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Atlantic Richfield Hanford Company
Richland, Washington 99352

ARH-CD-758

ATLANTIC RICHFIELD HANFORD COMPANY CALIFORNIUM
MULTIPLIER/DELAYED NEUTRON COUNTER SAFETY ANALYSIS

W. H. Zimmer

August 1976

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ADMINISTRATION UNDER CONTRACT E (45-1) 2130

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MULTIPLIER/DELAYED NEUTRON COUNTER SAFETY ANALYSIS

W. H. Zimmer

Chemical Technology Laboratory
Research Department
Research and Engineering Division

August 1976

Operated for the Energy Research and Development Administration by
Atlantic Richfield Hanford Company under Contract E(45-1)-2130

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ATLANTIC RICHFIELD HANFORD COMPANY CALIFORNIUM
MULTIPLIER/DELAYED NEUTRON COUNTER SAFETY ANALYSIS

1.0 INTRODUCTION

The Californium Multiplier (CFX) is a subcritical assembly of uranium surrounding ^{252}Cf spontaneously fissioning neutron sources. The function of the uranium fuel is to multiply the neutron source strength to a level useful for neutron activation analysis. The multiplication effect allows a partial shutdown of the system when it is not in use - an inherent radiation safety feature as compared with a system of the same neutron intensity using only an isotopic neutron source.

A pneumatic transfer system will transport samples between all points: an automatic sample loader, any of four detector termini, the CFX and the drop out to storage or disposal. The sole transfer vehicle for samples will be the National Bureau of Standards (NBS) 1.3 inch rabbit. All transfers will be under computer control. Only one rabbit will be in the system at any given time. All rabbits will be permanently sealed and used once only.

Products of irradiation will be analyzed, nondestructively and remotely. Delayed neutrons will be used to determine low levels of fissile material. Gamma, Beta, Positron, Electron Capture, etc., will be used on existing detector systems to determine isotopic and elemental composition in parts per million to parts per billion.

The CFX and Delayed Neutron Counter (DNC) are being designed and fabricated by IRT Corp., San Diego, California, under provisions of CPFF Contract No. 222. Reactor Experiments, Inc., of San Carlos, California, has designed, fabricated, and delivered the pneumatic transfer system. The IRT Corp./Atlantic Richfield Hanford Company contract provides that the "Contractor shall provide a written hazards and safeguard review of the CFX/DNC system within ten months after receipt of the executed Agreement^[1,2] (Statement of Work item 4.06)." This has been interpreted by both parties to mean sufficient safety analysis documentation to license the facility with the United States Nuclear Regulatory Commission. A preliminary Safety Analysis Review has been submitted by IRT Corp.^[3]

The present document does not pretend to supplant or to reduce the above requirement. It is the intent to summarize the safety analysis aspects of the CFX and to detail all other aspects of the total facility as a starting point for the ARHCO Safety Analysis Review. The format will be a general description of a component of the total facility, an itemization of recognized hazards, and the steps already taken to neutralize them.

2.0 CALIFORNIUM MULTIPLIER

2.1.0 General Description

The Californium Multiplier contains 40 milligrams of Californium-252 in two doubly sealed capsules. The Californium-252 provides neutrons through spontaneous fission (and decay with a half life of 2.73 years). The neutrons are moderated and reflected by light water. Approximately 1,800 grams of Uranium-235 in MTR type fuel plates at an enrichment level of 93.15 percent, absorb the thermalized neutrons, fission, and reemit neutrons for a net multiplication of thermal neutrons at the flux trap of a factor of approximately 25. Maximum thermal neutron flux density when the CFX-40 is fully loaded will equal or exceed 9.0×10^9 neutrons per second-centimeter squared. Thermal power output of the assembly is less than 160 watts. The k_{eff} is 0.990 (fission source multiplication of 100). There are a variety of units in use which relate to incremental reactivity changes. For incremental changes in nuclear worth, which are only valid about $k_{eff} = 0.99$; a $\Delta k/k$ equaling 0.01 k_{eff} may be stated as having a worth of \$1.28. Therefore, a dollar equals 0.0078 $\Delta k/k$.

The flux trap is a small right circular cylindrical air volume, doubly contained in aluminum, and an integral part of the pneumatic transfer system (Figure 1). The volume is designed to conform to the size of an NBS 1.3 inch irradiation capsule or rabbit. The center of the flux trap will be under ten feet of water, 15 feet below grade, and under an additional eight inches of reenforced concrete (Figure 2).

The CFX is provided with four aluminum clad cadmium safety rods (Figure 1). Two ion chambers are provided to drive three trip channels (two for flux level and one for flux period). A one-out-of-three logic drops all safety control elements when any channel exceeds its trip level setting. When fully shut down, the CFX k_{eff} is approximately 0.80.

One additional ion chamber is provided in close association with the flux trap to monitor flux density continuously through a current integrator for neutron activation data reduction purposes (Figure 1).

2.1.1 Californium Capsules

Twenty milligrams of Californium-252 will be contained in each of two capsules. The source capsule designation is SR-CF-2000. The capsule type is licensed and approved by the Nuclear Regulatory Commission. They will be fabricated and loaded at Savannah River Laboratory, the only licensed facility for this type capsule.

The inner containment is a cylinder 1.22 inches long by 0.218 inch in diameter with 0.049 inch thick walls. The material is 90 percent Pt and 10 percent Rh. Outer containment is a cylinder 1.51 inches long and 0.371 inch in diameter of Zircaloy-2 with a 0.200 inch #10-32 UNV threaded stud at one end. This stud threads into an "eyelet" of ASTM 410 or 416 stainless steel which allows mechanical or electromagnetic control of the movement of the capsule.

The californium capsules enter and are located in the CFX by means of two aluminum closed end tubes which extend from above the water line of the CFX site to the CFX core, on either side of the flux trap (Figure 1).

2.1.2 Fuel Plates

The fuel consists of MTR type fuel plates. This type of fuel has been used extensively throughout the world in many low-powered reactors over the last 20 years and is now being used in subcritical multiplier assemblies. The fuel plates are licensed and approved by the Nuclear Regulatory Commission. Ours are being fabricated by U. S. Nuclear under contract to IRT Corp. from uranium "leased" from Oak Ridge National Laboratory. U. S. Nuclear is a licensed MTR fuel fabricator.

Each plate contains $10.3 \pm .15$, $-.20$ grams Uranium-235 as a 20 percent uranium-aluminum alloy and a 93.15 ± 0.01 percent enrichment. Each plate has a 0.020 inch thick core of U-Al alloy with 0.010 walls of aluminum. The finished plate dimensions are 12.75 inches by 4.65 inches by 0.040 inch. Each plate is individually identified and assayed for Uranium-235 content. It has $44.2 \pm .6$, $-.8$ grams aluminum per plate, excluding the cladding.

Cladding of these fuel plates has been proven to contain the gaseous and soluble fission products at burn-up levels up to 45 percent. The anticipated burn-up over the lifetime of the CFX is negligible.

2.1.3 Fuel Assembly, Moderator, and Reflector

The fuel assembly consists of the uranium fuel plates rigidly mounted in aluminum frames (Figure 1). The entire fuel assembly is immersed in light water which acts as both the moderator and the reflector (Figure 2). The fuel plate loading pattern is computed to yield a k_{eff} of 0.990 and a hydrogen-to-uranium-atom ratio of 425:1, the critical mass minima (Figure 3). Approximately 95 percent of the fuel plates are loaded, the k_{eff} and H/U ratio measured, and the fuel plate loading pattern recomputed. The final loading pattern is verified one fuel plate at a time. A fuel plate in the periphery of the core assembly has a nuclear worth of approximately 20¢. The location of each fuel plate in the assembly is mapped by the identification number of the plate for reassembly at the ARHCO site.

The 425:1 hydrogen to uranium ratio is rigidly adhered to so that any rearrangement of fuel or moderator, accidental or otherwise, will result in a less than optimum minimum critical mass and therefore, a less reactive system (Figure 3).

The fuel assembly is axially indexed in the center of the CFX site by means of three standoff side guides in the lower section of the site tank (Figure 2). Rotationally it will be indexed by means of flange couplings at the top of the cylindrical CFX site water vessel.

The only penetrations of the reflector are the aluminum irradiation tube through the top of the assembly, the aluminum pneumatic transfer return air supply through the bottom (one "U" shaped tube) and the two aluminum guide tubes for the californium capsules through the top of the fuel assembly to either side of the flux trap.

2.1.4 Safety Rods

The CFX has four vertically mounted blade-type safety rods that are made of 0.030 inch thick, aluminum-clad cadmium. With cladding, each has a cross section of 3.75 inches by 0.090 inch and 15 inches of cadmium in an overall length of 22 inches (Figure 2). Pairs of rods are driven by two independent safety rod drivers. The rods are individually coupled to the rod drivers electromagnetically. To withdraw the rods from the core area, the rod drivers employ a worm drive and lift the rods vertically. Only one safety rod driver can be engaged at a time. If a scram condition is met, or a power failure occurs, the electromagnet coupler is turned off and the rods fall by gravity action into the fuel region. Full up to full down condition for the safety rods in a scram condition takes less than 0.50 second. The nuclear worth of the four safety rods is -\$16.50.

2.2.0 What if a Californium Capsule Leaks? What if a Uranium Fuel Plate Leaks?

If either a californium capsule or a uranium fuel plate leaks, it will eventually cause fission products to be dissolved in the moderating water. The moderating water is contained in a closed system. It is constantly demineralized and filtered while recirculating. The demineralizer will be located in the B-1-F stairwell (Figure 4). A routine radiation check will be made and logged on all air and water filters associated with the CFX. Should the demineralizer/circulator acquire a radiation reading, we would first determine by gamma spectrometry whether the radiation was due to fission products and consequently be due to either capsule or fuel plate leaks or due to irradiation products of the CFX components exposed to both neutron flux and water. If the former, additional gamma spectroscopy will confirm the leakage source, californium or much more likely uranium. The californium is triply contained while the uranium is present in quantities orders of magnitude larger and singly contained. Each californium source capsule is wipe tested for leaks semiannually.

An administrative judgment would have to be made as to what level of fission products released to the water constitute a hazard. At that point, the CFX would be shut down, the californium capsules unloaded, the CFX removed from the site, and the offending fuel plate located and replaced. In no case could a leak in source capsule or fuel plate contribute to a higher neutron flux or reactivity rate. The sole effect would be the gradual contamination of the CFX moderator and the radiation dosage increase from that source. Should it occur, the moderator would be pumped from the CFX site and disposed of in the same manner as contaminated reactor coolant water.

2.2.1 What if Electrical Power is Lost?

If electrical power is lost, the cadmium safety rods will decouple from the electromagnets which hold them out of the CFX core. The safety rods^[4] will drop into the core under the influence of gravity. This is the natural, maximum shut-down condition for the multiplier representing $k_{eff} \approx 0.80$.

Upon the return of electrical power, the cadmium safety rods must be recoupled to the electromagnets and a normal power-up of the CFX performed before the safety rods can be removed from the core and anything but minimum neutron flux or k_{eff} achieved.

With regard to rabbit transfer, all valves controlling transfer of rabbits are normally closed (NC), hence, they cannot cause transfer when power is withdrawn nor when it is reapplied. The sample must remain where it was at the time of the power outage. Any transfers in progress will be completed and all termini are shielded. If the motive air valve is open when the power outage occurs, it will close, because it is an NC valve.

2.2.2 What if the Total Moderating/Reflecting Water is Lost? What if the Level of Water in the CFX Site Tank is Reduced?

If the CFX is operating when this occurs, the safety rods would be scrammed. If the CFX is not in operation, the safety rods could not be withdrawn from core. Water level is a condition that is a part of the CFX operating console interlock system, not because it could damage the system, but because the k_{eff} and neutron flux levels would be reduced by a nonroutine mode. In the shut down mode, the CFX generates

only fractional wattage. Even in the case of failure of the water level detector and/or the console interlock, convective cooling is adequate to prevent damage. Once the water level drops to within approximately five inches of the core, the CFX effectively shuts itself down for lack of first reflector and then of moderator. Power output would reduce to a few watts which would be adequately dissipated by air convection.

2.2.3 What if the Water Circulating Pump Fails?
What if the Water Temperature Increases?

Nothing happens. Convection is more than adequate to prevent damage to the CFX. The k_{eff} will be marginally reduced as the water temperature in the core increases. The water temperature coefficient equals $-8.5 \times 10^{-5} \Delta k/k$. In the $^{\circ}C$

event the CFX is shut down at the time of the circulating pump failure, the safety rods cannot be removed from the CFX core and it will remain shut down.

2.2.4 What if the Water Temperature Decreases?

The k_{eff} will raise marginally as the water temperature around the core decreases. The water temperature coefficient equals $-8.5 \times 10^{-5} \Delta k/k$, therefore, a 20 degree reduction in $^{\circ}C$

temperature increases the k_{eff} by 0.0017 or 22¢ worth. The CFX is 17 feet below grade and under 10 feet of water; it cannot freeze.

2.2.5 What if the Amount of Neutron Moderator is Increased?
What if the Flux Trap Floods?

The hydrogen to uranium ratio is already at an optimum level of 425:1. If it is increased or decreased relative to the fixed uranium fuel loading, the k_{eff} will be decreased. This is not to say that the neutron flux in the flux trap will not increase, it will be a calculated 35 percent if flooded with water. This would not cause the linear or log-trip channel limits to be exceeded and the CFX to be scrammed because the increase is local to the flux trap. Outside the CFX core where the trip detectors are located, the net reaction would be a minor decrease in both power and flux levels associated with the reduction in k_{eff} .

2.2.6 What if a Water Line Fails?

The water moderator/reflector is a closed system that is continuously circulated, filtered, and demineralized. The main volume of water is in the CFX site tank while the pump, filter, and demineralizer are in Room B-1-F. The water lines connecting these two ends are tygon and are carried in one of the six inch PVC buried service tubes. No water line break can increase the water level in the CFX site because the system is closed. There is a check valve in the water line from the pump. Should any break occur, this will prevent establishing a syphon into B-1-F. When flow in the CFX input water line stops, a solenoid valve will shut off flow in the output line. At worst, a few gallons of water might be run into Room B-1-F which has a liquid capacity in excess of 750 gallons and no drain.

2.2.7 What if the Demineralizer Cartridge Fails?

The demineralizer is a commercial ion exchange resin cartridge. The circulating system is closed and will be initially filled with distilled water. Therefore, the failure of the demineralizer resin should only be a factor of shelf life. It will be changed routinely on the basis of shelf life or contamination build-up, whichever occurs first.

2.2.8 What if Evaporation Losses Reduce the Water Level in the CFX Site Tank?

The CFX site tank water surface will be covered with floating polypropylene spheres to minimize water evaporation and to minimize humidity in the CFX site. An upper level water indicator in the CFX site tank will indicate when the water level has dropped below that point, regardless of cause. Periodically, distilled water will be manually valved into the closed circulating system from the 222-S Building system. Additions will only be made until the upper level water indicator registers.

2.2.9 What if the Californium-252 Capsules are not in the CFX?

The safety rods cannot be withdrawn if the Californium-252 capsules are not in the CFX. The log channel of the CFX control panel has a low-level neutron trip. The purpose is to prevent an inadvertant super-critical mass being built up without a neutron source to initiate the nuclear reaction. The nuclear worth of each of the two Californium-252 capsules is -6¢.

2.2.10 What if the Uranium Fuel Plate Assembly Warps?
What if the CFX is Crushed?

The CFX is built with an atom ratio of hydrogen to uranium of 245 to 1, a criticality minima (Figure 3). Any change to the core configuration must reduce the k_{eff} .

2.2.11 What if the Neutron Flux Monitor(s) Fail?
What if the Control Cables to the CFX Fail?

If the ion chamber, neutron flux monitor attached to the log-trip channel fails while the CFX is in standby or scram condition, the safety rods cannot be withdrawn because of the low-level trip.

The ion chambers are extremely rugged and reliable as proven by many years of service in reactor applications. They have a very low incidence of failure. Should one fail during CFX operation, the other detector will supply all needed safety control. If both detectors fail without the loss of control panel, Direct Current (DC) voltage, the CFX would continue to operate but that is a combination of circumstances that cannot be credited. Even so, the CFX is still designed safe and nothing would happen. If the DC voltage from the control panel were lost as it would be if the control cables failed, the CFX would scram. The same control interlock would be activated as when the control panel was shut off by key or if the manual scram button were used.

In the event of any of these failures, the offending item would be replaced before the CFX was used again.

2.2.12 What if the Neutron Flux is Higher than Rated?
What if the Rate of Neutron Flux Increase is
Higher than Rated?

The CFX has three trip channels operating from the signals of two independent neutron flux detectors. Both the linear and the log-trips are set at 125 percent of rated power (160 watts) or 200 watts initially. The period trip is set at a calibrated rate of flux change. If any one of the three trip values is exceeded, the CFX will scram. That is, the safety rods will decouple from the electromagnetic couplers and drop under the influence of gravity into the CFX core.

All trip set level potentiometers are back panel adjustments. A weekly verification of their calibrations will be conducted.

2.2.13 What if the Neutron Flux Rate is Lower than Rated?

This is a safe condition but one that is economically untenable. Operating instructions call for recording fluence every time the CFX is powered-up. Any alteration other than the predictable reduction due to ^{252}Cf decay, indicates a nonstandard condition that must be immediately corrected.

2.2.14 What if the Safety Rod Drive Motors Burn Out?

If either safety rod drive motor burns out, the pair of safety rods associated with that motor will be incapable of withdrawal from the CFX core. System nuclear worth will be reduced by \$8.25. The motor will have to be repaired or replaced before the CFX can be used.

2.2.15 What if a Safety Blade Jams Up?

The system is safe because the other three safety blades have a nuclear worth of -\$12.37. However, after a shutdown, it will be apparent that one pair of safety rods cannot recouple. If one rod is up, the other is down and the CFX cannot be powered up. Repairs will have to be made.

2.2.16 What if a Safety Blade Jams Down?

If a safety blade jams down, the CFX cannot be powered up until the jam is cleared.

3.0 CFX SITE

3.1.0 General Description

The CFX Site is a pit entirely below grade level, covered by an eight inch thick, reinforced concrete slab (see Figure 2). All wall surfaces of the site are also composed of at least eight inch thick, reinforced concrete. The lower chamber is a vertical aluminum tank with half inch walls, an inside diameter of 4 feet, and a height of 12 feet 4 inches. The CFX will be contained at the bottom of the tank, centered by three standoffs welded to the tank walls. The tank will be the inner form for the concrete walls after being tarred and papered. The outer form will be "ARMCO" tunnel liner, 72 inch neutral axis diameter. The upper end of the tank will have a welded flange which will align and support the safety rod drive motors, the pneumatic transfer tube terminus, the californium capsule entry tubes, the in-core ion chamber, the two CFX monitoring ion chambers, etc. The tank will be filled to a depth of 12 feet with distilled, demineralized water. Molded into the side wall of the tank and extending below it are two stainless steel storage tubes for the temporary storage of the californium capsules.

The rectangular cross sectioned upper chamber has inside dimensions of eight feet by five feet, and is five feet deep. Interior and exterior wall surfaces are water sealed. The tank flange extends four inches above the upper chamber floor level. The floor slopes to a sump pit of approximately one and one half cubic feet capacity. The sump is pumpable from outside the chamber without removing the lid. The chamber contains the 60 gallon CFX air ballast tank and all the service connections from the 222-S Building, including a PAX phone.

Two 6-inch diameter PVC pipes connect the CFX site with the 222-S Building. One pipe contains all the pneumatic and water lines. The other contains all electrical and electronic lines. The latter pipe is also used to pull a continuous stream of air over the CFX site. The air is pulled through a filter in the B-1-F Stairwell where it is routinely surveyed for a build-up of radioactive particulate material.

The air inlet to the CFX site is a pipe entering the side opposite the six inch PVC pipes in the upper chamber. It goes above the ground level to one side of the lid and consists of a weather hood, a filter, and a prefilter.

- 3.2.0 What if an Attempt at Sabotage is Made?
What if an Attempt is Made to Remove the Uranium
Fuel Plates?
What if an Attempt is Made to Remove the Californium
Capsules?
What if the CFX Site Cover is Removed?

The only access to the CFX or any associated equipment located in the CFX site is through the top. A crane is needed to lift the lid; it cannot be dragged off without sufficient vertical displacement to trigger the alarms and interlocks. Any vertical displacement of the lid will cause an electrical switch to open which in turn opens a DC circuit. This will trigger two events. First, a signal will be sent to the 200 West - Main Gate Security Patrol Station indicating that the CFX site lid is being removed. Second, the switch is an integral part of the CFX interrupt circuit. If the CFX is not already at minimum flux level, interruption of the circuit will cause a scram. It will be impossible to withdraw the safety rods again until the circuit is restored.

The CFX site alarm circuit is entirely self-contained in the CFX site. It is battery operated and cannot be reached or affected from any point outside the CFX site. The alarm to the Security Patrol Station is a dedicated phone line that runs through a buried six-inch PVC tube. It is normally closed. To cut it is to open the circuit and to cause the alarm to be sounded.

A second independent electrical switch that is connected to 222-S Building power is a part of the CFX interlock circuitry. If this switch is opened, the CFX is scrambled and a light indicating the cause of the scram is lit on the CFX control panel.

- 3.2.1 What if the CFX Site Tank Leaks?
(See 2.2.2 for effects on CFX)

If loss of water in the CFX site is traced to a leak in the CFX site tank, the CFX would be shut down and the tank pumped out preparatory to repair. Prior to installation, the CFX site tank will be hydrostatically tested for leaks. Installation involves pouring eight inches of reinforced concrete around the tank. A leak is highly unlikely.

3.2.2 What if the CFX Tank Overflows?
What if External Water Enters the CFX Site?

The water level in the CFX site tank is to be manually maintained at a maximum height of four inches below the top of the tank. A level indicator at that level signals the need for an addition to the closed system from the 222-S distilled water supply. Should the valve break in the open position or not be fully closed after the level indicator again registers, the CFX site tank will overflow to the sump.

The sump contains a liquid indicator and pipe guide through which a flexible tube can be inserted to pump out the sump without removing the site cover. The pipe guide is capped with a screw-on cap. The liquid indicator will flash a warning on the CFX operating panel whenever it senses liquid. Obviously, it can also be tested through the pipe guide without removing the CFX site cover.

3.2.3 What if Excessive Humidity Causes Voltage Grounds?

In time a supersaturated atmosphere in the upper CFX site chamber would cause voltage grounds. Therefore, the humidity is being controlled. First, the water surface of the CFX site tank is covered with floating polypropylene balls, reducing the exposed surface area by 90 percent. Secondly, dry filtered air is continuously being drawn through the upper CFX site chamber, through one of the six inch diameter PVC service tubes and into Room B-1-F, 222-S Building.

3.2.4 What if There is a Sandstorm?

The CFX site cover has a gasket that effectively seals the CFX site from all weather induced conditions. The circulating air is prefiltered with a dust-stop filter before it passes through a standard 8 inch by 8 inch by 5 7/8 inch HEPA filter. Both filters will be replaced on a routine basis.

The CFX site cover will not be removed if winds over ten kilometers per hour are forecasted or if dust devil conditions prevail.

3.2.5 What if the Air Over the CFX Tank Becomes Contaminated?

The air over the CFX tank will be drawn through one of the six inch PVC service tubes and through a standard room air monitoring filter located in Room B-1-F, 222-S Building. This filter will be assayed in the air monitoring counter systems for contamination with the same frequency and operating limits as any working laboratory room air filter.

3.2.6 What if There is a Prolonged Cold Spell? Hot Spell?

The 150 cubic feet of water in the CFX site are at least five feet below grade. The temperature is governed exclusively by the ground temperature at that depth. This temperature has only long-term and minor seasonal variations. All service lines, which include the water circulating lines, are at least four feet below grade. These too are below the normal influence of the weather.

The temperature of the air drawn into the upper chamber of the CFX site is the only variable that could adversely affect operation. Because this air temperature could be below zero Fahrenheit for several days at a time, the air movement will be maintained at a low rate through the six inch PVC tube containing the electrical and electronic lines, not the air and water lines. The exposed water lines in the CFX site will be wrapped in heater tape as a precaution against freezing.

3.2.7 What if the CFX Needs Servicing?

What are the Radiation Readings at the CFX Site?

If the CFX needs servicing, a preliminary step will be the movement of the Californium-252 capsules from the CFX core to the storage tubes built into and under the CFX site. The CFX site cover will be removed by crane. The capsules will be withdrawn from the CFX core, temporarily into the six-inch PVC service tube using the permanent magnet, flexible cable controls from Room B-1-F, 222-S Building. Movement will be coordinated by a PAX phone in Room B-1-F and from a long extension in the CFX site. The PAX phone is part of the building system and can access any building PAX phone in case of need. Radiation monitors will follow the movement from the CFX to the service tube, where they will be drawn a predetermined distance. Once there, the flexible guide tube will be moved from the CFX capsule source pushed to the bottom of that tube.

The permanent magnet, flexible cables can be individually coupled to a cable to control movement of the californium capsules. This cable has a permanent stop on the cable to prevent the capsules being brought too close to or into the 222-S Building. When the cable is not in use, it is locked at the B-1-F end and decoupled at the CFX site end.

With the CFX site cover in place, gamma exposure readings will be at a maximum of 0.22 MR/hour directly over the center-line of the CFX. There will be no measurable neutron field since all neutrons are moderated and absorbed in the water blanket. A chain fence will enclose the CFX site to limit casual access and exposure.

With the site cover removed, the gamma radiation field at the surface of the water is approximately 3 MR/hour with locally high readings at the ends of the californium capsule source tubes and the rabbit tube. During remote movement of a californium source, radiation readings will reach a maximum during the few seconds when the capsule is only contained in the flexible guide tube between the six-inch PVC service tube and either the CFX source tube or the source storage tube. These readings will be monitored remotely with an enlarged radiation isolation zone to limit personnel exposure. At no time will the gamma or neutron exposure reading at any interior 222-S Building location exceed 1 MR/hour.

Should any part of the CFX require service that is not accessible from the upper chamber of the CFX site, the source capsules would first be stored as indicated earlier. All service lines would be disconnected and the CFX lifted out of the site by its lifting bails. This is a radical measure and would not be attempted without IRT representatives present nor without a prior cooling period for the decay of short-lived fission products in the uranium fuel plates.

3.2.8 What if There is a Fire in the CFX Site?

There is nothing in the CFX site that can start a fire nor support combustion. The motors are covered and there are no heat sources.

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4.0 PNEUMATIC TRANSFER SYSTEM

4.1.0 General Description

All samples irradiated in the CFX will be transported in a National Bureau of Standards 1.3 inch pneumatic capsule or rabbit. The rabbit dimensions are 33 millimeters OD, 95 millimeters in length, 26 millimeters ID, an air volume of 42 milliliters, and a maximum usable solid or liquid volume of 38 milliliters. The rabbits are molded of Phillips Petroleum Co. BMB Marlex[®] 5040, a polyethylene molding material chosen for its low uranium content. Rabbits will be sealed, using Loctite[®] Superbonds 422, prior to smear checks for external contamination and prior to entry into the pneumatic transfer system. Rabbits will be used one time only. They will not be reopened regardless of fissile content. No rabbit will make more than 100 trips to the CFX.

The rabbits are transported through flexible polyethylene tubes having a 1.5 inch (38 mm) ID. Twenty-five to 30 pound per square inch motive air is supplied from one of two 60 gallon ballast tanks in 1.25 inch ID tubing. Exhaust air is carried off and collected in the same type 1.25 inch ID tubing. The solenoid valves in the system are operated with 90 psi air carried in 0.25 inch tubing.

The pneumatic transfer system (Figure 4) has an auto-loader as the sole means of entering rabbits into the system. The system services four detector termini, one of which is the DNC, the CFX terminus, and a drop-out where the rabbits exit the system. All termini including the auto-loader are equipped with air cushions which slow the rabbit from 200 feet per second to zero speed in less than two feet of travel.

The movement of a rabbit into, through, and out of the pneumatic transfer system is controlled by a Digital Equipment Corporation (DEC) BDP 11/05 Central Processing Unit (CPU) operating through a CAMAC controller and interface. The controlling program in conjunction with the CAMAC interface and standard CAMAC modules

- Allows only one rabbit at a time in the system;
- Establishes rabbit routing;
- Checks routing prior to any rabbit movement;

- Monitors and records rabbit movement in the system;
- Initiates all solenoid valve operations to change routing or to move the rabbit;
- Times duration of motive solenoid valve operation;
- Times sample background, irradiation, decay, and sample count intervals;
- Counts number of irradiation-count cycles;
- Passively prechecks all sample to be irradiated for fissile content and rejects those over limits;
- Checks all samples entering B-1-A for radiation level and returns those over limits;
- Locks out all manual commands save two, active and/or passive assay;
- Continuously monitors and stores DNC background;
- Monitors and stores CFX sample perturbed neutron flux;
- Stores input routing and timing information;
- Turns on, turns off, and records data from analytical data gathering devices;
- Responds to interlock breaks;
- Errors out with a diagnostic message in response to all abnormal conditions.

The CFX and the CFX pneumatic transfer system are independently powered and operated. Manual operation of either system is only possible by opening the respective key lock.

The transfer system is equipped with a number of interlocks. All samples directed to the CFX in the input instructions are passively monitored in the DNC for fissile content. The trip level is set at the worst case level that would correspond to a 12¢ nuclear worth addition to the CFX. Rabbits at this level and higher are routed to the drop-out and the CPU terminal prints, the DNC scaler reading and the message "Too much fissile." The program does not abort but proceeds to the next sample.

All rabbits entering the B-1-A counting room are monitored for radioactivity level as they pass the entry point, whether or not it was intended that they go to B-1-A. Any rabbit with a gamma radiation level exceeding approximately one Rad will (a) sound an audible alarm to alert counting room personnel that their analyses may have been affected, (b) sets up and verifies routing of the rabbit to the drop-out, (c) fires the rabbit, and (d) aborts the program with the message "Too Hot". Resident time in the B-1-A counting room is less than two seconds of which at least one second is within a lead shield.

The B-1-F main floor exit and lower level staircase are monitored by photocells. The lower level photocell also monitors the area beyond the dam. Whenever either photocell light path is broken, the entire CAMAC crate is inhibited. This means no solenoid valve can be opened. If a rabbit is in the system, the first time a location check or route verification is not confirmed, the program will abort with an error message indicating the location of the sample. The photocell interlock must be manually reset, the rabbit manually routed to the drop-out, and the program reinitiated.

The only valid assay for Rad level samples is for low-level fissile content using the DNC. When it is known that high activity samples are being loaded into the auto-loader (which is shielded with four inches of lead), it will be done according to Standard Operating Procedures, under the direction of a radiation monitor. A "hot sample" switch located next to the auto-loader will be activated to remove power from the solenoid valves in diverter C (Figure 4). This forces the path to the DNC, the only detector terminus not in B-1-A. If the routing instructions do not verify this routing, the rabbit will not fire and the program will be aborted.

4.2.0 What if the Power to the CFX Transfer System Fails?
What if a Solenoid Valve Fails Open/Closed?

The CFX transfer system is on uninterruptable power, that is all AC power in this circuit is routed through an AC to DC converter, a bank of storage batteries, and a DC to AC converter. Besides acting as a noise filter, it allows approximately 15 minutes for an orderly shutdown of the systems powered by the circuit. In the case of the CFX transfer system, loss of AC power causes the battery system to pick up the power load. It also causes an interrupt to be sensed by the CPU, the same interrupt used when a photocell

light path in B-1-F is broken. This in turn caused the CAMAC crate to be inhibited, preventing any solenoid valve from opening. As soon as a rabbit location or routing is not verified, the CPU aborts with an error message indicating the location of the rabbit. The entire CFX transfer system has now been shut down without program disruption or rabbit damage.

4.2.1 What if a Rabbit Jams in the System?

About the only place a rabbit can jam in the system is in a terminus because only in a terminus is the rabbit path rigid with a few mils clearance. The flexible portions of the path provide two-tenths inch clearance for the rabbit and should that prove insufficient, the air pressure behind the rabbit will cause expansion of the tube for greater clearance. Partially open diverter positions or fully closed routings will result in error messages and abortion of the CPU program but not movement of the rabbit. All diverter positions are verified by limit-switch readings that are checked through the CPU immediately prior to any rabbit movement.

Should a rabbit jam in a terminus and repeated manual application of air fail to dislodge the rabbit, the terminus would have to be decoupled from the transfer system and the rabbit rodged out. Decoupling of even the CFX terminus can readily be accomplished with a minimum of effort and time. The CFX would not have to be removed from its site, however, the cover would have to be taken off and the source capsules put in their storage tubes.

4.2.2 What if a Rabbit Hits a Closed Diverter Position?

This is not possible under CPU control. However, it can be accomplished under manual control. It presumes the operator has the CAMAC interface key which alone allows manual operation. The sample moves in the tube because the air in front of it exhausts as fast as the air behind the rabbit is traveling. As soon as the air path in front of the rabbit is blocked, the rabbit slows to a stop. This is the principle of the air cushion. What happens to the rabbit? Nothing.

4.2.3 What if a Rabbit Hits a Partly Closed Diverter Position?

This is not possible under CPU control. It is only possible under manual control if failure of a diverter solenoid valve in mid-stroke is assumed. This is an untenable combination

of circumstances, but assuming it did occur, the rabbit would hit the partly open plate at about 200 feet per second and would shear or burst. Whatever the contents of the rabbit, they would contaminate the diverter box, all lines to the next terminus, the terminus air cushion, the exhaust line from the air cushion, and the exhaust filter box. All would have to be replaced.

4.2.4 What if a Rabbit Ruptures in the System?
What if Transfer System Components get Contaminated?

Rabbits are loaded using a Standard Operating Procedure. They are used only once. They are loaded so all exterior surfaces and threads are not contacted by the sample. The lids are threaded and they are sealed to prevent the lid from backing off or leaking. They are smeared and checked for surface contamination after loading and again before entering the B-1-A counting room. They have tremendous impact resistance. If never-the-less the rabbit ruptures while containing a radioactive sample, all affected parts of the transfer system are removed and replaced with new parts.

All motive air in the transfer system is collected and routed through a HEPA filter box in B-1-F. The filter is continuously monitored remotely and routinely monitored manually. Any radiation indicates a rabbit has leaked in the system.

4.2.5 What if a Rabbit Transfer Tube Ruptures?

Motive air in the rabbit transfer tube is 25 to 30 psi. All transfer tubes are tested at 50 psi and are rated to burst only at pressures higher than 50 psi. Should a transfer tube burst, the motive air would escape and the rabbit would not move as fast.

4.2.6 What if There is no Air Pressure?
What if a Pressurized Line Bursts?

The only means of moving a rabbit or changing a diverter position or loading a sample is air pressure. Without air pressure no movement within the system is possible.

4.2.7 What if a Radioactively Hot Sample is in the System?

As long as the rabbit doesn't leak and is not smearable, nothing happens.

4.2.8 What if a Radioactively Hot Sample is Misdirected
Into the B-1-A Counting Room?
What if a Rabbit is Misdirected?

No damage will be done. The only loss will be the time it takes to direct the sample properly and to irradiate and/or count it.

If the rabbit also has a reading of greater than 1 R/hour it will also sound an audible alarm, set up and verify return routing, shoot the sample to the drop-out, and abort the program with the message "Too Hot".

4.2.9 What if Someone Flips Control Toggles Intentionally
or Unintentionally?

Nothing happens. The toggle switches on both the CAMAC interface and the CPU are locked out without a key.

4.2.10 What Happens to the Argon-41 Formed in the Motive Air?

It is exhausted into Room B-1-F, 222-S Building, along with all exhaust motive air from the CFX transfer system. However, it is produced in such minute quantities it cannot be detected.

4.2.11 What if Two Rabbits are in the Transfer System
at the Same Time?

This cannot happen in the automatic mode of operation because the system is tested prior to the introduction of each rabbit. It could happen under manual control. This would require possession of the CAMAC interface key. Even granting it could happen, its difficult to theorize what harm could be done other than losing analytical time.

5.0 DELAYED NEUTRON COUNTER (DNC)

5.1.0 General Description

The DNC is a massive expansion of standard neutron counters. Such a comparatively small neutron flux is available in the CFX as compared to any reactor, in order to achieve the desired sensitivity for fissile content the difference must be made up in the detection geometry of the DNC. Target geometry is 40 percent. Never-the-less, this is still a passive detector system with no hazardous components. It is designed to retain neutron counting efficiency in high gamma or beta radiation fields originating in the sample but no higher than are routinely analyzed in the adjacent room, B-1-A, for gamma energy analysis.

The DNC consists of 42 BF_3 tubes arrayed around an internal bismuth gamma shield. The moderator is transformer oil, 750 gallons of it. The sample enters and leaves the DNC via the CFX pneumatic transfer system (Figure 4).

Power is supplied to the BF_3 detectors from two 19-inch rack mounted, +3500 VDC power supplies. Signals are collected in four Nuclear Instrument Modular (NIM) amplifiers and four NIM integral discriminators. The signals are combined in a four channel mixer and fed to the CAMAC scaler/timer system controlled and data reduced by the Scorpio 3000 CPU.

The DNC tank has an outside diameter of 60 inches and stands 65 inches high, not including leg/access height. The entire detector/shield/rabbit terminus assembly is supported and accessed from the 27.5 inch diameter tank lid. Therefore, vertical clearance of 5 feet by 32 inches is required above the DNC for installation and servicing. To achieve the clearance measurement the lower course and landing had to be rebuilt. The angle of the lower course of stairs was increased slightly and one stair tread removed from the upper course to increase the elevation of the landing by 7.75 inches and increase its width by approximately 12 inches. Access is provided through a trap door on the landing. It is hinged to fence the opening from the basement level.

In order to get the DNC tank into Room B-1-F, it will be cut into two sections, reassembled and welded in place. The interior surfaces will then be prepared and varnished using standard transformer techniques and varnish.

5.2.0 What if the Tank Ruptures?

Prior to being filled, the tank will be pressure tested to verify that it does not leak. If never-the-less, a rupture or fast leak develops after filling, the basement level of 222-S has no drains to accommodate water or, as in this case, oil. A dam is being built under the stairwell and across the entrance to the DNC chamber sufficient to contain ~800 gallons.

5.2.1 What if Water Moisture Accumulates in the DNC Tank?

A tap is provided at the bottom center of the DNC tank. During installation, a line will be led from that point to a point accessible from the side. Periodic checks will be made to draw-off water if it should accumulate.

5.2.2 What if a BF₃ Tube Fails?

What if a Bank of BF₃ Tubes Fail?

What if the DNC Needs Servicing?

If the DNC needs servicing, it will be powered down. All service lines and tubes will be decoupled. The stairway trap door will be opened and the DNC tank lid unbolted. A built-in chain hoist will raise the DNC detector assembly out of the tank. A drain pan will be held under the assembly while it is moved laterally to a fixed portion of the landing. The tank opening will be covered to prevent debris falling into the tank and the stairwell trap door will be closed. After the DNC detector assembly has drained, any defective components will be replaced and tested. The assembly will then be returned to the tank.

5.2.3 What if there is a Fire?

There is nothing in the B-1-F stairwell to start a fire or support combustion early in a fire. The room is equipped with heat sensor annunciators that are tied to the building alarm panel and to the 200 Area Fire Station. The room is also covered with an automatic water sprinkler system.

The DNC does contain a large volume of oil but it would take prolonged application of high-level heat to produce an oil leak and subsequent combustion. Transformer oil has a high tolerance to electrical arcing and will not burn or explode if arcing takes place in the liquid oil. In order to prevent any possibility of an explosive mixture above the oil, the void at the top of the tank will be purged with nitrogen every time it is closed.

A part of the Standard Operating Procedure for any repair to the DNC requiring that the tank lid be opened will be the presence of CO₂ fire extinguishers.

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6.0 INSTRUMENTATION

6.1 CONTROL INSTRUMENTATION

There are two distinct and separate sets of control instrumentation: for the CFX and for the pneumatic transfer system and connected radiation detectors. Both systems are described in conjunction with their major area of control. The control response of both sets of instrumentation will be summarized again in this section.

6.2 CFX CONTROL INSTRUMENTATION

The CFX is controlled from Room B-1-A, 222-S Building via two 19 inch, panel mounted chassis. One chassis functions as an instrument-monitoring panel and the other as a control panel.

The normal operating instrumentation for the multiplier consists of two independent channels, both of which are safety channels. One channel provides for log N and period information, and is equipped with an overpower trip, a period trip, and provides for a "flux-up" low-level interlock in the control system. The second channel is a linear power channel, and provides an additional overpower trip. Both of these safety channels utilize Reuter-Stokes RSN15A compensated ion chambers. The chambers are designed to be sensitive to the number of neutrons leaking from the assembly, and are positioned such that suitable readings are obtained over the range of operating levels associated with the CFX. The instrumentation chassis provides the readout for the two safety channels. The two channels utilize picoammeters, and the log N channel has in addition a logarithmic amplifier with a set range of 5 decades (10^{-10} to 10^{-5} amperes). Each channel has trip levels which when exceeded will scram the CFX. The linear channel is set such that if an overpower of a set value on each scale occurs, the system will scram. Normally, the scale will remain at the amperage range corresponding to the full power CFX nuclear flux. The log N channel trip is set for 125 percent of the maximum power level anticipated (~ 160 watts). In addition, the log N channel has a low-level trip which does not scram the CFX, but does not allow the rods to be removed until a set level of neutrons are present in the core, i.e., a source is in the core. The log N channel also feeds a period circuit which measures the differential or time rate of change of the log N current. This current has a trip level which will scram the system if the period of the assembly is less than a set value.

Any one of the three high-level trips, linear, log, or period, is sufficient to scram the subcritical assembly. The safety rods will fall into the core and the rod drives will automatically drive full in. This automatic drive sequence will occur, provided electrical power is available and the scram system is not reset. If the electrical power is interrupted, the safety rods will fall automatically into the core.

On the right side of the instrument panel are lights to indicate which electronic trip was actuated. At the bottom of the indication lights is the reset button that resets all of the electronic trip circuits.

The log and period meters can be calibrated from internal circuitry. A three-position, spring-loaded switch coupled to two potentiometers provides sufficient adjustment to calibrate the two meters. A zero calibration can be performed on the linear meter.

The rear panel of the instrument chassis contains the potentiometers to set the limits for the electronic trip circuits. The output connectors for the linear, log, and period recorders are here, along with the connectors for the signals from the linear and log ion chambers. The connector from the instrument chassis to the control chassis is also located on the rear panel.

The multiplier is equipped with an interlock and control system designed to force the operator to follow certain procedures in order to change the system reactivity and to provide for safe operation of the system such that there is little chance for exposure of personnel to significant amounts of radiation.

The safety interlocks are provided to assure that the system is ready for operation and startup, and that conditions for the protection of personnel are in effect. The breaking (interruption) of any of these interlocks will prevent operation of the system or cause the system to return to a safe condition. This system includes:

- Microswitch interlocks on CFX site cover.
- Cell scram buttons (panic buttons) located inside the CFX site.
- Manual scram button on console.

- Nuclear safety trips located at console:

- Log power - high level
 - Linear power - high level
 - Period - low level

- Core water level and interlock.

- Power key located at console.

The red "OPERATE-ON" light will light when the interlock key switch is turned on and all of the other necessary interlocks are closed. With the above interlocks complete, it is possible to reset the system scram holding relay and supply power to the control system. At this point, the magnet coil which couples the safety rod drives to the safety rods is energized and the rods can be withdrawn to bring the system to its maximum multiplication, provided that the following control system interlocks are satisfied.

- Low-level "flux-up" trip (source in core).

- Water circulatory system.

These interlocks will not scram the system, but will negate increasing the system reactivity (i.e., withdrawing either safety rod) if the water purification system is not in operation, or if the source is not present (inserted into the core).

The indicator lights for the safety rods represent limit conditions for the safety rods. Safety rods are fully withdrawn when the "ROD OUT" light is on. The rods and the rod drive mechanism are magnetically coupled when the "LATCH" light is on. A "SCRAM" light on indicates that the safety rods are fully inserted in the CFX core.

The safety rods motors are controlled by three-position, spring-loaded toggle switches. To activate the assembly from a shut-off condition, the source must have been moved in and the safety rods moved out. Both of the safety rod drive units may not be moved out of the core at the same time. If both safety rod toggle switches are held in the out position, then only safety rod drive No. 1 (on the left side of the assembly) will move.

If at any time it is necessary or desirable to scram the CFX, the red scram button on the front of the control panel will drop the safety rods into the core and will also automatically drive the safety rod drive units to the full-in position. Turning off the operate key will accomplish the same function. The automatic drive feature is in effect whenever the interlock chain is not complete.

6.2.1 What if There is a Fire in Room B-1-A?

Room B-1-A has a Halon[®] 1301 Fire Extinguishing System. If the room sensor system detects sufficient heat or products of combustion to trigger, the first function performed is the shut down of all alternating current power.

6.3 CFX PNEUMATIC TRANSFER CONTROL INSTRUMENTATION

The CFX pneumatic transfer control instrumentation is located in Room B-1-A, 222-S Building. Automatic control is the normal mode of operation. Programmatic control is achieved by a DEC PDP 11/05 CPU with 32,000 by 16 bit memory. The CPU is contained in and works in association with Canberra Industries Scorpio 3000[®]. Access is provided through a Texas Instruments TI733 KSR terminal. The controlling program is custom written in Fortran IV.

Hardware control is achieved through standard CAMAC instrumentation. A Kinetic Systems Corp. CAMAC crate controller routes signals between the CPU and other CAMAC modules. One of the latter is a 24 bit Input/Output (I/O) register. Other CAMAC registers include data storage and timing scalars.

The I/O register connects to a custom Reactor Experiment Inc. interface which controls all signals into and out of the Reactor Experiment Inc. pneumatic transfer system. This system routes and moves a rabbit from an auto-loader to any of four detector termini and from these to the CFX, the drop-out, or back to the auto-loader (Figure 4) (4.1.0). All diverters and all motive air valves are electrically operated solenoid valves, 12 in number. These are output controls. Also included under output control are the four inhibit signals to a CAMAC Quad scaler, resets for two in system photocells, and one mechanical rabbit locator switch, output stop-start control of the multichannel analyzer, and four spares. All diverter positions are monitored and verified by limit switches, 12 in number. The condition of a mechanical switch in the transfer line and three photocells in the line are monitored by input signals (one photocell is nonlatching, and, therefore, it does not require resetting). Two inputs provide control program "GO TO" commands and the remaining six inputs are spares.

The CFX pneumatic transfer system can be manually controlled and/or simulated from the Reactor Experiments Inc. interface using mechanical switches. However, these switches are only activated by a key lock with the exception of the two "GO TO" input switches which are always active.

Whenever the CFX transfer system is to be run, the control program is loaded into the CPU from disc. It will always be the foreground task. Any other Scorpio function must be loaded as the background task. When the program is initiated, it sets valves, scalars, timers, etc., to starting conditions and then checks the Input "GO TO" switch number zero. If the switch is set, the pneumatic transfer system is to be used for a passive sample loader only. If the switch is not set, all samples will first be passively assayed for fissile content in the DNC and only if they do not exceed the set limit will they be analyzed for background, irradiated in the CFX, and analyzed actively. As each sample rabbit leaves the system via the dropout, the in-line switch, LS-11, is set. A new sample cannot be entered unless LS-11 is set, and LS-11 is not reset until a new sample is entered. The status of LS-11 is monitored and echoed by a lighted panel which reads "Sample in System" whenever LS-11 is set.

6.3.1 What if Power to the CFX Transfer System Instrumentation is Lost?

The Scorpio 3000 CPU is on uninterruptable power. That is, the incoming AC power is converted to DC and used to continuously charge a bank of batteries. The DC power from the batteries is continuously converted to AC to power equipment on the system. When incoming AC power is interrupted, the batteries continue to provide AC power until they are discharged, approximately 15 minutes at full amperage drain. During that time the CPU is shut down in an orderly fashion so that no program damage results.

6.3.2 What if an Error in Irradiation Time is Made?
What if an Error in Decay Time is Made?
What if an Error in Counting Time is Made?

The rabbit will be irradiated for the time entered, right or wrong. If the entry error is discovered before the event timed has occurred, the error can be corrected. Ditto for decay time and/or counting time. All times as recorded on the Scorpio terminal become a permanent part of the sample analysis record.

6.3.3 What if the Control Program is Destroyed?

The control program will be resident in CPU core during use and stored on floppy disc at all times. A separate floppy disc containing the control program will be maintained in safe storage against the possibility of destruction in either of the other two locations. When so equipped, the Scorpio 3000 will also have available cartridge discs for storage of programs and data.

6.4 RADIATION SAFETY INSTRUMENTATION

Radiation Safety Instrumentation falls into three main groupings: instrumentation that prevents criticality in the CFX which has already been discussed in sections 2.0 and 6.2.0, instrumentation that prevents entry or removes unduely hot rabbits from the B-1-A counting room, and instrumentation that monitors radiation exposures.

As stated previously in 4.0 Pneumatic Transfer System, the primary concern for intensely radioactive samples in the B-1-A counting room is disruption of sample analyses in non-related detector systems. The amount of radiation added to a sample due to irradiation in the CFX will never be a significant part of sample activity in this context because of the low neutron flux density. , 9×10^9 thermal neutron/second.centimeter squared maximum. Add to that the fact that all termini are shielded and we come to the conclusion that the activity is essentially what it was at loading and the only time it is out of control is while it is in transit in Room B-1-A. Rabbits will not be moved while the CFX site cover is off nor after anyone has broken an interlock in Room B-1-F.

Samples entering B-1-A, as they must to be irradiated, must be surveyed for dose and surface contamination. If not ascertained earlier than that, samples with high dosages will be identified at that point. They must be accompanied by a radiation monitor to be loaded into the B-1-C auto-loader. The auto-loader magazine is shielded. Standard Operating Procedures call for either the radiation monitor or the sample loader to activate a "hot sample" switch in B-1-C any-time individual rabbits have surface readings equal to or greater than 1 R/hour. The switch will remove power from the solenoid valves in diverter C (Figure 4). This forces the rabbit routing to the DNC, the only detector terminus not in B-1-A. If the routing instructions do not verify this routing the rabbit will not fire and the program will be aborted.

Should a highly radioactive rabbit be fired into Room B-1-A despite the precautions, it must pass a 5 centimeter by 5 centimeter NaI(Tl) detector as it enters B-1-A. This detector is connected to a CAMAC quad scaler channel and set to trigger whenever a rabbit reading equal to 1 R/hour is exceeded, despite the fact that it will be traveling at approximately 50 meters per second. When the scaler triggers, it sets off an audible alarm, sets up and verifies routing of the sample to the drop-out, fires the sample, and aborts and program with the message "Too Hot".

The final category of radiation safety instrumentation is survey instrumentation. The air passing over the CFX site upper chamber is monitored for radioactive particulates just as any laboratory or operation room is. The water in the CFX which acts as moderator, reflector, and heat exchanger is monitored for radioactivity on a routine basis. The exhaust motive air in the transfer system is monitored both continuously and periodically. All rabbits entering the system must be free of smearable contamination. Routine alpha, beta, gamma field readings are taken at all locations associated with the CFX system. It is to be hoped that ultra-sensitive neutron survey instrumentation will be added to the radiation monitor's inventory of instrumentation.

An excursion alarm detector is installed in the upper chamber of the CFX site room to sound the excursion alarm in case a criticality does occur. These detectors are also sensitive to the unshielded radiation of a Californium-252 capsule and would cause an alarm if the capsules were moved without deactivating the alarm circuit.

6.5 DATA ACQUISITION INSTRUMENTATION

There are two types of data acquisition instrumentation: scalars and multichannel Pulse Height Analyzers (PHA). The former collect undifferentiated counts as from a pulse generator or differentiated counts in a single energy band as from ionization chambers and scintillation detectors for radiation intensity measurement. The latter is a collection of single channel analyzers or scalars programmed to collect differentiated radiation pulses in an energy versus count matrix.

In the CFX system both types are controlled through CAMAC. By controlled, I mean the device is started, stopped, read to the CPU, and reset. There are seven scalers in the CFX system. Three are independent, up-down CAMAC scalers which store pulses from a CAMAC pulse generator and act as clocks. Two of these clocks provide timing control for analytical sample acquisition data and one times the long-term DNC background monitor. All three are set to the count time desired by the CPU or by the CPU through the terminal. As soon as they are set, they start to count down to zero. At zero they generate a high priority "Look-At-Me" (LAM) which causes the CPU to stop whatever counting device the timer is controlling.

The remaining four scalers are located in one Quad CAMAC scaler. One monitors the B-1-A hot rabbit radiation alarm detector. One accumulates the background count in the DNC when it does not contain a sample. One accumulates both passive sample background and sample activation count in the DNC. The last scaler counts pulses received from a current integrator which in turn receives data from in the CFX core ionization chamber. This data is capable of interpolation to sample perturbed neutron flux. All of the Quad scaler count-up must be stopped by an external inhibit signal generated by the CPU through the CAMAC interface, and must be read and reset to zero. Quad scaler data is reduced in the Scorpio 3000 CPU.

Even though three termini service any of seven gamma or X-ray detector systems, only one of these will be in use at any one time. Consequently, only one pulse height analyzer is needed at a time. Scorpio 3000 PHA's are used and the one to be used is designated by means of a Scorpio console switch. This PHA becomes the only PHA that can be accessed by the CAMAC interface. The CAMAC interface starts and stops the PHA for the clock time stipulated by the timing scaler. Independently the PHA keeps track of and stores the live time or time the PHA is available to receive counts. Read-out is destructive to read to an NS880 for X-ray data reduction, to a Diablo cartridge disc for gamma data reduction in an NS660^[4] or to Scorpio magnetic storage device for interim storage.

6.5.1 What if No Acquisition System was Designated?

No data will be collected.

6.5.2 What if the Wrong Acquisition System was Designated?

No useful data will be collected.

6.5.3 What if a Timer Fails?

All data acquired will be erroneous and the collection device will be incapable of being shut off programmatically.

6.5.4 What if the Start Acquisition Signal Fails?

The acquisition won't start.

6.5.5 What if the Stop Acquisition Signal Fails?

The acquisition won't stop.

6.5.6 What if the Record Acquisition Signal Fails?

The acquisition won't record.

6.5.7 What if the Reset Signal Fails?
(Destruct readout for PHA)

After the first readout, the data will be erroneous because it will be continuously added to subsequent data.

6.5.8 What if the Data Transfer Fails?

The data will be either lost or not transferred depending on the mode of failure.

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7.0 ADMINISTRATIVE CONTROLS AND PROCEDURES

7.1 GENERAL DESCRIPTION

The operation of the ARHCO CFX will be governed by administrative, operational, and emergency procedures to guarantee the safe operation of the facility. These procedures will be documented and approved prior to the Safety Analysis Review and the Hazards Review of the facility. Both of the latter will be approved by the appropriate ARHCO and ERDA-RO teams before use of the CFX as an analytical facility is initiated.

7.2 ORGANIZATIONAL

The overall operation of the ARHCO CFX is the responsibility of the Nondestructive Assay Development team leader and in his absence the designated deputy. The Nondestructive Assay Development team is a part of Instrument Development subsection, Chemical Technology Laboratory section, and Research department. All members of the team will be trained in the operation of the CFX. Operation of the CFX will be subject to the same constraints as all tasks in the 222-S Redox Laboratory Building plus those special constraints imposed through the Safety Analysis Review and Hazards Review.

7.3 ACCOUNTABILITY

The uranium fuels are contained in discrete fuel plates, each with its own pedigree. This includes the enrichment, the total weight of uranium, and an identifying serial number. The fuel plates are rigidly mounted in an aluminum framework according to a serial number map. The core assembly is located in a reflective tank at the bottom of a 12 foot water moderator tank composed of half inch aluminum and at least 8 inches of reinforced concrete. The CFX site is capped by a reinforced concrete cover, 126 inches by 90 inches by 8 inches with a welded channel perimeter that overlaps the above grade portion of the CFX site. A mechanical electric switch opens whenever the CFX site cover is lifted causing an alarm to flash in both the 222-S Building and 200 West Area Security Patrol headquarters.

The uranium fuel plates will be physically inventoried by an ARHCO Special Nuclear Materials representative at IRT Corp., San Diego, California, shortly after they receive the fuel plates from U. S. Nuclear, Oak Ridge, Tennessee. The fuel plates will be physically inventoried again as they are loaded into the core assembly at the ARHCO CFX site.

The uranium fuel plate material will be under the control of the Nuclear Materials Control Department manager. No inventory is anticipated during operation unless the CFX core assembly is withdrawn from the CFX site for any reason.

The two Californium-252 capsules are similarly safeguarded. These capsules cannot be moved without opening the CFX site cover. Permanent magnet, flexible cables control movement of the californium, but they must first be coupled to the connecting cable that allows control from Room B-1-F. The CFX site cover must be removed to perform the cable coupling (3.2.7). The cable coupling provides a permanent stop that prevents the capsules from being brought too close to or into the 222-S Building. When the cable between B-1-F and the CFX site is not in use, it is locked. The cable connected to the source capsules are always left decoupled.

An excursion alarm detector is installed in the upper chamber of the CFX site to sound the excursion alarm in case a criticality does occur (6.4). The CFX site cover must be lifted to test these detectors.

The presence of both of the californium source capsules cannot be faked. Physical inventory after receipt and installation is not anticipated. However, any time the source capsules are stored in the CFX site source storage tubes (3.2.7) they must not be left unattended until the CFX cover is returned and all interlocks, locks, and seals are reiterated.

Sample contents will not be accounted. Rabbits will be sealed and used one time only (4.1.0). Any fissile or special nuclear materials that are encapsulated for analysis in the CFX, will be disposed after final analysis. Accountability will stop when the material is expended in the sample.

7.4 OPERATIONAL PROCEDURES

The Operational Procedures for the CFX cannot be finalized until IRT Corp. has built the ARHCO CFX and has it fully tested and ready for delivery. Only at that time will we have measured k_{eff} and measured effects to k_{eff} of sample components. Only at that time will we have a direct measure of the maximum fissile content that can be tolerated in a sample so as not to exceed a 12¢ addition in nuclear worth.

When this data is available, the operating procedures will be documented as a part of the Safety Analysis Review and the Hazards Review.

The Radiation Work Procedure for the B-1-A Counting Room will be in effect as it pertains to sample, detector, and instrumentation handling.

7.5 EMERGENCY PROCEDURES

The section 3.3, 222-S Building Emergency Procedures^[5] apply in their entirety. Emergency Procedure number 3.3.3 Nuclear Excursion - 222-S Building^[5] must be modified to recognize the CFX site as equally probable with Room 1GB as the most likely location in 222-S where such an incident could occur. The evacuation route must be redrawn to reflect the added location.

Any emergency requiring evacuation shall require the senior technical operator then operating the CFX to initiate a manual scram before evacuating.

If any fire, explosion, or accident involving release of radioactivity occurs in the vicinity of the CFX site, the CFX shall be manually scrambled and all ventilation and water circulation shall be secured by the senior technical person present that is responsible for the operation of the CFX.

7.6 CFX LOADING AND START-UP PROCEDURE

Under terms of the contract^[2], IRT Corp. shall provide in advance, written procedures for the CFX loading and start-up. These procedures must comply with ARHCO Standard Operating Procedures and Radiation Work Procedures. They are also subject to review and approval by U.S. ERDA and ARHCO personnel designated as responsible for the CFX-40/DNC project.

After approval has been obtained and at the contracted time, the CFX loading and start-up shall be performed under the technical direction of IRT Corp. personnel, Dr. R. L. Bramblett, K. L. Crosbie, and/or their deputies.

REFERENCES

1. INTEL-RT 4875-292P, January 7, 1976, IRT Corporation, "Californium Multiplier/Neutron Counter System - Proposal Prepared for Atlantic Richfield Hanford Company in Response to RFQ SA-222" (Proprietary Information).
2. Contract No. CPFF-222, Prime Contract No. E(45-1)-2130, May 4, 1976, Atlantic Richfield Hanford Company to Contractor: IRT Corp., "Californium Multiplier/Neutron Counter System."
3. Draft, September 27, 1976, "IRT Corporation's Preliminary SAR of ARHCO's CFX."
4. ARH-ST-114-1, December 1974, W. H. Zimmer, "Gamma, X-ray Data Reduction System Volume 1 - Gamma."
5. ARH-222, "Emergency Procedures," Personnel Protection Operation, Atlantic Richfield Hanford Company, Richland, Washington 99352.

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FIGURE 1

CFX CORE ASSEMBLY SECTION

The sample position is in the center. The Californium-252 neutron source capsules are on either side of the sample position. The four dark bars are the safety rods. All the remaining lines represent potential fuel plate positions. The outer wheel shaped trace represents the walls of the reflecting tank. The guide slots for positioning this assembly at the bottom of the CFX site tank are not cut or indicated.

FIGURE 2
CFX SITE SECTION

FIGURE 3

CRITICAL MASS AS A FUNCTION OF
THE ATOMIC RATIO OF HYDROGEN TO URANIUM

FIGURE 4

CFX-40/DNC RABBIT TRANSFER LAYOUT

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