SAFETY DEVICE TESTS
IN KEWB I

BY

CHARLES C. WEEKS
STEPHEN H. FITCH

ATOMICS INTERNATIONAL

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

CONTRACT: AT(11-1)-GEN-8
ISSUED: JANUARY 28, 1958

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISTRIBUTION

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

TABLE OF CONTENTS

	Page No.
Abstract	4
I. Introduction	5
II. Description of Safety System	6
A. Neutron-Absorber Release System	6
B. Electronic Trigger	6
III. Test Apparatus	9
IV. Results	13
A. In-Pile Tests	13
B. Response Time	13
C. Reactivity Effect	19
V. Conclusions and Recommendations	21
References	23

LIST OF FIGURES

1. Electronic-Explosive Safety Device	7
2. Electronic Trigger Circuit	8
3. Device Components	10
4. Installation of Safety Device in KEWB Facility	11
5. Instrumentation and Firing Circuitry	12
6. Part of a Typical Oscillograph Trace for Demonstration Test	14
7. Typical Reactor Power Time-Curve	15
8. Typical Oscillograph Trace for Response Determination	17
9. Expected Maximum Power Overshoot as Function of Reactor Period	18

ABSTRACT

The feasibility of the electronic-explosive safety device was demonstrated in KEWB-I reactor excursions. It was shown to be a fast, efficient safety system for reactor protection.

The safety devices inserted 1.5 per cent negative reactivity into the core region of the KEWB-I reactor to produce rapid shutdown. The system response time, i. e., that time interval between trip and insertion times, was found to be 4.2 milliseconds.

The complete freedom in choice of trip level and the flexibility of device geometry makes the system applicable to many types of reactor and critical assembly. The system does not offer the ultimate in reactor safety because it is not completely self-contained, but it is a practical, workable system for reactor protection.

I. INTRODUCTION

Safety of personnel in the vicinity of an atomic reactor, and the safety of the reactor itself, has always been a primary concern. The primary hazards of operation of a reactor, which must be taken into consideration in designing a control or safety system, are excessively high level of neutron flux and excessively short period of flux increase. The normal control system of a reactor has safety features built in so that under these circumstances the control rods will be returned to the core of the reactor to effect a shutdown. To provide for the possibility of an accident in which the control system is rendered inoperative, it is most desirable to have a back-up safety system that would shut the reactor down.

Maximum safety may be obtained by having a control system with many "fail-safe" features. However, so many interlocking features can be built into the system that it becomes quite complicated and a source of excessive "down time" of the reactor due to component failure. The use of independent safety devices offers a solution compromising neither reactor safety nor reactor operating time. The control system should be adequate to handle most circumstances, and the independent safety system should provide the ultimate safety.

A good safety system should cost the reactor little or no reactivity in its ready or standby state. In the case of an accident, it should be capable of rendering the reactor subcritical, without the aid of the control system, before it reaches an unsafe power.

Although power reactors will probably become the largest group eventually, the need at present is greatest in research reactors. Many of these have large amounts of excess reactivity included in the core to take care of those losses caused by experiments. Also, the programming of these reactors is usually not constant, with each start-up affected by different experiments and different configurations. In addition, due to the variety of applications of such an experimental machine, there is always the possibility of unforeseen situations which could cause a potential hazard. These considerations make the need of safety devices for research reactors most urgent.

A proved and useful independent safety device offers many attractive advantages to reactor operators, builders, and designers. There is a possibility of a decrease in insurance rates, an increase in allowable operating power levels, an increase in flexibility of design, plus greater public acceptance of reactors which could result in more convenient reactor locations.

There is a program at Atomics International to develop safety devices for reactor protection. This report is concerned with the design and testing of one such device, the feasibility of which has been demonstrated in actual reactor excursions.

II. DESCRIPTION OF SAFETY SYSTEM

A. NEUTRON ABSORBER RELEASE SYSTEM

The electronic-explosive safety device, shown in Fig. 1, is designed primarily for low temperature applications to research reactors and critical assemblies.^{1,2} The shell of this system is a receiver chamber that extends from within the core region of the reactor to the reflector region or beyond. A storage chamber is located at the end of the receiver farthest from the core, and contains the reactor poison, boron trifluoride, under high pressure. A detonation chamber containing an explosive is located at the same end. The geometry of this system is exceedingly flexible, for the detonation and storage chambers can be completely outside of the reactor if desired and the receiver chamber can be made in any shape convenient to the reactor core configuration. The storage chamber is designed so that diaphragms retain the poison until they are ruptured by detonation of the explosive. The explosive is fired when a signal of the proper magnitude is applied to the electronic trigger. The signal may be taken from any neutron-sensing type instrument such as those commonly used to record reactor power.

B. ELECTRONIC TRIGGER

The electronic trigger, Fig. 2, utilizes a 2D21 thyratron electron tube which has two control grids. The tube can be fired from loss of bias voltage to the first grid or an increase in positive voltage to the second grid.

Fig. 1. Electronic-Explosive Safety Device

Fig. 2. Electronic Trigger Circuit

In this application the second grid is used to trigger the system. On the KEWB demonstration model an ion chamber with a log n amplifier was used to monitor the neutron flux level and provide the trip signal when the reactor exceeded the predetermined trip point. The flux level at which the device triggers is set by selecting a value on a voltage divider used in the output circuit of the log n amplifier. At the appropriate flux level the signal produces ionization in the thyatron and causes it to conduct. A cathode follower is used to isolate the log n amplifier from the thyatron to minimize loading of the log n output.

An electrically detonated squib* is connected in series with the cathode of the thyatron and detonates when the signal from the log n amplifier causes the thyatron to conduct. When placed a considerable distance from the electronic trigger, care should be taken to select a squib with resistance equal to or greater than that of the wires connecting it to the trigger. The purpose is to provide that most of the energy stored in the power supply capacitor is dissipated in the squib rather than in the leads.

*DuPont S-68, four-grain blasting cap.

Several fail-safe features are built into the electronic trigger to shut the reactor down rather than let it operate without the safeguard of a safety system. These features make use of the required bias voltage on the first grid of the thyratron. The filament is in series with the circuit providing the bias voltage so that filament burnout causes a loss of bias voltage. The bias voltage decays rapidly enough to allow the thyratron to conduct before the cathode loses its heat. Loss of line voltage produces the same effect. It was possible to prevent tripping on momentary line interruptions by placing a capacitor and a resistor in the circuit from grid to ground. Thus the bias voltage would decay fast enough to cause tripping on loss of line power but not so fast as to cause tripping on short interruptions.

III. TEST APPARATUS

To establish the feasibility of the system as a reactor safety device, it was necessary to test the device in a reactor that could be made supercritical. KEWB was used for demonstrating the device even though it has its own efficient inherent shutdown mechanism.³ The trip point of the electronic-explosive system can be set low enough so that the system could be convincingly tested in KEWB.

Assemblies were fabricated that could be used in the horizontal through-facility of the KEWB reactor. The devices, shown in Fig. 3, were 1.6 inches in diameter and 41 inches long. The receiver extended from outside the reactor secondary enclosure to the opposite side of the core. The detonation chamber was located approximately 3 inches outside the secondary enclosure, and the storage chamber was located approximately 12 inches away from the core. The experimental arrangement is illustrated in Fig. 4.

The electronic trigger was placed outside the reactor room in the electrical building for convenience of electrical checking and testing. Trip level was set by bringing the reactor up to a given power level and adjusting the electronic trigger to fire at that level. Radiation in the electrical building was negligible during the trip set procedure.

Fig. 3. Device Components

Fig. 4. Installation of Safety Device in KEWB Facility

Data from the test were recorded on a recording oscillograph as galvanometer deflection as a function of time. Several channels of log and linear reactor power using the regular KEWB instrumentation were recorded. Specific instrumentation for the safety device test consisted of one channel to record receiver chamber pressure and one channel to record trip time by monitoring the explosive firing charge. The firing charge was recorded as the potential drop across a small resistor in series with the explosive. No amplification was necessary because of the magnitude of the voltage; hence, the galvanometer was connected directly across the resistor.

The receiver pressure channel consisted of a standard strain-gage bridge network, a balancing potentiometer, a d-c amplifier, a battery, and the galvanometer. The active and temperature-compensating arms of the bridge were located on the receiver of the safety device while the other two arms and the balancing potentiometer were in a relay rack located in the control room. All the other components were located in the reactor control room. The firing and instrumentation circuits are shown in Fig. 5.

Fig. 5. Instrumentation and Firing Circuitry

IV. RESULTS

A. IN-PILE TEST

The data were recorded on DuPont Linowrite 4 oscillograph paper and developed and fixed in a Consolidated Electrodynamics Corporation processor. Part of a typical oscillograph trace is shown in Fig. 6. Reactor power was monitored by two log channels and several linear channels; two of those shown had sufficient sensitivity to give a measurable power indication. Trip time was indicated by the receiver chamber pressure channel and by the firing pulse monitor. In this particular trace the trip indication on the latter channel was obscured by the power channels. However, the discontinuity in the pressure channel gave a good indication of trip time.

The response of the reactor to the insertion of the poison was quite rapid. In this particular instance reactor power decreased to 50 per cent of peak value within about 15 milliseconds and to 10 per cent of peak value within about 150 milliseconds. A noteworthy feature was that the safety device caused a sharp break in the power trace unlike the reactor control rod scram, also shown in Fig. 6.

The recorded data were reduced using Bensen-Lehner apparatus for reading and plotting. A typical plot is shown in Fig. 7. The data were plotted in the form of reactor power vs time and from this plot peak power and energy release were derived. These quantities, which are listed in Table I, illustrate the capabilities of the system as a safety device.

B. RESPONSE TIME

The time interval between the instant of trip and that time when the safety device is effective in shutting down a reactor is a very important feature of a safety system. On a fast transient, the power overshoot above trip level could become appreciable if the response time is slow. It is important that this delay time be determined for the system.

The response time for the electronic-explosive system can be considered to be the sum of three intervals defined by the following instants: trip signal, thyatron discharge, explosive detonation, and initial insertion of poison. The time

Fig. 6. Part of a Typical Oscillograph Trace for Demonstration Test

Fig. 7. Typical Reactor Power Time-Curve

TABLE I
EFFECT OF THE SAFETY DEVICE ON REACTOR BEHAVIOR

Safety Device	Reactor Period (sec)	Peak Power (kw)	Energy Release to Peak Power (kw-sec)	Peak Power Ratio
Yes	0.16	1.1	0.2	$\frac{1}{732}$
No	0.21	805	305	
Yes	0.20	64	12.2	$\frac{1}{12.6}$
No	0.21	805	305	
Yes	0.32	43	12.2	$\frac{1}{13.4}$
No	0.30	575	310	
Yes	0.67	118	78.9	$\frac{1}{3}$
No	0.63	352	400	
Yes	2.07	143	318	$\frac{1}{2.3}$
No	2.07	330	1045	
Yes	3.97	1.3	4.2	$\frac{1}{17}$
No	3.97	22	218	

it takes for the poison gas to come to equilibrium after firing apparently is not a very significant quantity. The rate of rise in power of a supercritical reactor is changed the instant that poison introduction begins, since any amount of poison changes the reactivity of the system.⁴ The reactor eventually must be made subcritical to prevent another power excursion, but this can be done after a relatively longer time.

The first interval in the response time is electronic in nature, dependent only on the components in the trigger circuit between input and thyatron. This time has been calculated to be of the order of microseconds and is short compared to the other time intervals.

The second interval is the finite time it takes electrical charge to cause the explosive to detonate. The determination of this time was done using the identical circuitry as for the inpile tests except that the trip signal was introduced from a battery instead of from a reactor power monitoring instrument. The pressure was determined by a strain gage channel and the detonating charge monitored by recording the potential drop across a resistor in series with the explosive. A typical trace is shown in Fig. 8. The potential drop decreases exponentially

Fig. 8. Typical Oscillograph Trace for Response Determination

because the charge flowing through the thyatron is from a condensor. The determinations ranged from 2.81 to 3.46 milliseconds and yielded an average value of 3.01 milliseconds.

The time between detonation and poison insertion was also determined from the same traces. The sharp break in the strain gage trace is assumed to be caused by the passing of a shock wave formed when the BF_3 gas is released by rupture of the diaphragm. This time was found to be 1.20 milliseconds. Thus, the overall time response of the system is 4.2 milliseconds. This determination checks very well with the inpile runs which showed that the maximum value of reactor power occurred within 7 milliseconds after trip indication.

It is instructive to compute the expected overshoot of reactor power based on the time delay between trip and poison insertion. This delay is negligible on slow transients but on faster transients it may become significant. The reactor overshoot as a function of reactor period is plotted in Fig. 9 assuming a 5-millisecond delay time.

Fig. 9. Expected Maximum Power Overshoot as Function of Reactor Period

C. REACTIVITY EFFECT

The reactivity effect of the safety device has been calculated on an IBM 704 machine utilizing the Atomics International Multigroup-Multiregion (AIM) code. AIM is a program using multigroup diffusion theory to calculate the reactivity or critical conditions, flux distributions, and fission density of a multiregion reactor. The code was written at AI and is based primarily on the similar code, DMM, Diffusion-Multigroup-Multiregion, described in reports ASAE-4 by the American Standard Corporation and R-218 by the Burroughs Corporation.

AIM is a one-dimensional code for use on reactors that may be approximated by a sphere, a cylinder, or a slab. In the case of a cylindrical safety element in a spherical core it was decided to use cylindrical geometry because the effect of the safety device was the important parameter. The core of the KEWB was approximated by a right equilateral cylinder of volume equal to that of the vessel core. The core composition was taken to be that of criticality plus the stainless steel cooling tubes and control rod thimbles and the aluminum control rod liners. This material was homogenized by assuming a uniform density throughout the core region.

Another approximation was made for the region between the safety device chamber and the core. This region consists of the safety device wall, the aluminum through-tube, the stainless steel re-entrant tube, and void spaces between these tubes. The region was homogenized to reduce the number of regions and the complexity of the problem. Also, the 56-inch cube of graphite reflector was converted into a right equilateral cylinder of equal volume for these calculations.

The geometry and composition of the reactor and safety device system is given in Table II.

Flux distribution, k-effective, and power distribution were calculated for this approximation of the KEWB reactor containing a safety element in the horizontal through-facility. The difference in reactivity for the two cases corresponding to the reactor with the safety device with and without boron trifluoride was 0.0132, or 1.32 per cent, which should be a good measure of the worth of the device.

The effectiveness of the device was also determined empirically by the danger coefficient method. Criticality was determined before the device was triggered

TABLE II

PARAMETERS FOR AIM CALCULATION OF SAFETY DEVICE IN KEWB

Region	Region No.	Radius (cm)	Case	Material	Atomic Density (atoms/cm ³)
Safety Device Chamber	1	1.75	without BF ₃	Hydrogen*	4.92×10^{22}
			with BF ₃	Hydrogen* Boron (150 psi)	4.92×10^{22} 2.932×10^{20}
Device Wall, Through-Tubes, and Voids	2	2.73	Both	Aluminum Stainless Steel	2.35×10^{22} Volume Fraction 0.441
Core	3	13.67	Both	Uranium-235 Uranium-238 Sulphur Oxygen Hydrogen Stainless Steel Aluminum	3.165×10^{20} 2.29×10^{19} 4.69×10^{20} 2.685×10^{22} 4.92×10^{22} Volume Fraction 0.0354 5.89×10^{20}
Core Vessel	4	14.305	Both	Stainless Steel	Volume Fraction = 1.0
Reflector	5	77.305	Both	Graphite	8.03×10^{22}

*Because of the use of the diffusion equation, peculiar results are obtained where there are regions of very low transport cross section, i.e., voids or gases. The addition of hydrogen to provide a reasonable transport cross section should have no effect on the absorption by the boron.

and again after triggering. The difference in the previously calibrated control rod positions of 1.02 inches yielded a value of effectiveness of 1.45 per cent. This is in good agreement with the calculated value.

V. CONCLUSIONS AND RECOMMENDATIONS

The results of the KEWB tests have established the feasibility of the electronic-explosive safety device. It is an effective, workable system capable of causing reactor shutdown in a very short time. However, the system has not as yet been, tested for such features as reliability, freedom from false scrams, shelf life, and lifetime in a reactor environment.

This safety system offers complete freedom in choice of trip level. The electronic trigger is used to convert a given input signal into an appropriate voltage for firing the thyratron. It can use as its input source either existing power monitoring channels or its own power monitoring channel. In the test program, the input signal was taken from a log power channel to allow a wide spread in trip points. However, for a given reactor or critical assembly, the power indication should be taken from a linear channel to facilitate greater accuracy in setting the trip point.

There are no restrictions on the size and shape of that part of the device contained in the reactor core. Of course, because the device is pressurized, a cylindrical shape would require the least amount of wall material. However, other shapes may provide greater reactivity effectiveness for a given amount of wall material or chamber volume. The choice of size and shape would depend upon the space available and the amount of control desired.

In this test program boron trifluoride gas was used as the reactor poison. However, other poisons in other forms could be used to produce the same results. It should be noted, though, that gas transfer is probably the fastest means of producing reactor shutdown. Other fluids or quasi-fluids such as powder could be used with approximately the same response time.^{5,6}

The system in its present form requires an external power source and connecting leads between device and source. The trigger has the safety feature of

firing on interruption of line power, but this could cause trouble from false scrams. A possible improvement would be to have a battery supplying the condensor charging current, which in turn is charged by a rectifier in the line circuit. In this way, a power interruption would require only reinstatement of the line power rather than replacement of the safety device. It is possible, however, that in certain applications it would be desirable to trip the device on power failure.

The question of reliability in these safety systems can be answered by duplication or triplication of the devices and triggers. The reliability of the explosives, according to the manufacturer, is good -- 999 out of 1,000 detonating satisfactorily. In a duplicated system there would be only one chance in a million of both systems not firing.

In conclusion, the electronic-explosive system was shown to be a fast, effective safety device for reactor protection. It has no unattractive features that could not be overcome with a modest amount of development and testing. The complete freedom in choice of trip level makes the system applicable to virtually any reactor or critical assembly, including those where power range rules out other systems.

The electronic-explosive device is considered to be a practical, workable system. Although it does not offer the ultimate in reactor safety, because it is not a self contained system, it should be useful in certain applications where other safety devices will not work.

REFERENCES

1. N. C. Miller, "Reactor Safety Quarterly Progress Report, August-December, 1956," NAA-SR-1954, August 15, 1957.
2. N. C. Miller, "Reactor Safety Quarterly Progress Report, January-March, 1957," NAA-SR-2157, (to be published).
3. M. E. Remley, et al., "The Kinetic Behavior of Water Boiler Type Reactors," NAA-SR-1618, April 1, 1956.
4. F. Schroder, et al., "Experimental Study of Transient Behavior in a Subcooled Water-Moderated Reactor," Nuclear Science and Engineering 2, No. 1, pp 96-115, February, 1957.
5. R. J. Spera, "Boron Velocities in Modified Annular Nuclear Fuses," XDC-54-11-95, November 22, 1954.
6. N. C. Miller, "Reactor Safety Quarterly Progress Report, April-July, 1957," NAA-SR-2224 (to be published).