ^{24}\text{Na/cm}^3$$

$$\lambda = \frac{0.693}{\text{half life of } ^{24}\text{Na}} = 4.62 \times 10^{-2} \text{ hr}^{-1}$$

$$= 1.283 \times 10^{-5} \text{ sec}^{-1}$$

$$N_{24} = \frac{4.32 \times 10^8}{4.62 \times 10^{-2}}$$

$$= 9.35 \times 10^9 \text{ atoms/cm}^3 = \text{equilibrium concentration of } ^{24}\text{Na in aluminum clad}$$

Assume that the corrosion rate of aluminum is 0.1 mils/yr =
 2.9×10^{-8} cm/hr

V = Volume of material removed from rods/hr

$$= \pi(n)(\ell)(r_1^2 - r_2^2)$$

where

n = number of rods

ℓ = length of rod

r_1 = radius of rod

$r_2 = r_1$ - corrosion rate in cm/hr

Assume that the multiplier will contain 252 rods each with OD of 0.4 in. and length of 22.75 in.

Substituting in these values yields

$$V = 1.41 \times 10^{-3} \text{ cm}^3/\text{hr}$$

$$P = \text{quantity of } {}^{24}\text{Na entering water/hr} = N_{24} V = (9.35 \times 10^7)(1.41 \times 10^{-3}) \\ = 1.32 \times 10^7 \text{ atoms/hr}$$

At equilibrium in the water

$$\frac{dN_{24}^1}{dt} = P - \lambda N_{24}^1 = 0$$

where N_{24}^1 = atoms of ${}^{24}\text{Na}$ in the water

$$N_{24}^1 = \frac{P}{\lambda} = \frac{1.32 \times 10^7}{4.62 \times 10^{-2}} = 2.85 \times 10^8 \text{ atoms at equilibrium}$$

$$\text{Activity} = \lambda N_{24}^1 = (1.283 \times 10^{-5})(2.85 \times 10^8) \\ = 3.65 \times 10^3 \text{ dis/sec} \\ = 0.099 \text{ } \mu\text{Ci}$$

Volume of water in 5-ft diameter x 20-ft deep pool = 11120
 liters

$$\text{Na activity} = 0.89 \times 10^{-5} \text{ } \mu\text{Ci/l}$$

APPENDIX C

ESTIMATION OF HEAT OUTPUT FROM NMA

The NMA will be operated with 100 mg of ^{252}Cf at an estimated fission rate of 3.3×10^{12} fission/second. This fission rate is based upon the following:

- Source emission - 2.4×10^{11} neutrons/second
- Neutron absorption by ^{235}U - 40%
- Probability of fission - 85%
- Multiplication factor - 40

$$\text{Rate} = (2.4 \times 10^{11})(0.4)(0.8)(40) = 3.3 \times 10^{12} \text{ fission/sec}$$

Since the energy release per fission is about 195 MeV⁽⁷⁾, the total energy released during operation is

$$(3.3 \times 10^{12})(195) = 6.44 \times 10^{14} \text{ MeV/sec}$$

since 1 MeV = 1.52×10^{16} Btu

$$\begin{aligned} E &= (6.44 \times 10^{14} \text{ MeV/sec})(1.52 \times 10^{-16} \text{ Btu/MeV}) \\ &= 0.0978 \text{ Btu/sec} \\ &= (0.0978 \text{ Btu/sec})(3600 \text{ sec/hr}) \\ &= 352.12 \text{ Btu/hr} \end{aligned}$$

$$1 \text{ Btu/hr} = 0.2931 \text{ watt}$$

$$\begin{aligned} E &= (352.12 \text{ Btu/hr})(0.2931 \frac{\text{watt}}{\text{Btu/hr}}) \\ &= 103.2 \text{ watts} \end{aligned}$$

APPENDIX D

CALCULATION OF REACTIVITY CHANGE IN NMA

If changes are made in the operating conditions of NMA, the reactivity of k_{eff} is altered. Calculation of these changes in reactivity or k_{eff} are based upon data taken from "Criticality Studies of a Neutron Multiplier Lattice"⁽¹⁾ Data from Figure 7, p. 18⁽¹⁾ is shown in Figure D-1.

Voiding 2-in. Diameter Center Tube

1/2 full of water	$\frac{N_c}{276.3}$	(p. 5)
filled with water	$\frac{281.9}{}$	(p. 10)

$$\Delta N_c = -5.6$$

$\frac{N_c}{252}$	$\frac{k_{eff}}{0.9799}$	
246.4	$\frac{0.9749}{}$	(From D-1)
Δk_{eff}	-0.0050	

$$1/2 \text{ full to void} \quad \Delta N_c = 4.9 \text{ rods} \quad (\text{Table X, p.27})$$

$\frac{N_c}{252}$	$\frac{k_{eff}}{0.9799}$	
256.9	$\frac{0.9842}{}$	(From D-1)
Δk_{eff}	+0.0043	

$$\text{Total } \Delta k_{eff} = 0.0050 + 0.0043 = +0.0093$$

Fuel Rod Addition

$$1/3 \text{ full rod in void of center tube } 1/2 \text{ full water} \quad \Delta N_c = +4.37 \quad (\text{Table V, p. 13})$$

$\frac{N_c}{252}$	$\frac{k_{eff}}{0.9799}$	
256.37	$\frac{0.9837}{}$	(From D-1)
Δk_{eff}	+0.0038	

1 Fuel Rod
centered vertically

$$\Delta N_c = +11.46$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
263.46	0.9899
Δk_{eff}	+0.0100

Graphite (1.75-in. O.D.)
in void in top half

$$\Delta N_c = +3.29$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
255.3	0.9827
Δk_{eff}	+0.0028

Source (200g SS)
in water, bottom half

$$\Delta N_c = -1.86$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
250.14	0.9782
Δk_{eff}	-0.0017

Bismuth (1.34 in. D tube)
in void in top half

$$\Delta N_c = +0.87$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
252.87	0.9806
Δk_{eff}	+0.0007

Mineral Oil (1.34 in. D tube)
in void in top half

$$\Delta N_c = -2.40$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
249.6	0.9777
Δk_{eff}	-0.0022

Boric Acid (6 g/l)

filled 2 in. center tube

$$\Delta N_c = -29.1$$

(Table V, p. 13)

N_c	k_{eff}
252	0.9799
222.9	0.9541
Δk_{eff}	-0.0258

2 in. Void Outside Lattice Plate

flush to lattice plate

$$\Delta N_c = -2.39 \text{ rods}$$

(Table VI, p. 14)

N_c	k_{eff}
252	0.9799
249.6	0.9777
Δk_{eff}	-0.0022

5 in. Diameter Void

flush to lattice plate

$$\Delta N_c = -5.97$$

(Table VI, p. 14)

N_c	k_{eff}
252	0.9799
246.03	0.9746
Δk_{eff}	-0.0053

4 in. Diameter Void (estimate)

flush to lattice plate

	N_c	Ratio
2"	-2.39	-1.195
5"	-5.97	-1.194

4-in. D. Void

$$\Delta N_c = (4)(-1.1945) = -4.78 \text{ Rods}$$

N_c	k_{eff}
252	0.9799
247.22	0.9756
Δk_{eff}	-0.0043

2 in. Tube Filled with
1.75 in. D. Graphite Rod
 flush to lattice plate

$$\Delta N_c = +1.25$$

(Table VI, P. 14)

N_c	k_{eff}
252	0.9799
253.25	0.9809
Δk_{eff}	+0.0010

2 in. Tube Filled with
Graphite Compared to Void

$$\Delta N_c = +3.63$$

(Table VI, p. 14)

N_c	k_{eff}
252	0.9799
255.63	0.9831
Δk_{eff}	+0.0032

2 in. Void with 1.34-in. D
Tube Mineral Oil
 flush to lattice plate

$$\Delta N_c = -0.90$$

(Table VI, p. 14)

N_c	k_{eff}
252	0.9799
251.1	0.9790
Δk_{eff}	-0.0009

2 in. Void with 1.34-in. D
Tube of Bismuth
 flush to lattice plate

$$\Delta N_c = -1.31$$

(Table VI p. 14)

N_c	k_{eff}
252	0.9799
250.7	0.9787
Δk_{eff}	-0.0012

2-in. Void with
1.25-in. D Wood

flush to lattice plate

$$\Delta N_c = -1.37$$

(Table VI, p. 14)

$\frac{N_c}{}$	$\frac{k_{eff}}{}$
252	0.9799
250.63	0.9787
Δk_{eff}	-0.0012

2-in. Void with
1.25 in. D Plexiglass

flush to lattice plate

$$\Delta N_c = -0.81$$

(Table VI, p. 14)

$\frac{N_c}{}$	$\frac{k_{eff}}{}$
252	0.9799
251.2	0.9790
Δk_{eff}	-0.0009

2-in. Void with 1.34-in. D
Mineral Oil Compared to Water

flush to lattice plate

$$\Delta N_c = +0.06$$

(Table VI, p. 14)

$\frac{N_c}{}$	$\frac{k_{eff}}{}$
252	0.9799
252.06	0.97995
Δk_{eff}	+0.00005

Temperature Effect

from 21 C to 48 C

$$\Delta N_c = +2.61$$

(Table II, p.6)

$\frac{N_c}{}$	$\frac{k_{eff}}{}$
252	0.9799
254.61	0.9820
Δk_{eff}	+0.0021

Fissile Material

For 1/3 rod or 7.4 grams
(or 0.59 rod/gram)

$$\Delta N_c = +4.37 \quad (\text{Table V, p. 13})$$

For 4 grams

$$\Delta N_c = (4)(0.59) = +2.36$$

N_c	k_{eff}
252	0.9799
254.36	0.9819
k_{eff}	+0.0020

Rod Removal

for removal of 12 rods

$$\Delta N_c = +6.7 \quad (\text{p. 26})$$

N_c	k_{eff}
252	0.9799
258.7	0.9857
Δk_{eff}	0.0058

$$\text{reactivity} = \frac{0.0058}{12} = 0.00048/\text{rod}$$

$$k_{eff} \text{ to Criticality} = 1 - 0.9924 = 0.0076$$

$$\text{rod equivalent} = \frac{0.0076}{0.00048} = 15.8 \text{ rods}$$

FIGURE D-1. Fuel Rod Loading Effect on Neutron Multiplication Factor, (k_{eff})

APPENDIX E

EVALUATION OF ^{252}Cf SOURCE TRANSFER METHODS

APPENDIX E

Evaluation of ^{252}Cf Source Transfer Methods

Manipulation of the ^{252}Cf sources during unloading from the transport cask will expose personnel to neutron and gamma radiation. Six sources ranging from 13.2 to 23.0 mg (at the time of fabrication) will require transfer from the transport cask to the NM pool. The largest source will have decayed to less than 20 mg at the time of delivery.

Exposure rates of various distances have been estimated from exposure data collected during field use of ^{252}Cf sources of different intensities (2 mg, 585 μg and 194 μg). These estimates are shown in Figure E-1.

In the past, ^{252}Cf source transfers during field use have been accomplished with manipulators, long-handled tools equipped with remotely operated jaws which engage the source. A maximum working manipulator length has been 12 ft. Radiation levels at this distance are estimated to be 4.5 rem/hr ($n + \gamma$). Time required for a source transfer cycle is estimated to be one minute, resulting in an exposure of 0.075 rem ($n + \gamma$) per source.

Another system has been devised to make the source transfer from the transport cask to the NM pool. This system is a 16-ft track mounted about 6 ft above the NMF roof, centered above the roof hatch opening and extending out from the wall so that the transport trailer can be parked directly under the outer end. A remotely operated trolley will be used to position a remotely operated lift line directly over the transport cask opening. A transfer manipulator tool which accompanies the shipment will be attached to the lift line. After the source is engaged by the manipulator, personnel will be cleared from the area. The source will be withdrawn from the cask and caused to contact the side of a paper-lined funnel located over the cask entrance. Lateral motion will be caused by a slight movement of the trolley. The source is then lowered into the cask and the paper liner of the funnel is checked for contamination. If contamination is found, the transfer will be terminated at this point. If the liner is free of contamination, the source will be withdrawn from the cask and raised vertically to the track with the trolley

held securely at the outer position. When the source manipulator has been raised to the track, the trolley will then be moved along the track to a point directly above the NM pool. The source will then be lowered into the pool and disengaged from the manipulator under water.

The control lines for the trolley and lift can be located 50 ft from the closest approach to the source. The exposure level is estimated to be 0.175 rem/hr ($n + \gamma$) at this distance. A complete source transfer cycle will require approximately 3 min for a total exposure of 0.009 rem ($n + \gamma$) per source.

An auxiliary transfer cask could be used to move the ^{252}Cf sources from the transport cask to the NM pool. From exposure data taken in the field, a 10-in. thick paraffin moderator will reduce radiation levels by about 1/3. A 20-in. diameter x 20-in. high cask would weigh over 200 lb. In use, the transfer cask would be placed adjacent to the transport cask and the source remotely transferred. The transfer cask would then be remotely moved adjacent to the NM pool and the source transferred into the pool.

This method requires additional manipulation of the sources as well as remote movement of the transfer cask. Positioning the transfer cask close to the transport cask would be difficult because of the size and configuration of the transfer cask and trailer.

FIGURE E-1. Exposure Rate Estimate from a 20 mg ^{252}Cf Source Versus Distance

APPENDIX F

RELEASE EXPOSURES FROM A NEUTRON
MULTIPLIER FACILITY CRITICALITY INCIDENT

Pacific Northwest Laboratories

Project Number _____

Internal Distribution

EC Watson
DL Strenge
File/LB

Date May 10, 1976

To George Rieck

From WE Kennedy, Jr. *WE Kennedy Jr*

Subject Release Exposures from a Neutron Multiplied Facility Criticality Incident

Calculations of the inhalation and external exposures from radionuclides released from a Neutron Multiplier Facility Criticality accident have been made and are listed in the following tables. The radionuclide quantities were calculated using the ORIGEN computer code, with input values of 23.7 gram-atoms of ^{235}U , 1.6 gram-atoms of ^{238}U , 1.6 gram-atoms of ^{27}Al , and 4.0×10^{-4} gram-atoms of ^{252}Cf . The facility was assumed to operate at an effective power of 1.3×10^{-4} MW for a period of two years prior to the accident levels of 1 MW for 1 second and 1 kW for 24 hours. Three release periods were assumed: the first at thirty minutes after criticality, the second at eight hours after criticality, and the third at one day after criticality. Each release assumed that 100% of the Kr and Xe isotopes, 10% of the iodine isotopes, and 1.0% of the volatile fission products (the isotopes of Cs, Se, and Te) were released. Dose calculations were performed for these inventories using these standard release fractions to allow for future scaling. The inhalation dose was calculated for Hanford moderately stable and very stable meteorological conditions, for both soluble and insoluble radionuclide conditions at the ten downwind distances shown in the tables. The organs of reference for the inhalation exposure were Total Body, Bone, Lungs and Thyroid. The total external exposures for the three release periods were calculated using the SUBDOSE computer code for the two stability cases, and are shown in the following tables.

WEK:mh

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	9.4E-03	7.7E-03	4.3E-03	2.4E-03	1.2E-03	4.1E-04	1.6E-04	6.4E-05	1.9E-05	7.4E-06
	BONE	4.9E-02	4.0E-02	2.3E-02	1.3E-02	6.9E-03	2.5E-03	1.1E-03	5.1E-04	2.1E-04	1.1E-04
	LUNGS	9.6E-02	7.2E-02	3.6E-02	1.9E-02	9.4E-03	3.1E-03	1.2E-03	4.1E-04	7.8E-05	1.4E-05
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.5E-02	1.2E-02	5.1E-03	2.3E-03	9.9E-04	3.1E-04	1.3E-04	5.4E-05	1.8E-05	8.5E-06
	BONE	2.0E-01	1.5E-01	6.5E-02	2.9E-02	1.3E-02	4.0E-03	1.6E-03	6.9E-04	2.3E-04	1.1E-04
	LUNGS	8.2E-03	6.2E-03	2.7E-03	1.2E-03	5.4E-04	1.7E-04	7.2E-05	3.2E-05	1.2E-05	6.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.8E-02	8.8E-03	3.2E-03	1.4E-03	6.1E-04	1.8E-04	7.0E-05	2.7E-05	7.4E-06	2.8E-06
	BONE	4.0E-04	1.9E-04	7.0E-05	3.0E-05	1.2E-05	2.9E-06	7.9E-07	1.4E-07	4.0E-08	2.8E-08
	LUNGS	1.9E-01	8.5E-02	3.1E-02	1.3E-02	5.5E-03	1.5E-03	5.1E-04	1.7E-04	3.7E-05	9.7E-06
	THYROID	1.0E+01	4.9E+00	1.9E+00	8.0E-01	3.4E-01	1.0E-01	3.9E-02	1.5E-02	4.3E-03	1.6E-03
CS,SE,TE	TOTAL BODY	2.8E-03	1.4E-03	5.2E-04	2.3E-04	1.0E-04	3.2E-05	1.3E-05	5.4E-06	1.7E-06	7.5E-07
	BONE	6.1E-03	3.2E-03	1.2E-03	5.5E-04	2.4E-04	7.5E-05	3.1E-05	1.3E-05	4.3E-06	1.9E-06
	LUNGS	1.2E-02	6.3E-03	2.5E-03	1.2E-03	5.6E-04	1.9E-04	6.8E-05	2.3E-05	5.5E-06	1.9E-06
	THYROID	2.4E-01	1.2E-01	4.5E-02	2.1E-02	9.4E-03	3.1E-03	1.2E-03	4.9E-04	1.4E-04	5.6E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 = 1/2 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	7.5E-03	6.1E-03	3.4E-03	1.9E-03	9.2E-04	3.0E-04	1.1E-04	4.2E-05	1.2E-05	4.5E-06
	BONE	3.9E-02	3.2E-02	1.8E-02	1.0E-02	5.3E-03	1.8E-03	7.7E-04	3.3E-04	1.3E-04	6.5E-05
	LUNGS	7.6E-02	5.7E-02	2.9E-02	1.5E-02	7.2E-03	2.3E-03	8.2E-04	2.7E-04	4.8E-05	8.7E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XF	TOTAL BODY	1.2E-02	9.3E-03	4.1E-03	1.8E-03	7.7E-04	2.3E-04	9.1E-05	3.6E-05	1.2E-05	5.2E-06
	BONE	1.6E-01	1.2E-01	5.2E-02	2.3E-02	9.8E-03	2.9E-03	1.2E-03	4.6E-04	1.5E-04	6.5E-05
	LUNGS	6.6E-03	5.0E-03	2.2E-03	9.8E-04	4.2E-04	1.3E-04	5.1E-05	2.1E-05	7.5E-06	3.9E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.5E-02	7.0E-03	2.6E-03	1.1E-03	4.7E-04	1.3E-04	4.9E-05	1.8E-05	4.6E-06	1.7E-06
	BONE	3.2E-04	1.5E-04	5.5E-05	2.4E-05	9.2E-06	2.1E-06	5.5E-07	9.5E-08	2.5E-09	1.7E-11
	LUNGS	1.4E-01	6.8E-02	2.4E-02	1.1E-02	4.2E-03	1.1E-03	3.6E-04	1.1E-04	2.3E-05	5.9E-06
	THYROID	8.1E+00	3.9E+00	1.4E+00	6.3E-01	2.6E-01	7.4E-02	2.7E-02	1.0E-02	2.6E-03	9.7E-04
CS,SE,TE	TOTAL BODY	2.2E-03	1.1E-03	4.1E-04	1.8E-04	7.7E-05	2.3E-05	9.0E-06	3.5E-06	1.1E-06	4.5E-07
	BONE	4.8E-03	2.5E-03	9.6E-04	4.3E-04	1.8E-04	5.4E-05	2.1E-05	8.5E-06	2.7E-06	1.2E-06
	LUNGS	9.6E-03	5.0E-03	1.9E-03	9.3E-04	4.3E-04	1.4E-04	4.7E-05	1.5E-05	3.4E-06	1.1E-06
	THYROID	1.9E-01	9.4E-02	3.6E-02	1.6E-02	7.2E-03	2.3E-03	8.7E-04	3.2E-04	8.9E-05	3.4E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 1/2 - 8 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	1.1E-03	9.4E-04	5.5E-04	3.3E-04	1.9E-04	8.0E-05	3.9E-05	1.8E-05	6.2E-06	2.7E-06
	BONE	5.9E-03	4.9E-03	2.9E-03	1.8E-03	1.1E-03	4.9E-04	2.6E-04	1.5E-04	6.9E-05	3.9E-05
	LUNGS	1.2E-02	8.8E-03	4.6E-03	2.6E-03	1.5E-03	6.0E-04	2.8E-04	1.2E-04	2.6E-05	5.2E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.9E-03	1.4E-03	6.6E-04	3.2E-04	1.6E-04	6.2E-05	3.1E-05	1.6E-05	6.3E-06	3.1E-06
	BONE	2.4E-02	1.8E-02	8.4E-03	4.1E-03	2.0E-03	7.8E-04	3.9E-04	2.0E-04	7.9E-05	3.9E-05
	LUNGS	1.0E-03	7.6E-04	3.5E-04	1.7E-04	8.4E-05	3.4E-05	1.7E-05	9.1E-06	4.1E-06	2.3E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	2.2E-03	1.1E-03	4.1E-04	2.0E-04	9.4E-05	3.5E-05	1.7E-05	7.6E-06	2.5E-06	1.0E-06
	BONE	4.8E-05	2.4E-05	8.9E-06	4.1E-06	1.8E-06	5.7E-07	1.9E-07	4.1E-08	1.3E-09	1.0E-11
	LUNGS	2.1E-02	1.0E-02	3.9E-03	1.8E-03	8.4E-04	2.9E-04	1.2E-04	4.9E-05	1.2E-05	3.5E-06
	THYROID	1.2E+00	6.0E-01	2.3E-01	1.1E-01	5.2E-02	2.0E-02	9.3E-03	4.3E-03	1.4E-03	5.8E-04
CS, SE, TE	TOTAL BODY	3.4E-04	1.7E-04	6.6E-05	3.2E-05	1.6E-05	6.2E-06	3.1E-06	1.5E-06	5.8E-07	2.7E-07
	BONE	7.3E-04	3.9E-04	1.6E-04	7.5E-05	3.7E-05	1.5E-05	7.3E-06	3.7E-06	1.5E-06	7.0E-07
	LUNGS	1.5E-03	7.6E-04	3.1E-04	1.6E-04	8.7E-05	3.6E-05	1.6E-05	6.4E-06	1.9E-06	6.8E-07
	THYROID	2.9E-02	1.5E-02	5.7E-03	2.9E-03	1.4E-03	6.0E-04	3.0E-04	1.4E-04	4.8E-05	2.0E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 8 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	8.1E-04	6.6E-04	3.8E-04	2.0E-04	9.8E-05	3.1E-05	1.1E-05	3.8E-06	8.3E-07	2.5E-07
	BONE	4.2E-03	3.4E-03	1.9E-03	1.1E-03	5.6E-04	1.9E-04	7.5E-05	3.0E-05	9.2E-06	3.6E-06
	LUNGS	8.2E-03	6.2E-03	3.1E-03	1.6E-03	7.7E-04	2.3E-04	8.0E-05	2.4E-05	3.5E-06	4.9E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.1E-03	8.1E-04	3.5E-04	1.6E-04	6.6E-05	1.9E-05	7.2E-06	2.6E-06	6.7E-07	2.4E-07
	BONE	1.4E-02	1.0E-02	4.5E-03	2.0E-03	8.4E-04	2.5E-04	9.2E-05	3.3E-05	8.5E-06	2.9E-06
	LUNGS	5.4E-04	4.3E-04	1.9E-04	8.5E-05	3.6E-05	1.1E-05	4.0E-06	1.5E-06	4.4E-07	1.8E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.6E-03	7.6E-04	2.7E-04	1.2E-04	4.9E-05	1.4E-05	4.8E-06	1.6E-06	3.3E-07	9.5E-08
	BONE	3.4E-05	1.7E-05	5.9E-06	2.5E-06	9.7E-07	2.2E-07	5.4E-08	8.5E-09	1.8E-10	9.7E-11
	LUNGS	1.5E-02	7.3E-03	2.6E-03	1.1E-03	4.4E-04	1.1E-04	3.5E-05	1.0E-05	1.7E-06	3.3E-07
	THYROID	8.7E-01	4.2E-01	1.5E-01	6.7E-02	2.8E-02	7.6E-03	2.7E-03	8.9E-04	1.9E-04	5.4E-05
CS,SE,TE	TOTAL BODY	2.4E-04	1.2E-04	4.4E-05	2.0E-05	8.2E-06	2.4E-06	8.9E-07	3.2E-07	7.7E-08	2.5E-08
	BONE	5.2E-04	2.7E-04	1.0E-04	4.6E-05	1.9E-05	5.6E-06	2.1E-06	7.7E-07	2.0E-07	6.6E-08
	LUNGS	1.0E-03	5.4E-04	2.1E-04	1.0E-04	4.6E-05	1.4E-05	4.6E-06	1.3E-06	2.5E-07	6.4E-08
	THYROID	2.1E-02	1.0E-02	3.4E-03	1.7E-03	7.6E-04	2.3E-04	8.5E-05	2.9E-05	6.4E-06	1.9E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	5.2E-03	3.8E-03	1.8E-03	8.9E-04	4.0E-04	1.2E-04	4.7E-05	1.8E-05	5.1E-06	2.0E-06
	BONE	2.7E-02	2.0E-02	9.5E-03	4.8E-03	2.3E-03	7.6E-04	3.2E-04	1.4E-04	5.7E-05	2.9E-05
	LUNGS	5.2E-02	3.5E-02	1.5E-02	7.1E-03	3.1E-03	9.3E-04	3.4E-04	1.1E-04	2.2E-05	4.0E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	8.4E-03	5.6E-03	2.1E-03	8.5E-04	3.3E-04	9.4E-05	3.7E-05	1.5E-05	5.1E-06	2.3E-06
	BONE	1.1E-01	7.2E-02	2.7E-02	1.1E-02	4.2E-03	1.2E-03	4.7E-04	1.9E-04	6.4E-05	2.9E-05
	LUNGS	4.5E-03	3.0E-03	1.1E-03	4.6E-04	1.8E-04	5.1E-05	2.1E-05	8.9E-06	3.3E-06	1.8E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.0E-02	4.3E-03	1.4E-03	5.4E-04	2.0E-04	5.4E-05	2.0E-05	7.5E-06	2.1E-06	7.7E-07
	BONE	2.2E-04	9.4E-05	2.9E-05	1.1E-05	4.0E-06	8.8E-07	2.3E-07	4.1E-08	1.1E-09	7.8E-12
	LUNGS	9.7E-02	4.2E-02	1.3E-02	5.0E-03	1.8E-03	4.4E-04	1.5E-04	4.9E-05	1.0E-05	2.7E-06
	THYROID	5.6E+00	2.4E+00	7.6E-01	3.0E-01	1.1E-01	3.0E-02	1.1E-02	4.3E-03	1.2E-03	4.4E-04
CS,SE,TE	TOTAL BODY	1.5E-03	6.7E-04	2.2E-04	8.6E-05	3.3E-05	9.6E-06	3.7E-06	1.5E-06	4.8E-07	2.1E-07
	BONE	3.4E-03	1.6E-03	5.1E-04	2.0E-04	7.9E-05	2.2E-05	8.9E-06	3.7E-06	1.2E-06	5.4E-07
	LUNGS	6.6E-03	3.1E-03	1.0E-03	4.4E-04	1.9E-04	5.6E-05	2.0E-05	6.4E-06	1.5E-06	5.2E-07
	THYROID	1.3E-01	5.8E-02	1.9E-02	7.7E-03	3.1E-03	9.2E-04	3.6E-04	1.4E-04	4.0E-05	1.6E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 - 1/2 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	4.1E-03	3.0E-03	1.4E-03	6.9E-04	3.1E-04	9.0E-05	3.3E-05	1.2E-05	3.2E-06	1.2E-06
	BONE	2.1E-02	1.6E-02	7.5E-03	3.8E-03	1.8E-03	5.5E-04	2.2E-04	9.4E-05	3.5E-05	1.8E-05
	LUNGS	4.2E-02	2.8E-02	1.2E-02	5.5E-03	2.4E-03	6.8E-04	2.4E-04	7.5E-05	1.3E-05	2.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	6.8E-03	4.6E-03	1.7E-03	6.8E-04	2.6E-04	6.9E-05	2.6E-05	1.0E-05	3.2E-06	1.4E-06
	BONE	8.7E-02	5.4E-02	2.2E-02	8.6E-03	3.3E-03	8.8E-04	3.3E-04	1.3E-04	4.0E-05	1.8E-05
	LUNGS	3.6E-03	2.4E-03	9.1E-04	5.6E-04	1.4E-04	3.8E-05	1.5E-05	5.9E-06	2.1E-06	1.1E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	7.9E-03	3.4E-03	1.1E-03	4.2E-04	1.6E-04	4.0E-05	1.4E-05	4.9E-06	1.3E-06	4.7E-07
	BONE	1.8E-04	7.5E-05	2.3E-05	8.7E-06	3.0E-06	6.4E-07	1.6E-07	2.7E-08	6.9E-10	4.7E-12
	LUNGS	7.7E-02	3.3E-02	1.0E-02	3.9E-03	1.4E-03	3.2E-04	1.0E-04	3.2E-05	6.3E-06	1.6E-06
	THYROID	4.4E+00	1.9E+00	6.0E-01	2.3E-01	8.6E-02	2.2E-02	7.9E-03	2.8E-03	7.3E-04	2.7E-04
CS, SE, TE	TOTAL BODY	1.2E-03	5.3E-04	1.7E-04	6.7E-05	2.6E-05	7.0E-06	2.6E-06	9.9E-07	3.0E-07	1.2E-07
	BONE	2.6E-03	1.2E-03	4.0E-04	1.6E-04	6.0E-05	1.6E-05	6.2E-06	2.4E-06	7.5E-07	3.2E-07
	LUNGS	5.2E-03	2.4E-03	8.2E-04	3.5E-04	1.4E-04	4.1E-05	1.4E-05	4.2E-06	9.4E-07	3.1E-07
	THYROID	1.0E-01	4.6E-02	1.5E-02	6.0E-03	2.4E-03	6.8E-04	2.5E-04	9.0E-05	2.5E-05	9.4E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 1/2 - 8 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	6.2E-04	4.6E-04	2.3E-04	1.2E-04	6.2E-05	2.4E-05	1.1E-05	5.1E-06	1.7E-06	7.4E-07
	BONE	3.2E-03	2.4E-03	1.2E-03	6.6E-04	3.5E-04	1.5E-04	7.5E-05	4.1E-05	1.9E-05	1.1E-05
	LUNGS	6.1E-03	4.3E-03	1.9E-03	9.7E-04	4.8E-04	1.8E-04	8.0E-05	3.3E-05	7.3E-06	1.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XF	TOTAL BODY	1.0E-03	7.0E-04	2.8E-04	1.2E-04	5.2E-05	1.9E-05	8.9E-06	4.4E-06	1.7E-06	8.5E-07
	BONE	1.3E-02	8.9E-03	3.5E-03	1.5E-03	6.6E-04	2.4E-04	1.1E-04	5.6E-05	2.2E-05	1.1E-05
	LUNGS	5.5E-04	3.7E-04	1.5E-04	6.4E-05	2.8E-05	1.0E-05	5.0E-06	2.6E-06	1.1E-06	6.4E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.2E-03	5.2E-04	1.7E-04	7.3E-05	3.1E-05	1.1E-05	4.8E-06	2.1E-06	6.9E-07	2.8E-07
	BONE	2.6E-05	1.2E-05	3.7E-06	1.5E-06	6.1E-07	1.7E-07	5.4E-08	1.2E-08	3.7E-10	2.8E-12
	LUNGS	1.2E-02	5.1E-03	1.7E-03	6.8E-04	2.8E-04	8.6E-05	3.5E-05	1.4E-05	3.4E-06	9.6E-07
	THYROID	6.7E-01	2.9E-01	9.7E-02	4.1E-02	1.7E-02	5.9E-03	2.7E-03	1.2E-03	4.0E-04	1.6E-04
CS, SE, TE	TOTAL BODY	1.8E-04	8.2E-05	2.8E-05	1.2E-05	5.2E-06	1.9E-06	8.9E-07	4.3E-07	1.6E-07	7.4E-08
	BONE	4.0E-04	1.9E-04	6.5E-05	2.8E-05	1.2E-05	4.4E-06	2.1E-06	1.0E-06	4.1E-07	1.9E-07
	LUNGS	7.9E-04	3.7E-04	1.3E-04	6.1E-05	2.9E-05	1.1E-05	4.6E-06	1.8E-06	5.1E-07	1.9E-07
	THYROID	1.6E-02	7.1E-03	2.4E-03	1.1E-03	4.8E-04	1.8E-04	8.5E-05	3.9E-05	1.3E-05	5.6E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
SOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 8 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	4.4E-04	3.2E-04	1.5E-04	7.4E-05	3.3E-05	9.3E-06	3.2E-06	1.1E-06	2.3E-07	7.0E-08
	BONE	2.3E-03	1.7E-03	8.1E-04	4.0E-04	1.9E-04	5.7E-05	2.2E-05	8.5E-06	2.6E-06	1.0E-06
	LUNGS	4.5E-03	3.0E-03	1.3E-03	5.9E-04	2.6E-04	7.0E-05	2.3E-05	6.8E-06	9.7E-07	1.4E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	6.0E-04	4.0E-04	1.5E-04	5.8E-05	2.2E-05	5.8E-06	2.1E-06	7.4E-07	1.9E-07	6.5E-08
	BONE	7.6E-03	5.1E-03	1.9E-03	7.5E-04	2.8E-04	7.4E-05	2.6E-05	9.4E-06	2.4E-06	8.2E-07
	LUNGS	3.2E-04	2.1E-04	7.9E-05	3.1E-05	1.2E-05	3.2E-06	1.2E-06	4.3E-07	1.2E-07	4.9E-08
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	8.6E-04	3.7E-04	1.2E-04	4.5E-05	1.6E-05	4.1E-06	1.4E-06	4.4E-07	9.2E-08	2.6E-08
	BONE	1.9E-05	8.1E-06	2.5E-06	9.3E-07	3.2E-07	6.6E-08	1.6E-08	2.4E-09	5.0E-11	2.7E-13
	LUNGS	8.4E-03	3.6E-03	1.1E-03	4.2E-04	1.5E-04	3.3E-05	1.0E-05	2.9E-06	4.6E-07	9.1E-08
	THYROID	4.8E-01	2.1E-01	6.4E-02	2.5E-02	9.2E-03	2.3E-03	7.7E-04	2.5E-04	5.3E-05	1.5E-05
CS,SE,TE	TOTAL BODY	1.3E-04	5.8E-05	1.8E-05	7.2E-06	2.7E-06	7.2E-07	2.6E-07	8.9E-08	2.1E-08	7.0E-09
	BONE	2.9E-04	1.3E-04	4.3E-05	1.7E-05	6.4E-06	1.7E-06	6.1E-07	2.2E-07	5.4E-08	1.8E-08
	LUNGS	5.7E-04	2.6E-04	8.8E-05	3.7E-05	1.5E-05	4.2E-06	1.3E-06	3.7E-07	6.8E-08	1.8E-08
	THYROID	1.1E-02	5.0E-03	1.6E-03	6.5E-04	2.5E-04	7.0E-05	2.5E-05	8.1E-06	1.8E-06	5.3E-07

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 = 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	9.05E-03	7.7E-03	4.3E-03	2.4E-03	1.2E-03	4.1E-04	1.6E-04	6.4E-05	1.9E-05	7.4E-06
	BONE	4.4E-02	4.0E-02	2.3E-02	1.3E-02	6.9E-03	2.5E-03	1.1E-03	5.1E-04	2.1E-04	1.1E-04
	LUNGS	9.5E-02	7.2E-02	3.6E-02	1.9E-02	9.4E-03	3.1E-03	1.2E-03	4.1E-04	7.8E-05	1.4E-05
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.5E-02	1.2E-02	5.1E-03	2.3E-03	9.9E-04	3.1E-04	1.3E-04	5.4E-05	1.8E-05	8.5E-06
	BONE	2.0E-01	1.5E-01	6.5E-02	2.9E-02	1.3E-02	4.0E-03	1.6E-03	6.9E-04	2.3E-04	1.1E-04
	LUNGS	4.2E-03	6.2E-03	2.7E-03	1.2E-03	5.4E-04	1.7E-04	7.2E-05	3.2E-05	1.2E-05	6.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.2E-02	5.7E-03	2.1E-03	9.4E-04	4.0E-04	1.2E-04	4.8E-05	1.9E-05	5.4E-06	2.1E-06
	BONE	1.5E-04	7.2E-05	2.5E-05	1.1E-05	4.4E-06	1.1E-06	2.9E-07	5.3E-08	1.5E-09	1.1E-11
	LUNGS	5.4E-01	1.4E-01	6.7E-02	2.9E-02	1.2E-02	3.5E-03	1.3E-03	4.9E-04	1.2E-04	4.1E-05
	THYROID	6.6E+00	3.2E+00	1.2E+00	5.3E-01	2.2E-01	6.8E-02	2.7E-02	1.1E-02	3.1E-03	1.2E-03
CS, SE, TE	TOTAL BODY	1.5E-03	7.6E-04	2.8E-04	1.3E-04	5.6E-05	1.8E-05	7.3E-06	3.0E-06	9.9E-07	4.4E-07
	BONE	3.4E-03	2.1E-03	8.1E-04	3.6E-04	1.6E-04	5.0E-05	2.1E-05	8.8E-06	3.0E-06	1.4E-06
	LUNGS	4.0E-02	2.0E-02	7.5E-03	3.4E-03	1.5E-03	4.9E-04	1.9E-04	7.3E-05	2.2E-05	8.7E-06
	THYROID	9.0E-02	4.6E-02	1.8E-02	8.8E-03	4.2E-03	1.5E-03	5.9E-04	2.2E-04	5.7E-05	2.0E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 - 1/2 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	7.5E-03	6.1E-03	3.4E-03	1.9E-03	9.2E-04	3.0E-04	1.1E-04	4.2E-05	1.2E-05	4.5E-06
	BONE	3.9E-02	3.2E-02	1.8E-02	1.0E-02	5.3E-03	1.8E-03	7.7E-04	3.3E-04	1.3E-04	6.5E-05
	LUNGS	7.6E-02	5.7E-02	2.9E-02	1.5E-02	7.2E-03	2.3E-03	8.2E-04	2.7E-04	4.8E-05	8.7E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.2E-02	9.3E-03	4.1E-03	1.8E-03	7.7E-04	2.3E-04	9.1E-05	3.6E-05	1.2E-05	5.2E-06
	BONE	1.6E-01	1.2E-01	5.2E-02	2.3E-02	9.8E-03	2.9E-03	1.2E-03	4.6E-04	1.5E-04	6.5E-05
	LUNGS	6.6E-03	5.0E-03	2.2E-03	9.8E-04	4.2E-04	1.3E-04	5.1E-05	2.1E-05	7.5E-06	3.9E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	9.3E-03	4.5E-03	1.7E-03	7.3E-04	3.1E-04	8.8E-05	3.3E-05	1.2E-05	3.3E-06	1.3E-06
	BONE	1.2E-04	5.7E-05	2.0E-05	8.7E-06	3.4E-06	7.9E-07	2.0E-07	3.5E-08	9.1E-10	6.4E-12
	LUNGS	3.0E-01	1.4E-01	5.3E-02	2.3E-02	9.4E-03	2.6E-03	9.2E-04	3.2E-04	7.6E-05	2.5E-05
	THYROID	5.3E+00	2.5E+00	9.3E-01	4.1E-01	1.7E-01	5.0E-02	1.9E-02	7.0E-03	1.9E-03	7.2E-04
CS,SE,TE	TOTAL BODY	1.2E-03	6.0E-04	2.2E-04	1.0E-04	4.3E-05	1.3E-05	5.0E-06	2.0E-06	6.1E-07	2.7E-07
	BONE	3.0E-03	1.6E-03	6.4E-04	2.8E-04	1.2E-04	3.6E-05	1.4E-05	5.8E-06	1.9E-06	8.4E-07
	LUNGS	3.2E-02	1.6E-02	5.9E-03	2.7E-03	1.2E-03	3.6E-04	1.3E-04	4.8E-05	1.3E-05	5.3E-06
	THYROID	7.1E-02	3.7E-02	1.4E-02	6.9E-03	3.2E-03	1.1E-03	4.1E-04	1.4E-04	3.6E-05	1.2E-05

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 1/2 - 8 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	1.1E-03	9.4E-04	5.5E-04	3.3E-04	1.9E-04	8.0E-05	3.9E-05	1.8E-05	6.2E-06	2.7E-06
	BONE	5.9E-03	4.9E-03	2.9E-03	1.8E-03	1.1E-03	4.9E-04	2.6E-04	1.5E-04	6.9E-05	3.9E-05
	LUNGS	1.2E-02	8.4E-03	4.6E-03	2.6E-03	1.5E-03	6.0E-04	2.8E-04	1.2E-04	2.6E-05	5.2E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.9E-03	1.4E-03	6.6E-04	3.2E-04	1.6E-04	6.2E-05	3.1E-05	1.6E-05	6.3E-06	3.1E-06
	BONE	2.4E-02	1.4E-02	8.4E-03	4.1E-03	2.0E-03	7.8E-04	3.9E-04	2.0E-04	7.9E-05	3.9E-05
	LUNGS	1.0E-03	7.6E-04	3.5E-04	1.7E-04	8.4E-05	3.4E-05	1.7E-05	9.1E-06	4.1E-06	2.3E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.4E-03	6.9E-04	2.7E-04	1.3E-04	6.1E-05	2.3E-05	1.1E-05	5.3E-06	1.8E-06	7.5E-07
	BONE	1.8E-05	8.7E-06	3.3E-06	1.5E-06	6.8E-07	2.1E-07	7.0E-08	1.5E-08	5.0E-10	3.8E-12
	LUNGS	4.5E-02	2.2E-02	4.5E-03	4.0E-03	1.9E-03	6.9E-04	3.1E-04	1.4E-04	4.1E-05	1.5E-05
	THYROID	7.0E-01	3.9E-01	1.5E-01	7.2E-02	3.5E-02	1.3E-02	6.4E-03	3.0E-03	1.0E-03	4.3E-04
CS, SF, TE	TOTAL BODY	1.8E-04	9.2E-05	3.6E-05	1.4E-05	8.7E-06	3.5E-06	1.7E-06	8.6E-07	3.3E-07	1.6E-07
	BONE	4.5E-04	2.5E-04	1.0E-04	5.0E-05	2.4E-05	9.7E-06	4.9E-06	2.5E-06	1.0E-06	5.0E-07
	LUNGS	4.8E-03	2.4E-03	9.5E-04	4.7E-04	2.4E-04	9.5E-05	4.5E-05	2.1E-05	7.3E-06	3.2E-06
	THYROID	1.1E-02	5.7E-03	2.3E-03	1.2E-03	6.5E-04	2.9E-04	1.4E-04	6.2E-05	1.9E-05	7.3E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD VERY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 8 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	4.1E-04	6.6E-04	3.8E-04	2.0E-04	9.8E-05	3.1E-05	1.1E-05	3.8E-06	8.3E-07	2.5E-07
	BONE	4.2E-03	3.4E-03	1.9E-03	1.1E-03	5.6E-04	1.9E-04	7.5E-05	3.0E-05	9.2E-06	3.6E-06
	LUNGS	8.2E-03	6.2E-03	3.1E-03	1.6E-03	7.7E-04	2.3E-04	8.0E-05	2.4E-05	3.5E-06	4.9E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.1E-03	8.1E-04	3.5E-04	1.6E-04	6.6E-05	1.9E-05	7.2E-06	2.6E-06	6.7E-07	2.4E-07
	BONE	1.4E-02	1.0E-02	4.5E-03	2.0E-03	8.4E-04	2.5E-04	9.2E-05	3.3E-05	8.5E-06	2.9E-06
	LUNGS	5.8E-04	4.3E-04	1.9E-04	8.5E-05	3.6E-05	1.1E-05	4.0E-06	1.5E-06	4.4E-07	1.8E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	1.0E-03	4.9E-04	1.8E-04	7.8E-05	3.2E-05	9.1E-06	3.2E-06	1.1E-06	2.4E-07	7.0E-08
	BONE	1.3E-05	6.1E-06	2.2E-06	9.3E-07	3.6E-07	8.1E-08	2.0E-08	3.2E-09	6.6E-11	3.6E-13
	LUNGS	3.2E-02	1.6E-02	5.6E-03	2.5E-03	1.0E-03	2.7E-04	9.0E-05	2.9E-05	5.5E-06	1.4E-06
	THYROID	5.7E-01	2.7E-01	1.0E-01	4.4E-02	1.8E-02	5.1E-03	1.8E-03	6.2E-04	1.4E-04	4.0E-05
CS, SF, TE	TOTAL BODY	1.3E-04	6.5E-05	2.4E-05	1.1E-05	4.6E-06	1.4E-06	5.0E-07	1.8E-07	4.4E-08	1.5E-08
	BONE	3.2E-04	1.8E-04	6.8E-05	3.1E-05	1.3E-05	3.7E-06	1.4E-06	5.2E-07	1.4E-07	4.7E-08
	LUNGS	3.4E-03	1.7E-03	6.3E-04	2.9E-04	1.2E-04	3.7E-05	1.3E-05	4.3E-06	9.7E-07	3.0E-07
	THYROID	7.7E-03	4.0E-03	1.5E-03	7.4E-04	3.4E-04	1.1E-04	4.0E-05	1.3E-05	2.6E-06	6.9E-07

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 0 - 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	5.2E+03	3.8E+03	1.8E+03	8.9E+04	4.0E+04	1.2E+04	4.7E+05	1.8E+05	5.1E+06	2.0E+06
	BONE	2.7E+02	2.0E+02	9.5E+03	4.8E+03	2.3E+03	7.6E+04	3.2E+04	1.4E+04	5.7E+05	2.9E+05
	LUNGS	5.2E+02	3.5E+02	1.5E+02	7.1E+03	3.1E+03	9.3E+04	3.4E+04	1.1E+04	2.2E+05	4.0E+06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	8.4E+03	5.6E+03	2.1E+03	8.5E+04	3.3E+04	9.4E+05	3.7E+05	1.5E+05	5.1E+06	2.3E+06
	BONE	1.1E+01	7.2E+02	2.7E+02	1.1E+02	4.2E+03	1.2E+03	4.7E+04	1.9E+04	6.4E+05	2.9E+05
	LUNGS	4.5E+03	3.0E+03	1.1E+03	4.6E+04	1.8E+04	5.1E+05	2.1E+05	8.9E+06	3.3E+06	1.8E+06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	6.4E+03	2.8E+03	8.8E+04	3.5E+04	1.3E+04	3.6E+05	1.4E+05	5.2E+06	1.5E+06	5.7E+07
	BONE	8.1E+05	3.5E+05	1.1E+05	4.1E+06	1.5E+06	3.2E+07	8.4E+08	1.5E+08	4.1E+10	2.9E+12
	LUNGS	2.1E+01	8.9E+02	2.8E+02	1.1E+02	4.1E+03	1.1E+03	3.8E+04	1.4E+04	3.4E+05	1.1E+05
	THYROID	3.6E+00	1.6E+00	5.0E+01	2.0E+01	7.5E+02	2.1E+02	7.8E+03	3.0E+03	8.5E+04	3.3E+04
CS,SE,TE	TOTAL BODY	8.1E+04	3.7E+04	1.2E+04	4.8E+05	1.9E+05	5.4E+06	2.1E+06	8.5E+07	2.7E+07	1.2E+07
	BONE	2.1E+03	1.0E+03	3.4E+04	1.3E+04	5.2E+05	1.5E+05	6.0E+06	2.5E+06	8.4E+07	3.8E+07
	LUNGS	2.2E+02	9.7E+03	3.1E+03	1.3E+03	5.1E+04	1.5E+04	5.5E+05	2.1E+05	6.0E+06	2.4E+06
	THYROID	4.9E+02	2.3E+02	7.7E+03	3.3E+03	1.4E+03	4.4E+04	1.7E+04	6.2E+05	1.6E+05	5.6E+06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER MANFORD MODERATELY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR Q = 1/2 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	4.1E-03	3.0E-03	1.4E-03	6.9E-04	3.1E-04	9.0E-05	3.3E-05	1.2E-05	3.2E-06	1.2E-06
	BONE	2.1E-02	1.6E-02	7.5E-03	3.8E-03	1.8E-03	5.5E-04	2.2E-04	9.4E-05	3.5E-05	1.8E-05
	LUNGS	4.2E-02	2.8E-02	1.2E-02	5.5E-03	2.4E-03	6.8E-04	2.4E-04	7.5E-05	1.3E-05	2.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	6.8E-03	4.6E-03	1.7E-03	6.8E-04	2.6E-04	6.9E-05	2.6E-05	1.0E-05	3.2E-06	1.4E-06
	BONE	8.7E-02	5.4E-02	2.2E-02	8.6E-03	3.3E-03	8.8E-04	3.3E-04	1.3E-04	4.0E-05	1.8E-05
	LUNGS	3.6E-03	2.4E-03	9.1E-04	3.6E-04	1.4E-04	3.8E-05	1.5E-05	5.9E-06	2.1E-06	1.1E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	5.1E-03	2.2E-03	6.9E-04	2.7E-04	1.0E-04	2.7E-05	9.5E-06	3.4E-06	9.2E-07	3.5E-07
	BONE	6.5E-05	2.8E-05	8.5E-06	3.2E-06	1.1E-06	2.4E-07	5.9E-08	9.9E-09	2.5E-10	1.7E-12
	LUNGS	1.6E-01	7.1E-02	2.2E-02	8.5E-03	3.1E-03	7.8E-04	2.7E-04	9.0E-05	2.1E-05	6.9E-06
	THYROID	2.9E+00	1.2E+00	3.9E-01	1.5E-01	5.7E-02	1.5E-02	5.4E-03	2.0E-03	5.3E-04	2.0E-04
CS, SE, TE	TOTAL BODY	6.5E-04	2.9E-04	9.4E-05	3.7E-05	1.4E-05	3.9E-06	1.5E-06	5.6E-07	1.7E-07	7.3E-08
	BONE	1.6E-03	8.0E-04	2.7E-04	1.1E-04	4.0E-05	1.1E-05	4.2E-06	1.6E-06	5.2E-07	2.3E-07
	LUNGS	1.7E-02	7.7E-03	2.5E-03	1.0E-03	3.9E-04	1.1E-04	3.8E-05	1.4E-05	3.7E-06	1.5E-06
	THYROID	3.9E-02	1.4E-02	6.0E-03	2.6E-03	1.1E-03	3.2E-04	1.2E-04	4.1E-05	9.8E-06	3.4E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR 1/2 - 8 HR RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	6.2E-04	4.6E-04	2.3E-04	1.2E-04	6.2E-05	2.4E-05	1.1E-05	5.1E-06	1.7E-06	7.4E-07
	BONE	3.2E-03	2.4E-03	1.2E-03	6.6E-04	3.5E-04	1.5E-04	7.5E-05	4.1E-05	1.9E-05	1.1E-05
	LUNGS	6.3E-03	4.3E-03	1.9E-03	9.7E-04	4.8E-04	1.8E-04	8.0E-05	3.3E-05	7.3E-06	1.4E-06
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	1.0E-03	7.0E-04	2.8E-04	1.2E-04	5.2E-05	1.9E-05	8.9E-06	4.4E-06	1.7E-06	8.5E-07
	BONE	1.3E-02	8.9E-03	3.5E-03	1.5E-03	6.6E-04	2.4E-04	1.1E-04	5.6E-05	2.2E-05	1.1E-05
	LUNGS	5.5E-04	3.7E-04	1.5E-04	6.4E-05	2.8E-05	1.0E-05	5.0E-06	2.6E-06	1.1E-06	6.4E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	7.7E-04	3.4E-04	1.1E-04	4.7E-05	2.0E-05	7.0E-06	3.3E-06	1.5E-06	5.0E-07	2.1E-07
	BONE	9.7E-06	4.3E-06	1.4E-06	5.6E-07	2.3E-07	6.3E-08	2.0E-08	4.3E-09	1.4E-10	1.1E-12
	LUNGS	2.5E-02	1.1E-02	3.6E-03	1.5E-03	6.3E-04	2.1E-04	9.1E-05	3.9E-05	1.2E-05	4.1E-06
	THYROID	4.3E-01	1.9E-01	6.3E-02	2.7E-02	1.2E-02	4.0E-03	1.8E-03	8.5E-04	2.9E-04	1.2E-04
CS, SE, TE	TOTAL BODY	9.9E-05	4.5E-05	1.5E-05	6.6E-06	2.9E-06	1.0E-06	5.0E-07	2.4E-07	9.2E-08	4.4E-08
	BONE	2.5E-04	1.2E-04	4.3E-05	1.9E-05	8.1E-06	2.9E-06	1.4E-06	7.1E-07	2.8E-07	1.4E-07
	LUNGS	2.6E-03	1.2E-03	4.0E-04	1.7E-04	7.8E-05	2.9E-05	1.3E-05	5.9E-06	2.0E-06	8.7E-07
	THYROID	5.9E-03	2.8E-03	9.8E-04	4.5E-04	2.2E-04	8.6E-05	4.0E-05	1.8E-05	5.4E-06	2.0E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
FIFTY YEAR INHALATION DOSE COMMITMENT, REM, AT DISTANCE SHOWN

05/10/76

DISPERSION UNDER MANFORD MODERATELY STABLE CONDITIONS
INSOLUBLE MATERIAL, 1 MICRON

INDIVIDUAL DOSE FOR B = 24 HRS RELEASE

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM RELEASE POINT, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	4.4E-04	3.2E-04	1.5E-04	7.4E-05	3.3E-05	9.3E-06	3.2E-06	1.1E-06	2.3E-07	7.0E-08
	BONE	2.3E-03	1.7E-03	8.1E-04	4.0E-04	1.9E-04	5.7E-05	2.2E-05	8.5E-06	2.6E-06	1.0E-06
	LUNGS	4.5E-03	3.0E-03	1.3E-03	5.9E-04	2.6E-04	7.0E-05	2.3E-05	6.8E-06	9.7E-07	1.4E-07
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
XE	TOTAL BODY	6.0E-04	4.0E-04	1.5E-04	5.8E-05	2.2E-05	5.8E-06	2.1E-06	7.4E-07	1.9E-07	6.5E-08
	BONE	7.6E-03	5.1E-03	1.9E-03	7.5E-04	2.8E-04	7.4E-05	2.6E-05	9.4E-06	2.4E-06	8.2E-07
	LUNGS	3.2E-04	2.1E-04	7.9E-05	3.1E-05	1.2E-05	3.2E-06	1.2E-06	4.3E-07	1.2E-07	4.9E-08
	THYROID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
I	TOTAL BODY	5.5E-04	2.4E-04	7.5E-05	2.9E-05	1.1E-05	2.7E-06	9.3E-07	3.1E-07	6.6E-08	1.9E-08
	BONE	7.0E-06	3.0E-06	9.2E-07	3.4E-07	1.2E-07	2.4E-08	5.8E-09	8.9E-10	1.8E-11	9.9E-14
	LUNGS	1.8E-02	7.6E-03	2.4E-03	9.1E-04	3.3E-04	8.0E-05	2.6E-05	8.1E-06	1.5E-06	3.9E-07
	THYROID	3.1E-01	1.3E-01	4.2E-02	1.6E-02	6.1E-03	1.5E-03	5.3E-04	1.8E-04	3.8E-05	1.1E-05
CS, SE, TE	TOTAL BODY	7.1E-05	3.2E-05	1.0E-05	4.0E-06	1.5E-06	4.1E-07	1.4E-07	5.0E-08	1.2E-08	4.1E-09
	BONE	1.8E-04	8.6E-05	2.9E-05	1.1E-05	4.3E-06	1.1E-06	4.1E-07	1.5E-07	3.8E-08	1.3E-08
	LUNGS	1.9E-03	4.3E-04	2.7E-04	1.1E-04	4.1E-05	1.1E-05	3.8E-06	1.2E-06	2.7E-07	8.2E-08
	THYROID	4.2E-03	1.9E-03	6.5E-04	2.7E-04	1.1E-04	3.3E-05	1.2E-05	3.6E-06	7.1E-07	1.9E-07

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
EXTERNAL DOSE (REM) AT DISTANCE SHOWN
DISPERSION UNDER HANFORD VERY STABLE CONDITIONS

05/10/76

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM SOURCE, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KW	TOTAL BODY	1.0E+00	2.6E-01	6.0E-02	2.7E-02	1.1E-02	1.9E-03	2.0E-04	1.4E-05	3.1E-06	9.9E-07
	SKIN	6.8E+01	1.4E+01	1.6E+00	3.9E-01	8.8E-02	9.8E-03	1.1E-03	9.6E-05	9.8E-06	2.7E-06
XE	TOTAL BODY	1.7E+00	6.7E-01	1.4E-01	2.7E-02	6.4E-03	9.8E-04	2.9E-04	7.9E-05	8.1E-06	1.1E-06
	SKIN	3.6E+01	9.7E+00	1.2E+00	1.9E-01	4.0E-02	6.3E-03	1.7E-03	3.6E-04	2.6E-04	2.8E-06
I	TOTAL BODY	6.6E-03	4.4E-03	2.2E-03	1.2E-03	5.8E-04	1.7E-04	5.1E-05	1.5E-05	3.2E-06	7.7E-07
	SKIN	4.7E-02	2.3E-02	9.0E-03	4.0E-03	1.6E-03	3.8E-04	1.0E-04	2.9E-05	6.3E-06	1.6E-06
CS, SE, TE	TOTAL BODY	1.7E-02	4.3E-03	6.1E-04	3.0E-04	1.4E-04	4.2E-05	1.1E-05	2.0E-06	4.5E-07	1.8E-07
	SKIN	7.6E-01	1.1E-01	9.1E-03	2.9E-03	9.0E-04	1.5E-04	3.2E-05	4.7E-06	7.6E-07	2.7E-07
TOTAL	TOTAL BODY	2.7E+00	9.4E-01	2.0E-01	5.6E-02	1.8E-02	3.1E-03	5.6E-04	1.1E-04	1.5E-05	3.0E-06
	SKIN	1.1E+02	2.4E+01	2.8E+00	5.9E-01	1.3E-01	1.7E-02	2.9E-03	4.9E-04	2.8E-04	7.3E-06

NEUTRON MULTIPLIER CRITICALITY ACCIDENT
EXTERNAL DOSE (REM) AT DISTANCE SHOWN
DISPERSION UNDER HANFORD MODERATELY STABLE CONDITIONS

05/10/76

NUCLIDE GROUP	ORGAN OF REFERENCE	DISTANCE FROM SOURCE, METERS									
		100	200	500	1000	2000	5000	10000	20000	50000	100000
KR	TOTAL BODY	1.3E+00	4.9E-01	9.6E-02	1.9E-02	4.3E-03	6.3E-04	1.8E-04	4.6E-05	4.2E-06	5.1E-07
	SKIN	2.0E+01	4.9E+00	5.4E-01	7.9E-02	1.5E-02	2.2E-03	5.8E-04	1.3E-04	9.3E-06	9.9E-07
XE	TOTAL BODY	7.5E-01	1.9E-01	4.3E-02	1.9E-02	7.3E-03	1.2E-03	1.2E-04	7.7E-06	1.5E-06	4.2E-07
	SKIN	3.7E+01	6.9E+00	6.9E-01	1.5E-01	3.3E-02	3.6E-03	3.9E-04	3.1E-05	3.5E-06	9.0E-07
I	TOTAL BODY	5.0E-03	3.2E-03	1.6E-03	8.2E-04	3.8E-04	1.1E-04	3.1E-05	8.6E-06	1.6E-06	3.5E-07
	SKIN	2.7E-02	1.3E-02	4.4E-03	1.9E-03	7.3E-04	1.7E-04	4.7E-05	1.3E-05	2.5E-06	5.9E-07
CS, SE, TE	TOTAL BODY	1.3E-02	3.1E-03	4.3E-04	2.1E-04	9.5E-05	2.7E-05	6.8E-06	1.2E-06	2.3E-07	8.4E-08
	SKIN	4.2E-01	5.3E-02	4.0E-03	1.2E-03	3.5E-04	6.1E-05	1.3E-05	1.9E-06	3.2E-07	1.1E-07
TOTAL	TOTAL BODY	2.0E+00	6.8E-01	1.4E-01	3.9E-02	1.2E-02	2.0E-03	3.4E-04	6.3E-05	7.6E-06	1.4E-06
	SKIN	5.8E+01	1.2E+01	1.2E+00	2.4E-01	4.9E-02	6.1E-03	1.0E-03	1.7E-04	1.6E-05	2.6E-06

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