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LIQUID ROCKET PLANT

PRE-IRRADIATION ANALYSIS REPORT NO. 8771:2570

CONSOLIDATED CONTROLS CORPORATION

LVDT PRESSURE TRANSDUCERS

MODELS 413M35 AND 412M102

MASTER

10 March 1964

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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Prepared by
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I ABSTRACT

Consolidated Controls Corporation (CCC)* LVDT Pressure Transducers, Models 413M35 and 412M102, were analyzed to determine their expected performance in a radiation field. It was estimated that they can withstand integrated fluxes of 5×10^{17} n/cm² or 1.1×10^{11} ergs/gram(C). The signal conditioning units are limited to 10^{13} n/cm² and 10^9 ergs/gram(C).

The maximum flux levels they may be subjected to depend upon the length of the exposure and the means devised to dissipate heat. The maximum field for a full duration NRX-A2 run without provision for cooling is 3.6×10^9 ergs/gram(C)-hr (.1 watt/gram(C)), based on the adiabatic heating rate of silver. A cooling jacket has been devised for cooling the transducers so they can be located in fields of 3×10^{10} ergs/gram(C)-hr (.84 watts/gram(C)). Since the design is based on steady state conditions, the time of operation at this level is determined by integrated dosage limitations.

II DESCRIPTION

A. MECHANICAL

Consolidated Controls Corporation pressure transducers, Models 412M102 and 413M35, are linear variable differential transformer type pressure sensors, with ranges of 0-750-1000 psia and 200, 100, and 50 psid. They weigh approximately 180 grams (6.4 ounces). Present schedules require six-1000 psia units and one-750 psia unit to monitor the NRX-A2 firing.

* Consolidated Controls Corporation, Bethel, Connecticut
and Inglewood, California

The construction of the transducers incorporates a stiff metal diaphragm or a bellows (Inconel) which moves a very short distance over the full pressure range. The sensing element is attached to a magnetic slug material (416 Stainless Steel) that moves in a longitudinal sleeve. The sleeve forms the inside of what is basically a transformer with variable coupling, obtained by movement of the magnetic slug. The primary coil is excited by an alternating current. The presence of two secondary coils working in a push-pull manner, represents a superior design known as a differential transformer type transducer. Its secondary output varies with the mutual inductance coupling between the primary and secondary coils when the coupling is altered by the mechanical signal to be measured.

One signal conditioning unit KAV1901 Symmetry Sensing Module is necessary for each transmitter, and one type KAN1907 oscillator power supply is required for each three channels of pressure instrumentation. Both units are manufactured by CCC.

B. ELECTROMECHANICAL COUPLING (Reference 1)

The CCC pressure transducer consists of two secondary coils surrounded by an electrically insulated primary coil.

A constant-current closed-loop power source is used for the differential transformer primary. Such a regulator reduces the errors caused by frequency, temperature, and non-linearity for large travels.

Operation of the differential transformer depends on the variation, with the slug position, of the mutual inductances between the primary winding and the two secondary windings. The equivalent circuit and the analysis are based on the following assumptions:

1. The mutual coupling between the two secondaries is negligible.

2. The mutual coupling between the conductive paths in the vicinity of the differential transformer exists only with the primary of the differential transformer. The slug, or a pressure barrier between the slug and the differential transformer, is coupled to the differential transformer as a single turn.

3. A current source is available to power the differential transformer primary.

Assumptions 1 and 2 are derived from the consideration that the ampere turns in the secondary windings are an order of magnitude less than the ampere turns in the primary windings, and therefore the flux generated by these sources is negligible. The choice of current rather than voltage in assumption 3 eliminates the need for including primary resistance, leakage inductance, and the reflected loss of eddy currents.

An equivalent circuit for the differential transformer is shown in Figure 1.

FIGURE 1

The variables in Figure 1 are defined as follows:

- i_p = Primary current
- R_s = Secondary coil and lead resistance
- R_a = Secondary load resistance
- N_p = Primary turns
- N_s = Secondary turns
- ω = 2π times frequency of primary current
- R_{fe} = Reluctance of magnetic slug and other magnetic members of the differential transformer
- l_o = Mean length of air gap in differential transformer with slug in center
- X = Variation from center of differential transformer slug
- A = Mean area of flux path through air gap

It can be seen from Figure 1 that the individual secondary currents are:

$$i_1 = \frac{j\omega 4\pi N_p N_s i_p}{(R_s + R_a)(R_{fe} + \frac{l_o - X}{A}) + j\omega (4\pi N_p N_s)} \quad \text{Eq. (1)}$$

$$i_2 = \frac{j\omega 4\pi N_p N_s i_p}{(R_s + R_a)(R_{fe} + \frac{l_o + X}{A}) + j\omega 4\pi N_p N_s} \quad \text{Eq. (2)}$$

The difference of the secondary currents is

$$i_1 - i_2 = W i_p \frac{2X/A}{(R_{fe} + W)^2 + \frac{l_o^2}{A^2} (R_{fe} + W) + \frac{l_o^2 - X^2}{A^2}} \quad \text{Eq. (3)}$$

where

$$W = \frac{j\omega 4\pi N_p N_s}{R_s + R_a}$$

The sum of the secondary currents is

$$i_1 + i_2 = W i_p \frac{2(R_{fe} + W + l_o/A)}{(R_{fe} + W)^2 + \frac{l_o^2}{A^2} (R_{fe} + W) + \frac{(l_o^2 - X^2)}{A^2}} \quad \text{Eq. (4)}$$

If the primary coil is excited by an amplifier of gain G with reference current i_r , supplied by a zener regulator, the primary current based on perfect diodes may be written

$$i_p = G \left[i_r - \frac{2}{\pi} (i_1 + i_2) \right] \quad \text{Eq. (5)}$$

Sum-of-currents-feedback is utilized as shown in Figure 2.

FIGURE 2

Substituting equation (4) into equation (5), and solving for i_p which is then substituted into equation (3), and taking the limit as G approaches infinity gives

$$(i_1 - i_2) \Big/_{G \rightarrow \infty} \text{Lim} = \frac{X i_r / A}{R_{fe} + W + l_o / A} \quad \text{Eq. (6)}$$

The non-linearity term $\frac{l_o^2 - X^2}{A^2}$ and the proportional dependence on frequency are eliminated in the process. Sources of temperature error R_s and R_a , which are in inverse proportion to the difference in currents in equation (3), have only a minor role (in the denominator of W) in equation (6).

In a practical differential transformer, the reluctance of the air gap l_o/A is much greater than the iron portion. Also, over the useful frequency range the mutual resistance from primary to secondary is much smaller than the secondary resistance. Thus

$$l_o/A \gg R_{fe}$$

and

$$\frac{j \omega 4 \mathcal{M} N_p N_s}{R_{fe} + \frac{l_o - X}{A}} \ll R_s$$

so that equation (6) reduces to

$$i_1 - i_2 \Big/_{G \rightarrow \infty} \text{Lim} = \frac{X}{l_o} i_r \quad \text{Eq. (7)}$$

The difference of the secondary currents is proportional to the reference current into the amplifier times the ratio of the travel of the slug from its center position to the total air gap in the differential transformer.

The closed-loop multiplier of Figure 2 is independent of ambient conditions of temperature, voltage, and frequency.

C. TEMPERATURE COMPENSATION (Reference 1)

In pressure and differential pressure transmitters that operate over broad ambient temperature, the spring constant of the driving element decreases lineally with temperature. A temperature sensitive resistor located at the transmitter can be placed in series with the amplifier reference input in Figure 2. The temperature change in resistance characteristic can change i_r in a manner that will correct for the error in the spring constant.

If a signal proportional to the difference-of-the-currents is fed back to the amplifier in addition to the sum-of-the-currents signal, an adjustable non-linear relation will exist between the slug position and the differential transformer output. Equation (5) becomes

$$i_p = G \left[i_r - \frac{2}{\pi} (i_1 + i_2) + \frac{2}{\pi} \alpha (i_1 - i_2) \right] \quad \text{Eq. (8)}$$

Using the same substitutions and inequalities as previously,

$$(i_1 - i_2) \Big/ \lim_{G \rightarrow \infty} = \frac{\alpha}{1 - \alpha} i_r \quad \text{Eq. (9)}$$

Slight deviations from a straight line are used to correct the non-linearities of springs in pressure transmitters; a potentiometer is used to set the value of α in equation (9) during calibration.

Inconel is used for the spring material in the CCC transducers. The change of modulus of elasticity (to which the spring constant is proportional) with temperature is 200 ppm/°F. A change in temperature of 1000°F causes a 20% change in modulus. The value of α is set so that a ten percent error in modulus causes a two percent error in pressure. Therefore, a 50° variation in temperature can be expected to cause a 0.2% error in the pressure reading.

III SUMMARY

A. ANALYSIS OBJECTIVE

The purpose of this analysis was to determine if the pressure transducers are compatible with a radiation environment, and to consider the mounting techniques and any special devices that are necessary to qualify the transducers to operate in NERVA flux levels.

B. CONCLUSIONS

It was concluded that the transducers can withstand total dosages of 5×10^{17} n/cm² and 2×10^{11} ergs/gram(C). The signal conditioning equipment can withstand total dosages of not more than 10^9 ergs/gram(C) and 10^{13} n/cm². In some instances cooling must be provided for transducers mounted on the thrust chamber of NRX-A2. The signal conditioning units must be remote from the transducers in the NRX-A2 environment.

IV ANALYSIS

A. RADIATION COMPATIBILITY OF MATERIALS

Assembly drawings and a materials list were obtained from the manufacturer. The major materials of construction are Inconel and Stainless Steel. The components and their compositions, which were identified, are given in Table I.

TABLE I

**MATERIALS LIST OF CCC PRESSURE TRANSDUCERS
MODELS 413M35 AND 412M102**

<u>COMPONENT</u>	<u>MATERIAL</u>	<u>WEIGHT IN GRAMS</u>
Body Assembly		
Sleeve	Inconel	
Body & Fitting Assembly	347 SS	50.0
Diaphragm Assembly		
Diaphragm, Button, Stem	Inconel	
Spring Assembly		
Springs	Inconel	12.3
Bell Housing	Inconel	4.2
Bellows Assembly		
Sleeve	Inconel X	
Housing, Bellows	Inconel X	30.5
Bellows	Inconel X	0.25
Cap, Bellows	Inconel	
Pin Assembly		
Pin, Stem	Inconel	1.0
LVDT Assembly		
LVDT Receptacle	304 SS	8.3
Cover	416 SS	
Temp. Compensating Coil	Secon .004 dia Hi Tempco Ceramic Type D coated	
Primary Coil	Secon #32 Gage Silver Ceramic Type D coated	
2 Secondary Coils	Same as Primary	
Bobbin Assembly		
Sleeve	304 SS	
Cap	Inconel	
Center Disc	304 or 316 SS	
Upper & Lower Disc	416 SS	
Lower End Disc	416 SS	
Sleeve	Inconel	
	Silver Brazing	
Pressure Element Assembly		
Slug	416 SS	
Housing, Diaphragm, Lower	Inconel	57.0
Diaphragm Assembly	Inconel	0.4
Housing, Diaphragm, Upper	Inconel	3.1

The bobbin is coated with Allen* PBX cement .003 in. thick to achieve 100 megohms minimum insulation resistance with 200V DC at room temperature. It is a ceramic base compound, the composition of which is considered proprietary. A communication from CCC (Reference 9) indicated that they were able to ascertain that it does not contain B, Mn, Fe, Co, Ni, Cu, As, Se, Br, Ag, Cd, I, Cs, Hg, or Pb.

The insulation material in the CCC pressure transducer between the primary and secondary coils is Novabestos and the potting compound is a mica mixture which has a curing agent composed of aluminum phosphate and phosphoric acid. The coil windings are No. 32 gage silver wire coated with Secon Ceramic - Type D which consists of Al_2O_3 , PbO, and SiO_2 . The radiation damage thresholds of similar materials are 1.1×10^{11} ergs/gram(C) (Reference 4); this is considered the limit for these materials in the absence of more definite information.

The remainder of the materials of construction are considered to be radiation resistant.

The signal conditioning units of the transducers are magnetic amplifiers. Wire-wound resistors are used in their construction. A silicon semiconductor diode 1N914 is used in the symmetry sensing circuit. Semiconductor diodes exhibit a radiation tolerance of about 10^9 ergs/gram(C) (Reference 5). The increase in forward voltage drop has been shown to vary widely with neutron exposure and diode number. Silicon diodes can remain useable up to dosages of 10^{13} nvt fast neutrons. Therefore, limitations on the signal conditioning unit are set at 10^9 ergs/gram(C) and 10^{13} fast neutrons/cm².

* Robert G. Allen Co., P.O. Box 110, Mechanicville, N. Y.

B. RADIATION EFFECTS

The effect of radiation on the electromechanical operation of the transducer is expected to be small because the transducer output (equation 9) is practically free of dependence on absolute physical properties. The output is given as

$$(i_1 - i_2) \Big/_{G \rightarrow \infty}^{\text{Lim}} = \frac{X}{l_0 - \alpha X} i_r$$

The values of i_r and l_0 are constants, which leaves the transducer output dependent upon the slug displacement and the temperature compensation constant.

Inconel X is the membrane whose displacement causes the magnetic slug displacement in the CCC LVDT's. The membrane elasticity is affected by temperature (which the α compensates for) and gradually by irradiation. Tests showed (Reference 2) that the tensile strength of Inconel increased about 9% when irradiated at 572°F with 7.5×10^{19} neutrons/cm² with energy greater than 500 ev, and the same amount when irradiated at 540°F with 4×10^{19} slow neutrons/cm². For irradiations at 120°F, the increase was about 28% for 1.3×10^{20} neutrons/cm² with energy greater than 500 ev and 10-21% for 4×10^{19} fast neutrons/cm².

These dosages are greater by two orders of magnitude than the dosage limitations that have been placed on the transducers in general. Therefore the effect will be negligible at the maximum dosage limitation of the transducer.

The magnetic properties of steel are not appreciably affected at the radiation dosages anticipated. The Curie temperature of 416 SS (1390°F) is important; however, other limitations fix the maximum allowable temperature below this value.

Several extensive studies of the effects of radiation on transformers (Reference 1) have substantiated the foregoing statements. Generally, transformers have not incurred sufficient damage to affect their electrical operation as a result of irradiation up to integrated fluxes of 5×10^{17} n/cm² and 2×10^{11} ergs/gram(C). The usual failures were physical damage caused by gas evolution of potting compounds which ruptured hermetically sealed cases. Gas evolution is not anticipated in the CCC transducers because of the use of inorganic electrical insulators.

C. RADIATION HEATING

1. Temperature Limitations

The allowable radiation dose rates of the transducers are based on the heating rates of the internal parts and a consideration of heat dissipation from them at such a rate that transducer temperature limitations are not exceeded. The upper temperature limitation of the transducers is set at 800°F by the manufacturer. At this temperature the gold plating in the connector migrates into Inconel X. At 1000°F silver grain growth occurs and it fuses with the insulation. The temperature compensation coil in the transducer predominantly compensates for the change in elasticity of the Inconel pressure sensing component (diaphragm or bellows). The percent of increase in the resistance of the windings, caused by gamma heating, will remain comparable in the primary and secondary coils and the effects will cancel because of the symmetry of the circuit and the constant current system.

The error limitations placed on the transducer are $\pm 3\%$ maximum of translator full-scale output between -150 and $+800^{\circ}\text{F}$, and $\pm 1\%$ over any 100°F temperature span between these limits (Reference 10).

In the NRX-A2 firing, the transducers will be mounted on the thrust chamber in full-power gamma fields which vary from 7×10^9 ergs/gram(C)-hr to 3×10^{10} ergs/gram(C)-hr (.19 to .84 watts/gram(C)). The adiabatic heating rate of silver in the higher environment is $6.4^{\circ}\text{F}/\text{sec}$, while that of steel is $3.3^{\circ}\text{F}/\text{second}$. Therefore it is necessary to consider a means of heat dissipation from the coils and internal parts to the outside surfaces. Because of the complicated structure it is only possible to make reasonable estimates. The validity of these estimates must be verified by actual tests.

2. Temperature Gradients

Separate heat transfer analyses were performed for various parts of the transducers.

Coils - The LVDT coils are .008 in. diameter silver wire with .002 in. of type D insulation which was stated to be ceramic. A thermal conductivity of nine BTU/ft-hr- $^{\circ}\text{F}$, which is typical of aluminum oxide, was assumed. The exact construction of the coils was not available; however, deductions were made that about five layers of wire are superimposed over each coil length. Assuming that the heat transfer area is one-fourth the wire circumference times the length of one turn, the gradient across each coil was computed to be about 10 degrees. The insulation (Novabestos) thickness between the primary and secondary coils was stated by the manufacturer to be less than 0.010 inch. A thermal conductivity of this material of 0.25 BTU/hr-ft- $^{\circ}\text{F}$ yields a temperature

gradient across the separator of about one degree. The total temperature gradient across the coils is about 20-25°F in a field of 3×10^{10} ergs/gram(C)-hr (.84 watts/gram(C)).

A small air gap (estimated as .010 in.) exists between the coils and the LVDT cover. Consideration of both convection and conduction across the gap yielded a temperature difference of 250°F.

Pressure Element Assembly - The pressure element assembly essentially consists of a single hollow 57 gram housing of Inconel. It is so shaped that about 0.6 in. of its length is available for conduction to the case exterior. All of the heat generated within it must be dissipated through this region. The gradient in the housing will be 70°F if the outer surface is maintained at a constant temperature.

The temperature gradient in the Inconel pressure sensing diaphragm will be about 50 degrees.

The engine mounting is to be accomplished by providing saddle blocks for the transducers which will be fastened to the engine. The mounting precludes heat dissipation by conduction to a cold surface. Convection, either free or forced, must be depended upon for the cooling technique.

If free convection and radiation (steel emissivity = 0.8) are depended upon to dissipate all of the heat generated (3×10^{10} ergs/gram(C)-hr) within the transducer assembly, the surface temperature will approach 1150°F at steady state. Therefore, the temperature limitations of the transducer dictate the necessity of forced convective cooling.

3. Cooling Requirements for NRX-A2

The amount of cooling required by the transducers depends on the maximum full-power gamma field, the power-time profile of the reactor, and the coolant specified. Two coolants (water and nitrogen) and two power profiles were considered for the NRX-A2 run. Water is considered most readily available and cheapest from a design standpoint, and most efficient from a heat transfer standpoint.

A simple heat exchanger was devised in which each transducer is to be mounted. The exchanger protects the transducer from radiant heating from the exhaust as well as dissipating the gamma heat. A diagram of the device is shown in Figure 3. The transducer has a 1.4 in. section that is 1 inch in diameter and a .75 in. section that is .75 inch in diameter. The coolant flow rates were established by determining the heat transfer coefficients required to maintain temperatures within allowable limits in the expression

$$h A (\Delta T) = Q$$

The quantity h is the heat transfer coefficient in $\text{BTU/hr-ft}^2\text{-}^\circ\text{F}$; A is the heat dissipation area; ΔT is the temperature difference between the transducer surface and the coolant; and Q is the total heat generated within the transducer. The transducer surface temperature was set at 200°F .

FIGURE 3

COOLING JACKET FOR CCC PRESSURE TRANSDUCERS
MODELS 413M35 AND 412M102

The following expression (for cross flow to a cylinder) was used to determine the heat transfer coefficient.

$$\frac{h D_o}{k} = \left\{ .35 + 0.47 \frac{D_o G}{\mu_f}^{.52} \right\} P_r^{1/3} \quad (\text{Reference 6})$$

where

D_o = Cylinder diameter, feet

k = Fluid thermal conductivity, BTU/hr-ft-°F

G = Fluid flow rate/area = $\dot{w}/A$ where $\dot{w}$ is fluid flow rate, lb/sec and A = cross-sectional area of flow

μ_f = Fluid viscosity, lbm/sec-ft

P_r = Prandtl number = $C_p \mu_f / k$

h = Heat transfer coefficient, BTU/hr-ft²-°F

C_p = Fluid specific heat, BTU/lb-°F

By considering the necessary products of Q/A for the various subassemblies within the transducer in a gamma flux of 3×10^{10} ergs/gram(C)-hr, the estimated steady-state temperatures are as follows:

Transducer surface temperature 200°F

Coil outer surface temperature 450°F

Coil inner surface temperature 475°F

Allowable temperature 800°F

Safety factor = 1.7

Gradients for other gamma fields are proportional to the flux.

The coolant requirements were estimated for a full-duration, full-power run and for a variable power run outlined in Reference 11. The coolant conditions and requirements, as functions of maximum

power gamma field, are given in Tables II, III, and IV. They are based on the heat exchanger design shown in Figure 3. The Wigner-Way expression for gamma power from fission products after shutdown was used to determine the heating during shutdown periods.

TABLE II
COOLING REQUIREMENTS FOR CCC PRESSURE TRANSDUCERS
AS FUNCTIONS OF GAMMA FIELD IN NRX-A2

<u>Full Power Gamma Field</u> ergs/gram(C)-hr (watts/gram)	<u>Variable Profile</u>	<u>Full Duration Full Power</u>
7×10^9 (.19)	No cooling required	Cooling required
10^{10} (.27)	No cooling required	see Table IV
3×10^{10} (.84)	Cooling required see Table III	

TABLE III
NITROGEN REQUIREMENTS FOR POWER PROFILE IN
FULL-POWER FIELD OF 3×10^{10} ERGS/GRAM(C)-HR
(Transducer Surface = 200°F)

<u>Temperature °F</u>	<u>Pressure</u>	<u>Flow Rate Required lb/sec</u>
75	14.7	1.43
75	1000	1.20
75	3000	0.90
-100	85	0.35

Cooling is required after the first shutdown period.

TABLE IV

STEADY STATE COOLANT REQUIREMENTS FOR
FULL POWER-FULL DURATION NRX-A2 RUN

Coolant	Coolant Inlet Conditions		Pounds/second Required		
	Temp °F	Press. psia	3×10^{10}	10^{10}	7×10^9
			ergs/gram(C)-hr .84 watts/gram	ergs/gram(C)-hr .27 watts/gram	ergs/gram(C)-hr .19 watts/gram
Nitrogen	75	14.7	1.43	.17	.09
Nitrogen	75	1000	1.20	.14	.07
Nitrogen	75	3000	.90	.11	.06
Nitrogen	-100	85	.35	.042	.02
Water	70	40	.20 (1.5 gpm)	.024 (.18 gpm)	.012 (.09 gpm)

The expression for the heat transfer coefficient shows that the required flow rate is a function of the gamma heating rate and is approximately $G^{0.52} \propto Q$. If the radiation field is increased by a factor of ten the required flow rate to maintain the same transducer surface temperature is increased by a factor of 83. If the radiation field is doubled the flow requirements are increased by a factor of 3.8. The temperature gradients within the heat conductors are proportional to the gamma heating rate and will increase by factors of ten and two if the gamma fields are increased by these factors.

These estimates of required cooling are intentionally conservative. They should be verified by tests, however.

V RADIATION HISTORY

One CCC Model 412M35-600 was irradiated in GTR test 9 in the later part of 1963 (Reference 7). The integrated dose was 6.7×10^{15} n/cm² and 4.2×10^{10} ergs/gram(C). The test temperature varied between -318 and -322°F. The transducer operated throughout the test with little or no effect directly attributable to the testing environment. The transducer was pressure cycled at 0, 150, 300, 450, and 600 psig at various periods throughout the test. The response dropped slightly between integrated dosages of 5 and 20×10^{14} n/cm², and leveled out thereafter. The maximum decrease was about 2 psi for 600 psig impressed pressure. Another transducer of the same model is scheduled for test in March 1964 in GTR 12.

One CCC Model 413M11 differential pressure transducer with a pressure range of 0-3 psid was tested in GTR test No. 4 (Reference 8). The transducer was irradiated while submerged in a LN₂ dewar. The integrated dosage received was 5.4×10^{15} n/cm² and 2.4×10^{10} ergs/gram(C). The test was interrupted by an explosion of the dewar after which the output of the transducer suddenly decreased.

Sales brochures on the CCC 413M series show that ambient variation of the transmitter from -65 to 1000°F is $\pm 3.5\%$ full-scale. In pre-irradiation tests of GTR test No. 4 the shift in output was about 20% when the temperature was decreased from ambient to -325°F. No comment was made concerning this shift. The temperature of the test was considerably below the minimum temperature specified by the manufacturer.

VI COMMENTS

The radiation susceptibility of linear variable differential transformers is known to be good if care is exercised in their construction. They are often mentioned as the most promising transducer for use in high radiation environments. The CCC transducers represent what is considered to be a good radiation hardened version.

VII PERFORMANCE REQUIREMENTS

Tests of the effectiveness of the coolant jacket as a function of radiation dose rates and coolant flow rates should be established as functions of impressed pressure. Plans for this type of test are being formulated by Department 8771. The dose rates which the transducers are expected to receive in the ~~NRX-A2~~ firing should be used to establish test conditions and location.

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