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WANL-TNR-099
Supplement 1 - Addendum 1

Westinghouse Astronuclear Laboratory

REVIEW OF FCX, WANL-TNR-099, SUPPLEMENT 1

July 19, 1965

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30

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REVIEW OF FCX, WANL-TNR-099, SUPPLEMENT 1

- 1.1 It is unclear why the core with the harder spectrum is expected to yield a greater doppler effect.
- A. A parametric study⁽¹⁾ of the effect of fuel loading (gm of U-235/cm³), void fraction, and reflector thickness on the Doppler coefficient of reactivity in FCX cores has been made (Section 2.2.3.1 and Section 6). The results indicate that the magnitude of the Doppler coefficient varies inversely with these parameters. Additional results also indicate that the median energy of fission throughout the central region of the core varies inversely with reflector thickness and void fraction and directly with fuel loading. The statement in Section 6 that the magnitude of the Doppler coefficient is smaller for reflected core of high fuel loading is correct but the effect should not be attributed to a higher median energy of fission.
- A significant contribution to the temperature coefficient results from the axial expansion of the core as temperature is increased. Radial expansion has not been included because of the loose radial bundling and clearance between individual fuel elements. However, if high temperature would be attained in the fuel, expansion would exceed the clearance and net radial expansion of the core would result. This effect would increase the magnitude of the temperature coefficient. Neglecting the effect of radial expansion over the entire temperature range therefore leads to conservative results.

(1) WANL-TME-749, "Analysis in Support of the Flexible Critical Experiment" (Section 3.0).

- 1.2 The reliability of the control rods is suspect. The flux-trap followers, which contain polyethylene, may be susceptible to swelling from either radiation or thermal environments. If so, binding may prevent adequate control of the system.

A. Radiation Damage

Neutron Flux in NERVA core (PAX) by energy group:⁽¹⁾

<u>Group</u>		<u>$\bar{\phi}$ (nv/fission/sec)</u>
10 Mev	- .821 Mev	1.5×10^{-4} (max)
.821 Mev	- 5.53 Kev	5.0×10^{-4} (max)
5.53 Kev	- 1.86 ev	1.8×10^{-4} (max)
	≤ 1.86 ev	0.4×10^{-4} (max)
		$\sim 9 \times 10^{-4}$ (max)

$$nv \text{ (total)} = \frac{9 \times 10^{-4} \text{ nv/fissions/sec}}{3.1 \times 10^{-11} \text{ watts/fissions/sec}} = 3 \times 10^7 \text{ nv/watt (max)}$$

$$\text{For 2 KW operation, } \bar{\phi} \text{ (max)} = 6 \times 10^{10} \text{ nv}$$

For one year of continuous (24 hour) operation,

$$nvt \text{ (max)} = 6 \times 10^{10} \text{ nv} \times 3.2 \times 10^7 \text{ sec} = 2 \times 10^{18} \text{ nvt}$$

The change⁽²⁾ in the specific volume of polyethylene that has been subjected to a radiation dose of 2×10^{18} nvt at room temperature (20°C) is 1% (Specific volume increases from 1.09 cm³/gm to 1.10 cm³/gm). The total radial clearance between the tie rod and the steel sleeve in the control element is .020 inches.

(1) WANL-TNR-128, Volume II, Figure 5-7 to 5-10.

(2) Atomic Radiation and Polymers,
A. Charlesby
Pergamon Press 1960

International Series of Monographs on: Radiation Effects in Materials, Chapter 13,
Figure 13.15.

This is more than adequate to accept the expansion of polyethylene due to irradiation effects (.003 inches), based on one year of continuous operation. However, the rods will be almost completely withdrawn from the core during reactor operation and should accumulate a much smaller radiation dose. During a postulated accidental excursion leading to an energy release as great as 3×10^9 watt-sec, the integrated neutron flux is 1×10^{17} nvt—a low value as far as radiation damage is concerned.

Since there is no information available on the dimensional stability of polyethylene in a fast neutron-gamma environment, the above analysis utilized the results of radiation damage experiments in a thermal reactor. This evaluation of the irradiation behavior of FCX control rods may therefore not be completely valid. In order to ensure reliability of the reactor control system, a periodic inspection will be performed to assess the overall mechanical integrity of the control rods including dimensional changes of the polyethylene. Routine rod worth calibrations will provide a very sensitive indication of any chemical changes in the poly, particularly carbon/hydrogen ratio.

Thermal Effects

From purely thermal effects⁽¹⁾, the specific volume of polyethylene increases from $1.09 \text{ cm}^3/\text{gm}$ to $1.25 \text{ cm}^3/\text{gm}$ as the temperature increases from 20°C to 120°C . This represents a 15% increase in volume and a 5% increase in radius. In addition to the void space within the control element itself, there is a radial clearance of 80 mils between the control rod and the guide tube. A 5% increase in polyethylene radius is equivalent to approximately 50 mils. Since polyethylene at 120°C would be a viscous fluid, expansion into the void region of the hardware above polyethylene cylinder would relieve the stress on steel sleeve.

(1)

ibid, Figure 13.14

Mechanical Design

The following WANL engineering drawings are pertinent to the mechanical design of the control element system:

600500 Sheet 1	-	General layout of FCX
600500 Sheet 2	-	Fuel element layout around control rods
600824	-	FCX control rod

Careful mechanical and electrical tests have already been made on parts of the FCX control rod system and additional ones will be made before FCX loading begins.

Tests on an FCX-type shock absorber have been made whereby twenty measurements with a simulated rod, having the same weight as an FCX rod and from the same height as an FCX rod at the full out position, showed no decelerations greater than 7G and no bouncing. The unit was disassembled afterwards and showed no signs of wear.

The rod drive circuits have been tested point-to-point in the test cell from Panel C through Panels F and E to the FCX stand. One rod has been test-operated and works as it should (in, out, scram), console lights indicate properly and the position indicator gives correct and reproducible readings. Operation has been attempted with the patch panels mixed but the interlock circuit prevented control rod out motion as it should.

The "drive-in" load capability of control drive mechanism is calculated to be 450 lbs.

- 1.3 We are unable to determine a basis for the assurance that the excess reactivity will be "guaranteed" to be less than 0.50\$.
- A. WANL believes that the excess reactivity of $\leq 50\%$ can be maintained by following the administrative and procedural rules that have been prepared. During the last 16 months and the 588 reactor startups, most of which involved manual reactivity change, similar rules⁽¹⁾ were successfully utilized on the PAX reactor to insure that manual reactivity changes of $\leq 33\%$ were maintained. The manual change procedure includes:
- 1) a complete evaluation by the Experimentalist-in-Charge of the desired change based on the experimental and/or analytical data,
 - 2) selection of the appropriate course of action depending upon whether the change is a minor, minimal, or major one, and
 - 3) completion of the pre-startup manual change checklist which stipulates the operational condition required for a reactivity change.
- Similar rules⁽²⁾ have been generated for operation of the FCX reactor within its 10\$ shutdown and 0.050\$ excess limits. In view of the successful demonstration of this type of administrative and procedural control, WANL can insure a very low probability of violating the 0.50\$ excess limit for FCX.

(1) WANL-TME-267, "WANEF Operations Manual".

(2) WANL-TME-267 Revision 1, "WANEF Operations Manual", Transmittal letter Faught to Ross dated 4/13/65 Attachment 3, "Approval for Changes to WANEF Operations Manual, WANL-TME-267 Revision 1".

1.4 The location of the FCX is essentially at grade level and is less protected from possible deluge of hydrogenous material than the PAX. It therefore appears to be more susceptible to flooding or water contamination which can cause a severe excursion.

A. Evaluation of vulnerability of WANEF site to flooding was reviewed in the WANEF SAR (Section 2.3.3). The facility is considered safe from flooding by any regular flowing stream. Protection against floor flooding resulting from run-off from the higher ground to the north during a severe summer storm is provided by a 3-foot interceptor trench that will divert the drainage. The area in the immediate vicinity of the WANEF facility has also been contoured to ensure good drainage. The base of the FCX core is approximately 3-4 inch above floor level and 6-8 inch above grade level. Furthermore any surface water that would reach floor level would drain into the 22 feet deep basement.

The FCX assembly is located beneath two work platforms and is well protected against roof leaks. The roof of the facility is comprised of a 9 inch thickness of reinforced concrete.

Strict administrative controls are imposed on the use and handling of hydrogenous fluids in the test cell. The adequacy of these controls has been demonstrated during PAX operations. It is concluded that there are sufficient safeguards in effect to protect the FCX assembly against any credible type of hydrogen insertion.

- 1.5 The patch board arrangement used to connect the detector and rod drives of either reactor to the common instrumentation control panels is not described in sufficient detail to determine the probabilities or consequences of faulty connections or failures of components.
- A. This discussion expands upon Section 3.1 (FCX-PAX Control System) of WANL-TNR-099, Supplement 1, and makes some minor changes thereto. The patch panels, shown in Figures 1 and 2, are program panels⁽¹⁾ which slip into a spring-loaded, hinged rack that locks into position with a motion that causes all mating pins to make positive contact simultaneously. Each program board functions as a multiple pole, single throw switch. The circuitry for each reactor is wired on one program board in a semi-permanent manner. Figure 3 shows the interlock circuit. It consists of two 90 V DC relays whose coil circuits go through both Panels F and G to the Source Transfer Circuit where microswitches detect the position of the source transfer switch. When the transfer switch is in position for the source to go to PAX, only the PAX select relay K-16 will be energized. Likewise, when the transfer switch is in position for the source to go to FCX, only the FCX select relay K-17 will be energized. The program panels for Panels F and G are wired so that only the K-16 relay circuit is wired on the PAX program panels and only the K-17 relay circuit is wired on the FCX program panels. If the program panels are intermixed (e.g., PAX Panel F and FCX Panel G) neither K-16 nor K-17 can be energized. Thus, satisfaction of the interlock requires the startup source, the instrumentation and the control elements to be consistent. From Figure 4 it can be seen that the control elements cannot be driven out unless the interlock circuit is satisfied and either K-16 or K-17 is energized.

(1)

AMP Incorporated, Harrisburg, Pa.

- 1.6 A number of comments and recommendations were submitted in the Regulatory review of the WANEF Safety Report. (Ref. memorandum from E. Price to F. Pittman, January 2, 1964). Because the FCX will be similar in many respects to the PAX-NRX experiments considered in the WANEF review (ie. instrumentation, kinds of material, etc.) we suggest that many of the comments on the WANEF may be equally applicable to the FCX.
- A. We believe that the comments and recommendations submitted in the 2 January 1964 memorandum were reviewed and resolved in our letter of 20 January 1964. (W. H. Esselman to R. W. Schroeder; Subject, DL&R Comments on Westinghouse Astronuclear Experimental Facility).
- The philosophy of design and operation followed in the setting up of the PAX experiment and the experience gained in its operation have been incorporated into the FCX design.
- 1.7 There is no indication of a secondary shutdown mechanism for the FCX. We suggest that one be provided.
- A. The FCX control elements which are located in the central region of the core are worth ~2-3\$/element. Hence, any single FCX control rod is capable of overriding the 0.50\$ excess reactivity present in the core. Since all FCX rods have independent drive and scram mechanisms and are designed to be fail-safe, (interruption of magnet-current will cause the control elements to drop into the core), an alternate shutdown system for FCX is considered to be unwarranted.

The circuits connected to the two patch panels are as follows:

Panel F (refer to Figure 1)

Control element circuits consisting of 20 leads each for 12 control elements⁽¹⁾ consisting of position indication (5 leads), magnet power (2 leads), field voltage (2 leads), armature voltage (3 leads), control relays (3 leads), console IN, OUT, CONTROL ON, and SCRAM lights (5 leads).

Source Transfer Switch Circuit (1 lead)

In Figure 1 the Interlock and Source Transfer Switch circuits are shown to the right of the control element circuits.

Panel G (refer to Figure 2)

Signal leads for nuclear instrumentation consisting of 3 linear, 2 long N and 4BF₃ channels (9 coaxial leads).

Gamma channel leads (8 leads).

Interlock circuit (2 leads)

In Figure 2 coaxial patch cords are shown for all but the interlock circuit.

(1) Wiring for one additional control element is programmed through Panel F to the FCX stand. The FCX has 6 spare sets of control element wiring.

1.8 The FCX Safety Report does not provide a parametric safety analysis for the anticipated "envelope" of conditions within which the experiments will be restricted nor is there a discussion of the operating philosophy or procedures upon which the safety of the operation primarily depends.

A. The FCX reactor experiment includes the same safeguards as the PAX experiment. These safeguards were discussed in detail in WANL-TNR-099, "Safety Report for the Westinghouse Astronuclear Experimental Facility" (Section 8). The FCX experiment has the additional advantage, when compared to the PAX, of a greater shutdown reactivity in the control elements and the available excess reactivity of the assembly is limited to 0.50\$.

A review of the conceivable accidents which may occur during operation of the FCX has been made along with the safeguards which have been instituted to guard against them. As concluded in the original SAR, all the accidents considered require more than two independent failures of equipment and/or procedures before they can occur and therefore, cannot be classed as "credible" by the usual definition. A minimum of three equipment failures and one operator failure is required for the "maximum" accident considered for the FCX to occur.

Although a parametric study of the magnitude of the maximum accident on the various FCX assemblies has not been supplied, the analysis presented in the FCX report was based on an overall appraisal of temperature feedback, power distribution, and fission product diffusion in all FCX assemblies as related to radiological effects. On the basis of this appraisal, a configuration of uncoated fuel with the smallest temperature feedback and the highest power peaking producing the greatest fission product release was selected for discussion.

The operating philosophy and procedures for the operation of the FCX are the same as those followed for the PAX and are contained in WANL-TME-267, "WANEF Operations Manual". By the very nature of the equipment only one of the assemblies, PAX or FCX, can be operated at a time and the operation on either reactor are carried out by the same staff.

- 2.1 Define what is meant by "standard FCX fuel" with respect to the chemical and physical form of the uranium and specify the ranges of enrichment to be used in the assembly. Is FCX fuel subject to quality control procedures as is the PAX fuel?
- A. Standard FCX fuel material consists of a matrix of graphite and highly enriched uranium (93.15%) in the form of UO_2 . During fabrication the element is extruded and baked with the uranium remaining in the UO_2 form. Fabrication of FCX fuel elements will be performed in accordance with Purchasing Department Specification WANL-30077, "FCX Fueled Graphite Elements." The standard FCX fuel will possibly be procured in the future.
- 2.2 Define what is meant by "reject NERVA fuel" and the criteria for subsequent secondary rejection of such fuel with respect to its use in the assembly.
- A. Reject NERVA fuel elements⁽¹⁾ are those which have been rejected for use in the NERVA reactors for various reasons such as scratches and chipping of cladding and other imperfections which are of little consequence in the FCX. The requirements for use of the NERVA reject elements in FCX are the following:
1. Availability of C, U, Nb weight data.
 2. Length to ± 0.010 "
 3. Tolerance across the flats $\begin{matrix} +0.000" \\ - .005 \end{matrix}$
 4. Elements can be assembled into clusters using FCX cluster plates. This eliminates elements having excessive bow and twist.

(1)

The NERVA fuel elements are fabricated in accordance with Purchasing Department Specification WANL-30021-Rev. E, "Graphite Shapes, Fueled."

In addition to the use of reject NERVA fuel, it is now planned that FCX will utilize spare and reject KIWI fuel elements from LASL and Oak Ridge. These include elements from the B4A, B4B, and B6A cores. The KIWI elements which have basically the same geometrical shape as the NERVA elements, originally contained enriched uranium in the form of uncoated UC_2 . Since the UC_2 was not protected by a pyro coating, the UC_2 has partially reverted back to UO_2 and U_3O_8 by hydrolysis with atmospheric moisture. The $UC_2 - UO_2 - U_3O_8$ ratios reach equilibrium values that are a function of the maximum value of relative humidity.

The requirements for use of the KIWI elements in the FCX are the same as for the reject NERVA fuel.

- 2.3 In Table 2.1, and in Section 2.2, WANL specifies that the FCX program is being constrained to the use of reject NRX-A2. However, in the proposed operating limits reference is made to the use of UO_2 type fuel. The basis for restricting to A-2 rejects and the discrepancy between the SAR and OL in the description of FCX fuel needs to be clarified.
- A. WANL did not intend to restrict the FCX to using only NRX-A2 reject fuel. The constraint, mentioned in the SAR, of using NRX-A2 elements was one imposed by schedular, programmatic, and fiscal considerations existing at the time the SAR was published. The original FCX program called for "standard FCX fuel", as defined in the Operating Limits, to be fabricated. When this standard fuel is procured for the FCX, it will, in general, replace the reject NERVA fuel. As stated in the preceding paragraphs the NERVA and KIWI elements will be utilized. At the present time, reject NERVA elements from the A3, A4 and A5 and the KIWI B4A, B4B, B5A and B6A elements are planned for use in the FCX. There is a negligible difference in the safety analysis due to the use of these various fuel elements as discussed under questions 1 and 5 of the Hazards Section.

- 2.4 Are any control drums to be used in the reflector for reflector experiments?
- A. Operable control drums will not be utilized in the FCX. Mockup experiments of control drums will probably be performed, however, in accordance with the procedures given in the Operations Manual.
- 2.5 Describe the construction of the water reflector.
- A. The water reflector mentioned in the SAR was used in the safety calculations to generate reactivity data associated with the worst case of body reflection. At the present time the use of a water reflector is not contemplated.
- 2.6 Are reflector experiments limited to graphite and water reflectors?
- A. No. Although the present experimental plans only call for C and Be reflector experiments, use of other materials (aluminum, steel, isolated hydrogenous media) must be considered.
- 2.7 During shutdown and for non-operating periods how will the assembly be maintained in a clean, as-was condition to prevent extraneous materials from getting into the core (dust, dirt, oil, etc.)?
- A. Normal maintenance of test cell cleanliness will provide protection of the FCX from significant quantities of dirt and dust. The presence of oil or other hydrogenous liquids in the test cell is under strict administrative control and under no circumstances will oil or other liquids be allowed to contaminate the fuel.

- 2.8 What is the relationship between a 500 mg/cc loading and the overall core dimensions?
- A. Maximum fuel loading in current NRX and KIWI fuel as well as the planned FCX fuel is a nominal 420 mg U/cc.
- A parametric study of FCX assemblies⁽¹⁾ provides the relationship between critical dimension and fuel loading, reflector thickness, and void fraction. Although the referenced study includes fuel loading up to 600 mg U/cc, the safety analysis has been limited to fuel loading of 420 mg U/cc. The critical radius of NRX-KIWI fuel of this loading is presented in Table 2.1 of the FCX Safety Report for various configurations.
- 2.9 What is the neutron interaction based on an edge-center separation between PAX and FCX?
- A. Discussion of neutron interaction between PAX and FCX based on LASL coupling experiments⁽²⁾ was presented in Chapter 5.0 of FCX safety report. Linear extrapolation of these data indicates that effectively no interaction exists at the 19-foot center-center separation between PAX and FCX. Certainly, interaction will be less than the 0.033\$ value observed at a 16-foot center-center separation of the two PAX-type reactors at LASL. Since one or the other reactor will be shutdown by at least 10\$, neutron interaction between the two assemblies does not constitute a safety problem.

(1) WANL-TME-749, "Analysis in Support of the Flexible Critical Experiment", April 1964.

(2) N-2-7932, "LASL Progress Report, August-September 1964".

2.10 Is the fuel brought into the test cell via the truck entrance to the cell or does it come through the fuel element check room and undergo inspection before it is brought into the cell?

A. Fuel elements will be received directly into the storage areas through either the facility personnel entrances or through the cell truck door. During receipt the element serial numbers will be checked for accountability purposes. Prior to its use, the elements will be inspected in either the fuel assembly room or an appropriate area of the test cell.

2.11 Will the test cell storage rack be also used for the storage of slightly irradiated fuel?

A. Yes.

2.12 Will there be any scrap handling or storage of scrap at WANEF under the new philosophy of operation.

A. No, only fuel intended for use in PAX or FCX experiments will be stored at WANEF.

2.13 With the FCX being essentially at floor level in the test cell (in contrast to the elevated PAX) what are the possibilities of water entrance into the test cell via the truck entrance?

A. As previously analyzed and reported in WANL-TNR-099, the uncontrolled presence of water in the test cell is considered remote. In addition, the ~22 foot deep basement below the main floor of the test cell and the stairway opening and many floor holes thereto make the accumulation of water on the main floor impossible.

- 2.14 What is the basis for the statement to the effect that 1200°C is the ceiling for fission product retention within the FCX fuel?
- A. FCX fuel consists of UO_2 dispersed in a graphite matrix while KWI fuel contains UC_2 which has been formed by reacting UO_2 with its graphite matrix. Hence, these fuels do not have the same degree of fission product retention as the coated NRX-A fuel. Although some information is available on the diffusion of fission products in this type of material, more extensive WANL data on NRX-A fuel that has been heat-treated to destroy this coating is considered to be pertinent and applicable (Type III fuel). The attached plot describes the release of the most volatile fission products from Type III fuel during 5-minute heating at various temperatures in vacuum. It should be noted that the threshold for release of gross fission product activity and that of the most radiologically significant elements occurs at approximately 1400°C . Tellurium has an extrapolated threshold of 1200°C and Cs^{137} extrapolates to the vicinity of $1100\text{--}1200^{\circ}\text{C}$. It is anticipated that these thresholds will be increased somewhat at atmospheric pressure. Hence, silver, which does not appear on the plot, and cadmium are the only elements which will be released below 1200°C . The fission product chains which contain silver and cadmium are not considered to have any real radiological significance. Furthermore, many of these chains contain isotopes of silver and cadmium whose half-lives are so short that the diffusion rate is actually determined by longer-lived daughters.
- Hence, it is concluded that release of fission products from the uncoated-type FCX and KWI fuel would be significant only at temperatures above 1200°C .

FIVE MINUTE HEATING IN VACUUM

DEGRADED NRX-A FUEL

2.15 What is the radiological effect of the consequences of a 0.50\$ reactivity insertion in an FCX assembly? Will it be the same for all the variables of FCX operations?

- A. The available excess reactivity of all FCX assemblies will be controlled by seven (7) control elements. As in the PAX assembly, the control system permits only one control rod to be withdrawn at a time. Hence, a control failure when all but one control rod are fully withdrawn from the core is the only situation when an inadvertent 0.50\$ reactivity insertion is credible.

The FCX will be protected by an automatic safety circuitry which will initiate a reactor scram at a power level not to exceed 2 KW. Based on the neutron kinetic response to a step insertion of 0.50\$ a 2KW power level would be reached approximately 35 seconds after start of the power ramp from one watt. Failure of the safety circuitry to initiate a scram would require corrective action by the operator. A manual scram initiated 30 seconds after a 2 KW power level is reached would terminate the excursion of a bare core of NRX fuel at approximately 50 KW resulting in an energy release of 2.5 MW-Sec. With temperature feedback acting to quench the excursion, the threshold for fission product release in NRX fuel (1500°C) is reached approximately 130 seconds after the power trip level is exceeded. As previously reported⁽¹⁾, a more detailed analysis of the time-temperature response of the core during this transient, using the temperature-dependent specific heat of graphite reveals that approximately 90 seconds are required for the core to reach the relatively low temperature of 100°C. Since any single FCX control element is capable of shutting down the reactor, it is considered incredible that shutdown is not achieved in the time available before fission product activity is released, whether by the automatic safety system or by manual scram.

(1)

WANL-TNR-099 - Supplement 1, "Safety Report for the Flexible Critical Experiment", January 1965.

In the incredible situation where automatic or manual corrective action is not taken in the relatively long period of time available to terminate the "excursion" (1-2 minutes), the energy release will be limited by temperature feedback. As discussed in the FCX safety report (WANL-TNR-099, Supplement 1, Chapter 6.0), only in a bare core where the power distribution is highly buckled will core temperatures exceed the threshold for fission product release. Based on a peak/average power ratio $P_c/P_{av} = 3.63$ for a bare cylindrical core, a localized hot spot in the order of 2100°C will be produced at the center while the average core temperature will reach only 600°C . For NRX fuel, a gross fission product release of 1% occurs at this peak temperature (2100°C) for a five minute heating period⁽¹⁾ - the same value assumed in the SAR for the total core in the analysis of radiological effects of the maximum credible accident. Although release in FCX-type fuel is high at this temperature ($\sim 18\%$ gross fission products and $\sim 90\%$ Sr^{89}), only a localized region of the core experiences this high diffusion rate and the average release for the entire core will be much lower. Weighting of the fission product diffusion according to temperature and power distribution yields an effective release fraction of 2% for gross fission products and 22% for Sr^{89} . Temperature feedback in reflected cores having a flat radial power distribution will maintain fuel temperature under 1000°C which is below the release threshold for NRX and FCX-type fuel. It should be pointed out that this analysis does not assume any heat conduction which in this situation should be most significant in lowering the peak fuel temperature. Thus, even in the incredible situation where termination of an FCX "excursion" is achieved exclusively by temperature feedback, the radiological effects appear reasonable.

(1) WANL-TME-1165, "Interim Report on Fission Product Release", Section 2.2.2, May 1965.

All assemblies in the proposed FCX program are limited to an excess reactivity of 0.50\$ and possess a temperature coefficient that is equal to or greater than the value used in this safety analysis. The behavior of an FCX during a 0.50\$ power ramp, including feedback effects, is therefore applicable for all assemblies.

2.16 Is the effect of a transient more or less than that discussed in the original SAR for PAX?

The maximum credible accident associated with operation of the FCX assemblies does not involve any release of radioactivity and consequently falls within the scope of the original SAR for PAX. In the incredible situation when an FCX "excursion" is terminated by temperature feedback above, there are cases where the fission product release can be greater than that analyzed in the SAR (2% gross fission product release vs 1% assumed in the SAR).

- 2.17 Has any water ever accumulated or been sensed by the detectors in the basement of the test cell during WANEF operations?
- A. Yes. Due to intermittent failure of the sump pump, water has accumulated in the sump causing the level alarm to register. At such time the pump is cleaned and repaired as soon as practical. One or two occasions water has accumulated on the basement floor to about a one-inch depth before the pump was repaired. Reactor operations are not automatically suspended when the sump and basement level detectors are activated. Repair and cleaning of the pump is performed as soon as possible consistent with availability of parts and plant services, and the need for completion of certain reactor runs. WANL feels that the temporary presence of a limited amount of water in the basement does not constitute a safety hazard.
- 2.18 Does the absence of humidity control in the basement have any influence on the step-reactivity control of FCX operations?
- A. The absence of humidity control in the basement and the test cell area will have an insignificant effect upon the ability to maintain the 50¢ maximum excess reactivity permitted. Experience with the PAX has shown approximately a 1¢ change in core reactivity for the extreme changes observed in cell humidity ($\sim 30\% - 90\%$). The main potential problem which could arise in the use of KIWI unbeaded fuel in FCX originates in the effect of environmental humidity upon H_2 content in the fuel. These KIWI fuel elements originally contained uranium in the form of UC_2^* . Since they are not protected by a pyrocoating the UC_2 has partially reverted back to UO_2 by hydrolysis with the moisture in the air. The released H_2 is then entrapped in the element. The following KIWI fuel elements are planned to be used in FCX:

* Formed from UO_2 during graphitization of the UO_2 -graphite matrix.

LASL-Stored Fuel - B4A, B4B, B5A

These elements have been stored in an environment whose relative humidity varies from 15% in winter to 60% in the summer. LASL estimated an H_2 content ~ 300 ppm. Movement of the fuel to Waltz Mills, where the relative humidity reaches 90% in the summer, would probably result in an increase in $H_2 \rightarrow \sim 500$ ppm. This increase is due to both water absorption and additional hydrolysis of the unbeaded fuel. However, after fuel comes to equilibrium with the environment, no additional significant changes are expected.

Y-12 Stored Fuel - B6A

The B6A elements, which are presently stored in sealed containers, will be exposed to the local Y-12 environment (probably identical to Waltz Mills). After equilibrium is reached, the elements will be gauged, probably broached if necessary, and shipped to Waltz Mills. Since the increase in hydrogen content in the fuel is a gradual process, the day-to-day reactivity checks will be adequate to determine any significant reactivity changes due to this mechanism. Adjustments in core reactivity will be made to ensure that the 0.50\$ limit on excess reactivity will not be exceeded.

2.19 III 7. What do these limits mean with respect to safety?

- A. Under normal conditions, 7 control rods will be operable having a minimum worth of \$12.8. It is conceivable that experiments involving less than 7 control rods will be required. Therefore, a minimum of 4 rods (eliminating the stuck rod problem, i.e., being critical with one rod stuck or a number consistent with the required \$10 shutdown, whichever is more, is required. Therefore, at all times sufficient shutdown capability is retained in the reactor to guarantee that the safety of operations is maintained.

2.20 III 9b. Does this mean that control rods will be changed as core density changes? What is meant by core density in this case?

- A. The fuel loading of the fuel follower sector will be changed to match that of the surrounding core. This will be done by installing machined elements of the proper loading. Core density refers to the effective uranium density in the core.

2.21 III 15a. Where is the intake of the one permanently installed air monitor with respect to PAX and FCX locations?

A. The intake of the air monitor will normally be placed midway between the PAX and FCX reactors.

2.22 III 19b. How are the FCX control elements locked in the least reactive position?

A. By means of key locks that mechanically couple the top of the control rod shaft (armature) similar to that exercised on PAX.

General Comments

Installation of the electrical and control wiring of the FCX has required minor changes in the description given in Chapter 3 of Supplement 1 of WANL-TNR-099. The following corrections should be made to the SAR:

3.1.1.1 - second paragraph

Add "Except for the armature simplytrol trip set" to the beginning of the first sentence.

Because the FCX drive motors require about 800 ma compared to the 80 ma of the PAX drive motors, it is necessary to make the appropriate adjustment of the meter trip in the armature simplytrol on the console. This adjustment and/or its check will be part of the daily checkout prior to operation. The trip will be set for about 125% of normal current level.

3.1.1.2 - second paragraph

Change word "set" to "sense".

3.1.1.4 - first sentence

Delete word "currents".

The drive currents for the two reactor drive motors are different. See discussion under 3.1.1.1.

3.1.1.6 - Patch Panel Interlock

Replace word "magnet" with "drive motor".

Drive motor current, and not magnet current, is interlocked by means of the patch panel interlock logic.

3.1.1.7

Add "and a larger range simplytrol meter to accommodate the FCX drive motor current requirement" to the end of the sentence.

Addition to Chapter 2 of WANL-TNR-099, Supplement 1

2.1.1.4

Because of schedular and programmatic reasons, reject and spare KWI fuel elements will probably be utilized in the FCX. These include elements from the B4A, B4B, B5A, and B6A cores. The KWI elements which are geometrically identical to the NERVA elements contain enriched uranium in the form of UC_2 . The UC_2 was converted from UO_2 during graphitization of the UO_2 -C matrix. Since they are not protected by a pyro coating as are the NERVA elements the UC_2 has partially reverted back to UO_2 and U_3O_8 by hydrolysis with atmospheric moisture.

FIGURE 1

FCX PATCH PANEL, PANEL F

FIGURE 2
FCX PATCH PANEL, PANEL G

FIGURE 3
INTERLOCK CIRCUIT

K-S Key Switch
 K 15 Time Delay Relay
 K 16 PAX Select Relay
 K 17 FCX Select Relay
 K 24 Key Capture By-Pass Circuit Relay
 K 50 AC Power Handling Relay
 K 51 By-Pass Relay

FIGURE 4

CONTROL ROD DRIVE CIRCUIT