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DEVELOPMENT PROGRAM PLANS FOR
REACTOR INSTRUMENTATION FOR
CONTRACT YEAR 1965 (NE2460)

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Prepared by:

H. P. Kalapaca
H. P. Kalapaca, Supervisor
Reactor Component Sensor Development
Instrumentation and Control

and

T. P. Weldon
T. P. Weldon, Supervisor
Propellant Sensor Development
Instrumentation and Control

Approved by:

H. S. Kirschbaum
H. S. Kirschbaum, Manager
Instrumentation and Control

R. L. Ramp
R. L. Ramp, Manager
Instrumentation Development
Instrumentation and Control

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DEVELOPMENT PROGRAM PLANS FOR REACTOR
INSTRUMENTATION FOR CONTRACT YEAR 1965 (NE2460)

1. General

As required by the Contract Year 1965 Work Program, Development Program Plans for reactor instrumentation have been prepared. The transducer areas presently under development include:

1. High Temperature Thermocouples
2. Pressure Transducers
3. Strain Gages
4. Accelerometers
5. Electrical Cables

Development plans for each of the above transducers are presented in this document. Any changes to these plans will be documented and submitted on a monthly basis.

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I-TEMPERATURE TRANSDUCER DEVELOPMENT

APPLICATION

In NERVA reactor and engine tests the measurement of temperature distribution within the reactor core is primary in establishing design limitations or performance problems. The prediction of reactor efficiency, power limitations, reactivity and/or coolant distributions must be verified by these measurements. These measurements also may be called upon for control purposes depending upon the desired control parameter for a given NERVA test.

OBJECTIVES

Thermocouples must be developed for accurate measurement of temperature distributions within the NERVA reactor cores. Thermocouples must be capable of accurate measurement when subjected to temperature gradients imposed in routing to the point of measurement within the core.

The following additional environmental conditions must be satisfied by these thermocouple designs:

(1) Pressure	0-750 psia
(2) Vibration	4 g from 5 to 45 cps, 14 g from 45 to 2000 cps.
(3) Fast Neutron Flux	up to 4.3×10^{15} n/cm ² -sec. (E > 1 mev)
(4) Gamma Dose Rate	up to 3.2×10^{12} ergs/g(c)/hr.
(5) Corrosion	Hydrogen-graphite environment
(6) Thermal Shock	210°R/sec
(7) Temperature Gradient	200°R to 4860°R
(8) Initial design accuracy objective	is 1% at 4500°R and 3% at 4800°R.

PROBLEM AREAS

Development effort to date has included improved sheath material designs and thermocouples capable of accurate measurements up to 3800°R within the reactor core.

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The principal problem area in the measurement of core temperatures is errors resulting from temperature gradients. These errors are due largely to the lower resistivity of insulating material at high temperature. There are corrosion effects on sheath materials as well.

Development effort is required to optimize designs for accuracy and increased service life in reactor testing.

Analytical studies have indicated that accuracy may be achieved by increasing the size of thermocouple conductors and/or insulators. Accuracy must, however, be compromised in design with limitations imposed by protective sheath dimensions and by thermocouple installation problems.

New designs must be tested under simulated NERVA temperature gradient conditions to obtain calibration curves. Additional work is also required in determining optimum application of materials in the minimum of space to achieve best accuracy and corrosion protection.

DEVELOPMENT APPROACH

A qualification specification for thermocouple testing will be prepared to establish application levels of new and existing thermocouple designs. A new furnace facility to achieve NERVA simulated test conditions for qualification testing will be designed and built.

To realize improved thermocouple performance in 32-inch and 45-inch reactor stations, investigations will be conducted to realize optimum advantages of thermocouple installation design. This in conjunction with analytical studies of thermocouple design and basic material investigation will result in advancing thermocouple design principles. Thermocouple models based on these design studies will be fabricated and tested under simulated application conditions.

Initial designs will be prepared for NRX-A4 applications utilizing materials and construction similar to present NRX designs except for increased sheath diameter. This approach is an extension of existing effort and affords predictable performance with a minimum of manufacturing problems.

Follow-up designs will be based upon utilizing tungsten tubing for conductors and protective sheathing. These designs will require extension of vendor manufacturing capability and development of new assembly and installation techniques. This design

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approach will allow improved accuracy within the dimensional limitations of NRX applications.

Analytical studies will be supplemented by in-house model fabrication and testing to accelerate development of optimum thermocouple designs. Fabrication of test models will further assist in development of specifications for vendor manufacturing process control in handling the new materials involved.

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II-PRESSURE TRANSDUCER DEVELOPMENT

APPLICATION

Pressure measurements are required to monitor reactor performance during test operation to ascertain proper distribution of reactor coolant as predicted by design. These measurements confirm or modify design calculations and are vital in the determination of design problem areas.

Two primary types of measurement are required, namely dynamic and static. Dynamic measurements must be made using transducers located within the reactor vessel proper to evaluate dynamic flow problem areas. Static pressure measurements can be made with pressure probes extending to shielded transducer locations. (Privy mounting)

OBJECTIVE

Pressure transducers will be developed and qualified to meet the following NERVA measurement requirements:

1. Measure reactor absolute pressures from 150 psia to 800 psia and differential pressures ranging from 30 psid to 200 psid.
2. The transducers must perform satisfactorily in the following environments:

A. Dynamic Pressure Measurement Applications

(1) Temperature	37°R to 1000°R
(2) Thermal Shock	45°F/sec
(3) Fast Neutron Rate	2.1×10^{14} n/cm ² /sec
(4) Ambient Pressure	0 to 750 psia
(5) Gamma Dose Rate	1.8×10^{11} ergs/gm(c)-hr
(6) Shock	14 g from 45 to 2000 cps
(7) Vibration	4 g from 5 to 45 cps
(8) Frequency Response	300 cycles

B. Static Measurement Applications (Test Car Transducer Panel)

(1) Temperature	460°R to 560°R
(2) Ambient Pressure	Atmospheric
(3) Line Pressure	to 1000 psia
(4) Fast Neutron Rate	1.5×10^{11} n/cm ² /sec
(5) Gamma Dose Rate	1.8×10^8 ergs/gm(c)-hr

(6)	Vibration	4 g from 5 to 45 cps 14 g from 45 to 2000 cps
(7)	Shock	15 g half-sine pulse, 11 msec duration
(8)	Frequency response	5 cycles
3. Pressure transducers shall perform within 1 per cent of full range accuracy for static applications and better than 8 per cent of full range for dynamic applications.
4. Transducers for dynamic applications shall be small in physical size for minimal restriction of coolant gas flow.

PROBLEM AREAS

A. Dynamic Applications

Testing and analytical studies performed on NRX candidate pressure transducers have indicated radiation heating problems exist at rates above 2.5 watts per gram. Application of presently available designs are therefore limited to locations above the reactor shield. The critical core inlet plenums are monitored from these locations by means of pressure probes with reduced high frequency capability. The existence or non-existence of pressure transients in excess of 60 to 80 cycles per second in these areas cannot be determined at this time.

The high nuclear heating rate problem in applications within the pressure vessel is compounded with environmental temperatures ranging from 200°R to 1000°R. The combined effect of this environment produces transducer errors as the result of nuclear heating induced temperature gradients. Designs must be capable of operation over a wide range of ambient temperatures with high internal temperature gradients.

Presently available transducer designs are at best at least 1-1/4" in diameter by 2" long. This size contributes to the nuclear heating problem in two ways. First, the internal heat path is long and secondly, the mounting structures within the pressure vessel must be correspondingly large, thus increasing the cooling problem. Size reduction can reduce the hot spot produced by transducer installation and minimize local effects on reactor coolant flow. Reduced size will also aid in reducing transducer internal temperature gradients.

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B. Static Applications

Earlier NRX-A2 measurement requirements required dynamic capabilities of all pressure measurements. As the result of NRX-A1 experience only a few critical dynamic measurements are required. The remaining pressure measurements may be made utilizing pressure probes affording shielded transducer locations. At present, the same transducers are used for both applications due to the earlier requirements.

The problems associated with the designs presently in use is a higher than required installed cost and special AC demodulator system requirements. Strain gage absolute pressure transducers have been developed which satisfy all requirements for test car applications. The differential pressure transducers of similar type, however, have error bands in excess of 3 per cent due to line pressure error. Differential pressure transducers of improved accuracy must be obtained to satisfy NERVA accuracy requirements.

DEVELOPMENT APPROACH

A. Dynamic Applications

Present transducer designs available for NERVA dynamic measurement applications are limited to 2.5 watts per gram nuclear heating with cryogenic cooling. Transducers must be obtained for application in nuclear heating rates up to 4 watts per gram to obtain the required dynamic pressure measurements.

In order to obtain earliest possible units for NRX applications, results of analytical studies conducted by WANL Radiation Effects activity and results of Plum Brook testing will be utilized to achieve design improvement. Design specifications based upon these results will be reviewed with Physical Sciences, Consolidated Controls or other interested vendors. Two designs will be established and procured for testing. Nuclear and non-nuclear testing will be performed by the vendor and WANL as required to qualify for 4 watts per gram heating rate applications in NERVA testing program.

Investigations will be conducted into development of new design concepts affording substantial transducer size reductions. Units on the order of 1/2" in diameter by 3/4" long or smaller are possible. The reduced gamma heating and installation cooling problems will afford significant advantages. Some experimental designs have been reported by other laboratories indicating promise in this area. Higher operating frequencies in reluctance devices has been the most promising approach to this end. Development specifications will be prepared and a development contract let to the selected vendor.

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B. Static Applications

Differential pressure transducers as used in NRX-A1, NRX-A2 or candidate transducers of the strain gage type which have successfully passed non-nuclear testing by WANL or AGC will be nuclear tested to qualify for test car transducer panel applications. One differential pressure transducer type will be qualified for test car transducer panel applications.

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III - STRAIN GAGE DEVELOPMENT

APPLICATION

Strain measurements are required within the pressure vessel of the NERVA reactor for the following reasons: (1) To determine the magnitude and frequency of radial displacements of the core components, and (2) to measure both static and dynamic strains in structural members of the core caused by temperature variations and fluid pressures. This information is necessary for verification of reactor design calculations and to permit improved designs. Locations where strain measurements are presently planned include: (1) Lateral support springs, (2) core tie rods, (3) core band, and (4) dome end support ring.

OBJECTIVES

Strain gages will be developed to meet the following requirements:

1. Measure strains up to 5000 microinches per inch.
2. To perform in the following environments:
  - a. Pressure: 0 to 750 psia
  - b. Vibration: Up to 14 g's from 45 to 2000 cps.
Up to 4 g's from 5 to 45 cps.
  - c. Temperature Range: -423°F to +600°F.
  - d. Fast Neutron Flux: Up to 10^{15} n/cm²/sec. (E > 1 Mev)
  - e. Gamma Dose Rate: Up to 10^{12} ergs/gram (c)-hr
  - f. Acoustic Noise: Up to 178 db
  - g. Shock: 15 g peak, half sine pulse of 11 milliseconds duration
  - h. Thermal Shock: 45° F/sec.
3. Accuracy of the strain gages while exposed to the above environments must be

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microinches per inch for dynamic measurements.

4. The strain gage including its associated leads and transitions must be kept to a minimum size consistent with its intended application location.

PROBLEM AREAS

Non-nuclear and nuclear tests conducted on the Microdot weldable strain gage (with integral leads) have demonstrated that this gage can provide accurate information while being subjected to the environments expected during NERVA reactor tests. Hence, it has been specified for use on the NRX-A2, A3 and A4 reactors. The major problem associated with this gage is the resistance spot welding technique used to attach the gage to the reactor component. It has been determined that resistance spot welding shortens the fatigue life of certain components such as the tie rods. How significant this factor is depends upon the extent to which such members are subjected to high frequency oscillatory conditions. On the titanium dome end support ring, concern has been expressed over the possibility of cracks, caused by the resistance spot welding, being propagated at cryogenic temperatures. Because of this concern, strain gages have not as yet been specified for the dome end support ring. Another problem area that exists on the tie rods is caused by the physical size of the transition between the strain gage and its lead. With the present configuration, the dimensional tolerances between this transition and the tie rod holder are very close, and might result in restricting the tie rod motion. There are two other problems which are of a more minor nature associated with the Microdot weldable strain gage. The first is related to the present installation techniques used on the lateral support springs. Tests run on gages attached to these springs have shown a marked reduction in fatigue life of the gages. This is classified as a minor problem since oscillations are not expected on the lateral support springs.

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The other problem with the Microdot weldable strain gage is caused by the fact that the strain sensitive element is situated approximately 16 mils above the bottom surface of the mounting flange. This causes a large increase in apparent strain sensitivity when the gage is mounted to thin components (such as the lateral support springs) and subjected to bending stresses. At present, this problem is overcome by calibrating the gage after it is installed on the reactor component. The need for such calibration work would be minimized if a gage could be developed that would bond more closely to the surface of the component.

DEVELOPMENT APPROACH

The development work planned for Contract Year 1965 basically consists of two major efforts. The first effort is aimed at developing attachment techniques for the Microdot weldable gages which do not involve resistance spot welding. It is planned to investigate the feasibility of using soldering techniques. The second effort involves the development of compensated wire and foil gages bonded both by the flame spray process and with inorganic cements. The flame spray process was selected over the Rokide process (previously worked on by Aerojet) for the following reasons:

1. A review of the work performed with the Rokide bonding technique on wire gages revealed that there was still a serious problem of obtaining reliable bonds on all of the NERVA materials of interest (titanium, inconel X, 6061 aluminum, and 301 stainless steel).
2. Due to the fact that the flame spray process produces a much finer spray of oxide powders than is possible with the Rokide process, better adhesion characteristics are expected for the former.

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3. Bonding of foil gages with the Rokide process is not practical due to the erosion caused by the high pressure spray of oxide powders.
4. Flame spray equipment is conveniently located in the WANL Materials Department.

In addition to the flame spray process, investigations will be made on gages bonded with inorganic cements such as Type H, Brimor U-529, and NBSX-142A. Also, a study will be conducted at the Westinghouse Research Laboratory on the feasibility of developing a special radiation-resistant, waterproof glass that would be suitable for strain gage bonding applications.

Gages attached to test samples of NERVA materials using the techniques described above will be subjected to complete non-nuclear and nuclear testing. As a first step in this effort, a qualification specification will be prepared detailing the expected NERVA environments and the tests which must be run to qualify a strain gage for operation in these environments.

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IV - ACCELEROMETER DEVELOPMENT

APPLICATION

Vibration measurements are required within the NERVA pressure vessel to support reactor design analyses through the characterization of both oscillatory and transient motions of the reactor component parts. Examples of locations where vibration measurements are being made include: (1) dome side of the core support plate, and (2) nozzle side of the control drums. Additional vibration measurements on components within the pressure vessel such as the nozzle end support ring and the tie rods have been requested. However, whether such a request can be met depends on the success one has in reducing the physical size and mass of the accelerometers presently under development.

OBJECTIVES

The objective of the program is the development of an acceleration transducer which will meet the following requirements:

1. Measure accelerations up to 10 g's over a frequency range of 5 to 1000 cycles per second.
2. Perform satisfactorily in the following environment:
  - a. Fast neutron flux: Up to 10^{15} n/cm²/sec (E > 1 Mev)
  - b. Gamma dose rate: Up to 10^{12} ergs/gm (c)-hr
  - c. Temperature range: From -423°F to +750°F.
  - d. Thermal Shock: 45°F/sec.
  - e. Acoustic noise: Up to 178 db
  - f. Ambient pressure: From 0 to 750 psia.
  - g. Shock: 15 g peak, half sine pulse of 11 milliseconds duration.
3. Sensitivity to be 1 mv/g, minimum.
4. Accuracy while exposed to the above environments to be $\pm 10\%$, minimum.
5. Minimum physical size and mass compatible with operational requirements.

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PROBLEM AREAS

Investigation of acceleration transducers has progressed to the point where it can be concluded that piezoelectric type devices will not function properly inside the pressure vessel because of their sensitivity to acoustic noise, changing temperature, changing radiation flux, and their inherent high thermal resistance. Consequently, no further development work is planned on piezoelectric accelerometers.

Development work on electro-mechanical type accelerometers, on the other hand, had shown that these units offered the greatest potential for in-vessel applications. Of these, the Wiancko AX-44 variable reluctance accelerometer was in the most advanced state of development. Based upon work performed on its predecessor, the Wiancko AX-40, and upon engineering analyses which had been conducted on the AX-44 design, it was concluded that this unit could be used reliably in certain restricted locations within the NERVA pressure vessel. Hence, it was specified for use on the NRX-A3 and A4 core support plate and control drums. In these locations, the physical size of the Wiancko AX-44 accelerometers is compatible with the space available. Also, in these locations the radiation heating rates will not exceed approximately 5 watts/gram. Heat transfer calculations performed on the Wiancko AX-44 had revealed that such a heating rate is about the maximum that could be tolerated by this unit under expected NERVA temperature conditions. Subsequent testing of the Wiancko AX-44 accelerometer, however, has shown that this transducer does not meet the required performance specifications. The major problem encountered has been a large sensitivity change when subjected to the range of temperatures expected during NERVA reactor operation. Review of the test data with the vendor has resulted in the conclusion that temperature-induced changes in the magnetic and electrical properties of the internal transducer materials are causing the difficulty. Hence, a basic re-design of the transducer appears to be required. Other possible problem areas that require further investigation include:

1. Thermal shock sensitivity.
2. Sensitivity to varying flux levels.
3. Acoustic noise sensitivity.
4. Sensitivity change due to total radiation dose.

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Assuming the above-listed problem areas are satisfactorily resolved, there is still the need to up-grade the ability of the accelerometer to operate properly under higher radiation heating levels. Also, further efforts must be made to reduce the overall size of the unit. Solution of these two additional problem areas will permit the measurement of vibration levels at locations within the pressure vessel that are presently unacceptable.

DEVELOPMENT APPROACH

The development work planned for Contract Year 1965 consists of two major efforts. First, evaluation tests will be conducted on the re-designed Wiancko AX-44 accelerometer in order to fully determine its operating characteristics. Close liaison will be established with the WANL Materials Department on the selection of new transducer materials. Secondly, improved accelerometers capable of operating in higher radiation heating rates and smaller in size will be procured. As a first step in this effort, a qualification specification will be prepared detailing the expected NERVA environments and the tests which must be run to qualify an accelerometer for operation in these environments. A major effort will be made to produce a transducer design with greatly increased thermal conductivity in order to minimize temperature rise due to radiation heating. Proposed designs will be subjected to heat transfer analyses before being approved for fabrication. Developmental units built by the vendors to meet these specifications will be thoroughly checked and evaluated in both nuclear and non-nuclear tests.

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V-ELECTRICAL CABLE DEVELOPMENT

APPLICATION

Metal sheathed cables are required for instrumentation located internally to the NERVA reactor pressure vessel. These cable assemblies must be capable of withstanding test environmental conditions while transmitting transducer output signals with minimum signal distortion. In addition, they must have an overall size and flexibility compatible with reactor installation requirements.

OBJECTIVES

Stainless steel sheathed, MgO insulated cables integral with transducers have been developed and are presently used for all internal reactor instrumentation. These cables extend from the transducers to a location within the privy where they are spliced to conventional signal leads. For certain transducer applications, however, a requirement exists for a smaller and more flexible lead wire than is available in the metal sheath variety. Consequently, since the metal sheath cable is still required for pressure sealing purposes in the instrument stalk, a hermetically-sealed, radiation-resistant splice must be developed between the metal sheath cable and the flexible leads. Present objectives are to design, procure and perform evaluation and qualification testing on splices of this type. This is primarily required in the measurement of strain but may be extended to other areas if the need arises.

PROBLEM AREAS

The problem inherent with inorganic insulation is moisture absorption due to its hygroscopic characteristic. A glass hermetic seal material has been developed which minimizes this problem. Since this material is now applied as an alcohol slip, development efforts must be continued toward preform beads of the sealant.

Also problems related to compatibility of brazing alloys to the glass firing temperature must be studied. This is essential to provide ease of handling and reliable transition splices and terminations.

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DEVELOPMENT APPROACH

Development of preforms of various configurations has been initiated and partially completed. The procurement of inorganic insulated flexible leads has been started. These leads present a problem in themselves in that they have to be very small and flexible. Inorganic insulation basically is not flexible. Therefore, special methods of manufacture have to be developed to satisfy size, moisture resistance and electrical insulation requirements.

In conjunction with this effort a study of compatible brazing alloys is planned. A series of both non-nuclear and nuclear evaluation testing will be conducted for different transition and terminating techniques. Based on these results the most reliable design will be selected and completely qualification tested for reliable reactor use.

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