NAA-SR-2157
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REACTOR SAFETY
QUARTERLY PROGRESS REPORT
JANUARY-MARCH 1957

ATOMICS INTERNATIONAL

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ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8

ISSUED: DECEMBER 1, 1957

DISTRIBUTION

This report is distributed according to the category "Instruments" as given in the "Standard Distribution Lists for Unclassified Research and Development Reports" TID-4500 (13th Edition), January 15, 1957. A total of 610 copies of this report was printed.

THE TWO PREVIOUS QUARTERLY PROGRESS REPORTS ARE:

NAA-SR-1810
NAA-SR-1954

MAY - JULY, 1956
AUGUST - DECEMBER, 1956

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ACKNOWLEDGMENT

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ABSTRACT

Seven special safety elements of the Mark II design were rebuilt and are ready for resumption of lifetime testing.

Precision-cast parts were received for ten Mark IV high-pressure chambers; one set was assembled and pressure tested to 2000 psi.

Two special assemblies of the NAA 109-3 experiment were completed and are being shipped to Hanford.

Conductivity measurements on stainless steel were continued in an effort to determine the cause of erratic behavior of the variable-cooled trigger. A vacuum chamber was used in an effort to eliminate local heat loss due to convection.

A study of corrosion rates of various container materials in liquid-metal poisons has been undertaken.

Experiments with the differential-pressure device on the rate of pressure rise that can be achieved by electrically heating a closed gas volume have been continued. An exponential generator is being constructed to enable simulation of reactor periods from 30 milliseconds to one second.

Three types of research reactor safety device have been chosen for further study: the pyrophoric, the double-diaphragm, and the electronic-explosive. Preparations are in process for demonstrating models of the latter two devices in the KEWB facility.

I. PRODUCTION REACTOR SAFETY DEVICE

A. MARK II

Seven special safety elements of the Mark II design were completely rebuilt for use in the lifetime test, in which the elements are vibrated mechanically while held at various temperatures between room temperature and 210° C. New parts were used insofar as possible in fabrication of these assemblies so that the failures experienced previously might be avoided (NAA-SR-1954). Six of the assemblies have been installed in the test rig and are ready for resumption of testing.

B. MARK IV

The fabrication of dies for precision casting of the phosphor-bronze pad and the beryllium high-pressure chamber was completed. The Missile Development Division of NAA cast enough parts for ten assemblies.

During this report period, effort was curtailed on the development of the Mark IV Safety Element. The precision casting technique and assembly of the cast parts were deemed to be of sufficient value to the program to justify a slight additional effort. Accordingly, the techniques of soldering the release tube to the cadmium liner, enclosing the liner in the high-pressure chamber, and installing the pad on the release tube were attempted and successfully demonstrated.

Figure 1 shows the precision-cast parts as received from the Missile Development Division, the aluminum rings used to hold together the halves of the high-pressure chamber, and the completed subassembly. This subassembly has withstood 2000 psi without leakage. Further testing is not planned due to the present scope of the program.

C. NAA 109-3 EXPERIMENT (HANFORD INPILE TEST)

Two special assemblies for this experiment were completed during the report period. There were no particular incidents in assembly except for a severe problem in welding the aluminum closure plug to the aluminum cladding of the element. Normally, the closure weld is easily accomplished by using a standing edge of about 1/16 inch in height at the circumference of the plug. If sufficient

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Fig. 1. Precision Cast Parts for Mark IV High Pressure Chamber Subassembly

heat is applied under this condition, a successful Heliarc weld is not too difficult to achieve. In the experimental assemblies, however, the proximity of soft-soldered connections for the instrumentation leads required local chilling to avoid melting the solder. After many unsuccessful attempts at welding, it was realized that the heat drain to the chill block was the critical source of difficulty. The problem was solved by increasing the height of the standing edge on the plug from 1/16 inch to 1/8 inch. The weld was then easily accomplished.

After closure of the assemblies, the electrical heaters and the pressure transducers were calibrated. During the heater calibration, it was determined that less than 8% of the electrical power supplied was lost in the leads to the heater; also, a current of five amperes produced a temperature differential of 60° C between the soldered plug in the fuse and the outer wall of the element. This temperature rise agrees well with calculations. The assemblies are being boxed for shipment to Hanford.

II. POWER REACTOR SAFETY DEVICE

A. VARIABLE-COOLED TRIGGER

Measurements of the thermal conductivity of stainless steel were continued in an effort to determine the sources of error which are suspected of causing spurious results in variable-cooled trigger experiments. The experimental procedure was to measure the temperature drops across cylindrical samples of pure copper and stainless steel placed in series with respect to heat flow. Measurements were carried out both in air and in vacuum to determine the effect of convection on the observed temperatures. The direction of heat flow was alternated in an attempt to average out convection and radiation losses.

The results of measurements in air showed that the heat loss due to convection was both large and unpredictable. Since the sample diameter was the same as the outer diameter of the tubing in the model of the variable-cooled trigger previously studied, there is ample evidence that the spurious results previously observed, with respect to thermal relaxation time and conductivity range, can be ascribed to convection.

By placing the stainless-steel and copper samples in a vacuum, the erratic behavior of the observed temperatures was eliminated. By alternating the direction of heat flow, it was ascertained that the apparent thermal conductivity of the hotter sample was consistently too large. This effect was traced to cooling of the surface of the sample by radiation. Since the thermocouples used to measure the temperature differences were spot-welded to the surface of the sample, the observed temperature drop in the hotter material was lower than the true internal temperature difference. A photograph of the vacuum thermal-conductivity apparatus is shown in Fig. 2.

B. POWDERED-POISON DISPERSAL

The experimental apparatus described in the previous progress report (NAA-SR-1954) has not been completed. About 100 rupturable diaphragms have been coined for use in the apparatus.

C. LIQUID-METAL POISONS

More experimental points on the Bi-In-Cd liquidus surface have been obtained by the method reported previously in NAA-SR-1810. A revised ternary diagram, showing the temperature contours on the liquidus surface, is shown in Fig. 3.

A study of the corrosion rate of various possible container materials (e.g. aluminum, stainless steel, mild steel, etc.) in the ternary Bi-In-Cd eutectic at temperatures between 300° F and 1000° F has been undertaken. In the study, test samples will be immersed in the eutectic and allowed to soak at temperature for periods ranging from one week to six months.

D. DIFFERENTIAL-PRESSURE DEVICE

A slightly improved concept of the differential pressure device is being studied. No fluorine nor fluorine compounds will be used, so as to alleviate the corrosion problem. A uranium-heated gas volume will still be used as a source of energy for bursting a diaphragm. It would at the same time disperse a poison, which might be either powder or liquid metal held in the region of the diaphragm.

Experiments on the rate of pressure rise that can be achieved by heating wires electrically in a closed gas volume have been continued at pressures up to 300 psi.

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Fig. 2. Vacuum Thermal-Conductivity Apparatus

Fig. 3. Bi-In-Cd Liquidus Surface Temperature Contours

A sketch of the experimental apparatus is shown in Fig. 4. It has been determined that increasing the electrical power input reduces the thermal relaxation time to a certain minimum which is a function of the chamber diameter. Also, the thermal relaxation time at low power input is a function of the heater wire size, specifically the ratio of the radiating surface to the mass of the wire. In a 3/8-inch-thick annulus, for instance, the thermal relaxation time was found to be one second for a 5-mil diameter copper wire and four seconds for a 10-mil copper wire. For the chosen experimental conditions, the pressure increase in the gas was found to be approximately 1% per 4-watt input.

Fig. 4. Differential Pressure Test Apparatus

It was proposed that an improved apparatus should be constructed for this experiment which would (1) allow for much higher pressure, such as 1000 psi, and (2) provide a source of exponentially-increasing electrical power input. An exponential generator is being assembled using two modified Variacs and a motor-driven rotary switch. The switch contacts will be connected to taps on the Variac

windings at intervals such that the output will approximate, in a step fashion, an exponentially-increasing electrical power. The apparatus will provide about three decades (seven e-folding periods) of electrical power input. The switching speed will be variable, by means of gears, to permit simulation of reactor periods from 30 milliseconds to one second.

E. OTHER

The design of a flux-sensitive trigger to operate over a wide range of ambient temperature would be greatly simplified by the use of a cooling pad made of a material having a thermal conductivity that increases rapidly with temperature. A literature search for such materials has been undertaken. A number of copper alloys show promise and are listed, along with the available data on rate of conductivity increase, in Table I.

TABLE I
RATE OF CONDUCTIVITY INCREASE
PER 100° C OF VARIOUS COPPER ALLOYS

Alloy	Approximate Increase in Conductivity per 100° C
60:40 CuNi	+15%
60:40 CuZn	+18%
90:10 CuMn	+23%
90:5:5 CuAlNi	+24%
95.5:4.5 CuMn	+30%

III. RESEARCH REACTOR SAFETY DEVICE

A. INTRODUCTION

Of the several concepts described in the preceding progress report (NAA-SR-1954), three systems have been chosen for further study and development. These will be referred to as the pyrophoric, the double-diaphragm, and the electronic-explosive devices.

It is proposed in the pyrophoric system to use a violent chemical reaction as a heat source for the vaporization or oxidation of a metallic poison and its subsequent transfer to a new geometry which would be more effective for neutron absorption. The chemical reaction would be initiated by a flux-sensitive trigger. All parts of this system would be stored in or near the reactor core and the system would be ideally self-contained, that is, not requiring external circuitry.

The double-diaphragm system (NAA-SR-1954) is a self-contained, pneumatic system using a flux-sensitive trigger.

The electronic system would use a small explosive charge to effect dispersal of a poison; the energy for initiating the explosion would be supplied by the discharge of a thyratron, triggered by a signal from normal reactor instrumentation. Also, an external power supply is required (NAA-SR-1954). It is not, therefore, independent of external circuitry.

B. PYROPHORIC EXPERIMENTS

In a search for an exceedingly fast-acting reactor safety device, it was thought that the photoflash principle might be of use. This is a mechanism which expends a great amount of energy in times as short as 20 milliseconds. The principles are simple, the techniques are well worked out, and the cost of materials is low.

The application of the photoflash technique to a reactor safety device involves the following mechanisms:

1) Sensing element:	enriched-uranium foil protected against premature oxidation
2) Poison:	a wire (or a deposit on a wire) of cadmium, samarium, gadolinium, or another efficient neutron absorber which can be burned or vaporized in a pyrophoric reaction.
3) Fuel-Oxidant Mixture:	the original concept was shredded magnesium or aluminum foil in oxygen. There is, however, no reason to rule out other gaseous oxidants such as fluorine or other fuels such as zirconium.

Preliminary experiments indicated that flashbulb reactions could be initiated using shredded aluminum foil (0.4 x 0.6 mil), zirconium priming paste on an aluminum filament, an oxygen atmosphere, and an electric trigger. However, the heat developed was not enough to vaporize a cadmium or copper wire.

A cylindrical steel pressure vessel was built so that heavier charges of fuel and oxidant could be handled. A "wire" of cadmium or copper was placed near the axis of the cylinder. At times, the cylinder was lined with a removable metal sheet so that the deposit of cadmium or cadmium oxide could be removed for analysis.

A typical charge was:

1g	aluminum shredded foil
1.3g	cadmium wire
20atm	oxygen

The tests were more than successful. Not only were the cadmium and copper wires completely disintegrated, but the metal liners (1-mil 10-20 steel sheet and 5-mil tantalum sheet) disappeared too. In all cases, whether or not the chamber contained a liner, metal globules were found adherent to the wall. Additionally, Al_2O_3 and CdO covered the chamber wall with an adherent coat.

In order to measure reaction rates, quartz chambers were designed as pressure vessels from which the light flux could be recorded. Time intensity measurements of the light output failed because of extreme variance in burning rates. One cause of the variable burning rates was found to be the electrical resistance of the filaments. Ignition time of filaments varied from 0.4 to 6.2 milliseconds as their resistance varied from 0.8 to 5.0 ohms.

Subsequently, a test was completed in which rise time of the pyrophoric reaction was recorded. In this run, the chamber was loaded with one gram of aluminum foil, 0.22 gram of cadmium, and ten atmospheres of oxygen. This constituted a slightly oxygen-deficient environment with respect to the amount of aluminum present. There was a sharp rise in light intensity beginning at 25 milliseconds, a peak intensity at 38 milliseconds, followed by decay until 55 milliseconds, at which time the silicon-dioxide vessel exploded and further observation was obscured.

For this test the filament resistance was known to be rather high, so that there is reason to believe the reaction was abnormally late in starting. Its behavior after ignition, however, is probably typical.

Further experimentation is contemplated after redesign of the apparatus, to contain the explosion.

C. DOUBLE-DIAPHRAGM DEVICE

Further work has been done on the time response of the double-diaphragm system. Experimental runs were made, as described in the preceding progress report (NAA-SR-1954), to measure the time interval between pressure release in the intermediate chamber release tube and rupture of the second diaphragm. It was determined that the use of helium in place of nitrogen in the intermediate chamber improved the response by a factor of about two; also, the introduction of a 90° bend near the end of the release tube (which might be a necessary condition of fuse geometry) increased the response time by about one millisecond.

Development of the fusible cap trigger (NAA-SR-1954) has continued with slight changes in materials and dimensions, but with no change in concept. Because of its geometry, this fuse lends itself to a one-dimensional heat flow analog. Such an analog was constructed and operated with a step-function input and a thermal relaxation time of 110 milliseconds was obtained. This figure is to be compared with 85 milliseconds calculated analytically, using certain simplifying assumptions. The agreement is considered reasonably good.

Further electrical analog experiments were performed using the exponential generator which was developed for analog experiments on the Mark II Hanford Safety Device Fuse (NAA-SR-2003). For these runs, a trip level of 1.5 times steady-state power was assumed, and the exponential input period was varied from 25 to 100 milliseconds. The delay time, measured between 1.5 power level and 1.5 fuse temperature, varied from 8 milliseconds to 50 milliseconds or, respectively, 1/3 period to 1/2 period. Delay times of this order are considered quite satisfactory for an effective safety device.

Development of a practical model of a fusible-cap trigger has proceeded simultaneously. The electrophoretic deposition method for forming the heat generating layer seemed especially well suited to this design of fuse. Therefore, the apparatus which had been built for the purpose of fabricating Hanford Mark IV fuses was modified by the construction of suitable jigs (see Fig. 5). It was decided that the fuse should be made of alternate layers of UO_2 , electrophoretically deposited, and copper, electroplated, in approximately equal volumes. The last coat should be nickel on top of copper to form the best surface for the solder layer.

The low-melting-point solder, which would be placed between the heat-generating layer and the fuse cap, is to be composed of 52Bi - 32Pb - 16Sn, which melts at 95° C.

Fig. 5. Plating Jig for Electrophoretic Deposition of UO_2

Such a fuse was made up and attached to the 36-inch-long release tube of the double-diaphragm test apparatus. The fuse was triggered by external heat. Release times of the order of two milliseconds were obtained, indicating that the fuse geometry does not retard gas release noticeably.

Extended pressure tests on the first fuses manufactured resulted in several failures, in one of which the cap blew off at 350 psi (one-third of the design pressure) and it was visually apparent that the heat generating layer had fractured along one of the deposition surfaces. In other instances, slow leakage through

the heat-generating layer was observed and, in one fuse, blistering of the nickel coating.

Two improvements in procedure have been made: 1) the deposited material was compressed at high pressure by a special die after each copper layer, and 2) the sintering time and temperature were increased (full details of procedures will appear in a future topical report). Following these improvements, three fuses have been made which have withstood pressurization at 1000 psi for several hundred hours.

D. ELECTRONIC-EXPLOSIVE DEVICE

Two-grain and six-grain squibs were obtained commercially and tested for suitability to the overall device. It was determined that they could be detonated reliably by the electronic trigger described in the preceding progress report (NAA-SR-1954); also, the response time was found to be negligible (less than one millisecond). A special chamber was fabricated for these tests, which would allow placement of rupturable diaphragms at various distances from the squib. Two diaphragms in series could be punctured reliably using a six-grain squib.

The use of two diaphragms in series is predicated on the concept of an intermediate chamber containing the gaseous poison BF_3 between the detonation and receiver chambers.

Further testing was done to verify calculated pressure rises in a two-foot-long receiver chamber.

It was concluded from the tests that the electronic-explosive system could easily be adapted to a practical safety element.

E. KEWB DEMONSTRATIONS

It was proposed that one or more research reactor safety devices be prepared for demonstration of feasibility in the Kinetic Experiment Water Boiler facility. From extrapolation of low-power excursions previously performed on this facility, aided by published data on SPERT I (IDO 16285), it was calculated that the fusible-cap trigger of the double-diaphragm system could be triggered in the KEWB with about a 2% insertion of excess reactivity. Even if this transient should not be

achieved, testing with smaller transients on properly instrumented fuse sub-assemblies should provide reliable information on temperature rise versus integrated flux, peak flux, and reactor period.

The electronic-explosive device was deemed to be more nearly ready for a demonstration of effectiveness; it was necessary only to know that the existing KEWB instrumentation could provide a satisfactory signal for the electronic trigger. With proper matching of impedance, no trouble could be foreseen.

Therefore, a KEWB demonstration program was planned which provides for:

- 1) Demonstration of a prototype electronic-explosive device by cutting off an excursion of predictable magnitude at a preset, much smaller magnitude.
- 2) Testing of double-diaphragm system fusible-cap triggers instrumented to record temperature at the solder layer.
- 3) Demonstration of a prototype double-diaphragm device, only if sufficiently large reactor transients should be available at the time of testing.

For the demonstrations, pressure in the receiver chambers would be recorded by strain gages.

At the end of this report period, most of the necessary predemonstration testing of the prototypes had been completed. This included containment of explosive by-products, chemical reaction with BF_3 (negligible), containment of transient pressures without deformation of chambers, and leakage at gaskets.

Adaptation of cabling to match existing KEWB instrumentation was also completed. A problem of excessive noise in the strain-gage network is being worked on. No serious difficulties have been encountered.