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Subcontract NP-1

WANL-TME-1863

DECEMBER 1968

Westinghouse Astronuclear Laboratory

NRX-A6 TRANSDUCER EVALUATION REPORT

(Title Unclassified)

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WANL-TME-1863

DECEMBER 1968

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NRX-A6 TRANSDUCER EVALUATION REPORT

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(U) ABSTRACT

(U) This document's purpose is to assess the operation of the WANL instrumentation transducers during the NRX-A6 test series. This includes a sampling and tabulation of data outputs at various times during the test and the evaluation of this data not from the standpoint of analyzing the reactor function, but from the standpoint of how well the sensor was transmitting valid data. A document such as this points out where the transducer problem areas lie and where more development is necessary. It also begins to show the limits of the radiation tolerance of the transducers and allows numbers to be attached to the radiation environment in which the various transducer types will give valid data.

(U) The document itself is divided into seven chapters; one chapter for each type transducer used by WANL in the NRX-A6 reactor. Each chapter is composed of an introduction, summary and a discussion section. The introduction describes the transducer, its installation and the measurement being made. The summary gives a brief description of the test results and any conclusions that are made in the discussion. The discussion describes in detail the operation of the transducer during the test and points out and explains any anomalous behavior in the output data attributable to a sensor. All tables, figures and illustrations referenced herein will be found at the end of each chapter.

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(U) SUMMARY

(U) A total of 265 WANL supplied sensors were used for measurements on the NRX-A6 reactor. Two hundred and fifty-nine (259) of these operated throughout the NRX-A6 test series. The majority of these measurements were identical to those performed on previous reactor tests.

(U) New measurements or those that required redesigned transducers were as follows:

- 1) Core radial displacement measurements were made successfully with new transducers designed and fabricated at WANL and used for the first time on NRX-A6.
- 2) Cluster exit gas temperature measurements were made successfully for the first time during a reactor test.
- 3) The successful use of a liquid nitrogen (LN_2) reference junction dewar installed in the test car privy rather than in the test cell.
- 4) A side by side actuator test that required the measurement of pressure, temperature and vibration to aid in the evaluation of the actuator test parameters.

Two transducer evaluation tests performed on NRX-A6 were:

- 1) Pressure transducer evaluation test which consisted of two redesigned open case type variable reluctance transducers and one thin film bonded strain gage transducer installed on the reactor core support plate and shield.
- 2) Rate sensor fast neutron and gamma detectors used to perform active radiation measurements during the NRX-A6 reactor test.

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(CRD) NRX-A6 TEMPERATURE SENSOR EVALUATION (U)

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CHAPTER 1

(CRD) NRX-A6 TEMPERATURE SENSOR EVALUATION (U)

(U) INTRODUCTION

(U) This chapter outlines in detail the operation of the WANL temperature sensors in the NRX-A6 reactor test series from the standpoint of the sensor and data system outputs. When references to reactor performance were necessary, the information was obtained and coordinated through WANL-TME-1613, "NRX-A6 Test Prediction Report," WANL-TME-1642, "NRX-A6 Data Book," and the cognizant design and analysis group personnel. The data curves in this chapter represent the raw data taken directly from the NRX-A6 Cal Comp Plots with no further analytical refinement. Because of this, these curves are to be used only for transducer comparison purposes cited in this report.

(U) Table 1-1 is included for a general reference. This table gives the predicted radiation levels for each WANL temperature sensor. The data was obtained from WANL-TME-1642, "NRX-A6 Data Book."

(U) SUMMARY

(U) In the NRX-A6 reactor test there were 187 WANL supplied sensors measuring temperatures at various reactor locations. The temperature sensors are considered to have performed as expected throughout the entire NRX-A6 test series.

(U) There were three significant temperature measurements that varied from previous reactor tests. They were:

- 1) Grounded junction thermocouples were used to measure the seal chamber gas and seal chamber exit gas temperatures. On previous reactors, exposed junction thermocouples were used. The results of the NRX-A6 test data indicate much less radiation heating error from these measurements than had been expected.
- 2) The high temperature cluster exit gas thermocouples were used for the first time on NRX-A6. All twenty-one of these thermocouples performed successfully throughout the NRX-A6 test series and exceeded expectations by recording peak temperatures in excess of 4700°R. Further evidence of how well they performed was their ability to measure the control temperature power trims on their output traces. In addition, they supplied diagnostic data by verifying the low temperature at the core periphery that had apparently been measured by the chamber thermocouples.
- 3) A liquid nitrogen dewar was installed in the test car privy and used to provide additional liquid nitrogen reference junctions for copper constantan thermocouples. The use of this dewar in the privy environment presented no problems and provided an adequate reference junction for the thermocouples connected to it.

(U) In connection with the NRX-A6 temperature data, there was concern that the beryllium reflector material temperatures could read as much as 35 degrees higher, due to nuclear heating, if the thermocouple junction did not remain in good physical contact with the reflector. Although the data does not readily show this happening, it could happen. New installation techniques to be used in the future will eliminate this problem.

(U) DISCUSSION

(U) Low Temperature Measurements

(U) The low temperature measurements (35°R to 1099°R) in the NRX-A6 reactor were made with copper-constantan (C/C) type thermocouples and platinum resistance temperature thermometers (RTT's). The thermocouples were stainless steel sheathed, MgO insulated, grounded junction and exposed junction types with various diameters.

WANL Dwg. No. 964B039 (45 mil diameter, Grounded Junction)

WANL Dwg. No. 963B363 (62 mil diameter, Grounded Junction)

WANL Dwg. No. 945C906 H01 (65 mil diameter sheath, Exposed Junction)

The platinum resistance thermometer was a Tem Tech (Model 1137-1) variable resistance, protected open sheath immersion probe type.

WANL Dwg. No. 979D161 H01A

(U) Internal to the NRX-A6 reactor there were 66 C/C thermocouples and 6 RTT's and externally 22 C/C thermocouples and 2 RTT's measuring material, liquid and gas temperatures. Ninety-five (95), out of a total of 96, of these sensors operated normally throughout the NRX-A6 test series with no apparent problems indicated. One of the exposed junction thermocouples (AT 787) installed in the core inlet plenum was damaged during reactor assembly and was cancelled. Ten other of these thermocouples were installed internal to the core radial displacement transducers and the evaluation pressure transducers. Their performance will be covered in those sections of this report.

(U) The accuracy of these thermocouples is that required for special thermocouple wire. This requires that the thermocouple be within $\pm 1\%$ of the NBS curve from -300°F to -75°F and within $\pm 3/4^{\circ}\text{F}$ from -75°F to $+200^{\circ}\text{F}$, then within $\pm 3/8\%$ from $+200^{\circ}\text{F}$ to $+700^{\circ}\text{F}$. In the cryogenic region, below -300°F , the accuracies are as stated in WANL-TME-1453 "WANL Calibrations for NRX-A6" which lists four different groups of curves with accuracies varying from $\pm 3^{\circ}$ to $\pm 7.5^{\circ}$ at 140°R and $\pm 10^{\circ}$ at 35°R . The accuracy of these thermocouple measurements at low temperatures is limited, however, by the capability of the data system to resolve the small voltage change in the thermocouple

output below 140°R . This increases the uncertainty bands of these readings from the data system to as much as 40° at 35°R .

(U) The accuracy of the Tem Tech RTT's is within 0.5° of the standard resistance-temperature curve. However, the accuracy of the RTT measurement is also limited by the capability of the data system. This increases the uncertainty bands of these readings from the data system to as much as 10° at 35°R .

(U) WANL-TME-1735, "Error Band Limits for WANL Measurements on NRX-A6," gives the overall system error band limits for all Westinghouse supplied transducers used in the NRX-A6 reactor.

1) Copper Constantan, Grounded Junction Type Thermocouples - There were 54 grounded junction copper constantan thermocouples measuring the material and gas temperatures in the reflector cylinder reflector, P.V. annulus, control drum No. 5, reflector bolts, core support plate and in the actuator side by side test. Of these 54 thermocouples, 11 were WANL Dwg. 964B039 type and 43 were WANL Dwg. 963B363 type. These were the same types of thermocouples used for these measurements on previous reactor tests.

a) Reflector Cylinder - There were 21 grounded junction C/C thermocouples installed in the reflector cylinders measuring the beryllium material temperatures (3-964B039 H04 and 18-963B363 H01). Figures 1-1, 1-2 and 1-3 show the typical installation methods for these measurements. Figure 1-4 shows the thermocouple outputs during the 60-minute full power hold. The difference in their outputs can be accounted for because they were installed at different station, radii and theta. The axial profile is readily discernible with thermocouples at station 21.0 to 21.4 (AT 301-312) recording higher temperatures than those at station 50.5 (AT 313-321).

The thermocouple set-up range was 35°R to approximately 1003°R . The maximum temperature fluctuations were within the set-up range and varied as follows:

AT 301-312 (Station 21.0-21.4) - varied from 525°R to 145°R at startup and reached as high as 435°R during the full power hold.

AT 313-321 (Station 50.5) - varied from 530°R to 75°R at startup and reached as high as 225°R during the full power hold.

These thermocouple outputs are normal and consistent with each other and are considered to have performed within their stated accuracies.

However, there is some question being raised by the design groups that indicate reflector material temperatures could be as much as 35° high because of radiation heating effects. Their calculations show that this could occur if the thermocouple junctions do not remain in physical contact with the beryllium reflector material during the power test. Although the possibility for this to happen does exist, the data does not show it. It would seem likely that the data would show greater differences between readings and even become erratic during periods of mechanical or temperature shock. This specific problem appears to be an installation problem and not a deficiency in the sensor design. Instrumentation Application has proposed some different installation techniques to alleviate the possibility of these uncertainties occurring in the future.

Also noticeable during the full power hold is that the temperature indications at station 50.5 show a gradual 25° to 30° rise in temperature. This same effect can be noticed in other material temperature measurements in high neutron flux regions such as the reflector bolts and core support plate. This is believed to be a real temperature change with the gradual temperature increase being caused by the high neutron flux (see Table 1-1) causing a change in the thermal conductance of the material at cryogenic temperatures. This phenomenon occurring at such a low flux level for these materials was discovered and first reported in GTR report number 21.

b) Control Drum No. 5 and Reflector Bolt Temperatures - There were four 964B039 H04 C/C thermocouples measuring control drum No. 5 material temperatures (AT 360-363) installed at the same radius and theta but two different stations and four 964B039 H02 C/C thermocouples (AT 331-334) installed in the reflector bolts at the same station and radius but different theta. The installation of the control drum thermocouples is shown in Figure 1-5 and the reflector bolt installation in Figure 1-6. The control drum No. 5 thermocouple outputs at 60-minute full power (Figure 1-7) show the temperature difference between the two stations where they were installed. Figure 1-8 shows the reflector bolt material temperature indication during the full power hold.

These thermocouple set-up ranges were 35°R to 1005°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied as follows:

AT 360 & 361 (Station 8) - varied from 525°R to 85°R at startup and reached 265°R during the full power hold.

AT 362 & 363 (Station 32) - varied from 525°R to 45°R at startup and reached 255°R during the full power hold.

AT 331-334 - varied from 530°R to 125°R at startup and reached 375°R during the full power hold.

There is some concern about the large spread in the outputs between AT 331-332 and AT 333-334. The data itself looks normal in that they all appear to have similar profiles during the full power hold and show no indication of being erratic. The pre- and post-test ambient readings and continuity measurements are normal. There is no evidence to doubt that these thermocouples are not measuring true temperatures within their stated accuracies.

c) Core Support Plate Temperatures - These were two (2) 963B363 H01 C/C thermocouples measuring the core support plate material temperatures

(AT 773-774) installed at the same station but different radius and theta. The installation of these thermocouples is shown in Figure 1-9. Figure 1-10 shows the thermocouple output indication during the reactor 60-minute full power hold.

(U) These thermocouple set-up ranges were 35°R to 1003°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied from 530°R to 195°R at start up and reached 415°R during the full power hold. These outputs also show the gradual increase in output ($\approx 25^{\circ}$) during the hold period as is evident on the reflector bolts and reflector cylinder temperatures. The thermocouples outputs indicate normal operation within their stated accuracies.

d) Side by Side Actuator Temperatures - There were twenty-two (22) C/C grounded junction thermocouples (WANL Dwg. No. 963B363) measuring gas and material temperatures for the actuator side by side test. They were installed at various locations around the actuator measuring drive, coolant and exhaust gas temperatures and material temperatures of the actuator torque motor, shaft bearings, cylinder liner, mounting flange, marman clamp and load fixture. The thermocouple installation details are shown on WANL Dwg. 938J496. Figure 1-11 shows the typical output for a few of these thermocouples during the NRX-A6 full power hold. The set-up range for these thermocouples was 137°R to 1099°R . The maximum temperature fluctuations were within the set-up range. All twenty-two thermocouples performed normally and showed the temperature fluctuations at various actuator locations as the input to the actuator was varied.

2) Copper Constantan, Exposed Junction Type Thermocouples - There were twenty-four (24) exposed junction copper constantan thermocouples (WANL Dwg. No. 945C906 H01) measuring the gas temperatures of the reflector exit, shield dome end plenum and the core inlet plenum. This is the same type of thermocouple

used on previous reactor tests. One of these thermocouples (AT 787), installed in the core inlet plenum, was damaged during reactor assembly and cancelled before the reactor was shipped. The remaining twenty-three (23) exposed junction thermocouples performed normally throughout the test series with no anomalous behavior indicated. These thermocouples, mainly due to their construction, do not raise the question of output uncertainties due to radiation as does the grounded junction type. Due to the small mass at the sensing end, they are extremely fast responding to temperature changes (less than 30 milliseconds) and ideal for measuring gas temperatures. Their disadvantages are that they are extremely fragile and hence hard to work with and the identification of leads during transitioning is a problem increasing the possibility of lead reversals.

a) Reflector Exit Temperature - Five (5) 945C906 H01 C/C exposed junction thermocouples were installed on the forward reflector cylinder to measure the exit gas temperature of the drum vane, drum annulus and reflector cylinder (AT 342-346). The installation of these thermocouples is shown in Figures 1-12 and 1-13. Their outputs during the 60-minute full power hold is shown on Figure 1-14. The thermocouple set-up range was 35°R to 653.5°R . The maximum temperature fluctuations were within the set-up range varying from 530°R to 80°R during start-up and reaching as high as 310°R during the full power hold. Their outputs are normal and consistent with each other and show no indications of anomalous behavior. They are considered to have performed within their stated accuracies.

b) Shield Dome End Gas Temperature - There were six (6) 945C906 H01 C/C exposed junction thermocouples measuring the shield dome end gas temperature (AT 501-506). They were all installed at the same station and radius but different theta. The installation is shown in Figure 1-15. Their output profiles during the 60-minute full power hold is shown on Figure 1-16. The thermocouple set-up range was approximately 35°R to 660°R for the NRX-A6 test. The maximum temperature fluctuations were within

the set-up range varying from 535°R to 105°R during start up and reaching $+215^{\circ}\text{R}$ during the full power hold. The thermocouple outputs are normal and consistent with each other and are considered to have performed within their stated accuracies.

c) Core Inlet Plenum Gas Temperatures - There were thirteen (13) 945C 906 H01 C/C exposed junction thermocouples measuring the core inlet plenum gas temperature (AT 776-788). However, AT 787 was damaged during reactor assembly and was cancelled. They are all installed at the same station but various radii and theta. The installation is shown in Figure 1-17. Their output profiles during the 60-minute full power hold are shown in Figure 1-18.

The thermocouple set-up range was approximately 35°R to 660°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range varying between 535°R to 110°R during start up and reaching 248°R during the full power hold. The following table indicates how consistent these thermocouples were reading. It shows the expected temperature radial and theta distribution at CRT = 15, 200 seconds. They show very accurately the temperature at the outer periphery reading lower temperatures than those towards the center line of the core.

<u>Meas. No.</u>	<u>Radius (in.)</u>	<u>Theta ($^{\circ}$)</u>	<u>Output at CRT = 15, 200 sec</u>
AT 776	1	0	232°R
AT 777	9	318	230°R
AT 778	9	73	232°R
AT 779	9	198	225°R
AT 780	13.4	195	220°R
AT 781	13.4	130	220°R
AT 782	13.4	75.5	220°R
AT 783	13.4	15	218°R

<u>Meas. No.</u>	<u>Radius (in.)</u>	<u>Theta (°)</u>	<u>Output at CRT = 15, 200 sec</u>
AT 784	13.4	315	218°R
AT 785	13.4	255	220°R
AT 786	16.8	315	218°R
AT 788	16.8	195	218°R

These thermocouple outputs were normal and consistent with each other throughout the test and are considered to have performed within their stated accuracies.

3) Platinum, Resistance Temperature Thermometers - There were eight (8) integral lead, variable resistance immersion probe, protected open sheath type platinum RTT's (WANL Dwg. No. 979D161 H01) measuring the gas temperature in the reflector inlet plenum and the liquid temperature in the LN₂ reference dewar.

This was the first use of the Tem Tech RTT's during a reactor test. Previously, on NRX-A5, modified Rosemount RTT's (WANL Dwg. No. 979D162 G02) were used with exposed junction thermocouples as back up measurements. The results of the NRX-A5 test indicated no serious problems with the platinum sensing element in the radiation environment of the reflector inlet plenum other than verifying that the RTT is slower responding than the exposed junction thermocouple. In fact, the RTT, which has a higher sensitivity and a better accuracy below 140°R than the copper constantan thermocouple, did indicate lower temperatures during the startup and shutdown phases of the NRX-A5 reactor test. However, at 140°R and above, the thermocouple and RTT are in good agreement. The results of the NRX-A6 reactor test further verified the NRX-A5 results.

a) Reflector Inlet Plenum Gas - There were six (6) Tem Tech, Inc., RTT's (979D161 H01) measuring the reflector inlet plenum gas temperature (AT 370-375) installed on the aft reflector ring at the same station and radius

but different theta. The installation of these RTT's is shown in Figure 1-19.

(U) The RTT set-up ranges were 35°R to 540°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied from 525°R to 65°R during start-up and reached 165°R during the full power hold.

(U) Figure 1-20 shows the RTT outputs during the 60-minute full power hold. The indicated temperature spread shows the temperature variation of the inlet plenum gas as a function of the different theta positions at which the RTT's were installed. Also noticeable on the output indications is the gradual 5° to 10° increase in temperature throughout the 60-minute full power hold period.

(U) A gradual increase of 5° can be accounted for as being due to the neutron flux field (Table 1-1). This phenomenon was reported previously by WANL and more recently by AGC (RN-S-0370) indicating the platinum RTT to be affected by neutron radiation becoming noticeable at 5×10^{14} neutrons/cm² and reaching a 2.5° error at 5×10^{16} neutrons/cm². Since the predicted radiation level in the reflector inlet plenum is approximately 1×10^{17} neutrons/cm² for a full power 60-minute run, a 5° increase in temperature due to radiation can be accounted for.

(U) Thermocouple measurement AT 381 (reflector-pressure vessel annulus), which measures approximately the same temperature as the RTT's, is shown for comparison in Figures 1-19 and 1-20. In addition, Figure 1-21 shows a comparison between thermocouple AT 381 and RTT AT 374 which are installed close to each other. Figure 1-21 compares the operation of the 60 mil diameter grounded junction thermocouple with the RTT during the startup transient and low temperature operation. Two things are apparent from this figure. One is that the RTT measures a much lower temperature below 140°R than the thermocouple. This is as expected since the RTT has a better sensitivity in this region and is considered more accurate than the thermocouple. Above 140°R they agree very well. The second thing that is

apparent is the RTT response is much faster than the 60 mil diameter grounded junction thermocouple. This shows up very well at initial start of flow as the temperatures begin dropping rapidly. This is in contrast to the NRX-A5 test where an exposed junction copper constantan thermocouple was compared with the RTT and the exposed junction thermocouple showed the faster time response.

These RTT measurements in the NRX-A6 reflector inlet plenum performed normally and consistently throughout the NRX-A6 test within their predicted accuracies. There was no indication of any serious problems in using these RTT's in the temperature and radiation environment experienced in this test.

b) LN₂ Reference Junction Dewar in Privy - There were two (2) Tem Tech, Inc., RTT's (979D161 H01) measuring the liquid nitrogen (LN₂) reference temperature inside the privy mounted LN₂ reference junction dewar (AT 876 & 877). The RTT outputs were normal and indicated a constant LN₂ reference temperature throughout the NRX-A6 test. Figure 1-22 shows the RTT outputs during the 60-minute full power hold.

The eighteen (18) thermocouples that used this reference junction (AT 342-346, 381, 776-786 and 788) showed no differences in their operation or accuracy than the thermocouples that used the LN₂ reference junction in the pit or the Pace reference junction in the privy. The use of the LN₂ reference junction dewar in the NRX-A6 privy environment is, therefore, considered entirely adequate for these measurements.

(U) Medium Temperature Measurements

(U) The medium temperature measurements (137°R to 1969°R) in the NRX-A6 reactor were made with chromel/alumel (Ch/Al) and tungsten-tungsten, 26% rhenium (W/W-26Re) grounded junction type thermocouples and resistance temperature detectors (RTD's). The chromel/alumel thermocouples were stainless steel sheathed, MgO

insulated, grounded junction type with various diameters.

WANL Dwg. No. 963B362 (65 mil diameter)

WANL Dwg. No. 963B361 (45 mil diameter)

WANL Dwg. No. 978D186 (20 mil diameter)

The sensing ends of the tungsten-tungsten, 26% rhenium thermocouples were wrought tungsten sheathed, vitrified BeO insulated, grounded junction type thermocouples.

WANL Dwg. No. 979D149 (62 mil diameter)

The resistance temperature thermometers (RTD's) were Engelhard Industries Inc. standard platinum wound resistance thermometer encased in an aluminum ceramic envelope.

WANL Dwg. No. 945C985

(U) Internal to the NRX-A6 reactor, there were twenty-two (22) chromel/alumel and two (2) medium temperature sensing W/W-26Re type thermocouples measuring material and gas temperatures. Externally, there were twelve (12) chromel/alumel thermocouples and six (6) RTD's installed in the calorimeters. The calorimeter temperature measurement performance will be covered in the calorimeter section of this report.

(U) The calibration curve used for the chromel/alumel thermocouples conforms to, "Table 4 - Ch/Al Thermocouples, Cryogenic Laboratory, NBS, Boulder Colorado," from 10°R to 492°R and to NBS Standard Circular 561 from 492°R to 2960°R. The thermocouple accuracies are within $\pm 10^\circ$ at 1700°R, $\pm 7^\circ$ at 1100°R, $\pm 7^\circ$ at 350°R and $\pm 11^\circ$ at 140°R. However, as in the case of the copper/constantan thermocouples, the data system limits the uncertainty band of the measurements to 30°-40° at 140°R and 20°-30° above 400°R.

(U) The tungsten-tungsten, 26% rhenium thermocouples use the Hoskins calibration curve with a $\pm 50^\circ$ accuracy from 492°R to 4060°R and increases to $\pm 140^\circ$ at 4660°R.

(U) The RTD's accuracy from the standard curve varied from $\pm 0.5^\circ$ at 492°R to $\pm 8.7^\circ$ at 1840°R. The data system limits the uncertainty band of the measurements to 8°-15° at 492°R to 9°-18° at 1500°R.

1) Chromel/Alumel and W/W-26%Re, Grounded Junction Thermocouple -

There were twenty-two (22) chromel/alumel thermocouples and two (2) tungsten-tungsten, 26% rhenium thermocouples measuring material and gas temperatures in the seal chambers 10, 11, 12 and 14, the seal chamber exit gas, station 1 - core element and the tie rod material. Of these thermocouples, fourteen (14) were WANL Dwg. 978D186, eight (8) were 963B361 and the two (2) W/W-26%Re were WANL Dwg. 979D149. The tie rod material and core station 1 thermocouple were the same types used to make these measurements on previous reactors. However, for the seal chamber gas measurements, exposed junction type thermocouples were used previously. On NRX-A6, grounded junction type thermocouples were used. This change was made primarily to alleviate the large failure rate and insulation resistance rework problem inherent with the exposed junction thermocouples and to reduce the possibility of lead reversal during transitioning.

a) Seal Chamber 10, 11, 12 and 14 Gas - There were four (4) 963B361 H01 grounded junction Ch/Al thermocouples installed in seal chambers 10, 11, 12 and 14 measuring the gas temperature in these chambers at the same radius and theta but different station (AT 421-424). The installation of these thermocouples is shown in Figure 1-23.

The thermocouple set-up range was 137^oR to 1969^oR for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied as follows:

	<u>Startup Lowest Temp (°R)</u>	<u>Full Power Hold High Temp (°R)</u>
AT 421 (Seal 10)	335	725
AT 422 (Seal 11)	350	765
AT 423 (Seal 12)	370	810
AT 424 (Seal 14)	370	1015

The thermocouple output profiles for the NRX-A6 60-minute full power hold is shown in Figure 1-24. The data itself looks normal in that the outputs have similar profiles and show no indication of being erratic. All four thermocouples performed normally, as expected, throughout the A6 test series.

b) Seal Chamber Exit Gas - There were four (4) 963B361 H01 chromel/alumel thermocouples (AT 425, 426, 428, 429) and two (2) 979D149 H01 W/W-26Re thermocouples (AT 427, 430) measuring the seal chamber exit gas temperatures at the same reactor station and radius but at different theta. The installation of these thermocouples is shown in Figure 1-25.

The thermocouple set-up ranges were 137°R to 1969°R for the chromel/alumel thermocouples and 492°R to 4785°R for the W/W-26Re thermocouples. The maximum temperature fluctuations were within the set-up range for the chromel/alumels but too low for the W/W-26Re when the temperature dropped below 492°R. The typical temperature fluctuations were as follows:

	<u>Startup Lowest Temp (°R)</u>	<u>Full Power Hold High Temp (°R)</u>
AT 425	375	1015
AT 426	405	965
AT 427 (W/W-26%Re)	Below Set-up Range	955
AT 428	410	970
AT 429	405	870
AT 430 (W/W-26%Re)	Below Set-up Range	885

The thermocouple output profiles for the NRX-A6 60-minute full power hold is shown in Figure 1-26. The data itself looks normal and the outputs are consistent with each other except for AT 429 at CRT = 17800 seconds. At this time, AT 429 shows a sudden 65° drop in temperature. Post-test resistance measurement compares favorably with the pre-test measurement

and gives no indication of transducer error. It must be concluded from this that the temperature reading was real.

An interesting observation here is the close agreement between the four chromel/alumel thermocouples and the two W/W-26%Re thermocouples at these temperatures. The W/W-26%Re thermocouples are apparently much more accurate than the published $\pm 50^{\circ}$ error band at these temperatures.

The six thermocouples performed normally throughout the A6 test series.

c) Station 1, Core Element - There were four (4) 978D186 H03 chromel/alumel thermocouples (AT 601-604) measuring the station 1 - core element material temperature at various radii and theta. The installation of these thermocouples is shown in Figure 1-27.

The thermocouple set-up range was 137°R to 1969°R for the A6 test. The maximum temperature fluctuations were within the set-up range and varied as follows:

	<u>Startup Lowest Temp ($^{\circ}\text{R}$)</u>	<u>Full Power Hold High Temp ($^{\circ}\text{R}$)</u>	<u>Shutdown Lowest Temp ($^{\circ}\text{R}$)</u>
AT 601 (1.1 radius)	250	685	210
AT 602 (16.5 radius)	210	510	180
AT 603 (17.0 radius)	215	510	170
AT 604 (5.1 radius)	255	680	210

The thermocouple output profiles for the NRX-A6 60-minute full power hold is shown in Figure 1-28. The curves show the radial distribution of temperature with those in the outer periphery reading colder as expected. The outputs are normal and consistent with each other. One noticeable occurrence on these curves is the large upward drift in temperature during the full power hold. The cause for this can be related back to the comments made about the material temperature drift in the reflector cylinder.

However, further testing must be performed with these thermocouples in this high radiation environment to rule out any transducer effects.

d) Tie Rod Material - There were ten (10) 978D186 H02 chromel/alumel thermocouples (AT 711-720) measuring the tie rod material temperatures at the same station but various radii and theta. The installation of these thermocouples is shown in Figure 1-29.

The thermocouple set-up range was 137°R to 1969°R for the A6 test. The maximum temperature fluctuations were within the set-up range and varied as follows:

	<u>Startup Lowest Temp (°R)</u>	<u>Full Power Hold High Temp (°R)</u>	<u>Shutdown Peak Temp (°R)</u>
AT 711 (r = 16.3)	390	630	930
AT 712 (r = 16.3)	390	570	870
AT 713 (r = 2.0)	440	710	1030
AT 714 (r = 12.8)	395	650	890
AT 715 (r = 14.0)	370	630	855
AT 716 (r = 16.3)	400	620	895
AT 717 (r = 15.9)	350	570	830
AT 718 (r = 8.0)	440	710	1030
AT 719 (r = 6.0)	430	730	1050
AT 720 (r = 4.0)	485	750	1095

The above data shows the consistency between readings as evidenced by the radial profile; i.e., the thermocouples closer to the center of the core read higher than those nearer the core periphery. Slight variations to this general statement do occur, however, when the difference in radius between two thermocouples is small. This is because they are installed at different reactor theta.

Figure 1-30 shows the thermocouple outputs during the 60-minute full power hold. It can be seen from these curves that the thermocouple outputs

are normal and consistent with each other. The ten thermocouples are considered to have performed well throughout the A6 test series within their stated accuracies.

(U) High Temperature Measurements

The high temperature measurements (492°R to 4785°R) in the NRX-A6 reactor were made with tungsten/tungsten-26% rhenium (W/W-26%Re) grounded junction type thermocouples.

WANL Dwg. No. 978D270 H01 (97 mil diameter) - sensing end is molybdenum tubing with BeO insulation.

WANL Dwg. No. 978D270 H02 (97 mil diameter) - sensing end is tungsten coated molybdenum tubing with BeO insulation.

WANL Dwg. No. 979D149 H02 (64 mil diameter) - sensing end is tungsten-26% rhenium sheathed with BeO insulation.

During NRX-A6 EP-I, one in-core thermocouple output (AT 642) acted suspiciously and had to have the channel signal conditioner replaced. It performed normally in EP-III abort and EP-IIIA test. One cluster exit gas thermocouple (AT 708) became noisy during the EP-III abort test. Subsequent checks revealed no problems with the thermocouple or the data system. This thermocouple performed normally during the EP-IIIA test. One other in-core thermocouple at station 26 (AT 629) showed anomalous behavior. At CRT = 16800 seconds, the output from this channel decayed by 250°. Post-test resistance checks indicated the thermocouple was normal. During reactor disassembly, it was found that the graphite plug in the bottom of the element hole had come out, thus allowing colder gas to flow by the thermocouple and cause it to sense a lower temperature. All other high temperature measurements showed good correlation with both predicted values and their core radial profiles throughout the NRX-A6 test series.

The calibration curve for these thermocouples was the Hoskins curve published in TME-1453, "WANL Calibrations for NRX-A6." The calibration curve was checked

by sample calibrating thermocouples from the ones to be used in the reactor. The accuracy of these thermocouple outputs was $\pm 50^{\circ}$ from 492°R to 4060°R and increased to $\pm 140^{\circ}$ at 4660°R .

1) Tungsten/Tungsten-26% Rhenium, Grounded Junction Type Thermocouples -

There were fifty (50) high temperature W/W-26% thermocouples measuring core material and core exit gas temperatures in the NRX-A6 reactor. Twenty-nine (29) 978D270 type thermocouples were used to measure core station temperatures and twenty-one (21) 979D149 type thermocouples were used to measure the cluster exit gas temperatures. The in-core station temperature measurements were identical to those made on previous reactors. However, the cluster exit gas measurement was a new development for NRX-A6.

a) Station 20, Core Element - There were eight (8) 978D270 H01 W/W-26%Re thermocouples measuring the station 20 core element material temperatures at various radii and theta. The installation of these thermocouples is shown in Figure 1-31.

The thermocouple set-up range was 492°R to 4785°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied during the full power hold as shown in Figure 1-32. The temperature spread in the outputs is primarily due to the normal radial distribution of the core temperatures. This is shown in the following tabulation at CRT = 17800 seconds:

	<u>T/C output ($^{\circ}\text{R}$)</u>
AT 614 (r = 16.1)	3285
AT 615 (r = 10.1)	3465
AT 619 (r = 14.6)	3335
AT 621 (r = 14.0)	3285
AT 622 (r = 2.1)	3585
AT 628 (r = 2.1)	3565
AT 641 (r = 10.8)	3335
AT 642 (r = 16.5)	3285

b) Station 26, Core Element - There were twenty-one (21) 978D270 H02 W/W-26%Re thermocouples measuring the station 26 core element material temperatures at various radii and theta. The installation of these thermocouples is shown in Figure 1-31.

The thermocouple set-up range was 492°R to 4785°R for the NRX-A6 test. The maximum temperature fluctuations of interest* were within the set-up range and varied during the full power hold as shown in Figure 1-33. The temperature spread in the outputs is primarily due to the normal radial distribution of the core temperatures at station 26. Except for AT 629, all outputs are normal and consistent with each other. However, even AT 629 which appears to behave erratically after CRT 16150 seconds, has been determined to be reading a true temperature indication (see detail Figure 1-34) because during reactor disassembly it was found that the graphite plug in the bottom of the element hole had come out. When this plug fell out, it would have allowed colder gas to flow by the thermocouple and cause it to react as shown in the figure.

All the station 26, core element thermocouples are considered to have operated normally within their stated accuracies.

c) Cluster Exit Gas - There were twenty-one (21) 979D149 H02 thermocouples measuring the core cluster exit gas temperatures at various reactor radii and theta. The installation of these thermocouples is shown in Figure 1-35.

The thermocouple set-up range was 492°R to 4785°R for the NRX-A6 test. The maximum temperature fluctuations were within the set-up range and varied during the full power hold as shown in Figure 1-36. This figure shows the thermocouples performed exceedingly well during the NRX-A6 60-minute full power test. All twenty-one (21) of the cluster

*It is recognized that these thermocouples will not show any output change below 492°R even though the core reaches lower temperatures during cold flow and reactor startup times.

exit gas thermocouples performed successfully, and well within expected tolerances throughout the test. In addition, they verified the fact that the chamber thermocouples low readings were indeed real measurements because the four exit gas thermocouples (AT 703, 704, 705, 706) on the outer periphery of the core were affected by the same phenomenon. None of the thermocouples gave any indication of saturation or shunting, even though four of them recorded peak temperatures above 4700°R and steady state temperatures above 4400°R for one hour. During the full power hold, four control temperature trims of 40° , 20° , 10° and 60° were clearly evident on the data traces of these thermocouples. It is now believed that these thermocouple measurements, at these temperatures, can be made as the thermocouples can be calibrated.

TABLE 1-1
 NRX-A6 TEMPERATURE SENSOR
 PREDICTED RADIATION LEVELS AT
 REACTOR FULL POWER

Meas. No.	Neutron Flux E 1.00 $n/cm^2 - sec$	n/cm^2	Thermal Neutron 1.86 $n/cm^2 - sec$	n/cm^2	Gamma Ray Dose Rates R/hr
AT 301	2.7×10^{14}	9.72×10^{17}	1.1×10^{15}	3.96×10^{18}	3.0×10^9
↑	↓	↓	↓	↓	↓
AT 312	2.7×10^{14}	9.72×10^{17}	1.1×10^{15}	3.96×10^{18}	3.0×10^9
↑	↓	↓	↓	↓	↓
AT 313	5.0×10^{13}	1.8×10^{17}	4.7×10^{14}	1.692×10^{18}	3.0×10^9
↑	↓	↓	↓	↓	↓
AT 321	5.0×10^{13}	1.8×10^{17}	4.7×10^{14}	1.692×10^{18}	3.0×10^9
AT 322	7.0×10^{13}	2.52×10^{17}	3.3×10^{14}	1.19×10^{18}	1×10^9
AT 323	7.0×10^{13}	2.52×10^{17}	3.3×10^{14}	1.19×10^{18}	1.6×10^9
AT 324	1.7×10^{13}	6.12×10^{16}	4.5×10^{13}	1.62×10^{17}	4.7×10^8
AT 331	2.3×10^{14}	8.28×10^{17}	2.2×10^{15}	7.92×10^{18}	3.9×10^9
↑	↓	↓	↓	↓	↓
AT 334	2.3×10^{14}	8.28×10^{17}	2.2×10^{15}	7.92×10^{18}	3.9×10^9
AT 342	8.0×10^{13}	2.88×10^{17}	1.5×10^{14}	5.4×10^{17}	$.75 \times 10^9$
AT 343	8.0×10^{13}	2.88×10^{17}	1.5×10^{14}	5.4×10^{17}	$.75 \times 10^9$
AT 344	1.8×10^{14}	6.48×10^{17}	2.0×10^{14}	7.2×10^{17}	2.3×10^9
AT 345	1.8×10^{14}	6.48×10^{17}	2.0×10^{14}	7.2×10^{17}	2.3×10^9

TABLE 1-I
(Pg. 2)

Meas. No.	Neutron Flux E 1.00 $n/cm^2 - sec$	n/cm^2	Thermal Neutron 1.86 $n/cm^2 - sec$	n/cm^2	Gamma Ray Dose Rates R/hr
AT 346	1.16×10^{14}	4.18×10^{17}	1.5×10^{14}	5.4×10^{17}	3.0×10^9
AT 360	1.10×10^{14}	3.96×10^{17}	8.3×10^{14}	2.99×10^{18}	9.5×10^8
AT 361	1.10×10^{14}	3.96×10^{17}	8.3×10^{14}	2.99×10^{18}	9.5×10^8
AT 362	1.5×10^{14}	5.4×10^{17}	1.04×10^{15}	3.74×10^{18}	2.8×10^9
AT 363	1.5×10^{14}	5.4×10^{17}	1.04×10^{15}	3.74×10^{18}	2.8×10^9
AT 370	3.0×10^{13}	1.08×10^{17}	6.0×10^{13}	2.16×10^{17}	8.0×10^8
↑	↓	↓	↓	↓	↓
AT 375	3.0×10^{13}	1.08×10^{17}	6.0×10^{13}	2.16×10^{17}	8.0×10^8
AT 381	9.0×10^{12}	3.24×10^{16}	2.0×10^{13}	7.2×10^{16}	3.5×10^8
AT 421	1.07×10^{15}	3.85×10^{18}	2.0×10^{15}	7.2×10^{18}	1.2×10^{10}
↑	↓	↓	↓	↓	↓
AT 424	1.07×10^{15}	3.85×10^{18}	2.0×10^{15}	7.2×10^{17}	1.2×10^{10}
AT 425	2.0×10^{14}	7.2×10^{17}	3.2×10^{14}	1.15×10^{18}	2.1×10^9
↑	↓	↓	↓	↓	↓
AT 430	2.0×10^{14}	7.2×10^{17}	3.2×10^{14}	1.15×10^{18}	2.1×10^9
AT 501	1.0×10^{13}	3.6×10^{16}	4.0×10^{13}	1.44×10^{17}	5.5×10^7
↑	↓	↓	↓	↓	↓
				1.44×10^{17}	

TABLE 1-1
(Pg. 3)

Meas. No.	Neutron Flux E 1.00 $n/cm^2 - sec$	n/cm^2	Thermal Neutron 1.86 $n/cm^2 - sec$	n/cm^2	Gamma Ray Dose Rates R/hr
AT 506	1.0×10^{13}	3.6×10^{16}	4.0×10^{13}	1.44×10^{17}	5.5×10^7
AT 601	1.07×10^{15}	3.85×10^{18}	5.5×10^{13}	1.98×10^{17}	9.0×10^9
AT 602	4.5×10^{14}	1.62×10^{18}	3.0×10^{14}	1.08×10^{18}	4.7×10^9
AT 603	4.5×10^{14}	1.62×10^{18}	3.5×10^{14}	1.26×10^{18}	4.5×10^9
AT 604	1.0×10^{15}	3.6×10^{18}	4.5×10^{13}	1.62×10^{17}	8.3×10^9
AT 611	4.2×10^{15}	1.51×10^{19}	8.6×10^{13}	3.10×10^{17}	3.0×10^{10}
↑	↓	↓	↓	↓	↓
AT 613	4.2×10^{15}	1.51×10^{19}	8.6×10^{13}	3.10×10^{17}	3.0×10^{10}
AT 614	3.5×10^{15}	1.26×10^{19}	2.5×10^{15}	9.0×10^{18}	1.1×10^{10}
AT 615	3.5×10^{15}	1.26×10^{19}	2.0×10^{14}	7.2×10^{17}	2.7×10^{10}
AT 616	3.5×10^{15}	1.26×10^{19}	2.0×10^{14}	7.2×10^{17}	2.7×10^{10}
AT 617	2.5×10^{15}	9.0×10^{18}	6.4×10^{14}	2.3×10^{18}	1.8×10^{10}
↑	↓	↓	↓	↓	↓
AT 618	2.5×10^{15}	9.0×10^{18}	6.2×10^{14}	2.23×10^{18}	1.9×10^{10}
AT 619	2.3×10^{15}	8.3×10^{18}	6.0×10^{14}	2.16×10^{18}	1.75×10^{10}
AT 620	1.75×10^{15}	6.3×10^{18}	1.6×10^{15}	5.76×10^{18}	1.2×10^{10}
AT 621	2.5×10^{15}	9.0×10^{18}	4.7×10^{14}	1.69×10^{18}	1.7×10^{10}
AT 622	4.4×10^{15}	1.58×10^{19}	9.0×10^{13}	3.24×10^{17}	3.2×10^{10}

TABLE 1-1
(Pg. 4)

Meas. No.	Neutron Flux E 1.00 $n/cm^2 - sec$	n/cm^2	Thermal Neutron 1.86 $n/cm^2 - sec$	n/cm^2	Gamma Ray Dose Rates R/hr
AT 623	1.75×10^{15}	6.3×10^{18}	1.6×10^{15}	5.76×10^{18}	1.4×10^{10}
AT 624	2.0×10^{15}	7.2×10^{18}	9.0×10^{14}	3.24×10^{18}	1.6×10^{10}
AT 625	3.5×10^{15}	1.26×10^{19}	2.0×10^{15}	7.2×10^{18}	2.7×10^{10}
AT 626	3.6×10^{15}	1.30×10^{19}	2.0×10^{15}	7.2×10^{18}	2.7×10^{10}
AT 627	2.5×10^{15}	9.0×10^{18}	6.4×10^{14}	2.3×10^{18}	1.8×10^{10}
AT 628	4.3×10^{15}	1.55×10^{19}	9.0×10^{14}	3.2×10^{18}	3.2×10^{10}
AT 629	3.2×10^{15}	1.152×10^{19}	2.5×10^{14}	9.0×10^{17}	2.3×10^{10}
↑	↓	↓	↓	↓	↓
AT 640	3.2×10^{15}	1.152×10^{19}	2.5×10^{14}	9.0×10^{17}	2.3×10^{10}
AT 641	1.75×10^{15}	6.3×10^{18}	1.6×10^{15}	5.76×10^{18}	1.4×10^{10}
AT 642	1.75×10^{15}	6.3×10^{18}	1.6×10^{15}	5.76×10^{18}	1.4×10^{10}
AT 773	5.3×10^{14}	1.91×10^{18}	3.0×10^{13}	1.08×10^{17}	5.8×10^9
AT 774	7.5×10^{14}	2.7×10^{18}	2.7×10^{13}	9.72×10^{16}	6.7×10^9
AT 776	8.0×10^{14}	2.89×10^{18}	1.0×10^{13}	3.6×10^{16}	7.8×10^9
AT 777	6.5×10^{14}	2.34×10^{18}	2.7×10^{13}	9.72×10^{16}	6.7×10^9
↑	↓	↓	↓	↓	↓

TABLE 1-I
(Pg. 5)

Meas. No.	Neutron Flux E 1.00 $n/cm^2 - sec$	n/cm^2	Thermal Neutron 1.86 $n/cm^2 - sec$	n/cm^2	Gamma Ray Dose Rates R/hr
AT 779	6.5×10^{14}	2.34×10^{18}	2.7×10^{13}	9.72×10^{16}	6.7×10^9
↑	↓	↓	↓	↓	↓
AT 780	5.0×10^{14}	1.8×10^{18}	3.0×10^{13}	1.08×10^{17}	5.7×10^9
↑	↓	↓	↓	↓	↓
AT 785	5.0×10^{14}	1.8×10^{18}	3.0×10^{13}	1.08×10^{17}	5.7×10^9
↑	↓	↓	↓	↓	↓
AT 786	3.0×10^{14}	1.08×10^{18}	3.0×10^{13}	1.08×10^{17}	4.8×10^9
↑	↓	↓	↓	↓	↓
AT 788	3.0×10^{14}	1.08×10^{18}	3.0×10^{13}	1.08×10^{17}	4.8×10^9

Figure 1-1. (U) NRX-A6 Central Reflector Ring Thermocouples

Figure 1-2. (U) NRX-A6 Aft Reflector Ring Thermocouples

Figure 1-3. (U) NRX-A6 Forward Reflector Ring Thermocouples

Figure 1-4. (U) NRX-A6 EP-III A Reflector Cylinder Thermocouples

Figure 1-5. (U) NRX-A6 Control Drum Material Thermocouples

Figure 1-6. (U) NRX-A6 EP-III A Reflector Cylinder Thermocouples

Figure 1-7. (U) NRX-A6 EP-III A Control Drum No. 5 964B039H04

Figure 1-8. (U) NRX-A6 EP-III A 964B039H02 in Reflector Bolts

Figure 1-9. (U) NRX-A6 Core Support Plate Material and Core Inlet Plenum Thermocouples

Figure 1-10. (U) NRX-A6 EP-III A Core Support Plate 963B363H01

Figure 1-11. (U) NRX-A6 EP-III A Sample Temperature Profile - Actuator Side-by-Side (S/S)

Figure 1-12. (U) NRX-A6 Control Drum Vane and Annulus Exit Gas Thermocouples

Figure 1-13. (U) NRX-A6 Reflector Cylinder Exit Gas Thermocouples

Figure 1-14. (U) NRX-A6 EP-III A 945C906H01 Exit Gas Temperature In: Drum Vane, Drum annulus, Reflector Cylinder

Figure 1-15. (U) NRX-A6 Shield Dome End Plenum Thermocouple

Figure 1-16. (U) NRX-A6 EP-III A Shield Dome End Gas 945C906H01

Figure 1-17. (U) NRX-A6 Core Support Plate Material and Core Inlet Plenum Thermocouples

Figure 1-18. (U) NRX-A6 EP-III Core Inlet Plenum 945C906H01

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Figure 1-19. (CRD) NRX-A6 Reflector Inlet Plenum RTT's and Reflector /Pressure Vessel Annulus Thermocouple (U)

~~CONFIDENTIAL~~

Figure 1-20. (U) NRX-A6 EP-III A Reflector Inlet Plenum RTT's Reflector P.V. Annulus 936B363H01

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Figure 1-21. (U) NRX-A6 EP-III Comparison Between RTT & T/C Response at Reflector Inlet Gas Temperature

Figure 1-22. (U) NRX-A6 EP-III LN₂ Dewar Ref. Temperature 979D161H01

~~CONFIDENTIAL~~

Figure I-23. (CRD) NRX-A6 Seal Chamber Thermocouple (U)

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

Figure 1-24. (U) NRX-Ay EP-III A Seal Chamber Gas 963B361H01

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~~CONFIDENTIAL~~

Figure 1-25. (CRD) NRX-A6 Seal Chamber Exit Gas Thermocouples and Core Exit Plenum Pressure Measurements (U)

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Figure 1-26. (U) NRX-A6 EP-III A Seal Chamber Exit Gas

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Figure 1-27. (CRD) NRX-A6 Station 1.0 Fueled Element Thermocouples (U)

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Figure 1-28. (CRD) NRX-A6 EP-III Station No. 1 Core Element Thermocouples 978D186H03

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Figure 1-29. (CRD) NRX-A6 Tie Rod Material Thermocouple (U)

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Figure 1-30. (CRD) NRX-A6 EP-III A Tie Rod Material Temperature 978D186H02

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NOTE: TWELVE HOLES ARE SHOWN ONLY FOR LOCATION IDENTIFICATION. ONLY THOSE HOLES REQUIRED FOR INSTRUMENTATION ARE EXTRUDED IN A GIVEN UNFUELED ELEMENT. THERMOCOUPLES ARE IN EVEN-NUMBERED (CORNER) HOLES ONLY.

Figure 1-31. (CRD) NRX-A6 Unfueled Element Thermocouple (U)

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Figure 1-32. (CRD) NRX-A6 EP-III Thermocouples

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Figure 1-33. (CRD) NRX-A6 EP-III A Thermocouples

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Figure 1-34. (CRD) NRX-A6 EP-III Thermocouples

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CONFIDENTIAL

Figure 1-35. (CRD) NRX-A6 Cluster Exit Gas Thermocouple (U)

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CONFIDENTIAL

Figure 1-36.

CONFIDENTIAL

CHAPTER 2

NRX-A6 STRAIN GAGE EVALUATION

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CHAPTER 2

NRX-A6 STRAIN GAGE EVALUATION

INTRODUCTION

(U) For NRX-A6 reactor internal strain measurements, the Microdot integral lead weldable type strain gages were used. These same types of strain gages have been used internal to the reactor by WANL throughout the NERVA test series. This type of gage is unique for in-core application in that it can be spotwelded to the test piece rather than having to be bonded with materials that may not stand up under high radiation environments. The strain gage itself is a dual filament half bridge configuration with a 120 ohm active and a 120 ohm dummy strain element inside a single tightly compacted ceramic insulated stainless steel tube. The basic strain element is a short length of resistance wire (nickel chromium alloy) with an approximate diameter of 0.001 inch. A thin mounting flange that extends out along both sides of the tube is spotwelded along the length of the tube. When the flange is spotwelded to the test specimen the strain to be measured is transferred through the flange to the strain sensing element inside the tube. The gage excitation and readout is accomplished through the use of MgO insulated integral leads that are transitioned to the legs of the bridge through a hermetically sealed transition.

(U) Two types of integral leads were used for the NRX-A6 strain gage application. Each instrumented tie rod strain gage (978D803H02, SG323/15-4A-10-inconel 718) had three separate $0.031" \pm \begin{smallmatrix} .002 \\ .001 \end{smallmatrix}$ diameter stainless steel sheathed, MgO insulated single copper conductor ($0.010" \pm \begin{smallmatrix} .002 \\ .000 \end{smallmatrix}$) cables attached. Each instrumental reflector bolt strain gage (978D802H02, SG333/8-4A-20-Ti) and each core radial displacement strain gage (978D802H03, SG323/21-4A-20-inconel 718) had single $0.062" \pm \begin{smallmatrix} .003 \\ .000 \end{smallmatrix}$ diameter stainless steel sheathed, MgO insulated, four conductor ($0.010" \pm \begin{smallmatrix} .002 \\ .002 \end{smallmatrix}$) cables attached. The fourth conductor in the above configuration was a constantan wire and used to make a copper-constantan thermocouple junction in the gage transition area.

(U) In order to increase the accuracy of the outputs from the strain gages during the reactor run, they are calibrated in their installed configuration over the expected operating temperature range. This enables the reduced data to be corrected for most of the environmentally induced errors except for radiation. Theoretically, accuracies better than 5% full scale are attainable with these measurements if high radiation levels were not present. However, as will be pointed out, radiation effects are a significant factor in these measurements and require more basic studies in this area in order to resolve what is happening. It is significant to note that these gages did survive the 60-minute full power test inside the reactor.

(U) SUMMARY

(U) In the NRX-A6 reactor there were installed a total of twenty (20) Microdot, Inc. half bridge weldable type strain gages composed of a single active leg and single dummy leg. Eighteen (18) of the twenty strain gages were operable at the beginning of the NRX-A6 test series and they remained operable throughout the test. Ten (10) of these strain gages were installed on the instrumented tie rods. These tie rod measurements were identical to those measurements performed on all previous NRX reactor tests. Ten (10) other Microdot weldable strain gages were used for the first time to perform core radial displacement and reflector bolt strain measurements. These gages were essentially the same as used on the tie rods except that a fourth lead of constantan wire was used to form a copper-constantan thermocouple junction in the integral lead-to-strain gage transition area.

(U) The NRX-A6 instrumented tie rod full power test data indicated a large gradual zero drift. This has been attributed to a radiation effect on these transducers at their installed locations. A maximum radiation level at cryogenic temperatures for these gages can now be established. These levels are as tabulated for AS 709 and AS 710 in the discussion section of this chapter.

(U) All six (6) of the core radial displacement strain gage transducers performed normally and indicated output profiles consistent with the reactor operation. The output zero drift was practically non-existent since the radiation level was lower than for the tie rods. In addition, the six integral thermocouples in the transition area of these transducers operated normally throughout the test within their stated accuracies.

(U) Three (3) of the four (4) reflector bolt strain gage measurements performed normally throughout the test series. The fourth gage was damaged and cancelled before the test series began. These measurements also experienced very little zero drift during the full power hold. The outputs were consistent with the reactor operation.

(U) DISCUSSION

A (U) Instrumented Tie Rods

(U) There were a total of ten (10) strain gages installed on five (5) reactor instrumented tie rods for the purpose of measuring the axial stress on the rods at various positions in the reactor. Each of these instrumented tie rods had two gages spotwelded 180° apart. (See Figure 2-1) When each tie rod was installed in the reactor, it was positioned such that one gage faced the center of the core (AS 701, 703, 705, 707, 709) while the other gage faced outward (AS 702, 704, 706, 708, 710) toward the core periphery. The reason for these two gages on one tie rod mounted in this manner was primarily an attempt to measure any bowing effect of the rods and, secondarily, to ensure the axial stress measurement would still be obtained even if one gage failed.

(U) When installed in the reactor, the strain gages on the tie rods are positioned inside the core support plate, halfway between the top and bottom of the plate. The five instrumented tie rods are placed at different radial and angular positions in the reactor ranging from the center of the core out to the periphery. In this area, the most severe environment for these gages consists of temperature radiation. The temperature ranges from 540°R before start up down to 140°R of gaseous hydrogen at full power. The predicted radiation levels at full power for these locations were:*

<u>Meas. No.</u>	<u>Fast Neutron Flux Rate</u>	<u>Thermal Neutron Flux Rate</u>	<u>Gamma R/hr</u>
	$E > 1.00 \text{ MeV}$ $n/\text{cm}^2 - \text{sec.}$	$E < 1.86 \text{ eV}$ $n/\text{cm}^2 - \text{sec.}$	
AS 701	$4.9 \times 10^{+14}$	$1.03 \times 10^{+14}$	$3.6 \times 10^{+9}$
AS 702	4.9	1.03	3.6
AS 703	4.6	1.01	3.4
AS 705	4.16	1.0	3.2
AS 706	4.16	1.0	3.2

(Continued on next page)

* Taken from WANL-TME-1642, "NRX-A6 Nuclear Subsystem Thermal and Nuclear Design Data Book"

Meas. No.	Fast Neutron Flux Rate	Thermal Neutron Flux Rate	Gamma R/hr
	$E > 1.00 \text{ MeV}$ $\text{n/cm}^2 - \text{sec.}$	$E < 1.86 \text{ eV}$ $\text{n/cm}^2 - \text{sec.}$	
AT 707	3.4	0.95	2.8
AT 708	3.4	0.95	2.8
AT 709	1.8	1.35	1.9
AT 710	1.8	1.35	1.9

(U) During reactor assembly, one strain gage (AS 704) indicated a short between the compensating leg and the metal sheath and had to be cancelled. Therefore, going into reactor test at NTO, nine (9) of the tie rod strain gages were operating normally and all nine were still operating after reactor test. The results of the cold flow test (NRX-A6, EP-I) indicated the instrumented tie rods were operating with reversed polarity. The polarity of the excitation voltage was reversed in order to obtain the correct outputs for the full power run. The results of the next test (NRX-A6, EP-III Abort) indicated normal outputs with correct polarities.

(U) The strain gage outputs during the NRX-A6, EP-III A full power hold is shown in Figure 2-2. Note the large gradual change in output during the full power hold. This change in output appears to be primarily a permanent zero shift, the effect of which tends to decrease on instrumented tie rods that are further away from the center of the core. This same effect was evident on previous reactor tests only to a much lesser degree because the power holds were only 15 minutes long. The NRX-A6, 60-minute full power hold, shows this shift to continue and be cumulative but not repeatable from gage to gage and hence "not predictable." The permanent zero shift between pre- and post-test ambient data is shown in Table 2-1, Column 3. The permanent zero shift has been added to the output data at the end of the full power hold and tabulated in Column 6, Table 2-1. Column 7, Table 2-1, shows the comparison between the instrumented tie rod outputs at the beginning and end of the full power hold after the data has been corrected for the permanent zero shift. The cause of these output zero shifts becomes evident when one looks at the change in resistance of the tie rod gages. This is tabulated in Table 2-II and shows the gage resistance decreases between pre-and post-test

measurements. Again, the same pattern is observed as seen in the measured outputs. The resistance changes, except for AS 701, are less for gages mounted further out from the center of the core axis. The fact that AS 701 does not follow the resistance pattern is not explainable at this time.

(U) The more bothersome fact is that for some reason the active and dummy arms do not show the same resistance change. Whether the cause of the resistance change is due to temperature or radiation, the dummy arm should show the same effect as the active arm and, hence, keep the bridge balanced. Since this does not happen, there is some speculation that this unbalance may be due to some mechanical effect. However, it is hard to understand how such a large resistance change could be caused mechanically and not ruin the gage.

(U) It is apparent, from the above discussion and the results of the NRX-A6 test, that the Microdot weldable gages appear to need more basic development work if they are to be used for instrumented tie rod application. Assuming that radiation effects are the cause of the above problems, these gages work reasonably well up to the maximum radiation levels indicated for AS 709.6A and AS 710.6A.

(U) Core Radial Displacement Measurements

(U) There were a total of six (6) Microdot weldable type strain gages (WANL Drawing No. 978D802 H03) spot welded to six cantilever beam type springs to measure the gap changes between the core and the reflector. They were installed in the reflector cylinder at the aft end of the core. (See Figure 2-3) This was a new application for this gage, since on all previous reactors the gage was installed on the reactor lateral support springs on the inner reflector cylinder. Integral to each gage assembly was a copper-constantan thermocouple with the junction in the gage to sheathed cable transition. As in the case of the tie rods, the most severe environment for these gages consisted of temperature and radiation. The temperature variation at full power, as shown in Figure 2-5, ranged from 540°R, before start-up, down to a low of 85°R during the 2000°R hold, and then approximately 215°R during the full power hold. The predicted radiation levels at full power for these locations were:

Meas. No.	Fast Neutron Flux Rate	Thermal Neutron Flux Rate	Gamma R/hr
	$E > 1.00 \text{ MeV}$ $n/\text{cm}^2 - \text{sec.}$	$E < 1.86 \text{ eV}$ $n/\text{cm}^2 - \text{sec.}$	
AD 301	1.75×10^{14}	4.0×10^{14}	$1.9 \cdot 10^9$
AD 302	"	"	"
AD 303	"	"	"
AD 304	"	"	"
AD 305	"	"	"
AD 306	"	"	"

(U) All six of these transducers indicated normal and consistent outputs throughout the NRX-A6 test. The output profiles were consistent with the reactor operation.

(U) The Core Radial Displacement strain gage outputs during the NRX-A6, EP-III A full power hold is shown in Figure 2-4. The indicated outputs from these transducers do not show the "large" zero drifts experienced on the tie rods. However, there is a zero drift "slightly" evident on the traces that also appears cumulative. The effect is there, but much less than is the case with tie rods. This seems to bear out the fact that since the radiation exposure was less than for the tie rods, the zero drift is not nearly so serious. In addition, these gages showed very little resistance changes after the test. They were all less than an Ohm change.

(U) Instrumented Reflector Bolts

(U) There were a total of four (4) strain gages installed on four (4) reactor reflector bolts for the purpose of measuring the axial load of the core on the pressure vessel. They were positioned in the reflector inlet plenum area of the reactor. (See Figure 2-6) This was a new application for this gage. The gage itself (WANL Drawing No. 978D802 H02) was identical to the one used for the core radial displacement except that the flange material was of a gold alloy type to enable spot welding to titanium.

(U) The most severe environment for these gages consisted of temperature and radiation. The temperature variation ranged from 540°R before start up, down to 145°R during the 2000°R hold and then approximately 265°R during the full power hold. The predicted radiation levels at full power for these locations were:

Meas. No.	Fast Neutron Flux Rate	Thermal Neutron Flux Rate	Gamma R/hr
	$E > 1.00 \text{ MeV}$ $\text{n/cm}^2 - \text{sec.}$	$E < 1.86 \text{ eV}$ $\text{n/cm}^2 - \text{sec.}$	
AS 301	0.7×10^{14}	3×10^{14}	1.5×10^9
AS 302	"	"	"
AS 304	"	"	"

(U) One of these measurements (AS 303) had to be cancelled at the test site, before EP-I, when 10 VDC was erroneously applied across the active gage and the bridge opened up.

(U) The remaining three measurements operated normally throughout the test series and appeared to be giving good data. (See Figure 2-7) The indicated outputs did not show the large zero drifts experienced on the tie rods and showed even less of a tendency to drift than the core radial displacement transducers. This also is what would be expected since the radiation exposure is less than for the tie rods or core radial displacement transducers. The resistance change measured on these gages after the reactor test was less than 0.20 Ohms.

TABLE 2-1
 NRX-A6, EP-IIIA INSTRUMENTED TIE RODS

	(1) Pre Test Ambient Kpsi	(2) Post Test Ambient Kpsi	(3) Permanent Zero Shift Δ Kpsi (2) - (1)	*(4) Start of Full Power Hold CRT=14285 Kpsi	*(5) End of Full Power Hold CRT=17880 Kpsi	(6) Column (5) Corrected for Zero Shift (5) + (3) Kpsi	(7) % Increase Over (4) %
AS 701	+0.32	-56.5	56.8	+45.0	-7.0	+49.8	+10.7
AS 702	0.21	-30.8	31.0	41.0	+13.0	42.0	2.4
AS 703	0.20	-24.4	24.6	45.0	20.5	45.1	0.2
AS 705	0.38	-38.7	39.0	50.0	9.0	48.0	-4.0
AS 706	0.28	-31.7	32.0	47.5	25.0	57.0	+20.0
AS 707	-0.18	-32.3	32.1	55.0	29.5	61.6	12.0
AS 708	+0.15	-24.3	24.5	45.0	21.0	45.5	23.5
AS 709	0.41	-18.8	19.2	58.8	46.0	65.2	10.9
AS 710	0.26	-26.6	26.9	53.0	36.0	62.9	18.6

* Data corrected for temperature shift and non-linearity.

TABLE 2-11

NRX-A6, EP-III A - TIE ROD STRAIN GAGE RESISTANCE CHANGES
BETWEEN PRE & POST TEST RESISTANCE MEASUREMENTS

	<u>Total ΔR Active & Dummy</u>	<u>Active Arm ΔR</u>	<u>Dummy Arm ΔR</u>
AS 701	-0.06	+0.12	-0.03
AS 702	-5.63	-2.87	-2.68
AS 703	-5.05	-2.62	-2.44
AS 705	-5.12	-2.66	-2.44
AS 706	-4.70	-2.45	-2.28
AS 707	-3.73	-2.11	-1.87
AS 708	-3.92	-2.04	-1.89
AS 709	-1.78	-0.94	-0.77
AS 710	-1.69	-0.91	-0.74

Figure 2-1. (U) NRX-A6 Tie Rod Strain Gage Assembly Installation

Figure 2-2. (U) Instrumented Tie Rod Output During NRX-A6 60-Minute Full Power Hold

Figure 2-3. (U) NRX-A6 Core Radial Displacement Strain Gage Assembly Installation

Figure 2-4. (U) Core Radial Displacement Strain Gage Output During NRX-A6 60-Minute Full Power Hold

Figure 2-5. (U) Core Radial Displacement Thermocouple Outputs During the Full Power Hold

Figure 2-6. (U) NRX-A6 Reflector Bolt Strain Gage Assembly Installation

Figure 2-7. (U) Reflector Bolt Strain Gage Output During NRX-A6 60-Minute Full Power Hold

CHAPTER 3

NRX-A6 CALORIMETER EVALUATION

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CHAPTER 3

(U) NRX-A6 CALORIMETER EVALUATION

(U) INTRODUCTION

(U) The WANL calorimeters are integrating types used to measure integrated nuclear heating on varying types of core material. The container is an evacuated stainless steel cylinder with an outer shield 6-3/8" long by 3-7/8" in diameter. It is of welded construction utilizing two chromel/alumel thermocouples to measure the inner and outer shell temperatures and an RTT embedded in the core that is housed in the inner shell. The core and inner shell are supported and thermally isolated by porcelain studs. The technique used here is to determine the heat rise in the core material due to nuclear heating while discounting any heat rise due to radiant or conductive heating from outside the calorimeter.

(U) SUMMARY

(U) The eighteen (18) temperature sensors that made up the six (6) external calorimeters for NRX-A6 operated satisfactorily. However, three measurements went off scale due to under ranging of their data channels, but these measurements came back on scale during cooldown.

(U) DISCUSSION

(U) Six calorimeters were installed externally to the NRX-A6 reactor to obtain nuclear heating rates for stainless steel, aluminum, beryllium, and titanium. (See Figure 3-1) Each calorimeter measurement consists of a resistance temperature thermometer (RTT) to measure core sample temperatures and two chromel/alumel (CH/A) thermocouples to measure the temperatures of the inner shell and the outer case respectively. The descriptions, part numbers, data channel set-up ranges and transducer ranges of the NRX-A6 calorimeters appear in Table 3-I.

(U) Differences in temperatures between each calorimeter's slug, shell and case are plotted on Figures 3-2, 3-3, 3-4, 3-5, 3-6, and 3-7. Higher temperature data could have been obtained for measurements AT 884 (RTT), AT 896 (RTT) and AT 897 (CH/A) had their data channels been ranged higher. However, the slopes of the data plots for AT 896 and AT 897 (Figure 3-6) indicate that even if the maximum transducer ranges had been used for the data channel ranging, the temperature may have been too high for these sensors. Therefore, it is apparent that for future tests a higher temperature thermocouple should replace the resistance temperature thermometers to ensure sufficient data ranging when calorimeters are to be used in a high radiation environment such as AT 896 (Beryllium Slug). The neutron flux and gamma ray heating prediction associated with each calorimeter are referenced in Table 3-II.

(U) The calorimeters are calibrated by testing in a furnace with a known heating rate to determine how good a vacuum has been made and also to determine correction factors to be applied to the reactor test data because of radiant heat affecting the calorimeter core.

TABLE 3-1
(U) NRX-A6 CALORIMETERS

<u>Measurement No.</u>	<u>Description</u>	<u>Data Channel Set-Up Range, °R</u>	<u>Transducer Range, °R</u>	<u>Transducer Drawing No.</u>
AT 830 (RTT)	Car Deck Stainless Steel Slug	500-1250	30-1482	945C985H01
AT 831 (CH/A)	Car Deck Stainless Steel Shell	492-1365	140-1960	963B362H01
AT 832 (CH/A)	Car Deck Stainless Steel Case	492-1365	140-1960	963B362H01
AT 834 (RTT)	Car Deck Aluminum Slug	500-1000	30-1482	945C985H01
AT 835 (CH/A)	Car Deck Aluminum Shell	492-1365	140-1960	963B362H01
AT 836 (CH/A)	Car Deck Aluminum Case	492-1365	140-1960	963B362H01
AT 838 (RTT)	TCC Wall Aluminum Slug	500-1000	30-1482	945C985H01
AT 839 (CH/A)	TCC Wall Aluminum Shell	492-1365	140-1960	963B362H01
AT 840 (CH/A)	TCC Wall Aluminum Case	492-1365	140-1960	963B362H01
AT 880 (RTT)	Privy Roof Titanium Slug	500-1500	30-1482	945C985H01
AT 881 (CH/A)	Privy Roof Titanium Shell	492-1365	140-1960	963B362H01
AT 882 (CH/A)	Privy Roof Titanium Case	492-1365	140-1960	963B362H01
AT 884 (RTT)	Privy Roof Aluminum Slug	500-1000	30-1482	945C985H01
AT 885 (CH/A)	Privy Roof Aluminum Shell	492-1365	140-1960	963B362H01
AT 886 (CH/A)	Privy Roof Aluminum Case	492-1365	140-1960	963B362H01
AT 896 (RTT)	Nozzle Beryllium Slug	500-1250	30-1482	945C985H01
AT 897 (CH/A)	Nozzle Beryllium Shell	492-1365	140-1960	963B362H01
AT 898 (CH/A)	Nozzle Beryllium Case	492-1365	140-1960	963B362H01

TABLE 3-2
(U) NRX-A6 CALORIMETERS

<u>Measurement No.</u>	<u>Material</u>	<u>$n/cm^2 - s$</u>	<u>Watts/gm</u>
AT 830 (slug)	Stainless Steel	5×10^7	5×10^{-4}
AT 831 (shell)	Stainless Steel	5×10^7	5×10^{-4}
AT 832 (case)	Stainless Steel	5×10^7	5×10^{-4}
AT 834 (slug)	Aluminum	5×10^7	6×10^{-4}
AT 835 (shell)	Aluminum	5×10^7	6×10^{-4}
AT 836 (case)	Aluminum	5×10^7	6×10^{-4}
AT 838 (slug)	Aluminum	5×10^9	2×10^{-2}
AT 839 (shell)	Aluminum	5×10^9	2×10^{-2}
AT 840 (case)	Aluminum	5×10^9	2×10^{-2}
AT 880 (slug)	Titanium	5×10^{11}	2.7×10^{-1}
AT 881 (shell)	Titanium	5×10^{11}	2.7×10^{-1}
AT 882 (case)	Titanium	5×10^{11}	2.7×10^{-1}
AT 884 (slug)	Aluminum	5×10^{11}	3×10^{-1}
AT 885 (shell)	Aluminum	5×10^{11}	3×10^{-1}
AT 886 (case)	Aluminum	5×10^{11}	3×10^{-1}
AT 896 (slug)	Beryllium	1.5×10^{13}	1.5
AT 897 (shell)	Beryllium	1.5×10^{13}	1.5
AT 898 (case)	Beryllium	1.5×10^{13}	1.5

Figure 3-1. (U) NRX-A6 Calorimeters

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Figure 3-2. (U) Full Power Output Profiles

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Figure 3-3. (U) Full Power Output Profiles

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Figure 3-4. (U) Full Power Output Profiles

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Figure 3-5. (U) Full Power Output Profiles

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Figure 3-6. (U) Full Power Output Profiles

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Figure 3-7. (U) Full Power Output Profiles

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CHAPTER 4

NRX-A6 LINEAR VARIABLE DIFFERENTIAL TRANSFORMER EVALUATION

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CHAPTER 4

(U) NRX-A6 LINEAR VARIABLE DIFFERENTIAL
TRANSFORMER EVALUATION

(U) INTRODUCTION

(U) There were three (3) Physical Sciences Corporation linear variable differential transformers (LVDT's) used for NRX-A6 displacement measurements. The Physical Sciences LVDT (Model DT-4002-20) is an electro-mechanical type transducer which produces an electrical output proportional to the displacement of a movable core. This transducer is designed to measure linear displacements of ± 0.100 inches with a functional overrange of ± 0.200 inches over a temperature range of -320°F to $+500^{\circ}\text{F}$. It is composed of a cylindrical shaped transformer encased in a stainless steel body 1-1/2 inches long and 1/2 inch in diameter with an axial hole for the probe. Attached is an integral stainless steel, MgO insulated, 4-conductor lead for excitation and read out. The transducer excitation voltage is 5 volts rms at 5 kHz and operates into a 4 wire amplifier-demodulator system.

(U) SUMMARY

(U) The displacement measurements made by the LVDT's mounted on the NRX-A6 core support plate were identical, with the exception of the demodulator-amplifier read out system, to those measurements made on previous reactor tests. Two problems are evident in looking at the NRX-A6 test data. One was the large difference between transducer outputs apparently indicating a large distortion in the core support plate to core motion. It is shown quite conclusively from other measurements that the core support plate to core displacement was normal and that the transducer readings must be in error. Further investigation before EP-II and III indicated that the problem was in the demodulator-amplifier set-up procedure. Adequate set-up procedures using this system were not available at the time of initial transducer calibration here at WANL and is probably the main reason for the erroneous output comparison of the readings. Post calibrations at NTO using the reactor transducers and the demodulator system may clarify the problem and help correct the NRX-A6 data.

(U) The second problem was the gradual 50 mil decrease in output during the 60-minute full power hold. This same effect was apparent on previous reactor tests for these measurements and is attributed to radiation effects. On previous reactor tests, however, the full power holds were shorter (15 minutes) and the effect was less pronounced. The NRX-A6 full power hold (60 minute) showed the radiation effect to be continuous, reasonably linear and cumulative with exposure. This fact alone makes the radiation effect fairly predictable.

(U) Despite the above mentioned problems, the data is usable qualitatively if the radiation effect is corrected in the data. They do show the displacement profile across the core support plate along with the effect of the power trims.

NOTE: The data curves in this chapter represent the raw data taken directly from the NRX-A6 Cal Comp Trace with no further analytical refinement. Because of this, these curves are to be used only for transducer comparison purposes cited in this report.

(U) DISCUSSION

(U) The three LVDT's part number 945C921H01, were mounted on the dome side of the core support plate to measure the axial gap changes between the cluster and support plates of the core inlet surface. (See Figure 4-1) The probes of the LVDT's passed through the support plate and had a predicted movement range of 250 mils. Because the only radiation resistant LVDT's available have a full scale range of ± 100 mils, the LVDT's had to be overranged to ± 150 mils and offset 100 mils in the aft direction during installation to make it possible for predicted direction of motion during the full power run. It is evident, therefore, that data could be lost in earlier cold gaseous type runs if the core to core support plate motion exceeded 50 mils in the forward direction.

(U) The transducer environment in the core support plate is primarily temperature and radiation. The temperature varies from 540°R before start-up to approximately 140°R of gaseous hydrogen at full power. Table 4-3 shows full power predicted radiation exposure.

(U) During the NRX-A6, EP-I test, channel AD 702 appeared to be functioning correctly except that the initial offset only measured 80 mils. AD 701 indicated no output at all and AD 703 showed little initial offset and very little output. However, the output that AD 703 was indicating did follow the same profile as AD 702. This tended to indicate that it was measuring a real output but that it had a set-up problem.

(U) Post EP-I checks found that AD 701 had a loose connection and this was repaired. Then a measurement of the a-c outputs from the transducers indicated close correlation to WANL supplied transducer calibrations. From the a-c measurements, these transducers were still indicating their installed 100 mil offset.

(U) This tended to indicate a problem in the demodulator system. It was the first use of this demodulator system with WANL supplied transducers at Test Cell "C". In order to set up the demodulator system at the Test Site, data must be obtained during transducer calibration by using a transducer simulator box in the channel. The transducer simulator box is then used in place of the transducer to set up the channel at the Test Site. For some reason, the simulator box settings were not giving correct set-up outputs to the demodulator. The answer to this problem should be readily obtained during post-test calibrations when the entire system will be

checked out with the transducers. At this same time corrections can be generated for any difference in core displacements from that used during data analysis.

(U) It was decided after the EP-I test that the gains of the demodulator should be adjusted to give the correct 100 mil offset. This appeared to clear up the problem. However, the results of the EP-III Abort test indicated that AD 701 and 703 were now showing a reasonable output for the 2000^oR hold but AD 702 was way high and would go off-scale during the full power test. All three output profiles, however, showed the same shapes. A check of other test parameters did not indicate any anomalous reactor behavior. Therefore, it was concluded that something must be wrong with the demodulator set-up for AD 702. Since one adjustment had already been made to this channel, it was decided to range the data system to accept this output. In this way, the test profile could be used to indicate any reactor problems. An accurate displacement reading would be obtained during post-calibrations.

(U) During the EP-IIIA full power hold, AD 702 did exhibit the expected large output over AD 701 and 703. However, they all exhibited another problem during the full power hold. Their output profiles sloped downward and tended to indicate that the axial gap between the core and core support plate was decreasing during the full power hold. (See Figure 4-2) This same effect was evident on previous shorter reactor tests and the longer 60-minute full power hold period of NRX-A6 showed this effect to be cumulative. There is no evidence to indicate that this is a real movement being measured. There is good reason to believe that it is being affected by radiation. It is apparent that these instruments need more basic development work in two areas. One is the need for an LVDT with a longer measurement length and the other is to determine what the radiation effects are and how to eliminate or correct them.

(U) Each LVDT's primary and secondary coil resistance was measured before and after the NRX-A6 test to check a resistance change relationship which might explain the decrease in axial gap during the full power hold. As may be seen from Table 4-1, no correlation can be drawn from the change in resistance data.

(U) Likewise, the pre-and post-ambient gap values are shown in Table 4-2. Again, the small difference in pre- and post-ambient gap values does not explain the decreasing slope of the axial gap data. Whether deformation to the transducer or the core support plate can be attributed to radiation cannot be determined until further LVDT testing is performed.

TABLE 4-1

(U) RESISTANCE CHANGES

<u>Measurement</u>	<u>Primary Resistance</u>	<u>Secondary Resistance</u>	<u>Primary Δ Resistance</u>	<u>Secondary Δ Resistance</u>
AD 701	14.48 (pre) 16.00 (post)	20.75 (pre) 23.20 (post)	+1.52	+2.45
AD 702	13.55 (pre) 13.55 (post)	20.27 (pre) 20.27 (post)	0	0
AD 703	14.18 (pre) 15.62 (post)	20.26 (pre) 22.27 (post)	+1.44	+2.01

TABLE 4-2

(U) PRE AND POST AMBIENT GAP VALUES

<u>Measurement</u>	<u>Ambient (mils)</u>	<u>Δ Ambient (mils)</u>
AD 701	125.3264 (pre) 145.1770 (post)	19.8506
AD 702	118.7467 (pre) 136.1124 (post)	17.3657
AD 703	116.8721 (pre) 139.1016 (post)	22.2295

TABLE 4-3
(U) RADIATION LEVELS

Measurement Number	Gamma Dose Rate, Rad (carbon)/hr	Neutron Flux Rate, $n/cm^2 - s(nv)$	Integrated Neutron Flux, n/cm^2 (nvt)	Gamma Heating Rate, w/gm
AD 701	1.7×10^9	2.0×10^{14}	2.5×10^{14}	2.8
AD 702	1.4×10^9	1.7×10^{14}	2.0×10^{14}	2.8
AD 703	0.9×10^9	1.4×10^{14}	1.8×10^{14}	2.8

Figure 4-1. (U) NRX-A6 L.V.D.T. Assembly Installation

Figure 4-2. (U) LVDT Full Power Output Profiles

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CHAPTER 5

(U) NRX-A6 PRESSURE TRANSDUCER EVALUATION

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CHAPTER 5

(U) NRX-A6 PRESSURE TRANSDUCER EVALUATION

(U) INTRODUCTION

(U) Three basic types of pressure transducers were used for WANL pressure measurements in the NRX-A6 reactor test. They were the bonded and unbonded strain gage types and the variable reluctance type.

(U) The unbonded strain gage types, which have been used on previous reactor tests, consisted of Consolidated Electrodynamic Corporation (CEC) absolute and differential transducers and Statham Instruments Corporation differential transducers. The one bonded strain gage type was a Statham Instruments thin film transducer used for evaluation on the NRX-A6 reactor. Four Wiancko variable reluctance transducers were used, two of which were a new open case design being evaluated on this test.

(U) The transducers used in NRX-A6 testing are summarized giving vendor, vendor and WANL part numbers and type.

<u>Vendor</u>	<u>Vendor Model No.</u>	<u>WANL Dwg. No.</u>	<u>Type</u>
CEC	172549-0103	978D220	Unbonded Strain Gage - Absolute
	172550-0103	978D231	Unbonded Strain Gage - Differential
Statham	PL 749	978D255	Unbonded Strain Gage - Differential
	RPH-034 (PA 822)	979D718	Thin-Film Bonded Strain Gage - Absolute
Wiancko	54726	945C923	Variable Reluctance - Absolute
	54727	945C922	Variable Reluctance - Differential
	600755	979D717	Variable Reluctance - Absolute (Open Case)

(U) SUMMARY

(U) There were thirty-five (35) WANL supplied unbonded strain gage pressure transducers mounted external to the NRX-A6 reactor and connected to pressure probes installed internal to the P. V. for diagnostic measurement purposes. These transducers were mounted in two aluminum boxes on the right hand (14) and left hand (19) sides of the reactor test car and in the actuator cylinders 1 and 2. All thirty-five strain gage pressure transducers performed within their stated accuracies throughout the NRX-A6 reactor test series.

(U) One variable reluctance pressure transducer was mounted internal to the reactor pressure vessel, on the internal shield, for the core exit diagnostic pressure measurement. Two problems appeared evident on the data output from this transducer. The sensitivity appeared to be low throughout the test indicating a set-up problem in the demodulator-amplifier and the full scale output showed a gradual drift upward during the full power hold. The suspected demodulator-amplifier problem will be resolved during the NRX-A6 transducer post-calibrations being performed at NTQ. The upward drift was a known characteristic of this transducers' output during a full power run. A redesigned open case version of the variable reluctance transducer is an attempt to resolve this problem.

(U) The NRX-A6 results of the WANL pressure transducer evaluation test indicate that the open-case variable reluctance type pressure transducers and the thin film type pressure transducers both indicate excellent possibilities for operating accurately in high radiation environments with cryogenic (210°R) coolant flow.

(U) However, the open-case variable reluctance transducer indicated a need to resolve two problem areas before additional testing. One is to resolve the uncertainty in the transducers' residual unbalance. Second is to determine if the neutron flux is high enough above the reactor internal shield to affect the transducer output. It is likely that the neutron flux could be affecting the transducer phase angle thus causing the output to be low.

(U) The thin film type bonded strain gage, on the other hand, showed no degradation in output during the NRX-A6 test in the environment it encountered above the reactor internal shield. Further evaluation of this type transducer into higher radiation areas must certainly be attempted in order to increase the capability of obtaining and specifying accurate pressure measurements to fulfill present and future application needs. Thermal calculations already indicate this transducer will survive the environment below the internal shield on the core support plate.

(U) DISCUSSION

(U) There were a total of forty (40) WANL supplied pressure transducers used in the NRX-A6 reactor test. Thirty-five (35) of these were unbonded strain gage types that were installed outside the reactor; 33 in two aluminum boxes on the sides of the test car and 2 mounted in the actuator pod for the actuator side-by-side test. Stainless steel tubes were routed from the transducers in the aluminum box through the reactor seal braze to the reactor locations where pressure was to be measured. The remaining five pressure transducers, one unbonded thin film strain gage and four variable reluctance types were installed internal to the reactor. The thirty-five externally mounted strain gage transducers and one internally mounted variable reluctance transducer were used for diagnostic reactor measurements. The other four internally installed, one thin film strain gage and three variable reluctance type, were used for transducer evaluation purposes.

(U) (U) Diagnostic Pressure Transducers

(U) All except one of the thirty-six (36) diagnostic pressure transducers used in NRX-A6 were temperature compensated (-90°F to $+300^{\circ}\text{F}$) strain gage types. They utilized the unbonded strain gage principle with a four active arm spring type sensing element and a force summing diaphragm. Both CEC and Statham transducers were used as in previous reactor tests. They were 10 Vdc excited transducers with full scale outputs of 40 millivolts and 20 millivolts for CEC and Statham transducers respectively. The other diagnostic pressure transducer used in NRX-A6 was a Wiancko variable reluctance type (WANL Dwg. No. 945C923 H04) with a temperature compensated range from -320°F to $+500^{\circ}\text{F}$. This transducer is a 5 Vac, 5 kHz excited sensor with the output connected to an EGG demodulator-amplifier unit for conversion of the transducer AC output to a 100 mVdc output. All the diagnostic pressure transducers operated throughout the NRX-A6 test series.

(U) Of the thirty-five (35) externally mounted strain gage pressure transducers on the NRX-A6 reactor, two of these were mounted in the actuator cylinders 1 and 2 for the NRX-A6 actuator side-by-side test. Three others, installed in the left hand

transducer box, monitored the actuator drive, coolant and housing plenum pressures. All five of these transducers performed within their predicted accuracies throughout the A6 test. Details of these pressure measurements during the side-by-side test are documented in the WANL Control Systems Engineering report for the NRX-A6 actuator side-by-side test.

(U) The remaining thirty (30) externally mounted WANL supplied strain gage pressure transducers were installed in two protective aluminum boxes mounted on each side of the test car.

(U) One problem occurred after the EP-I gaseous nitrogen (GN_2) and liquid nitrogen (LN_2) flow tests. Seven of the differential strain gage pressure transducers showed significant zero shifts. The cause of this zero shift was due to the introduction of nitrogen gas into the reference pressure lines of the differential transducers. The diffusion of nitrogen gas through the lines into the low side of the transducers changed the heat transfer characteristics of the bridge circuit that was compensated for a helium and/or hydrogen environment. This problem had been anticipated and the data people were instructed not to re-zero any of the data channels. After the nitrogen was removed and helium was re-introduced into the lines, the zero shifts disappeared. This problem was not expected to occur during a full power run since an inerting procedure prior to test is designed to clear any residual nitrogen from the reactor.

(U) During the NRX-A6 EP-IIIA full power test, these thirty externally mounted strain gage pressure transducers indicated accurate operation within their stated accuracies. Table 5-1 shows the pressure transducer output correlation between the predicted value versus the actual measured pressure from fourteen transducers at CRT = 14600 seconds. The seal chamber pressures are tabulated for reference only. Figures 5-1 and 5-2 show the NRX-A6 pressure measurement locations. It is evident from Table 5-1 that where two transducers are measuring the same pressure, the outputs correlate very closely with each other. In addition, the post-test electrical continuity and insulation resistance measurements show no abnormal conditions that would indicate these transducers did not perform normally.

(U) One other diagnostic pressure measurement (AP 708) was made by a Wiancko variable reluctance absolute pressure transducer (945C923 H04) mounted on the reactor internal shield. A stainless steel tube was routed from the transducer pressure port to the reactor core exit plenum for this pressure measurement. The output from this transducer during the EP-III A test is plotted on Figure 5-3. Two other core exit pressure measurements (AP 702 and AP 704) are plotted on this figure for comparison purposes. It is evident from the data plots that the AP 708 output is not reading correctly. The sensitivity is apparently low and the transducer output is showing a gradual increase throughout the 60-minute full power hold period.

(U) The low sensitivity which shows up initially at the 2000°R hold is believed to be caused in the demodulator-amplifier set-up. This is the only logical explanation for this low reading at this time. If the problem had been caused by the temperature effect of the cold gas, the transducer would have read higher rather than lower due to the transducer temperature zero shift. A radiation effect is discounted since the radiation fields above the shield are relatively low during the 2000°R hold periods. If we assume the low sensitivity at the 2000°R hold is in the demodulator-amplifier, then the full power output can be corrected accordingly. This correction amounts to approximately +20 pounds and is indicated by the dashed line in Figure 5-3. The corrected data agrees more closely with the expected low output from this transducer during full power operation as experienced on previous reactor tests. These transducers are known to read approximately 60 pounds low during the full power reactor run. This has been attributed to a radiation effect on these transducers in the reactor shield and core support plate environment. This was one of the problems expected to be solved with the open case transducer design. The NRX-A6 transducer post-calibration effort being performed at NTO will resolve whether the demodulator-amplifier set-up gain caused the output to be low initially.

(U) The gradual increase in the transducer output during the 60-minute full power hold has been determined to be caused by temperature effects within the transducer itself. This is substantiated by the two open case type variable reluctance transducer

outputs, which have excellent internal temperature characteristics, and their outputs do not show this drift.

(U) In conclusion, it must be recommended that the demodulator set-up procedures be reviewed and modified where necessary in order to insure the channels are functioning correctly before a reactor test.

(U) Evaluation Pressure Transducers

(U) There were four (4) pressure transducers mounted internal to the NRX-A6 reactor for evaluation purposes. Three of these were Wiancko variable reluctance type (-320°F to $+500^{\circ}\text{F}$), two of which were the absolute open case design (WANL Dwg. No. 979D717 G01C) and the other was the older design differential pressure transducer (WANL Dwg. No. 945C922 H01C). The fourth evaluation pressure transducer was a Statham Instruments thin film deposited absolute strain gage design (WANL Dwg. No. 979D718 G01B) with a temperature compensation range from -320°F to $+300^{\circ}\text{F}$.

1) Variable Reluctance Type - The variable reluctance type pressure transducer was redesigned and evaluated for internal reactor use because of its demonstrated ability to survive the radiation environment and still give useable data during and after the A3, EST and A5 reactor tests. Previous testing and calculations had shown the closed case design would survive a 1.4 watt/gram gamma radiation field and still maintain reasonable internal coil temperatures if the hydrogen coolant gas was $\leq 247^{\circ}\text{R}$. This limited the installation of this transducer to very few areas in the NRX reactors and practically eliminated its internal use in the proposed larger reactor designs. Calculations indicated the limiting factor in the transducer design was the internal coil and core temperatures exceeding the Curie temperature of the mu-metal core (800°F). A redesign of the transducer was performed which involved opening the case of the new unit and allowing the coolant gas to flow over the internal parts of the transducer. This allowed the transducer to operate in a four Watts/gram gamma radiation field with an $\leq 247^{\circ}\text{R}$ hydrogen coolant gas and not exceed the 800°F Curie

temperature point of the mu-metal core. The calculated internal temperature distribution of the closed- and open-case transducers in a four Watts/gram environment is shown in Figure 5-4. Note the open-case design indicates a 757 degree lower temperature reading at the center of the core than the closed-case transducer. The evaluation open-case design also incorporated copper-constantan thermocouples installed in the transducer coils to enable further refinement of the calculated transducer temperature distribution during a reactor test.

Two Wiancko open-case variable reluctance type pressure transducers performed successfully the non-nuclear qualification test requirements in WANL-E-675576. The results of these non-nuclear qualification tests were reported in TME-1643, "Non-nuclear Testing of NERVA Candidate Pressure Transducers." With the successful completion of these qualification tests and the favorable gamma heating rate calculations, the transducer was considered acceptable for nuclear evaluation on the shield and core support plate of the NRX-A6 reactor.

Two of these open-case transducers were installed in the NRX-A6 reactor. One was installed above the reactor internal shield (AP 502) and the other (AP 772) in the higher radiation environment below the internal shield on the core support plate. A closed-case variable reluctance differential pressure transducer (AP 503D) was installed, with AP 502, on the reactor shield with the high and low ports open to the shield ambient pressure. Any unknown output indication from this transducer would then be recognized as a zero shift caused by radiation. The predicted radiation levels in these areas were:

	Fast Neutron Flux Rate $E > 1.00 \text{ MeV}$ $\text{n/cm}^2 - \text{s}$	Thermal Neutron Flux Rate $E < 1.86 \text{ EV}$ $\text{n/cm}^2 - \text{s}$	Gamma R/hr
Shield	1.0×10^{13} (3.6×10^{16} nvt)	4×10^{13} (1.44×10^{17} nvt)	5.5×10^7 ($\approx 0.2 \text{ watts/GM}$)
Core Support Plate	1.5×10^{14} (5.4×10^{17} nvt)	1.5×10^{14} (5.4×10^{17} nvt)	1.5×10^9 ($\approx 4.2 \text{ watts/GM}$)

The test data for the NRX-A6, EP-III Abort run is shown in Figure 5-5. This data has been corrected for known linearity and temperature parameters where necessary. The curves show excellent agreement between the evaluation transducers and the diagnostic transducer measurement of the core inlet plenum (AP 604) during initial ramp-up to power and during the hold period. However, after reactor scram and shut-down, the variable reluctance transducer (AP 772) does not return to its initial pre-test pressure measurement (approximately 20 pounds high). This is attributed to the residual unbalance problem that was identified with these transducers in the non-nuclear qualification testing (TME-1643) and is not caused by radiation. The residual unbalance problem on the open-case variable reluctance transducer was considered solvable and not a limiting factor for the overall transducer evaluation.

The NRX-A6 ramp-up and 60-minute full power test data for these transducers is shown on Figure 5-6. Both evaluation VR pressure transducers (AP 502 and AP 772) are indicating approximately 75 psi below the true pressure during the 3700°R and full power hold periods. The data output during the 2000°R hold period shows a slightly low output from these transducers, but well within the transducer error band. It can be concluded from the results of the NRX-A6, EP-III Abort and the EP-IIIA test that the VR open-case transducer operates within its error band limits to 2000°R. During the 3700°R and full power hold levels, the transducer outputs were consistently indicating 75 psi low after all known corrections have been applied to the data. This is in contrast to the closed-case design (AP 708, Figure 5-3) that indicated an output 105 psi low at the beginning of the full power hold and gradually increased until the output was only 60 psi low near the end of the run. This upward drift during the full power hold is not evident on the open-case variable reluctance transducers which have been designed to reduce gamma radiation temperature problems (see below). This absence of drift in the open-case design lends credence to the argument that the drift is due to the internal temperature change in the

closed-case transducer. However, the fact that the open-case transducers still have outputs 75 psi low indicates that internal temperature due to gamma radiation was only part of the problem. Further evaluation testing must be performed on these transducers to determine (and more accurately predict) the effect of neutron flux on the operation of the variable reluctance pressure transducer in these radiation fields.

The open-case variable reluctance transducers' internal temperatures during the EP-III A full power hold are shown in Figure 5-7. Thermocouples AT 507 and AT 508 are measuring the internal coil temperatures of the shield mounted transducer (AP 502) and thermocouples AT 771 and AT 772 are measuring the internal coil temperatures of the core support plate mounted transducer (AP 772). This figure shows a temperature difference between the two transducers of only 75°R during the full power hold even though the predicted gamma radiation on the core support plate is 20 times greater than that on the shield. In addition, the transducer internal temperatures remain relatively constant during the full power hold showing only a slight 10°R rise. It is evident from this data that the thermal characteristics of the open-case transducer, in the high radiation environment of the core support plate, is excellent.

One other transducer was included as part of this evaluation. AP 503D (945C 922 H01C), a closed-case variable reluctance differential pressure transducer, was installed beside AP 502 on the reactor shield. Both pressure ports of this differential transducer were open to the shield inlet ambient pressure. The purpose of the test was to determine any unknown temporary or permanent zero shifts in the transducer output. The results of this test showed no unknown zero shifts throughout the NRX-A6 test. This tends to indicate the suspected neutron flux effect on the VR pressure transducers decreases the transducer sensitivity and doesn't cause a zero shift in the output during or after a reactor test.

Several conclusions can be made from the results of the NRX-A6 open-case variable reluctance pressure transducer evaluation test.

- 1) The transducer will survive the thermal and radiation environment of the NRX-A6 reactor core support plate.
- 2) The full power neutron flux radiation effect on these transducers is predictable in the magnitude of +75 psi that must be added as a correction factor to the transducer output.
- 3) The transducer outputs can be corrected to an accuracy of $\pm 4\%$ full range at the present state-of-the-art.
- 4) The low output reading during a reactor full power run is caused by a decrease in transducer sensitivity and not by a transducer zero shift.

Further testing and evaluation of these transducers should concentrate on resolving the three problem areas. The first would be to correct the uncertainty in the residual unbalance of the transducer. The second would be to determine the critical neutron flux value and what its effect is inside the transducer. There is a good possibility this is just a materials problem either in the coil wires or the mu-metal type magnetic core that is used. The third problem area that does not appear serious at this time is the fact that the resistance of the coils show a 10 percent increase between pre- and post-test continuity measurements. There is speculation that this is a radiation effect on the properties of the coil wire itself and could be resolved if a study was made along these lines.

Strain Gage Type (Thin Film) - One Statham Instruments thin film absolute strain gage pressure transducer (Model RPH-034, PA 822) was used for transducer evaluation purposes internal to the NRX-A6 pressure vessel. It is 10 Vdc excited and has two integral stainless steel three conductor cables attached for excitation and readout purposes. The six leads were supplied to facilitate the use of shunt calibration. This transducer was originally selected for internal reactor evaluation because its unique construction solves two important problems that have limited the use of strain gage pressure transducers in high radiation fields and extreme temperature environments. These limiting items are:

- 1) All organic strain gage bonding material deteriorates when exposed to radiation and temperature.
- 2) Excessive internal heat buildup in the sensing element when exposed to gamma radiation.

The vacuum deposition process used by Statham Instruments in the fabrication of the thin-film pressure transducer eliminates the use of organic bonding agents for the attachment of the strain gage to the diaphragm. In addition, this type of construction gives minimum mass to be affected by gamma radiation. At the same time, it provides good thermal conduction and dissipation of any heat that is internally generated. Results of a thermal analysis study performed on this transducer are shown in Figure 5-8. This shows that the maximum transducer internally generated temperature, in a 4 Watt/gram gamma radiation environment with $\leq 247^{\circ}\text{R}$ hydrogen coolant gas, would be 728°R (268°F). This is below the transducer's maximum compensated temperature of 860°R (400°F). It should be noted that four Watts/gram is very nearly the predicted gamma radiation intensity on the reactor core support plate (4.2 Watts/gram). It appeared from these calculations that the thin film transducer may be able to survive the radiation environment on the NRX-A6 core support plate. It had been hoped to evaluate this transducer by installing one on the internal reactor shield (0.2 Watts/gram) and another on the core support plate, (4.2 Watts/gram). However, due to data system channel limitations, only one channel was available for these measurements. Because of the uncertainty in the heating calculations coupled with the unknown affect of high neutron flux fields on the performance of the thin film strain gage, a conservative approach was taken and the transducer was installed in the lower radiation area on the internal shield. Marginal performance of the transducer in this lower radiation area of the shield would yield more information on the effect of the thin film strain gage technique than having the transducer possibly fail totally in the higher radiation field of the core support plate.

Before the thin film pressure transducer could be considered for use in the reactor, it was necessary to demonstrate compliance to the qualification specifications in WANL E-675576. Three Statham 800 psia thin film strain gage pressure transducers were tested successfully per the requirements of this specification. The results of these non-nuclear qualification tests were reported in WANL-TME-1643, "Non-nuclear Testing of NERVA Candidate Pressure Transducers."

The transducer was now acceptable to be installed on the internal shield of the NRX-A6 reactor for nuclear evaluation. The readout for this measurement (AP 504) was through the NTO test cell "C" narrow band data system.

The NRX-A6 thin film pressure transducer output data is shown in Figures 5-5 and 5-6. This data has been corrected for all known parameters such as non-linearity and temperature effects. Figure 5-5 shows the output profile of the thin film transducer (AP 504) during the EP-III Abort run. Note how well AP 504 agrees with the output from the externally mounted core inlet plenum pressure transducer (AP 604) before, during and after the 2000^oR hold period. Pre-test and post-test resistance readings agreed within 1 percent of each other. No problems were evident with this transducer during the EP-III Abort run. It performed normally and within the required accuracy. Figure 5-6 shows the output profiles of AP 504, AP 304 and AP 604 before, during and after the NRX-A6 60-minute full power hold test (EP-IIIA). Again, note how well the internally installed thin film strain gage transducer follows the externally mounted strain gage transducers, AP 604 and AP 304. The thin film transducer is responding identically to the pressure fluctuations that are evident on the externally mounted strain gage transducer data traces. Some indication of how accurate the thin film pressure transducer performed can be shown by comparing the pressure measurement drops from the reflector outlet plenum (AP 304), to the shield (AP 504) and then to the core inlet plenum (AP 604) during the 60-minute full power hold period. The data trace in Figure 5-6

shows the shield pressure measurement to be as predicted and follows consistently between the reflector outlet plenum and core inlet plenum pressure measurements.

Continuity and insulation resistance (IR) measurements taken before and after the 60-minute full power hold test show no significant changes.

The results of the NRX-A6 60-minute full power reactor test show that the Statham Instruments thin film absolute strain gage pressure transducer (WANL Dwg. No. 979D718 G01B) could operate accurately ($< 1\%$ F.S.), with no measurable transducer degradation, in the environment at the top surface of the internal reactor shield. The predicted environment at the top surface of the shield included:

1) Radiation:

- a) Fast neutron flux ($E > 1 \text{ MeV}$) $1 \times 10^{13} \text{ n/cm}^2 - \text{s}$ and integrated flux of $3.6 \times 10^{16} \text{ nvt.}$
- b) Thermal neutron flux ($E < 1.86 \text{ eV}$) $4 \times 10^{13} \text{ n/cm}^2 - \text{s}$ and integrated flux of $1.44 \times 10^{17} \text{ nvt.}$
- c) Gamma Dose Rate $5.5 \times 10^7 \text{ R/hr}$ ($\approx 0.2 \text{ watts/gram}$)

2) Temperature: 190°R (-270°F) to 560°R (100°F)

This type transducer shows excellent possibilities for accurate pressure measurements in higher radiation environment. It has been shown previously, by calculation, that this transducer could operate above a 4 Watt/gram gamma radiation environment with $\leq 247^\circ\text{R}$ hydrogen coolant flowing over the sensor. It must be strongly recommended that further testing be performed on the thin film transducer to define its upper limit, not only to gamma radiation, but also to higher neutron flux. In addition, redesign of this transducer, possibly by adding short lengths of tubes for pressure ports, would make it more versatile for internal reactor measurements and eliminate time response problems. Finally, if the maximum radiation tolerance of the thin film type transducer can be shown to be high enough (greater than $1.8 \times 10^{14} \text{ n/cm}^2 - \text{sec}$ and

greater than 5 Watts/gram), this technique could be investigated for use on other transducers such as displacement transducers and strain measurements.

TABLE 5-I

(U) SELECTED NRX-A6 PRESSURE TRANSDUCER OUTPUT COMPARISONS

<u>Measurement</u>	<u>Meas. No. 1</u>	<u>Meas. No. 2</u>	<u>Predicted (psi)</u>	Measured (CRT = 14600)	
				<u>Xdcr 1 (psi)</u>	<u>Xdcr 2 (psi)</u>
Reflector Inlet Plenum	AP 300	AP 302	746	741.7	745.2
Refl. Axial Pressure Drop	AP 301D	AP 303D	24	15.6	15.5
Refl. Outlet Plenum	AP 304	-	722	728.9	-
Refl. Outlet to Core Inlet	P 501D	-	-	13.2	-
Core Inlet	AP 602	AP 604	706	709.1	709.5
Core Axial Press. Drop	AP 603D	AP 605D	135	121.8	120.2
Core Exit	P702	P704	571	585	587.7
Reactor Pressure Drop	AP 701D	AP 703D	175	153.4	151.6
Seal Chamber 10	AP 414	-	-	700.0	-
Seal Chamber 8 to 10	AP 415D	-	-	7.1	-
Seal Chamber 18	AP 416	-	-	652	-
Seal Chamber 9 to 10	AP 417D	-	-	3.25	-
Seal Chamber 10 to 11	AP 419D	-	-	4.0	-
Seal Chamber 10 to 12	AP 421D	-	-	8.2	-
Seal Chamber 14 to 18	AP 423D	-	-	26.18	-
Seal Chamber 16 to 18	AP 425D	-	-	8.25	-
Seal Chamber 18 to 20	AP 427D	-	-	18.8	-
Seal Chamber 18 to 21	AP 429D	-	-	26.2	-
Seal Chamber 18 to 22	AP 431D	-	-	40.1	-

Figure 5-1. (U) NRX-A6 Pressure Measurement Locations

Figure 5-2. (U) NRX-A6 Measurement Locations Lateral Support System

Figure 5-3. (U) NRX-A6, EP-III A Core Exit Pressure Transducer Outputs

CLOSED CASE WIANCKO
PRESSURE TRANSDUCER -P/N 54727

OPEN CASE WIANCKO
PRESSURE TRANSDUCER P/N 600755

HEAT GENERATION RATE 4 WATTS/GRAM
 TEMPERATURES IN °R
 HYDROGEN COOLANT IS 247 °R

Figure 5-4. (U) Comparison of Estimated Internal Temperatures During Irradiation Testing

Figure 5-5. (U) NRX-A6, EP-III Abort Shield and Core Pressure Transducers

Figure 5-6. (U) NRX-A6, EP-III A Core Support Plate and Shield Pressure Transducers

Figure 5-7. (U) NRX-A6, EP-III A Internal Temperature of Pressure Transducers on Shield and Core Support Plate

Figure 5-8. (U) Estimated Internal Temperature During Irradiation Testing and Internal Assembly Details. Statham Thin Film Pressure Transducers

CHAPTER 6

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CHAPTER 6

(U) NRX-A6 ACCELEROMETER EVALUATION

(U) INTRODUCTION

(U) Two basic type accelerometers were used for WANL vibration measurements in the NRX-A6 reactor test. They were the variable reluctance and unbonded strain gage types. Both transducer types have been used on previous reactor tests. The variable reluctance units were manufactured by Pace Wiancko and the strain gage units were manufactured by Statham Instruments.

(U) These are summarized giving vendor and WANL part numbers as follows:

<u>Vendor</u>	<u>Vendor Model No.</u>	<u>WANL Dwg. No.</u>	<u>Type</u>
Wiancko	AX44-1	978D227H02	Variable Reluctance
Statham	A519-50-350	946C558H03	Strain Gage
	A519-15-350	946C558H05	Strain Gage

(U) These transducers were connected to the NTO test cell "C" wide band data system by a-c coupling their outputs through Type I band pass filters (10-1000 Hz). These a-c coupling blocked the d-c zero shift inherent in these transducers under temperature and radiation and enabled the data system to record the vibration data only. In past reactor tests, when the output was d-c coupled to the data system, some accelerometer outputs drifted off-scale and the data was lost.

(U) The NRX-A6 vibration data was recorded on magnetic tape during the reactor run. After the test, the data was played back at various speeds on oscillographic recordings for analysis purposes. In addition, the data was further processed by obtaining power spectral density plots to obtain the frequency of the vibration data.

(U) SUMMARY

(U) Five (5) of six (6) WANL supplied accelerometers for the NRX-A6 reactor test performed normally throughout the test series. The sixth transducer, VR accelerometer measurement number AA 702, was cancelled when the transducer coil shorted before the reactor test series began.

(U) The data from the five accelerometers are considered valid and within their stated accuracies in the NRX-A6 Error Band limits Report, WANL-TME-1735. It must be pointed out, however, that the VR accelerometer outputs reduce to zero at reactor full power. This is a known transducer limitation and the output cannot be considered valid during this period. The transducer is not permanently damaged by this, however, and begins to operate normally again when the reactor power level is decreased. It must be noted that the VR accelerometer does survive the core support plate radiation environment and gives good internal reactor vibration data before and after a power test. This information is not attainable with any other accelerometer developed to date. This test does show where future development on these transducers will be necessary in order to get a truly radiation hardened accelerometer that will operate throughout the full power test.

Astronuclear
Laboratory

WANL-TME-1863

(U) DISCUSSION

(U) A total of six (6) WANL supplied accelerometers were used for diagnostic testing in the NRX-A6 reactor. Three (3) of these were of the variable reluctance type and three (3) were of the strain gage type. The three (3) variable reluctance types were installed on the core support plate; two (2) on the outer periphery measuring radially, (AA 701R and AA 702R) and one (1) on the dome surface measuring longitudinally (AA 703L). Of the two (2) on the outer periphery, one (AA 702R) was cancelled resulting from damage during reactor test preparation, with no repair or replacement feasible. The three (3) strain gage types were mounted on the side-by-side actuator with their axes oriented to measure longitudinally (AA 801L), radially (AA 802R) and tangentially (AA 803T).

(U) Variable Reluctance Type

(U) The Wiancko (AX44-1) variable reluctance type accelerometer has a 347 stainless steel hexagon case measuring 1.25 inches across the flats by 1 inch high. Two (2) internal coils connected in a half bridge configuration, are electrically connected to a three (3) conductor (62 mil dia.) stainless steel sheathed, MgO insulated cable integral with the accelerometer case. Mu-metal pads are welded to opposite faces of a non-magnetic dynamic mass. The mass is displaced when acceleration is applied to the frame thus changing the reluctance of the magnetic circuit proportionally. The bridge is completed in the demodulator system where the coil inductance is compared. These units were used in conjunction with Edgerton, Germeshausen and Grier, Inc. (EG&G) demodulator amplifier system. The transducer excitation voltage was 3.536 VAC (rms) at 5 kHz. Its operating temperature range is -320°F to +600°F.

(U) These transducers were essentially the same types used for internal reactor vibration measurements on previous reactor tests such as NRX-A3 and NRX-A5. They were selected for internal reactor use because they were the only type accelerometers that would survive the internal reactor environment (core support plate) and still give usable vibration data before and after the full power hold. The maximum radiation levels these transducers were exposed to was the following:

Meas. No.	Fast Neutron Flux Rate	Thermal Neutron Flux Rate	Gamma R/hr
	$E > 1.00 \text{ MeV}$ $\text{n/cm}^2 - \text{s}$	$E < 1.86 \text{ eV}$ $\text{n/cm}^2 - \text{s}$	
AA 701R	1×10^{14}	8×10^{12}	1.4×10^9
AA 703L	0.2×10^{14}	5×10^{12}	1.8×10^9

(U) Output data was obtained from both variable reluctance accelerometers (AA 701R and AA 703L) throughout the NRX-A6 test series. As expected, however, the accelerometer output decreased to zero as the reactor approached full power. It begins to operate normally when the radiation is removed at reactor "SCRAM." These phenomena were recognized on previous reactor tests where these transducers were used for internal measurements.

(U) This decrease in output that occurred at the 3700°R hold is not considered to be a real vibration measurement but has been attributed to radiation effects on the transducers. Two things could be happening to these transducers which were cited in WANL-TME-1292, "NRX Candidate Accelerometers Irradiated at Plum Brook Reactor Facility."

- 1) Gamma heating could cause the internal temperature of the transducers' metal core to exceed its Curie temperature which would decrease the permeability of the magnetic material and hence affect the inductance of the coil. This would cause the output to decrease.
- 2) It was also found that the transducer sensitivity decreased as the integrated flux increased. The major portion of the decrease appeared to be caused by materials property change due to fast neutron bombardment. The integrated fluxes of the Plum Brook test were of the order of 6.5×10^{17} to $2.1 \times 10^{18} \text{ n/cm}^2$. This amount of integrated neutron flux (attainable in Nerva after approximately one hour at full power) did not cause the accelerometer to become inoperative, but it did cause the sensitivity to decrease.

- (U) (U) No mention is made in the Plum Brook report about the flux rate which can only be attained in the Nerva reactor. Since the effect on the transducer output is immediate upon ramp up to full power, it may be the flux rate and not just integrated flux that could be causing the decrease in output.
- (U) The above comments on the possible causes of the transducer operation at reactor full power should not detract from the fact that the transducer does survive the core support plate radiation environment and gives good internal reactor vibration data before and after a power test. This is information that is not attainable with any other accelerometer developed to date. These comments do point out, however, where future development on these transducers should be pointed. (i.e. a higher temperature core material such as a HYPERCO with a Curie temperature of 1650°F.)
- (U) Table 6-1 gives a tabulation of the accelerometer outputs showing the significant frequency content in the signal at various times during the NRX-A6 EP-III A test. The frequency that is marked with an asterisk is the predominant frequency in the output signal at the time specified. The last column gives the peak-to-peak output (g's) of the signal at the same time. This data is shown for illustrative purposes only and has not been corrected for any temperature effects.
- (U) The output data from these variable reluctance transducers are considered valid and within their stated accuracies over their expected operating range.

Strain Gage Type

- (U) The Statham (A-519) transducer is an unbonded strain gage accelerometer having a cylindrical case 0.88 inches in diameter, 1.52 inches high, with a 1.0 inch square mounting base. The case material is 410 stainless steel. The strain sensitive wire elements, made from a platinum alloy and connected in a full bridge configuration are electrically connected to an attached four (4) conductor (90 mil dia.) stainless steel sheathed, MgO insulated, cable integral with the accelerometer core. This transducer is compensated for ambient temperature within the -65°F to +250°F range. Five (5) volts d-c excitation is required for a nominal sensitivity of ± 20 millivolts, full range. All three (3) accelerometers were mounted on the side by side actuator to

measure the longitudinal, radial and tangential acceleration levels. Details of these acceleration measurements are documented in the WANL Control Systems Engineering report for the NRX-A6 actuator side by side tests.

(U) The three strain gage accelerometers operated throughout the NRX-A6 test series with no apparent anomalous behavior. The temperature environment for these transducers reached as low as -200°F and as high as $+150^{\circ}\text{F}$ during the EP-III A full power test. In order to obtain more accurate data, therefore, the data from the NRX-A6 test should be corrected for the decrease in transducer output due to the temperature at the times of interest.

(U) As mentioned previously, Table 6-1 gives the tabulation of these outputs showing the significant frequency content and amplitude of the signal at various times during the NRX-A6 EP-III A test. This data is shown for illustrative purposes only and has not been corrected for any temperature effects.

(U) The output data from these strain gage accelerometers are considered valid and within their stated accuracies over their expected operating range.

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TABLE 6-1

(U) NRX-A6 EP-IIIA ACCELEROMETERS OUTPUT AT SIGNIFICANT DATA TIME

Meas. No.	Control Room Time (Sec)	Measurement Output Frequency (Hz)																												Max. Output Amplitude (g's)					
		130	170	180	240	260	280	300	320	340	380	400	410	450	480	500	550	575	590	600	630	650	675	700	740	755	770	800	840		860	880	920	940	970
AA 701R	T = 13688	X																X*													X				± 1.0
	13902														X			X*																± 1.0	
	14162										X			X				X*																± 2.5	
	14199													X*		X*																		± 1.1	
	17967	X																	X*		X*				X		X	X	X	X			± 0.9		
	17982										X					X*		X*								X			X	X				± 2.3	
18067	X						X		X				X					X*					X			X				X			± 0.8		
AA 703	T = 13688												*		X																			± 1.2	
	13902												*			X								X*										± 1.9	
	14162			X									X				X*																	± 1.1	
	17967												X*							X													± 3.7		
	17982															X		X		X*								X					± 2.3		
	18067											X*				X												X		X				± 2.2	
AA 801L	T = 13688				X					X*	X*			X		X																		± 4.0	
	13902		X		X					X*				X		X																		± 3.8	
	14162		X		X					X															X*									± 2.5	
	14199		X		X					X										X*														± 3.0	
	17967									X*			X							X		X											± 3.3		
	17982									X*			X								X			X									± 2.6		
18072									X*																								± 3.0		
AA 802R	T = 13688	X			X					X*												X												± 5.0	
	13902									X*												X												± 5.5	
	14162	X	X		X					X												X*												± 3.3	
	14199	X	X		X					X*												X*												± 3.0	
	17967									X*											X													± 4.5	
	17982									X*											X													± 4.0	
18072									X*											X													± 7.5		
AA 803T	T = 13688			X					X*	X											X*											X		± 2.3	
	13902			X	X		X		X*					X							X										X		± 2.8		
	14162			X	X			X		X				X								X*									X		± 2.0		
	14199			X	X				X*			X		X								X*									X		± 2.0		
	17967								X				X*		X*						X										X		± 1.8		
	17982					X			X				X		X*						X									X		± 1.8			
18077						X		X*				X		X						X										X		± 2.8			

X SIGNIFICANT OUTPUT FREQUENCY
 X* PREDOMINANT OUTPUT FREQUENCY

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CHAPTER 7

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CHAPTER 7

(U) NRX-A6 RATE SENSOR TRANSDUCER EVALUATION

(U) INTRODUCTION

(U) There were two fast neutron detectors and one gamma detector installed external to the pressure vessel, beneath the NRX-A6 reactor dome (on the top surface of the privy roof).

(U) The fast neutron detectors were integral cable argon filled ionization chambers. They contained U_{238} (2200 ppm U_{235}) and were covered with 0.030" thick cadmium to decrease the effect of thermal neutrons reacting on the U_{235} and contributing to the output error. The high level detector (WANL Dwg. 979D738 H01) had a 304 stainless steel cylindrical outer shell of 0.25" dia. x 0.018" wall x 1.613" long while the low level detector (WANL Dwg. 979D738 H02) had a 1100 aluminum cylindrical outer shell 1" dia. x 0.031" wall x 11.675" long. Each detector had a ten-foot long 304 stainless steel sheathed triax cable attached for excitation and signal output.

(U) These fast neutron detectors were part of complete a-c coupled mean current monitoring systems purchased from Reuter Stokes, Incorporated, of Cleveland, Ohio. Each system consisted of the ion chamber detector, a preamplifier and an a-c rectifier-amplifier as shown below

<u>System No.</u>	<u>Detector</u>	<u>Preamplifier</u>	<u>Rectifier-Amplifier</u>
RSS 98 (High Level)	RSN 298	Milletron Mod. 301	Milletron Mod. LLAC-31A
RSS 99 (Low Level)	RSN 299	Milletron Mod. 301A	Milletron Mod. LLAC-31A

(U) The gamma ionization chamber (Reuter Stokes Model RSG-12A-MI; WANL Dwg. 979D739 H01B) had a cylindrical outer shell of 1100 aluminum 1" dia. x 0.032" wall x 7" long. Two ten-foot long 304 stainless steel coaxial cables were attached as integral parts of the detector. One was used for high voltage application to the detector electrodes and the other was used for signal readout. The gamma ionization chamber output was connected directly to an automatic ranging type pico-ammeter capable of measuring currents from 10^{-12} to 10^{-2} amps.

(U) SUMMARY

(U) There was one gamma detector and two fast neutron detectors installed on the outside top surface of the NRX-A6 privy roof. These detectors were purchased by WANL from Reuter Stokes, Inc., for use on the XE-1 reactor. Because of subsequent changes in test requirements and schedule, these detectors were adapted for use on the NRX-A6 reactor test.

(U) The gamma detector performance was considered excellent during the A6 test series. The data was valid and accurate within an estimated error band of ± 6 percent. System resolution was good enough to track hydrogen flow rate changes as small as 10 percent.

(U) The fast neutron detector performance could not be determined because of the failure of the preamplifier and a-c amplifier in the readout system. These units were part of the overall fast neutron detection system that was purchased from Reuter Stokes. It could only be shown that the detectors did survive the environment and would have given good data if the electronics had remained operative.

(U) DISCUSSION

(U) Of the three ionization chambers installed on the privy roof of the NRX-A6 reactor, the one gamma detector output (SN 042 and 142) was a diagnostic type measurement and the two fast neutron detector outputs (AN 801 and AN 803) were for transducer evaluation purposes. The system interconnection diagrams for these measurements are shown in Figures 7-1, 7-2 and 7-3.

(U) Gamma Ionization Chamber

(U) The one Reuter Stokes RSG-12A-M1 gamma ionization chamber installed on the NRX-A6 reactor privy roof was a nitrogen filled (76 cm Hg) chamber of 1100 aluminum with two 304 stainless steel integral cables attached (WANL Dwg. No. 979D739 H01). This type of unit had originally been purchased for use on the XE-1 reactor test at ETS-1. Since the environmental and flux range requirements for this measurement on NRX-A6 were within this detector's capabilities, the unit was selected for use on NRX-A6.

(U) This transducer has a gamma flux range of 10^1 to 10^9 R/hr and a gamma sensitivity of 5.7×10^{-13} A/R/hr ($\pm 5\%$). This sensitivity figure is a refinement on that supplied by the vendor. The detector was calibrated at WANEF using the 20 curie Cs^{137} source. A description of this calibration and the results are given in WANEF-402-67, "Calibration of the Reuter-Stokes RSG-12A Gamma Ionization Chambers."

(U) The NRX-A6 gamma detector was set-up at the test site through an automatic ranging pico-ammeter having the capability of measuring currents from 10^{-12} to 10^{-2} Amperes. The data readout utilized two channels of data. One channel (SN 042.C) gave the current reading in "Amps ($\times 10$) to the exponent", while the second channel (SN 142.C) gave the value of the exponent (i.e., the scale of the pico-ammeter). The output of these channels during the NRX-A6 EP-III A start-up and full power hold is shown in Figures 7-4, 7-5 and 7-6. In order to utilize the data, the detector current can be obtained from the curves and then divided by the detector sensitivity figure to obtain the gamma flux (R/hr) at any specific time.

(U) The data shown by the curves indicate the detector outputs follow the reactor power level and hydrogen flow rates very closely. The Radiation and Shielding Group

indicate that hydrogen flow rate changes as small as 10 per cent were tracked by the detectors.

(U) It is concluded that this detector's performance was excellent during the NRX-A6 test. The data is considered valid and accurate within an error band of ± 6 per cent. This error band is based on combining the ± 5 percent calibration data and a ± 3 percent figure for the data system and pico-ammeter.

(U) Neutron Ionization Chamber

(U) The NRX-A6 high level and low level fast neutron monitoring systems were originally purchased for application on the XE-1 reactor test at ETS-1. Subsequent changes in requirements and changes in reactor test schedules necessitated adaptation of these systems for NRX-A6 use. The main area of concern was the preamplifier. It was not radiation hardened to the levels expected inside the NRX-A6 test car privy. Contacts with the preamplifier manufacturer (Milletron) about the suspected Philbrick P2 and P2A modules they were using inside the preamps, indicated the preamps would operate through all low power runs and for at least five minutes at full power before radiation may seriously affect them. The WANL Nuclear Design Group indicated this would be acceptable since the measurements were primarily experimental.

(U) The high level detectors (RSN 298) were designed to operate from 3×10^{10} to 2×10^{13} neutrons/cm²-sec and the low level detectors (RSN 299) from 3×10^7 to 3×10^9 neutrons/cm²-sec.

(U) Originally each fast neutron rate sensor system was purchased with a preamplifier, one a-c amplifier channel and a rate sensor matched as a complete system. The null and gain settings of each preamplifier and amplifier channel had been adjusted and locked for a given d-c output at the specified flux levels. This technique proved to be inadequate, however, since a failure of the a-c amplifier power supply and one of the amplifier circuit boards resulted in the loss of the a-c amplifier set-up gains. The system calibration was lost and necessitated additional testing for calibration purposes. This was performed at WANEF during the PAX-E2 reactor tests. However, data could only be obtained from the low level detector system since the PAX-E2 did not

generate high enough levels to be detected by the high level detector system.* It was decided that extrapolated data would be used to set-up the high level detector system.

(U) The time involved in repairing the electronics and calibrating the systems delayed shipment to NTO until two weeks before the NRX-A6 EP-I reactor test. Because of the late arrival of the neutron rate sensor systems at NTO, the difficulty NTO personnel had with the system set-up since they were not familiar with it and the last minute preparation for the NRX-A6 test, the high and low level fast neutron rate sensor systems were not set-up and operated for the EP-I test. This was unfortunate since the low power data was extremely important for predicting, with more confidence, the expected levels at full power for the high level detector system.

(U) In the process of setting up the high level detector system for the NRX-A6 EP-III full power test, the preamplifier null control was adjusted inward too far, stripping the threads of the screw adjustment. It could not be used for further adjustment. All attempts to repair this module in the limited time available were unsuccessful. Further attempts to substitute the low level preamplifier for the high level preamplifier in order to salvage some full power data were also unsuccessful since the two modules had different internal adjustments.

(U) In conclusion, it can only be pointed out that the high and low level fast neutron detectors did survive the temperature, vibration and radiation environment on the top surface of the NRX-A6 privy roof. Although no usable fast neutron data was obtained from these measurements, invaluable experience was obtained from this effort to ensure adequate active fast neutron measurements in other reactor applications.

(U) The following recommendations will be used to aid in the design and selection of fast neutron measuring systems for subsequent reactor measurements.

- 1) Design the electronic equipment such that it will have the capability to be set-up and checked (calibrated) independent of the detector.
- 2) Radiation harden the electronics associated with the detector to the expected level at their installed locations. This requires that the radiation levels be defined well in advance of reactor test.

*WANEF-505-67, "Calibration of NRX-A6 Neutron Rate Sensors"

- 3) **Impose** stringent reliability requirements on the electronic equipment backed up by qualification testing.
- 4) **Fabricate the detector with much purer U_{238} than 2200 ppm of U_{235} .** The cadmium covering used on the NRX-A6 detectors was not entirely adequate.

Figure 7-1. (U) Gamma Monitoring System

Figure 7-2. (U) High Level Fast Neutron Monitoring System

Figure 7-3. (U) Low Level Neutron Monitoring System

Figure 7-4. (U) Gamma Detector Output (SN 042.C), 13600-13800 Seconds

Figure 7-5. (U) Gamma Detector Exponent (SN 142. C), 13600-13800 Seconds

Figure 7-6. (U) Gamma Detector Output (SN 042.C), 14000-18000 Seconds

Figure 7-7. (U) Gamma Detector Exponent (SN 142.C), 14000-18000 Seconds