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MASTER

SEFOR TRANSIENT FLUX DETECTION SYSTEM

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U.S. ATOMIC ENERGY COMMISSION
UNDER CONTRACT AT(04-3)-540

GENERAL ELECTRIC

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SECTION 1

INTRODUCTION

SEFOR (Southwest Experimental Fast Oxide Reactor) is a 20 MW(t) fast spectrum reactor fueled with $\text{PuO}_2\text{-UO}_2$ and cooled with sodium. SEFOR will have characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-UO}_2$. Economic studies of these large power reactors indicate the potential for producing low cost power. SEFOR will be used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristic of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

The SEFOR Project consists of two major parts: the design and construction of the reactor and a related research and development program. Funds for the design and construction of the facility are being provided by the Southwest Atomic Energy Associates (a group of seventeen investor-owned utility companies located in the South and Southwest part of the United States), together with the Karlsruhe Laboratory of West Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the research and development program. The R and D Program consists of two phases:

Phase I - Pre-Operational Research and Development

Phase II - Post-Construction Research and Development (the Program)

This report describes work performed in Phase I of the Research and Development Program under Task 4.2, Core Flux Detector System. The objective of Task 4.2 was to develop and supply a suitable detector system for recording the transient reactor power during the SEFOR fast transient tests. The data will be used to determine the total power and energy generation and the net reactivity as a function of time during the transient.

SECTION 2

SYSTEM DESCRIPTION

2.0 GENERAL

The transient flux detector system is designed to measure transient gamma radiation and neutron flux at several locations outside the SEFOR core (see Figure 2-1). Because neutron detectors also measure gamma radiation, additional "gamma only" detectors are provided in a single unit with the neutron detectors so that the gamma signal can be subtracted from the combined neutron-gamma signal (gamma compensation), leaving a signal representing neutron level only.

Each of the four flux signals is individually amplified in a corresponding high-speed, calibrated amplifier. The amplifier converts input current to output voltage in a selected linear or log scale relating input to output. The output signals of the four amplifiers are directed to a data acquisition system via four individual circuits having one common return.

Each amplifier is provided with four separate feedback networks which can be selectively connected to achieve operation in either one of three linear ranges and one logarithmic range. An external range switch is connected to each amplifier. These range switches selectively energize one of four reed relays in the amplifier to connect an appropriate feedback network between output and input of the amplifier.

All amplifiers and corresponding detectors are interconnected through a calibration box that contains 30 switching relays and a network of calibrating resistors. The switching relays can either be controlled remotely under commands from the data acquisition system or they can be controlled locally by means of two selector switches. The local selector switches are wired so that if either switch is in any position but OFF, an interlock circuit is interrupted. This prevents manually selected calibration signals from being misinterpreted as measured signals.

SECT. AA

Eight high voltage power supplies are used in the system to provide polarizing voltage to the detectors and to provide the calibrating current used in conjunction with the calibration box.

Two low voltage power supplies are used to supply operating current to the four amplifiers. These dual 24 volt power supplies are fully described in GE publication GEK 906 (low voltage power supply per GE drawing 194X457G1).

Two type of ion chambers are used in this core flux detector system: one to measure the gamma flux and the other to measure the fast neutron flux. The gamma detector is a miniature ion chamber about 1/4-inch diameter and about 3 inches in length. The gamma-compensated fast neutron detector is approximately 3 inches in diameter and 16 inches in length. Both types of ion chambers are hermetically sealed and cannot be repaired except by the factory.

The theory underlying all ion chambers is that an enclosed gas becomes ionized through bombardment by neutrons or gamma particles so that electrical conduction through the gas thereby increases. An external source of current, connected to the ion chamber in series with an amplifier/converter to convert input current to output voltage, provides the polarizing voltage needed to sensitize the ion chamber. The exact way in which an ion chamber will respond to different sorts of radiation depends on the inner electrode spacing, the sort of gas contained, the gas pressure, and the material of which the chamber electrodes are made or with which they are coated. Further discussion of this subject is found in Section 2.2.

In the case where neutron flux alone is required, the desired result is achieved by using two chambers, one of which measures gamma only. The polarizing voltage for the gamma only detector is reversed from that of the fission gamma chamber and the resulting gamma current is in opposite sense to the gamma current flowing the fission gamma chamber circuit. The two chambers are wired together to subtract the gamma current at the source thereby leaving only the fast neutron current to reach the amplifier.

The compensated ion chambers (neutron detectors) are mounted on carriages, as shown in Figure 2-2, and inserted in the appropriate holes in the reactor shield shown in Figure 2-1. B_4C and lead shot shielding surround these detectors to reduce the "background" signal caused by slow neutron capture and gamma reactions in the chamber materials.

Figure 2-2. Neutron Detector Carriage

2.1 AMPLIFIER DESCRIPTION

The purpose of the amplifier is to convert input current to output voltage in a selected linear or log scale relating input to output. The input to the amplifier is normally furnished by externally situated flux detectors and the output is directed to a data acquisition system.

This amplifier is a fast response feedback amplifier. It is a linear amplifier when linear resistors are used in the feedback path and it is a logarithmic amplifier when logarithmic elements (diodes) are used in the feedback path. Figure 2-3 shows the amplifier elementary diagram.

Feedback resistors of 1K, 10K, and 100K ohms produce respectively outputs of -1, -10, and -100 volts per milliampere of input. The maximum output voltage swing is about -9 volts and the stability is such that measurements in the millivolt region are feasible. That is, input currents on the order of 10^{-7} amperes are practical with the 100K feedback resistor in place.

Five series diodes are used as the logarithmic feedback element. The output voltage is proportional to the log of the input current from 10^{-7} amperes to 9×10^{-3} amperes. When used as a log amplifier, the minimum output voltage is about -0.7 volts and the maximum output voltage is about -3.5 volts. This is equivalent to about 0.57 volts/decade of input current. The output rise time is partly a function of the feedback element being used but in all cases is about 1 μ sec.

Before examining details of the amplifier circuit, two general statements will be made. A Darlington amplifier consists of two transistors directly coupled in such a way that they behave as one transistor having current gain equal to the product of the individual current gains. In this discussion the Darling pair will be treated as though it were one transistor with a 1.2 volt base-emitter voltage drop. The Darling connection is used in the output stage of this amplifier as well as in a differential amplifier connection in the stage that precedes the output stage. In a differential amplifier an increase of emitter current in one side is balanced by a decrease of emitter current in the other side. This means that current flowing in a commonly shared emitter resistor will remain constant with a correspondingly fixed voltage drop. With these two ideas expressed, the behavior of the amplifier can now be examined.

Figure 2-3. SEFOR Amplifier Elementary Diagram

In the absence of input current to the amplifier, the output is expected to be at zero volts. This means that the emitter of Q9 is at zero volts and the base of Q8 must accordingly be at about -1.2 volts. Under these conditions there will be 10 volts across R12 which means that 10 ma are flowing in this circuit. Because of the extremely high current gain realized by the Darlington output stage, the base current of Q8 may be considered a negligible fraction of the Q5 collector current. Therefore, the 10 volt drop across R12 may be considered a resulting only from Q5 collector current.

Assuming for the moment some undefined voltage at the base of Q4, it is stated that the voltage at the base of Q7 can be adjusted to obtain the conditions described in the preceding paragraph. That is, there will be zero output voltage at the emitter of Q9. R17 is the ZERO ADJUST control. The combination of Q4 through Q7 is a dual Darlington differential amplifier. All of which means that it is subject to the two general statements made at the opening of this discussion. Because the right half of the differential amplifier is grounded, it acts as a source of temperature compensated constant voltage for the left half. Under these conditions the voltage gain of the differential amplifier is expressed as: $\frac{R12}{R13+R15} = \text{about } 20$. The presence of C3 between collector and ground establishes an open loop breakpoint at 20 kHz. This insures that spurious oscillations resulting from stray and junction capacitances will not occur before the amplifier gain has fallen to unity.

Input to the differential stage is provided by the combination of Q2 and Q3. Together these two transistors make up a complementary doublet. The voltage gain of this combination is expressed as: $\frac{R7}{R8-R9} = \text{about } 4$. C2 swamps out stray capacitance between Q2 emitter and ground which otherwise would cause spurious oscillation. C1, a variable trimmer capacitor, is provided to neutralize the combined capacitance. The emitter of Q3 is held at a constant +5.6 volts by zener diode VR3. Heavy negative feedback is provided through R7 between collector and emitter of Q3 and Q2. Additional negative feedback is provided through the scaling resistors R23, R24, and R25, which are selected as needed to fit the application. Altogether this combination of negative feedback with voltage stabilized emitters makes for an extremely stable amplifier.

Q1 is used primarily to isolate the detector cable capacitance from the amplifier input. If this capacitance (≈ 500 pf) were present at the summing point of the circuit (base of Q2), it would be difficult to provide a stable amplifier with the required frequency response. Current furnished to the emitter of Q1, through the three 1-megohm resistors, R1, R26, R27, lowers its input impedance so that this impedance times the cable capacitance yields a cutoff frequency much higher than that of the remaining circuitry. For a high gain transistor, I_C is approximately equal to I_E ; therefore, Q1 appears to be a current source similar to the detector but without the associated cable capacitance. The base of Q1 is set at roughly +2 volts by a low resistance voltage divider and R1 is trimmed until the base of Q2 is at zero volts with no input current and without feedback.

Plus and minus 24 volts is furnished to the amplifier by the external power supply. As the amplifier circuits require only about half this voltage for operation, zener diodes, VR4, VR5, VR6, and VR7 are used to set the operating voltages at plus and minus 11.2 volts.

2.2 RADIATION DETECTOR DESCRIPTION

Many possible combinations of detector types and locations have been investigated and this report discusses the two that have been selected for use in SEFOR. This combination is: (1) a miniature gamma sensitive chamber located in the reflector region and (2) a large, fast neutron sensitive, gamma compensated chamber located in the first serpentine region (see Figure 2-1).

The miniature gamma-sensitive chamber is similar to General Electric's standard miniature gamma-sensitive chamber, Type NA15, with the following exceptions:

1. The gap is 0.008 in.;
2. The fill gas is nitrogen at one atmosphere absolute;
3. The cable is triaxial, quartz insulated;
4. The operating potential is 300 volts.

The large, fast neutron sensitive, gamma compensated chamber is similar to General Electric's standard gamma compensated ion chamber, Type NA01, with the following exceptions:

1. The neutron sensitive volume is lined on two surfaces with U-238, in the form of U_3O_8 , to the maximum practical thickness ($\sim 2 \text{ mg cm}^{-2}$);
2. The gap in the neutron sensitive volume is 1/16.
3. The gap in the gamma sensitive volume is as close to 1/16 in. as possible (compatible with the requirement of the two volumes being nearly equal);
4. The fill gas is nitrogen at one atmosphere absolute;
5. The operating temperature is 250°F ;
6. The operating potentials are ± 1000 volts.

2.2.1 Properties of the Miniature Gamma Sensitive Chamber Located in the Reflector Region

Max. and Min. Power. The currents due to prompt and delayed gammas, with the reflector in, are given by

$$I_{gp} = 0.58 \times 10^{-7} P, \text{ and} \quad (1)$$

$$I_{gd} = 0.58 \times 10^{-8} P_0 (1+F), \quad (2)$$

respectively, where P is the reactor power, in MW, P_0 is the reactor power at the start of a pulse, in MW, and F is the transient fractional change in the delayed gamma flux (given in Reference 1). These currents are based on gamma fluxes tabulated in this same memo.

With the reflector out, the prompt and delayed gamma currents are given by

$$I_{gp} = 1.89 \times 10^{-8} P, \text{ and} \quad (3)$$

$$I_{gd} = 2.36 \times 10^{-9} P_o (1+F), \quad (4)$$

respectively. These currents are based on gamma fluxes provided in Reference 1.

Since the maximum current obtainable from a miniature chamber with 0.008 in. gap and operated at 300 volts is 3.1×10^{-2} amp, the maximum power measurable is

$$P_{\max} = \frac{3.1 \times 10^{-2}}{.58 \times 10^{-7}} = 5.3 \times 10^5 \text{ MW}$$

with the reflector in, and

$$P_{\max} = \frac{3.1 \times 10^{-2}}{1.89 \times 10^{-8}} = 1.6 \times 10^6 \text{ MW}$$

with the reflector out.

The minimum power will be limited by some factor other than statistical fluctuations in the current, for, at 16 kHz bandwidth, the fractional standard deviation of the current does not exceed 1% until reactor power becomes less than 0.073 MW with reflector in or 0.22 MW with reflector out. At these powers the chamber current is 4.2×10^{-9} amperes. One possible lower limit to measurable power is cable leakage, which is estimated to be 2×10^{-8} amp at 650°F. Ten times this value of current corresponds to a minimum power of

$$\frac{2 \times 10^{-7}}{.58 \times 10^{-7}} = 3.4 \text{ MW}$$

with the reflector in, and

$$\frac{2 \times 10^{-7}}{1.89 \times 10^{-8}} = 11 \text{ MW}$$

with the reflector out. However, the severest limitation on lower limit is interference by delayed gammas. Using, for example, the transient shown in Figure 1.3-2, Reference 1, noted above, the delayed gamma current starts to exceed 2% of the prompt gamma current at 720 MW with the reflector in, and at 850 MW with the reflector out.

Delayed Gamma Interference. For the transient shown in Figure 1.3-2, Reference 1, noted above, the prompt and delayed gamma currents will have the following values, with the reflector in:

1. At 720 MW, increasing flux

$$I_{gp} = 4.2 \times 10^{-5} \text{ amp}$$

$$I_{gd} = 1.2 \times 10^{-7} \text{ amp}$$

2. At 5.4×10^4 MW (peak)

$$I_{gp} = 3.1 \times 10^{-3} \text{ amp}$$

$$I_{gd} = 3.0 \times 10^{-7} \text{ amp}$$

3. At 720 MW, decreasing flux

$$I_{gp} = 4.2 \times 10^{-5} \text{ amp}$$

$$I_{gd} = 8.2 \times 10^{-7} \text{ amp}$$

Note that in the worst case (#3) the delayed gammas represent ~2% of the signal (total current).

The prompt and delayed gamma currents will have the following values, with the reflector out,

1. At 850 MW, increasing flux

$$I_{gp} = 1.6 \times 10^{-5} \text{ amp}$$

$$I_{gd} = 5.0 \times 10^{-8} \text{ amp}$$

2. At 5.4×10^4 MW (peak)

$$I_{gp} = 1.0 \times 10^{-3} \text{ amp}$$

$$I_{gd} = 1.2 \times 10^{-7} \text{ amp}$$

3. At 850 MW, decreasing flux

$$I_{gp} = 1.6 \times 10^{-5} \text{ amp}$$

$$I_{gd} = 3.2 \times 10^{-7} \text{ amp}$$

In the worst case (#3) the delayed gammas represent ~2% of the signal.

2.2.2 Properties of the Large, Fast Neutron Sensitive, Gamma Compensated Chamber Located in the First Serpentine Region, Reflector Out

Max. and Min. Power. The currents due to neutrons, prompt gammas, delayed gammas, thermal neutron capture gammas, and constant gammas, with the reflector out, are given by

$$I_n = 0.82 \times 10^{-6} P, \quad (5)$$

$$I_{gp} = 0.55 \times 10^{-6} P, \quad (6)$$

$$I_{gd} = 1.86 \times 10^{-8} P_o (1+F), \quad (7)$$

$$I_{gt} = 0.67 \times 10^{-5} \text{ at 20 MW,} \quad (8)$$

$$I_{gc} = 1.01 \times 10^{-7} \text{ at 20 MW,} \quad (9)$$

respectively.

These currents are based on neutron and gamma fluxes provided by Reference 1.

Since the maximum current obtainable from a large chamber with 1/16 in. gap and operated at 1000 V is 1.0×10^{-2} amp, the maximum power measurable is

$$P_{\max} = \frac{1.0 \times 10^{-2}}{1.71 \times 10^{-6}} = 5.8 \times 10^3 \text{ MW.}$$

Cable leakage in a guarded (tri-axial) quartz or MI cable should be less than 10^{-13} amp.

Alpha current from either Civilian Application grade or the High Purity Grade of U-238 will be about 2×10^{-11} amp, and if we set a practical lower limit to the neutron current at ten times this value, the minimum measurable power is

$$P_{\min} = 2.4 \times 10^{-4} \text{ MW.}$$

Some values of fractional standard deviations versus reactor power at various bandwidths are tabulated below:

<u>Bandwidth</u>	<u>Reactor Power</u>	<u>Neutron Current</u>	<u>σ_I/I</u>
16 kHz	10 MW	8.2×10^{-6} amp	0.78×10^{-2}
16 kHz	1	$.82 \times 10^{-6}$	2.5×10^{-2}
16 kHz	10^{-1}	8.2×10^{-8}	7.8×10^{-2}
320 Hz	10^{-1}	8.2×10^{-8}	1.2×10^{-2}
320 Hz	10^{-2}	$.82 \times 10^{-8}$	3.5×10^{-2}
320 Hz	10^{-3}	8.2×10^{-10}	12×10^{-2}
320 Hz	10^{-4}	$.82 \times 10^{-10}$	35×10^{-2}

Gamma Compensation. Assuming 95% gamma compensation, the net current, I , from the chamber will be

$$I = I_n + 0.05 I_g \quad (10)$$

where I_g is the gamma current from all causes. For the Figure 1.3-2 transient of Reference 1, the terms in this equation will have the following values:

1. At 20 MW (start).

$$\begin{aligned} I_n &= 1.64 \times 10^{-5} \text{ amp} \\ 0.05 I_{gp} &= .055 \times 10^{-5} \text{ amp } (=3.4\% \text{ of } I) \\ 0.05 I_{gd} &= .0019 \times 10^{-5} \text{ amp } (=0.12\% \text{ of } I) \\ 0.05 I_{gt} &= .033 \times 10^{-5} \text{ amp } (=2.0\% \text{ of } I) \\ 0.05 I_{gc} &= .0005 \times 10^{-5} \text{ amp } (=0.03\% \text{ of } I) \end{aligned}$$

$$I = 1.73 \times 10^{-5} \text{ amp}$$

2. At 5.8×10^2 MW (time of scram).

$$\begin{aligned} I_n &= 4.8 \times 10^{-4} \text{ amp} \\ 0.05 I_{gp} &= .16 \times 10^{-4} \text{ amp } (=3.2\% \text{ of } I) \\ 0.05 I_{gd} &= .029 \times 10^{-4} \text{ amp } (=0.58\% \text{ of } I) \\ 0.05 I_{gc} &= .00005 \times 10^{-4} \text{ amp } (=0.001\% \text{ of } I) \end{aligned}$$

$$I = 4.99 \times 10^{-4} \text{ amp}$$

Note that neither the delayed nor the constant gammas make a significant contribution to the signal, but that the thermal neutron activation gammas, in the steady state, contribute 2% of the signal. Their contribution during the decay of the pulse will be greater than 2% (at the assumed 95% compensation), and this effect should be further investigated.

Another contribution to uncompensated gamma current is photofission in the U-238. The current due to this cause is 1.4% of that due to neutron-induced fissions.

Pu-239 Interference. At this location the Pu-239 contribution to the detector current will be 13% of the U-238 contribution after 20 MW-years of operation with the reflector out. It would be greater after 20 MW-years of operation with the reflector in.

The following bar chart summarizes the various upper and lower operating bounds for the two types of detectors, which have been discussed above.

2.3 CALIBRATION UNIT DESCRIPTION

The purpose of the calibration box is to permit the data acquisition system to transfer the input of a selected amplifier from the associated flux detector to a network of calibrating resistors that are sequentially selected to apply known increments of current to the amplifier input. The amplifier output level is examined during the application of ten different values of input current and the input/output curve applied to compensate the amplifier calibration as used for a subsequent measurement.

Elementary diagram 920D142 shows the circuit arrangement of the calibration box. Relays K25 through K29 selectively transfer the individual amplifier inputs from the measuring detectors to the calibration resistor network. Relays K1 through K9 and including K30 establish a series resistance path by which a 500 volt power supply furnishes a calibrated input current to the amplifier selected for calibration. Each of the relays thus far mentioned can be energized either by contact closure on other relays controlled by the data acquisition system or else by contacts on the two selector switches used for local calibration. The remote control relays bear designation numbers K10 through K24. Relays K10 through K19 establish the magnitude of calibration current and relays K20 through K24 determine which of the five amplifiers is to have its input transferred to the calibration circuit. In certain cases it is necessary to energize more than one relay to obtain the desired combination of resistances in the calibration circuit. In these cases diodes are used to multiply the number of effective contacts on the control relay or the selector switch.

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A selector switch (S3) and meter with calibrating resistors can be used when the individual amplifier output levels are to be examined. Full scale of the meter indicates an output level of -10 volts.

The following table shows the measured current output at the ten steps of the calibration unit.

Applied Voltage - Input Offset Voltage (2.6 volts) = 100.0 volts.

<u>Data Acquisition Step</u>	<u>Front Panel Setting</u>	<u>Measured Output $\pm 0.1\%$</u>
1	10^{-7} amp	1.163×10^{-7} amp
2	2.5×10^{-7} amp	2.62×10^{-7} amp
3	5×10^{-7} amp	5.22×10^{-7} amp
4	10^{-6} amp	1.054×10^{-6} amp
5	5×10^{-6} amp	5.024×10^{-6} amp
6	5×10^{-5} amp	5.043×10^{-5} amp
7	5×10^{-4} amp	5.026×10^{-4} amp
8	10^{-3} amp	1.0046×10^{-3} amp
9	2.5×10^{-3} amp	2.482×10^{-3} amp
10	5×10^{-3} amp	4.995×10^{-3} amp

SECTION 3

DETECTOR TEST RESULTS

3.0 INTRODUCTION

Four engineering prototype ionization chambers were tested at Vallecitos to verify preliminary design calculations. Descriptions of the units are as follows:

<u>GE Drawings</u>		<u>Detector Element Properties</u>			
<u>Assembly</u>	<u>Detector Element</u>	<u>Outside Diameter</u>	<u>Electrode Spacing</u>	<u>Gas and Pressure</u>	<u>Sensitive Coating</u>
129B2818G1	129B2814	1/4"	.008	1 atm N ₂	None
129B2818G2	129B2814	1/4"	.008	1 atm N ₂	U-235
846D575G1	846D575G1	3"	.062	1 atm N ₂	U-238
846D575G2	846D575G2	3"	.062	1 atm N ₂	U-235

The 129B2818G1 1/4" gamma chamber and the 846D575G1 fast fission chamber were prototype duplicates of the detectors to be delivered for use in SEFOR. It was necessary to build U-235 coated duplicates of the two designs in order to use the thermal neutron sources available at Vallecitos to measure the static linearity and response characteristics of the chambers.

3.1 SUMMARY OF RESULTS

The following is a tabular summary of the characteristics of the above described chambers based upon the measurements made in accordance with Test Instructions PESE-66-107. In general, most of the results indicate that the chambers as designed should fulfill their functional requirements in SEFOR. The only really questionable result is whether the miniature gamma chamber will be linear at maximum power. (Transient tests in Super-Kukla indicated that the chamber would be linear - see Section V.) See Figures 3-4 and 3-5 for saturation characteristics curves.

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<u>Characteristic</u>	<u>In-Core</u>		<u>Out-of-Core</u>	
	(Gamma) <u>129B2818G1</u>	(U-235 Fission) <u>129B2818G2</u>	(U-238 Fission) <u>846D575G1</u>	(U-235 Fission) <u>846D575G2</u>
Insulation Resistance	$*1.5 \times 10^{12} \Omega$	$*2.1 \times 10^{13} \Omega$	--	--
Alpha Current	--	--	$1.9 \times 10^{-11} \text{ a}$	$10 \times 10^{-9} \text{ a}$
Capacitance				
Collector-to-Case (Other electrodes grounded)	560 pf	--	550 pf	--
Collector-to-(+) HV Elec. (-HV grounded)	--	--	330 pf	--
Collector-to-(-) HV Elec. (+HV grounded)	--	--	250 pf	--
Breakdown Voltage				
Collector-to-Case (Other electrodes grounded)	1350 v	--	4400 v	--
Gamma Compensation [†]				
Lead Shield	--	--	67%	66%
Polyethylene Shield	--	--	25%	25%
Gamma Sensitivity [†]				
Lead Shield	3.6×10^{-14} A/R/hr	3.5×10^{-14} A/R/hr	9.9×10^{-12} A/R/hr	9.8×10^{-12} A/R/hr
Polyethylene	3.1×10^{-14}	3.5×10^{-14}	21.6×10^{-12}	21.6×10^{-12}
Neutron Sensitivity				
Thermal	--	8.2×10^{-17} a/nv	--	1.2×10^{-13} a/nv
Fast	--	--	--	--
Saturation Voltage (Minimum)				
To Collect 3.5 ma.	--	90 v	--	--
To Collect 6.0 ma	--	--	--	350 v
Power Spectrum				
Power Spectral Density - 3db PT.	--	>140 kHz (325v)	--	30 kHz (1000v)

*In Triax Mode at 25°C (measured)

†Calculated from measurements taken in the Co-60 Facility in the "B" ring configuration using indicated shields to change energy spectrum. (uncompensated)

3.2 DISCUSSION

Significant details concerning the interpretation or method of obtaining the foregoing results are presented in the following section.

3.2.1 Insulation Resistance

For the in-core detectors the values of insulation resistance were obtained by measuring the resulting leakage current with the cable in the triax mode. In order to minimize the effects of cable charging, etc., the measurements were done incrementally using equal voltages and times, and the results averaged. The resulting values are somewhat lower than might be expected at 25°C for cables as short as 16' in length operating triaxially. One might suspect a small alpha current due to the uranium coating, but the resistance of the fission chamber proved to be higher than that of the gamma. Therefore, the most logical reason seems to be leakage across the coaxial seal termination of the cable within the chamber itself. This makes the use of triaxial cable somewhat ineffective and could raise the lower limit of the operating range by a decade or more depending on the delayed gamma content of the gamma radiation.

For the large ion chambers it was not possible to measure the insulation resistance due to the shunting effect of the generated alpha current.

3.2.2 Alpha Current

The value of alpha current measured for the U-238 lined large ion chamber was almost exactly the value calculated (see Section 2.2.2) and it therefore verifies the minimum measurable power of 2.4×10^{-4} MW.

3.2.3 Capacitance

Interelectrode capacitances have been measured and included since they have a bearing on the power spectral density upper breakpoint characteristics of each detector. They were measured with a capacitance bridge using a signal of 1000 HZ.

3.2.4 Breakdown Voltage

The breakdown voltages are indicators of upper limits of applied voltages to stay safely below. The values shown were taken with no exciting radiation flux field and at room temperature. Measurements from other tests indicate that breakdown decreases as the strength of exciting flux field increases but as yet no quantitative expression for the increase has been developed. The best rule of thumb is to use the change of the onset of gas multiplication as the modifier of the anticipated breakdown voltage.

3.2.5 Gamma Compensation

Fission chambers generally are not gamma compensated because the fission fragment energies and hence the neutron ionization currents are so much greater in a given gas volume than the corresponding gamma-produced Compton electron energies and hence gamma ionization currents that the gamma contributes is insignificant. Difficulties in making a compensated fission chamber arise from the fact that photoelectrons due to lower energy gammas that are also produced from the walls of the chamber are highly dependent upon the atomic number of the wall material. Since SEFOR fast fission chambers had to also be gamma compensated to near 100%, the problem became one of how to test the compensation characteristics at Vallecitos facilities which all had a fair amount of "soft" gamma energy components, when the actual SEFOR spectrum would be considerably "harder".

The approach taken was to test the engineering prototypes in the Cobalt-60 Facility in both a lead and a polyethylene shield to illustrate the energy dependence of the chamber gamma compensation. It was hoped that the lead would "harden" the spectrum at the chamber enough to approach the desired compensation but the best that could be achieved was about 67%. (See Figure 3-1) Apparently there was enough scattering in the lead to produce significant low energy gammas.

FIGURE 3-1
GAMMA COMPENSATION CHARACTERISTICS

SEFOR TASK 4.2 Out-of-core Fission Detector
Dwg. No. 846D575G2

Tested at Co-60 facility 9-22-66
in "B" ring configuration of fuel pins
with shields around detector as shown.

Note: There is a slight difference between the levels of compensation shown on these curves and those listed in the results table. This is due to minor difference in the measurement of the currents and computation of compensation for these curves.

Calculations using the most recent SEFOR gamma flux spectral data, showed the energies to be high enough that insignificant photoelectrons would be generated from the Uranium coated walls. Figure 3-2 shows the calculated specific electron emission rate vs. gamma energy for uranium and aluminum for both Compton and photo-electric wall emissions. Assuming the average gamma energy of 6 MeV then from the curves, it can be seen that over 3-1/2 decades difference exists between the photoelectrons generated from the uranium and the Compton electrons coming from either the uranium or the aluminum. (See Reference 2, Pages 25-28 for fuller quantitative treatment.)

In view of the foregoing results and calculations for the production prototype fission chambers, it has been decided to check the gamma compensation of the chambers in a fixture prior to coating with uranium. Once the volumes have been adjusted for compensations greater than 95%, then uranium coating and final welding will take place.

3.2.6 Gamma Sensitivity

The gamma sensitivities for the miniature gamma and fission chambers were calculated from currents measured with the chambers in the lead and polyethylene shields alternatively. The gamma fluxes were determined by Fricke Dosimetry performed at the time of the tests. (See Figure 3-3 for plots of dosimetry results.) The resulting sensitivities are somewhat mysterious particularly after the arguments presented in the previous section concerning photoelectron emission. One would expect the polyethylene shielded sensitivity to be higher than the lead shielded one for the U-235 coated chamber. However, the gamma chamber also exhibits a lower polyethylene shielded sensitivity suggesting an error in the dosimetry. Assuming both sensitivities of the gamma chamber to be 3.6×10^{-14} A/R/hr then the polyethylene sensitivity of the fission chamber would then become 4.0×10^{-14} A/R/hr which is more like one would expect. Considering the techniques of irradiating bottles of ferric sulfate in performing the dosimetry, then it seems logical that the sharper peaked flux distribution is the one most likely to be in error. Assume, therefore, that the gamma sensitivity for the incores is 3.5×10^{-14} A/R/hr.

Gamma sensitivities for the large ion chambers are the uncompensated sensitivities of the signal volume only calculated from the compensation measurements taken. It is included with the results only to illustrate the effect of hardening the gamma energy on the sensitivity.

Figure 3-2. Specific Electron Emission Rate (Electrons/Photon)

3.2.7 Neutron Sensitivity

The neutron sensitivities for the two U-235 coated chambers were calculated using a predetermined thermal neutron flux based upon the standard handbook fission cross section for U-235 of 545 barns and 0.025 eV thermal neutrons together with the measured currents. The use of the neutron energy and fission cross section quoted is standard procedure at the NTR for determining neutron fluxes there when dosimetry is performed. Previous history testing incores at NTR have shown very little resultant perturbation so that the latest unperturbed thermal flux can be used with confidence. GETR data was used only to determine the minimum saturation voltage required to collect the higher current. It is known that a thermal neutron energy of 0.028 eV and U-235 fission cross section of 479 barns are used, but apparent larger perturbation effects make flux determination difficult. The fast flux sensitivity of the U-238 coated chamber was calculated using previously measured fast flux energy distributions and the measured output current of the chamber. It can be modified analytically by considering the SEFOR spectrum and cross sections.

3.2.8 Saturation Voltages

The minimum voltages required to collect all of the ions were determined by plotting the current vs. voltage saturation characteristics of each chamber and observing the "knee" of the resulting curve where the current was at least within 5% of being completely collected.

For the incore chambers above about 0.3 ma, (see Figures 3-4 and 3-5) the location of the "knee" seems to change quantitatively in accordance with the theory (see Reference 3, Pages 156-158) and therefore is almost exactly as predicted (Reference 4, Page 2). It was only possible, however, to generate a maximum current of 3.5 ma using existing static reactor facilities. Extrapolating therefore using the relationship $\Delta V \propto \sqrt{\Delta I}$ (see Reference 3, page 158) then the voltage required to collect 31 ma would be:

$$\Delta I = \frac{31}{3.5} \approx 9$$

$$\therefore \Delta V = \sqrt{9} = 3$$

Therefore the minimum voltage required to collect all ions would be $3 \times 90 = 270\text{v}$.

Figure 3-4. Saturation Characteristics-
SEFOR Compensated Fission Chamber

Figure 3-5. Saturation Characteristics-
SEFOR Gamma Chamber

Similarly for the out-of-core chambers to collect 10 ma instead of the maximum measurable 6 ma then:

$$\Delta I = \frac{10}{6} \approx 1.7$$

$$\therefore \Delta V = \sqrt{1.7} \approx 1.3$$

Therefore the minimum voltage required to collect all ions would be $1.3 \times 350 = 455$ v. The additional voltage up to 1000 v recommended for use not only insures complete saturation, but is also necessary in the case of the large ion chamber to establish adequate transient response (see next section).

3.2.9 Power Spectrum

Problems were encountered using only the spectrum analyzer for measuring the power spectral density of the chambers. At low frequencies the large zero pip (which could not be completely nulled out) masked out much of the spectrum information, therefore, another measuring scheme was developed to use in addition to the spectrum analyzer. When the results were comparable, the two systems agreed quite well. The system was composed of the following:

On calibrate position the spectrum for the system was obtained by using a white noise scintillation-random radiation signal source and measuring the resultant spectrum with a variable filter. The white noise source had a known spectrum which was flat far above the desired measurement so that the resultant calibration spectrum was that of the instrumentation system. The detector-neutron source system being tested was then substituted and a new spectrum obtained. The desired spectrum was then obtained by subtracting the two spectra.

Figure 3-6 shows the spectrum for the large fission chamber showing transition from the ion-plus-electron collection region to the electron collection region for applied voltages of 500 and 1000 volts.

No spectrum for the miniature chamber is shown since it was flat up to 140 kHz which is far in excess of the required 16 kHz minimum. Therefore measurements beyond 140 kHz were not taken and the transition region was never determined.

3.3 CONCLUSIONS

From the foregoing results it appears that both the out-of-core fission chamber and the in-core gamma chamber will probably satisfy their immediate requirements as designed. Results of testing have verified the calculations consistently and to an amazingly close degree.

The in-core chamber displayed two characteristics which should be further considered even though they did not appear to limit the ability of the detector to satisfy the present SEFOR requirements.

3.3.1 Insulation Resistance

Care should be taken during the assembly of the production units to insure that the coaxial insulator inside of the chamber which seals the triaxial cable has an insulation resistance $>5 \times 10^{13}$ ohms or else it will become the limiting factor should extended range requiring the guarded cable be required.

3.3.2 Saturation Characteristics

The detector was tested up to 3.5 ma of output current and the required saturation voltage as calculated was verified. However, the onset of gas multiplication dropped from about 400 volts at lower current levels to near 300 volts at the highest level tested. This could have an effect on the linearity of the chamber at the peak required current should it drop back even further. The planned transient test should determine this.

Figure 3-6. Frequency Response-
SEFOR Compensated Fission Chamber, SEFOR Gamma Chamber

SECTION 4

AMPLIFIER TEST RESULTS

Figure 4-1 shows the output of the prototype amplifier as a function of input current on the logarithmic scale. The data of Figure 4-1 were obtained using $\pm 1\%$ test equipment, while Figure 4-2 shows the results using 0.1% equipment. Figure 6-3 shows the amplifier frequency response. These results indicate that the amplifier design meets the requirements established in Ref. 1. Detailed calibration data was obtained on each production amplifier for use in the actual SEFOR transient test analyses.

Figure 4-1. SEFOR Amplifier Output Log Scale

Figure 4-2. Log Output Characteristics of SEFOR Amplifier

Figure 4-3. SEFOR Amplifier Output Voltage versus Frequency

SECTION 5

SYSTEM TEST RESULTS

5.1 INTRODUCTION

Two engineering prototype ionization chamber assemblies together with their instrumentation were tested at the SUPER-KUKLA pulse reactor to verify the capability of the detection channels to faithfully reproduce fast fission pulses having periods as short as 1 msec. The test facility selected has the most nearly representative fast reactor fluxes to that expected in the SEFOR reactor. It is located at the Nevada Test Site and is operated by Lawrence Radiation Laboratory. The following is a description of the equipment tested:

<u>Identification</u>		
<u>Assembly</u>	<u>Detector Element</u>	<u>Description</u>
129B2818G1	129B2814	Gamma sensitive in-core ion chamber assembly having 0.008" gap and nitrogen filled.
846D575G1	846D575G1	Compensated fast-fission detector (U-238) with 0.062" gap and nitrogen filled.
SK8-6148-124	-	Amplifier, linear and logarithmic with remotely programmable ranges (SEFOR).
175A8361	-	Power Supply, 0 to 2100 v variable high voltage supply (modified J. Fluke Model 412-B).

5.2 SUMMARY OF RESULTS

Two reactor bursts were monitored using the SEFOR detectors with the SUPER-KUKLA instrumentation channels followed by a third where both detectors

were connected to SEFOR logarithmic amplifier channels. Comparison of the resulting pulse shapes with those produced by the SUPER-KUKLA detection channels showed the G. E. systems to meet the SEFOR test requirements. Table 5-1 and Figures 5-1 and 5-2 summarize the significant results observed. It was estimated by the SUPER-"K" reactor supervisor that the maximum flux levels during the first burst at the G. E. detector locations would be as follows:

<u>Flux</u>	<u>Maximum Intensity</u>	<u>Detector Location</u>
Gamma	1.5×10^{10} R/hr	Gamma chamber located inside upper core half 3" from top.
Neutron	5×10^{12} nv	Fast fission chamber located 21' from reactor behind an 8" lead wall.

The neutron flux was the least well known, and the sensitivity of the fission chamber was somewhat in doubt due to the unknown energy spectrum to be expected. Therefore the initial burst was expected to be somewhat exploratory.

Only three reactor bursts were produced during four days of testing limiting to a great extent the amount of significant data available to analyze. G. E. was performing their measurements "piggyback" to the primary customer and therefore had little control over the testing pace or size of the reactor bursts. Heat-up of the reactor core as a consequence of the bursts together with radioactivity of the surrounding environment were the main deterrents to testing at faster rates.

5.3 DISCUSSION

5.3.1 General

Two unknown detector characteristics in particular stimulated the need for transient testing in the first place. They are as follows:

1. Saturation

Would the detectors fully saturate when the calculated maximum polarizing voltages were applied and maximum expected detector currents were collected? If a reactor burst of sufficient magnitude could be generated then the faithfulness of reproduction by the detector of the pulse would be a method of qualitatively checking whether it is well saturated or not.

TABLE 5-1

SUMMARY OF SIGNIFICANT SUPER-K BURST RESULTS
FOR SEFOR TRANSIENT TESTS

Burst No.	Minimum Period	SUPER-KUKLA Detectors ⁽¹⁾			GE Detectors	
		410 PD "A"	410 PD "B"	FW 114 "C"	Neutron	Gamma
424		0.14 ma	-	1.2 ma	*0.3 ma	**-
425	0.4 msec	2.35 ma	1.31 ma	17.4 ma	+24.3 ma	2.7 ma
426	1.8 msec	0.17 ma	0.063 ma	-	0.4 ma	0.06 ma
SEFOR (2)	1.0 msec	-	-	-	10 ma (6×10^3 MW)	2.9 ma (4×10^4 MW)

*Detector 21' from reactor core behind 8" lead wall.

** Gamma chamber initially incorrectly connected so no first pulse.

+Detector 15' from reactor core with no lead wall.

- Note: 1) See appendix for details regarding SUPER-K detectors and their locations.
- 2) For comparison, the maximum expected currents in the SEFOR transients are also shown.

Figure 5-1. Results of Super-Kukla Burst No. 425

Figure 5-2. Results of Super-Kukla Burst No. 426

2. Response Time

Would the response time of the detectors be fast enough to reproduce burst pulses of 1 msec period or faster? A fast reactor burst of sufficient magnitude and having a period faster than 1 msec could provide a means of answering both questions.

The first burst (#424) was of relatively low yield and was therefore only used to establish the detector pulse heights vs. yield magnitude. Unfortunately an error in hookup connection prevented initial observation of a gamma pulse.

The second burst (#425) was used to observe the two detector outputs through two of the SUPER-K linear amplifier channels with gains preset to the anticipated full-scale currents. This allowed the two SEFOR pulses to be compared to the SUPER-K detector pulses for faithfulness of reproduction. The burst yield was quite high and the pulse very fast resulting in significant pulse outputs. Figure 5-1 shows the results of the burst.

The third burst (#426) was used to observe the two complete SEFOR detection channels including the amplifiers. The burst yield was low but adequate for the intended observation.

5.3.2 Significance of Results

Figures 5-3 and 5-4 show the results of the SUPER-KUKLA transient tests, comparing the SEFOR detection systems with the SUPER-K facility instrumentation. These curves have been plotted with the peaks normalized to 1.0, so that differences in the shapes are illustrated. All SUPER-K detectors are gamma-sensitive.

In Figure 5-3. (SUPER-KUKLA Burst No.425), the SEFOR detector curves are within the "envelope" defined by the SUPER-K channels on the rising portion of the transient. Initially, the SEFOR gamma chamber has an anomalous "bump" in the record which is believed to be caused by core vibration after the "burst rods" were fired. The gamma chamber was fastened to the upper core structure; motion of this structure was not recorded. It is clear that the SEFOR detectors and amplifier (used with SUPER-K "C" detector) are capable of faithfully following a flux rise on a 0.4-millisecond period; we expect a 1.0-millisecond (or longer) period in SEFOR. On the "tail" of the pulse in Figures 5-3 and 5-4, the SEFOR neutron chamber clearly shows a somewhat

FIGURE 5-3

SUPER-K REACTOR DETECTOR VERTICAL LOCATIONS AND DESCRIPTIONS

SEFOR DETECTOR VERTICAL LOCATIONS

410 P.D. "A"
410 P.D. "B"

Identical gamma detectors consisting of type FW127 Photodiodes (painted black with tygon paint to minimize light sensitivity) immersed in constant density oil baths and placed into buckets of ammonium pentaborate (to thermalize and shield out neutrons).

FW 114 "C"

Neutron burst detector consisting of neutron sensitive scintillation crystal together with two type FW 114 photo diodes.

NOTE: Both of the above detector types are special products by E.G. and G.

FIGURE 5-4
SUPER-K REACTOR ROOM AND DETECTOR LOCATIONS

BURST #424

BURSTS #425, 426

slower pulse decay than do the other, gamma-sensitive, channels. This may be caused by either or both of the following:

- a. The gamma energy distribution may change with time so that the low energy gamma flux increases during the tail of the pulse. The gamma compensation would thus be affected because of the photoelectric effect interaction of the low energy gammas with the U-238 coating. This would produce a higher current from the neutron-sensitive volume, thus causing the pulse "tail" to appear to decay more slowly than is actually the case. In SEFOR, lead shielding is placed around the U-238 chamber to stop low energy gammas.
- b. The U-238 coating in the fission chamber actually contains 0.4 percent U-235. It has been demonstrated at SUPER-K that there is an appreciable effect on reactor dynamics caused by low energy, "room-return" neutrons. Also, calculations using an estimated SUPER-K flux distribution at the U-238 chamber location indicate that the U-235 fission and U-238 fission current components are of the same order of magnitude. Thus, it is possible that the low energy "room-return" neutrons are causing an appreciable U-235 fission current component in the pulse tail. Calculations show that in SEFOR, the U-235 fission current component (due primarily to thermal neutrons) would be no more than 10 percent of the U-238 current component, using the 0.4 percent U-235 content uranium. For this reason, the chambers for use in SEFOR will be made using high purity U-238, which has 100 ppm U-235. The U-235 fission current component for this high purity material is calculated to be less than 2.5 percent of the U-238 fission current in SEFOR.

Unfortunately, more time was not available at SUPER-K to determine the cause of the longer "tail" in the U-238 chamber record. However, SEFOR conditions are such that the possible causes identified in (a) and (b) above are expected to be greatly reduced in SEFOR, compared with the SUPER-K test conditions.

In Figure 5-4, the SEFOR gamma chamber record has a rate of rise similar to that of the other channels, but offset higher than the other three channels. The small peak, superimposed on the overall pulse shape prior to the reactor

pulse peak, is thought to be caused by core vibration. The gamma chamber follows the SUPER-K detectors on the "tail" of the pulse, except for some "valleys" which are unexplained but thought to be caused by core vibration.

5.3.3 Transient Test Conditions

Table 5-2 shows the important conditions of the SUPER-K transient tests compared with the SEFOR test conditions.

As shown in Table 5-2, the SUPER-K No. 425 test had a shorter period than that expected in the fastest SEFOR test. Since the SEFOR detectors followed this pulse faithfully, they should follow the slower SEFOR pulses. The cable capacitance is significant because it, together with the amplifier input impedance, determines the amplifier transient response capability. A high capacitance leads to a high "RC" time constant and consequently a slower response time. Here again, the SEFOR cable conditions should produce a faster response system than the SUPER-K cable conditions.

TABLE 5-2

TRANSIENT TEST CONDITIONS

	<u>SEFOR</u>	<u>SUPER-K Tests</u>
Minimum Period	1.0 msec	0.4 msec (No. 425) 1.8 msec (No. 426)
Chamber to Amplifier Cable Capacity	$\approx$ 500 pF	$\approx$ 3000 pF - gamma chamber $\approx$ 4000 pF - Neutron chamber

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