INTERNUC-47(Pts. A and B)
REACTORS—GENERAL

EXPERIMENTAL AND ANALYTICAL STUDIES OF REFLECTOR CONTROL FOR THE ADVANCED ENGINEERING TEST REACTOR

Part A by
W. S. Delicate
M. J. Kornfeld
A. M. Larson

Part B by
P. C. Bertelson
T. L. Francis

October 21, 1959

Internuclear Company, Inc.
Clayton, Missouri

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INTERNUC-47

EXPERIMENTAL AND ANALYTICAL STUDIES OF REFLECTOR CONTROL FOR THE ADVANCED ENGINEERING TEST REACTOR

Work Performed for the
Chicago Operations Office
U. S. Atomic Energy Commission
Contract No. AT(11-1)-688

PART A

by

W. S. Delicate
M. J. Kornfeld
A. M. Larson

PART B

by

P. C. Bertelson
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PREFACE

In December, 1956, the Chicago Operations Office of the U.S.Atomic Energy Commission requested Internuclear Company to conduct a survey of reactor concepts and submit recommendations for a reactor system or systems which would meet certain requirements for an Advanced Engineering Test Reactor. In its report[1] to the Commission, Internuclear Company recommended a facility consisting of seven separate reactor systems, each of the "flux-trap" type, for each major fuel assembly test loop.

In September 1957, the Commission requested Internuclear to conduct further studies toward optimization of the "flux-trap" reactor concept and the seven reactor complex. In fulfillment of its contract with the Commission, Internuclear Company submitted Report INTERNUC-23, "An Advanced Engineering Test Reactor" on March 15, 1958. This report presented a conceptual design of a seven reactor facility utilizing optimized "flux-trap" type reactors. One of the unique features of the reactors proposed in INTERNUC-23 was the utilization of reflector control for both power regulation and safety.

In October, 1958, the Commission requested Internuclear Company to a) make a preliminary hazards evaluation of the reactor facility described in INTERNUC-23, b) design, construct and operate pilot models of the reflector safety and power regulation control systems, and c) make a detailed engineering design of a "flux-trap" type nuclear mockup facility incorporating a reflector control system.

This report is submitted in fulfillment of part (b) of the contract with the Commission. Part A of this report describes the experimental work with the reflector model and Part B describes the analytical parameter studies performed toward selection of an optimum reflector control scheme.

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PART A

EXPERIMENTAL STUDIES WITH THE REFLECTOR CONTROL SYSTEM MODEL

1.0 INTRODUCTION

A reflector control system was selected for the Advanced Engineering Test Reactor because it offered the possibilities of minimizing flux perturbations in the core and test region and reducing the mechanical complexity associated with control rods. Because of the time limitations and because an optimum control system was of secondary importance in the INTERNUC-23 studies, only a limited effort was expended on studies of nuclear and mechanical design parameters of the reflector control system presented in that report.

Early in the working period of the present contract, mechanical design studies and hazards analysis indicated that the particular reflector control scheme presented in INTERNUC-23 was not necessarily an optimum one. Accordingly, a study of reflector control schemes was initiated. Detailed design of the reflector model was delayed pending the results of these studies. As the studies progressed, it became apparent that three control schemes had nearly equal merit. Because the model design had already been delayed three months, and because analytical studies probably could not completely resolve the relative merits of the different control schemes, it was decided to design a reflector model and model system that would be sufficiently versatile to simulate the safety and shim reflector actions of most of these control schemes.

The experimental work accomplished in the laboratory and with the model of the AETR reflector control system is presented in this part of the report. Reflector drop time was obtained for a variety of conditions. Rates of reactivity removal were calculated from the drop time data. The use of electrical conductivity for determining boric acid concentration was tested and other methods were investigated. Flow patterns were observed in the shim reflector of the model by injecting dye solution and the ion exchange equipment was tested for boric acid removal.

2.0 SUMMARY

Operation of the reflector control system model proved the operability and reliability of the functional design concepts embodied in the reflector control system presented in INTERNUC-23 and most subsequent variations of that design developed as a result of the reflector control system optimization and selection studies performed with funds provided by AEC contract AT(11-1)-688.

Detailed experiments conducted with various parts of the reflector control system model helped to determine their relative adequacy to perform their design functions in an operating nuclear system. These experiments also aided in bringing additional problem areas and possible functional design improvements to attention.

2.1 Safety Reflector Drop Time

Operation of the safety reflector portion of the model proved its operability and reliability in the performance of all the basic functions desired of it. Safety reflector water drop times achieved in the model were not as short as those predicted in INTERNUC-23. The experimental drop times achieved, however, are considered entirely adequate to warrant their use for the safety control of the flux trap type reactors presented in INTERNUC-23. A brief comparison of percent reactivity removed versus time, as calculated from drop times achieved in the model and as determined for the safety control rods of the ETR, is presented in Table 2.a.

Table 2.a

Percent Reactivity Removed Versus Time: Comparison of ETR Safety Control Rods and AETR Safety Reflector

Time After Scram, secs	Percent Reactivity Removed by ETR Safety Rods[2] (Shim rods fully removed)	Probable Percent Reactivity Removed by AETR Safety Reflector Based on Drop Times from Tests 403 and 406	
		Clean Shim	Fully Poisoned Shim
0	0	0	0
0.05	0.072	1.05	0.63
0.15	8.930	7.70	4.62
0.30	14.40*	26.7	16.00
0.98	-	50.0*	30.00*

*Total reactivity available

The safety reflector drop time experiments also indicated improvements in design details that are expected to decrease considerably the drop time achieved with a given area ratio.

2.2 Laboratory Experiments on Measuring Boric Acid Concentration and Ion-Exchange Resin Capabilities for Boric Acid

Conductivity measurements of a number of solutions of differing boric acid concentration indicate that electrical conductivity may be used to determine boric acid semi-quantitatively at concentrations greater than 0.5 gram per liter provided boric acid is the only ionized substance in solution. Small amounts of highly ionized corrosion products, however, perturb the solution conductivity sufficiently to make this method too inaccurate for semi-quantitative determinations of boric acid in solutions having such impurities.

Boric acid was shown to be easily removed from solution by use of ion exchange resins. Resin columns containing Rohm and Haas monobed resin MB-1 and columns containing anion resin IRA-400 followed by a polishing section of MB-1 resin were used with equal success. The capacity of these resin systems for boric acid was about 0.1 gram boric acid per gram of wet resin or about 4 pounds per cubic foot.

2.3 Dye Injection Experiments

The major significance of the dye injection experiments is that they provided considerable insight to the problems to be encountered in achieving power regulation with a shim reflector control system.

In conjunction with the experiments summarized in Section 2.4 below, the dye injection experiments helped prove the functional utility of the shim reflector system to perform nuclear shim control of an operating reactor. Some minor changes in mechanical design are indicated to improve the functional utility of the shim reflector and its auxilliary system.

2.4 Shim Reflector Experiment with Boric Acid Injection, Measurement and Removal

These experiments demonstrated that the conductivity measurements and ion exchange resin behave as would be expected from the results of the laboratory experiments. Conductivity was suitable for semi-quantitative measurement of the boric acid concentration in the system only at relatively high concentrations. However, changes in boric acid concentration were easily observed as changes in the conductivity. The ion eschange resin easily removed boric acid from the system.

The shim reflector system reliably performed all the design functions required of it. The rate of boric acid injection is limited by the head available across the flow control valve (V-3) but this can easily be corrected, if necessary, by a change in piping.

3.0 DESCRIPTION OF EQUIPMENT

This section presents a detailed general description of the reflector model and the laboratory equipment used in conducting the experiments reported. Alternative piping arrangements and other special arrangements or equipment involved in the experiments are described in detail in Appendix 2.0.

3.1 The Model of the Reflector Control System

The reflector control system model used to conduct a number of the experiments reported here was not entirely a simulation of the reflector control system presented in INTERNUC-23. It was a system incorporating features both of the three alternative reflector control systems outlined in Part B of this report and the reflector control system presented in INTERNUC-23. With a few exceptions, the reflector control system model used was able to simulate the four reflector control systems, as noted above, reasonably well. The two most notable exceptions were that a centrifugal pump, rather than the suction of a water jet eductor, was used to provide circulation in the main circulating system and no narrow-annulus shim reflector was provided. The type of data required from the shim reflector portion of the reflector model did not make it necessary to simulate exactly the shim reflector portion of any of the proposed control systems, however.

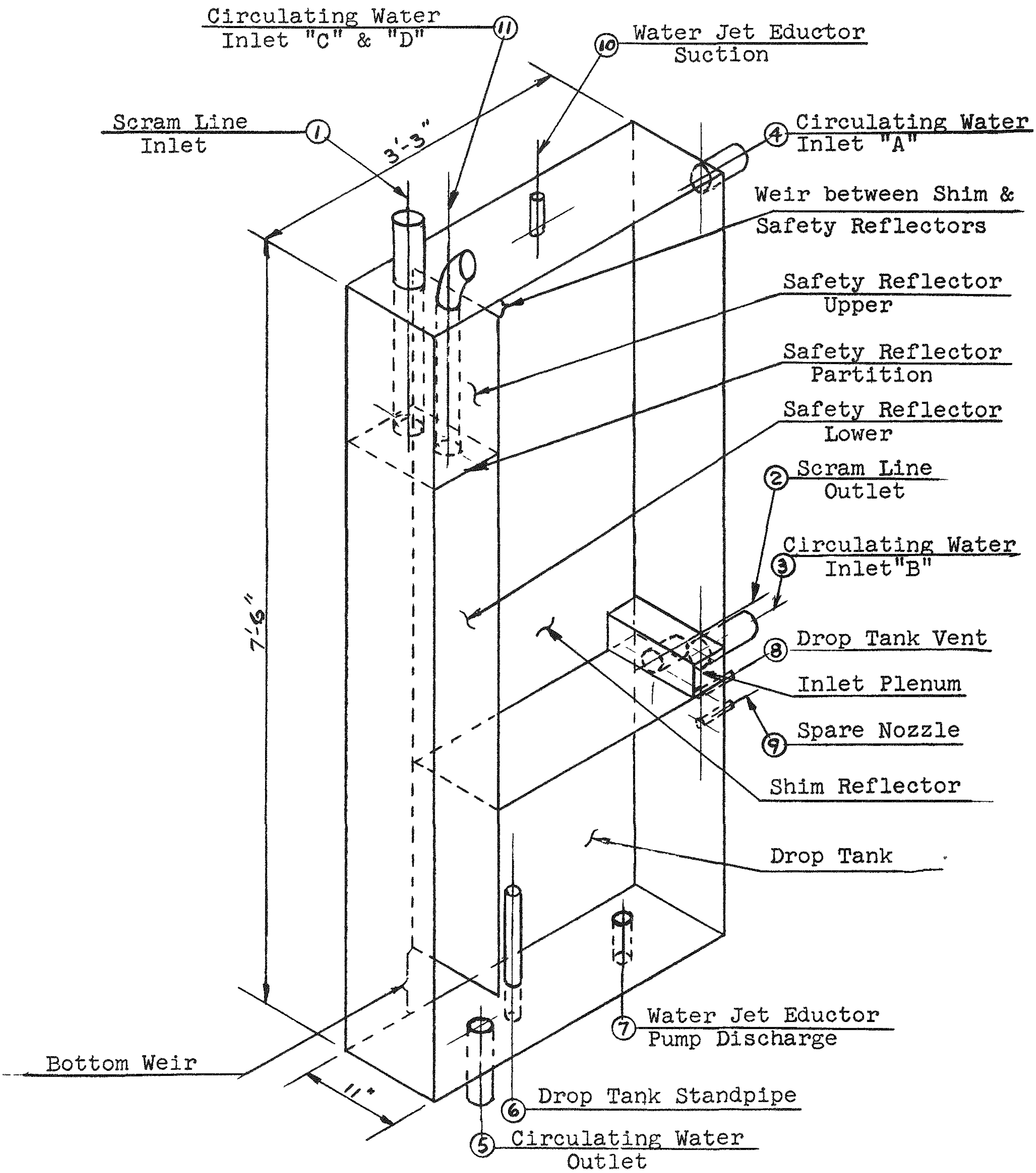
3.1.1 The Reflector Model

The reflector model is a right rectangular parallelapiped having the two largest opposing faces constructed of plexiglass to permit visual observation of the interior. An isometric view of the model, indicating the location and nomenclature of all major areas and pipe nozzles and major dimensions is shown in Figure 3.A. Both volumetrically and on a flow area basis, the model is a one-eight scale of the reflector design presented in INTERNUC-23 while its height is the full scale of that design. Other than this, the design of the reflector model varies considerably from the reflector design presented in INTERNUC-23. For example, the shim and upper safety reflector areas are connected by a weir so that one external pump and piping system can provide circulation in both the shim and safety reflector areas simultaneously.

The model is divided into four interconnecting compartments by internal partitions of half-inch thick aluminum plate as shown in Figure 3.A. The shim reflector area occupies the upper right hand portion of the model and is the largest of the

Figure 3.A

Isometric View of the Reflector Model



four areas. An inlet plenum, 4 inches square in cross-section and 11 inches long occupies the lower right hand corner of the shim reflector area. A total of thirteen 1 inch diameter holes on a 1-1/2 inch square pitch, skewed at a 45° angle with the horizontal, were drilled in the vertical face of this inlet plenum to provide flow distribution. Alternate inlets for the main circulating system into the shim reflector area were provided by nozzles 3 and 4, located as shown in Figure 3.A. A 1 inch pipe nozzle, nozzle 10, in the top of the model provides a connection between the suction line of the water jet eductor and the shim reflector area. A 1 inch wide by 11 inch long weir in the partition between the shim and upper safety reflectors allows for main circulating flow to occur between these two areas.

The upper safety reflector area in the upper left hand corner of the model is penetrated by two nozzles. Nozzle 1 provides the scram line inlet and nozzle 11 provides an alternate inlet for the main circulating water. The horizontal safety reflector partition forms the lower boundary of the upper safety reflector. Besides being penetrated both by the extensions from nozzles 1 and 11, the safety reflector partition has a 3 inch wide by 8 inch long rectangular opening that may be filled either by a blank plate, or an orifice plate with a 1 inch wide by 8 inch long opening in it. The blank plate is used when it is desired to completely separate the upper safety reflector from the lower safety reflector and the orifice plate is used when it is desired to use the upper and lower safety reflectors as a full length safety reflector unit.

The lower safety reflector extends from immediately below the safety reflector partition down to the bottom weir. Circulating or dropping water flows down the lower safety reflector column and into the drop tank, at the bottom of the model, through the bottom weir. The drop tank occupies the lower right hand portion of the model as seen in Figure 3.A. The circulating water outlet, nozzle 5, is a 2 1/2 inch nominal diameter pipe stub welded flush with the bottom of the drop-tank. The drop-tank standpipe,nozzle 6, is a 1 1/2 inch nominal diameter pipe stub penetrating the bottom of the drop-tank and extending 11 inches above it, or 3 inches higher than the bottom weir which is an 11-inch wide by 8-inch high opening. The water jet eductor pump discharge, nozzle 7, is a 1-1/4 inch nominal diamter pipe stub welded flush with the bottom of the drop tank. Nozzle 9 is a spare nozzle, originally intended to check various methods of indicating the water level in the drop-tank. Nozzle 8 is a 3/4 inch nominal diameter pipe stub welded flush in the side of the drop-tank and utilized as a system vent. The scram line outlet, nozzle 2, is a 3 inch nominal diameter pipe stub welded flush with the side of the drop-tank and near the top where it is unlikely to be choked with water. The main framework of the model is 1/4 inch and 1/2 inch thick aluminum plate. The 1/4 inch aluminum plate forms both sides and the top of the model. One-half inch thick aluminum plate was used for the bottom and all internal partitions. The two open faces of the aluminum frame are covered by plexiglas sheets. Two 4 foot by 8 foot sheets of 1/4 inch thick Rohm and Haas type G Plexiglas, trimmed to size and drilled for the attaching bolts, were used for the opposing faces of the model. Sealing strips for the joints between the plexiglas sheets and the aluminum framework are 1/2 inch wide by 1/8 inch thick and cut from black rubber gasket stock. These strips were liberally covered on both sides with plastic rubber cement (air-setting) just prior to making the seals. Thus the internal dimension between the opposing plexiglas faces of the model is nominally 11-1/4 inches. The plexiglas faces of the model are reinforced on the outside with both horizontal and vertical reinforcing bars of mild steel and on the inside with vertical aluminum angles. Twelve 1/2 inch diamter through-bolts inside the model helped to increase the rigidity of this reinforcing frame work and also to keep it from bowing in or out and thereby decreasing or increasing, respectively, the volumetric capacity of the model. The model is mounted on a stand of mild steel angle such that the bottom of the model is 2 feet above floor level.

3.1.2 The Main Circulating System

The design of the main circulating system of the reflector model is based on attempting to fulfill the system requirements of the main circulating systems of the 4 alternate reflector control schemes mentioned above. Since it was considered that downward water flow in the safety reflector was probably more conducive to short reflector drop times than upflow, no provision was made for upflow in the reflector model circulating system. The length of piping in the circulating system of the model was based partly on simulating the fraction of total system volume represented by the circulating systems of the four actual reflector control systems and partly on the necessity of providing a length of pipe as a calming section, both upstream and downstream, for the orifice plate. The relative elevations of the piping in the circulating system were based primarily on the necessity of providing a suction head for both pumps and secondarily on attempting to achieve the same relative elevations as would probably be encountered with the actual reflector control systems.

An isometric drawing of the entire piping system for the reflector control system model is presented in Figure 3.B. The pump suction line, between nozzle 5 and the inlet to the main circulating pump, is 2-1/2 inch nominal diameter, schedule 40 aluminum pipe. All the rest of the pipe in the main circulating system is 2 inch nominal diameter, schedule 40 aluminum pipe. All the valves in the main circulating system are 2 inch Jamesbury Double Seal aluminum ball valves. All fittings in the main circulating system are screwed aluminum fittings except the orifice plate flanges, which are cast iron, and the orifice plate, which is 316 stainless. The circulating pump is a Jacuzzi Model 3AM2 close-coupled centrifugal pump rated at 140 gpm at 50 feet H_2O total head. All parts of the pump in contact with the water are either high-tin bronze or stainless steel. Valve V-21 is a 3/4 inch brass spigot through which samples of the circulating system water may be drawn. Valve V-15, also a 3/4 inch brass spigot is used to fill the system with water via a garden hose from the building water supply.

3.1.3 The Water Jet Eductor System

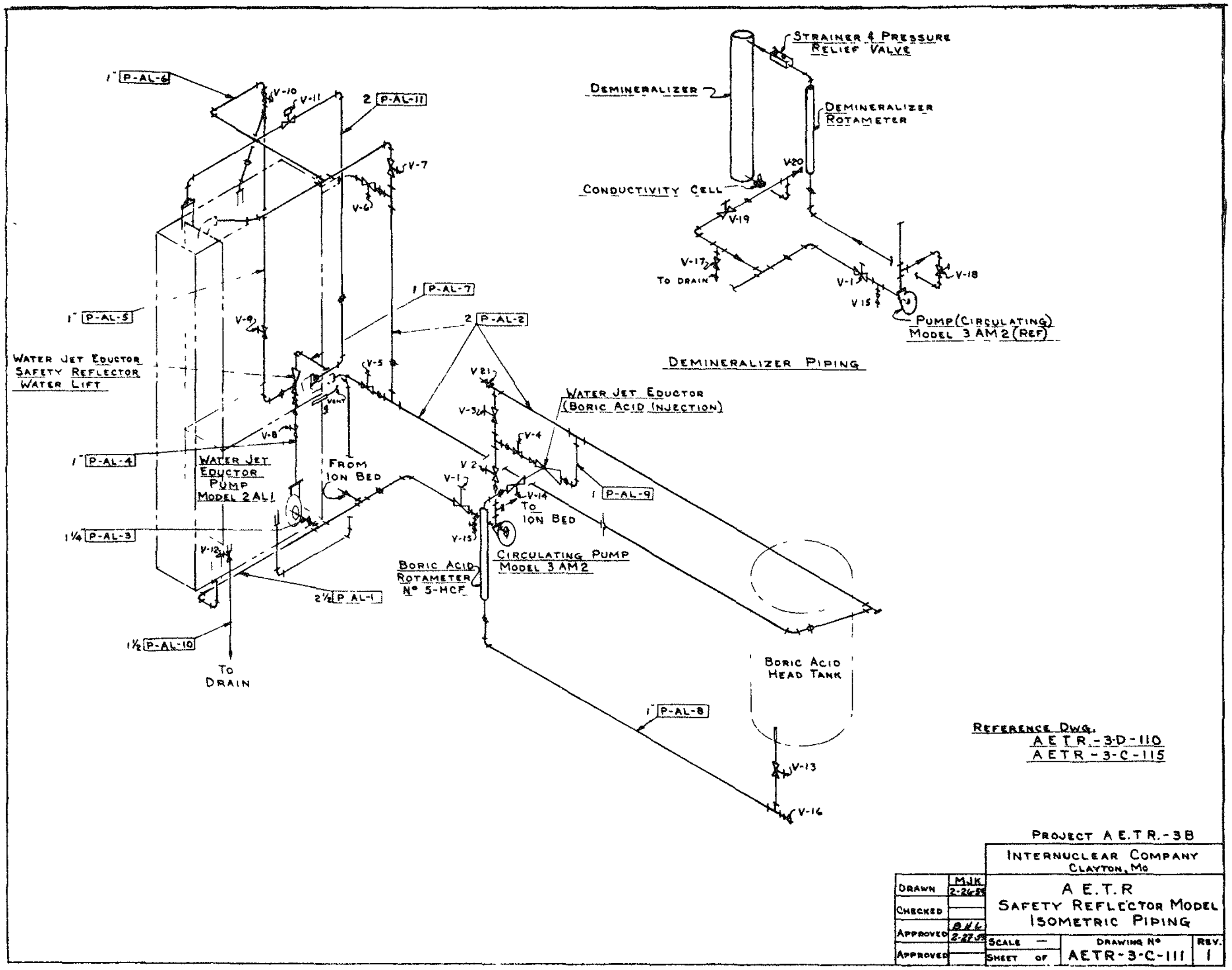
As indicated in Figure 3.B, the water jet eductor system consists of the following pipe lines: 1 1/4 inch P-AL-3, the inlet to the water jet eductor pump; 1 inch P-AL-5 and 1 inch P-Al-6 which are the vacuum lines from the water jet eductor suction to the top of the reflector model and the high point in the main circulating piping system, respectively; and 1 inch P-AL-7, the common pump and water jet eductor discharge line back into the bottom of the drop tank. All pipe in the water jet eductor system is aluminum and sized as indicated in the pipe designations of Figure 3.B. All valves in the system are 1 inch Jamesbury Double Seal aluminum ball valves. All fittings in the system are screwed aluminum. The eductor is a Schutte-Koerting Figure 264-1 one incn water jet eductor in bronze. A Jacuzzi model 2AL-1 close-coupled centrifugal pump rated at 25 gpm at 100 ft H_2O head provides the necessary pressure head across the water jet eductor.

3.1.4 The Boric Acid Injection System

The boric acid injection system, as shown in Figure 3.B, consists of a boric acid head tank, metering rotameter and water jet eductor for injecting the solution from the head tank into the main circulating system. The boric acid head tank is a 55 gallon 316 stainless steel drum with bottom outlet and removable seal cover. The rotameter is a Schutte-Koerting Figure 1827 Rotameter No. 5HCF with a 50-J float and direct reading scale calibrated for boric acid solution of 1.06 specific gravity. The flow rate range of this rotameter is

Figure 3.B

Isometric View of Reflector Control System, Model and Piping



1.0 to 12 gpm. The water jet eductor used in the boric acid injection system is the same kind, in all respects, as that used in the water jet eductor system. All pipe and fittings in the boric acid injection system are nominal 1 inch diameter aluminum. All valves in the boric acid injection system are 1 inch Jamesbury Double Seal aluminum ball valves. The pressure head necessary to operate the water jet eductor in this system is developed across valve V-3. Valve V-16 is a 3/4 inch brass spigot valve used to drain the boric acid system.

3.1.5 The Demineralizer System

The demineralizer system is shown in Figure 3.B, transposed from its actual location for clarity, and consists of a metering rotameter and a demineralizer. The rotameter is a Schutte-Koerting Figure 1827 Rotameter No. 4HCF with a 40-J float, regular scale and calibration chart. The demineralizer is an Elgin Junior 120, a trade-mark name of a rental unit supplied by the Elgin-Refinite Products Company. It uses approximately 1/2 ft^3 of Rohm and Haas MB-2 resin and has a rated capacity of 6300 grains (0.9 lb) of absorbed ionic solids. All pipe and fittings in the demineralizer system are 3/4 inch nominal diameter screwed aluminum with the exception of the 1/2 inch lines at the inlet and outlet of the demineralizer and the short section of 2 inch line attaching the demineralizer outlet to the main circulating system. Valves V-18 and V-19 are 3/4 inch Powell aluminum globe valves. Valve V-17 is is a 2 inch Jamesbury Double Seal aluminum ball valve used to drain the entire system and the reflector model. Valve V-20 is a 3/4 inch brass spigot used to obtain samples of the outlet water from the demineralizer.

3.2 Laboratory Equipment

A small amount of laboratory equipment was required for boric acid and ion exchange resin studies. This equipment was necessary for preparing and diluting solutions, measuring the conductivity of these solutions, and measuring the capacity of ion exchange resin for boric acid.

3.2.1 Equipment for Measurement of Boric Acid Concentration

A number of standard boric acid solutions were prepared by dissolving a measured amount of boric acid in 250 and 500 ml volumetric flasks. All dillutions and titrations were made with standard volumetric glassware. The boric acid was measured by weighing on a triple beam balance. The boric acid concentrations were then measured by two methods - electrical conductivity and titration with standard caustic. The resistivity, the recripocal of conductivity, of the samples was measured by a conductivity cell and meter. The conductivity meter, an Industrial Instruments Type RC-16 meter, is basically a Wheatstone bridge. The conductivity cell is an Industrial Instruments Model Cel-2A with platinized electrodes and a cell constant of 0.1

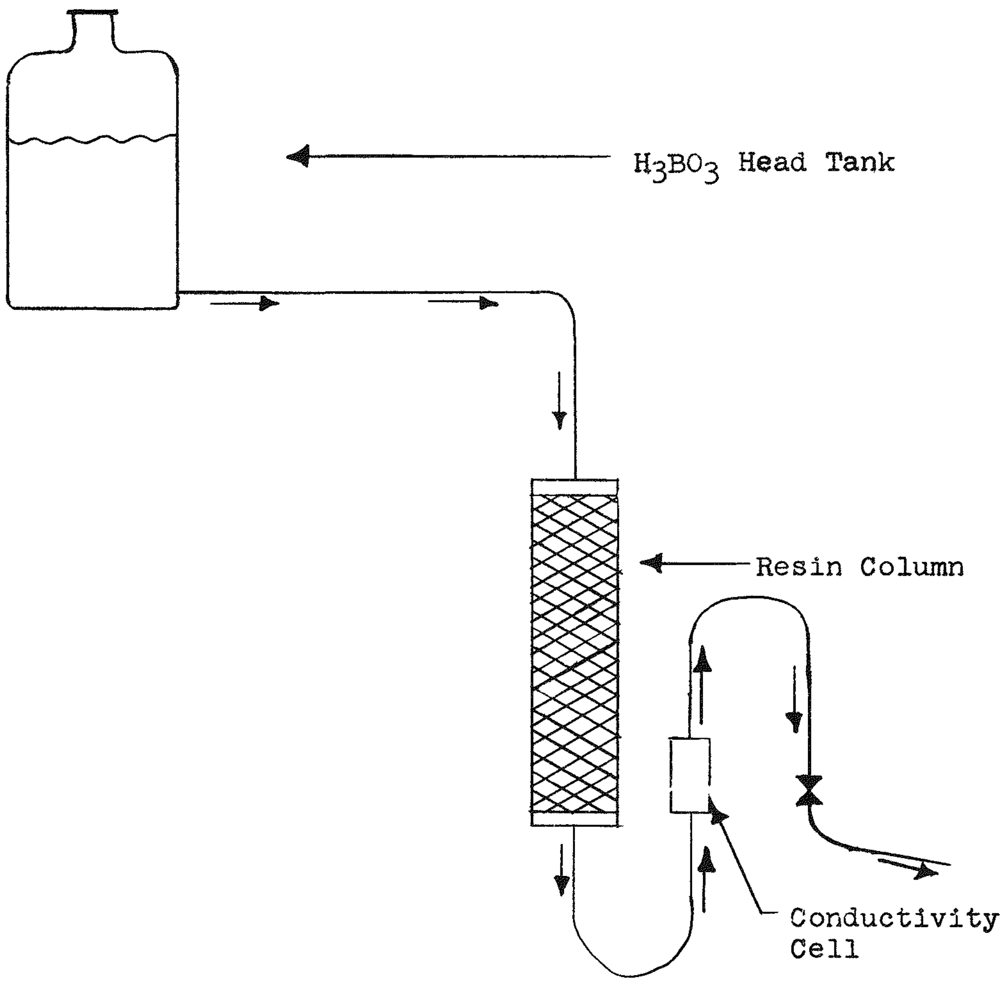
This conductivity cell and meter combination permitted measurement of resistivity over a range of 2 to 2.5×10^7 ohm-cm at frequencies of both 50/60 and 1000 cycles per second.

3.2.2 Equipment to Determine Ion Exchange Capacity of Resins for Boric Acid

The capacity of ion exchange resins for boric acid was determined by measuring the effluent resistivity from a small resin column. The experimental set up is shown in Figure 3.C. The resin column used was a glass tube 25 mm outside diameter and about 20 inches long. The effluent resistivity was measured with an Industrial Instruments Model D01 flow type conductivity cell and the conductivity meter described in Section 3.2.1.

Figure 3.C

Breakthrough Curve Setup



4.0 EXPERIMENTAL METHODS AND RESULTS

This section presents a brief outline and description of the experimental methods employed in both the laboratory experiments and the reflector model experiments conducted under AEC contract AT(11-1)688. Where applicable, a detailed presentation of the experimental methods, test conditions and special equipment arrangements used, is made in the Appendices. A brief presentation of experimental results is also made in this section with a detailed presentation of results usually appearing in the Appendices. In addition, certain phenomena that were observed during the course of the experiments with the reflector control system model, that are not reported in the detailed numerical data presented but never-the-less help to provide a better understanding of the relative effects of some of the parameters involved in the drop time, are described and discussed. In either case, the text will indicate whether all experimental methods or all results are presented in this section or in the Appendices.

4.1 Experimental Methods - Safety Reflector Drop Time

The basic method used to determine the drop time of the water in the safety reflector column was to take moving pictures of the water drop and a high speed timer simultaneously. The action of the water drop and that of the timer were initiated simultaneously by an electric "scram" circuit. Details concerning this procedure are presented in Appendix 2.0. In order to obtain a more representative set of data, five separate filmings of the water drop were taken for each combination of test conditions investigated. Details concerning the methods used to extract the numerical time-displacement data from the movie film are given in Appendix 3.0.

4.2 Experimental Methods - Conductivity of Boric Acid Solutions

The conductivity of a number of boric acid solutions was measured by use of the equipment described in Section 3.2.1. The boric acid solutions were made up by dissolving a measured amount of boric acid in deionized water. These solutions were successively diluted and the resistivity and temperature of each solution measured. The resistivity of the water used in making and diluting all solutions was always greater than one megohm-cm. A detailed description of the procedure used is presented in Appendix 8.0.

The resistivity of various other solutions was measured in order that an estimate of the effect of corrosion products and other impurities could be evaluated. The solutions measured included sodium chloride and/or aluminum oxide as impurities and mixtures of these with boric acid.

4.3 Experimental Methods -Ion Exchange Resin Capacity for Boric Acid

The ability of ion exchange resins to remove boric acid from the shim reflector was investigated by use of breakthrough curves. To obtain these breakthrough curves, a solution of known concentration was passed through the resin. The resistivity of the ion exchange column's discharge was then monitored. After a measured volume of liquid had passed through the column, the effluent resistivity was measured. Periodically the temperature of the effluent was measured so that the resistivity readings could be corrected for temperature variations. The liquid flow rate was also measured periodically.

The capacities of the ion exchange resins used in these tests were obtained from the breakthrough curves. The resistivity of the effluent water was plotted against the volume of liquid passed through the column. When a large decrease in the effluent resistivity occured, breakthrough was assumed to have occured.

4.4 Experimental Methods - Dye Injection Experiments

The rate of dye diffusion in the shim reflector was obtained by taking moving pictures of the dye diffusion and a high speed timer simultaneously. The action of the dye injection and that of the timer were initiated, as nearly simultaneously as possible, by manual operation of the dye injection valve (V-14) and the timer start switch. In order to obtain a more representative set of data, four separate filmings of the diffusing dye were taken for each set of test conditions investigated. The major parameters in the dye injection experiments were main circulating system flow rate and dye injection rate. The only circulating system piping arrangement used was pipe arrangement "B", described in detail in Appendix 2.0. The numerical time-diffusion data were extracted from the movie film in much the same manner as were the numerical time-displacement data for the safety reflector drop time (as described in Appendix 3.0). A grid, drawn to a scale that essentially converted the area of the shim reflector, as shown in the enlargement, to fractions of a square foot on the basis of the size of the shim reflector, was placed over each enlargement to aid in determining the area of the shim reflector covered by the dye solution at a given time.

4.5 Experimental Methods - Shim Reflector Experiment with Boric Acid Injection, Measurement and Removal

The dynamic behavior of the shim reflector and the conductivity method of measuring boric acid concentration were investigated. The general procedure used in all runs is described below. The operating log and specific details of each run are presented in Appendix 9.0.

Prior to boric acid injection, the water in the model was cleaned up by passing it through the ion exchange resin column. Cleanup was continued until the resistivity of the water in the model was about 1.5 megohm-cm purity.

After the system had been cleaned up, a fresh charge of resin was placed in the ion exchange column. Samples were taken from both the model and the boric acid head tank for boric acid analysis.

When steady operation had been achieved after replacing the resin in the ion exchange column, the column was shut off and boric acid injection started. During the addition, as many reading and samples were taken as was possible. After 20 to 25 gallons of the boric acid solution had been added, the injection was stopped. Circulation with no cleanup was continued until equilibrium appeared to have been achieved. Then the ion exchange column was placed on stream. The system was allowed to run until either the boric acid was cleaned-up or the resin exhausted.

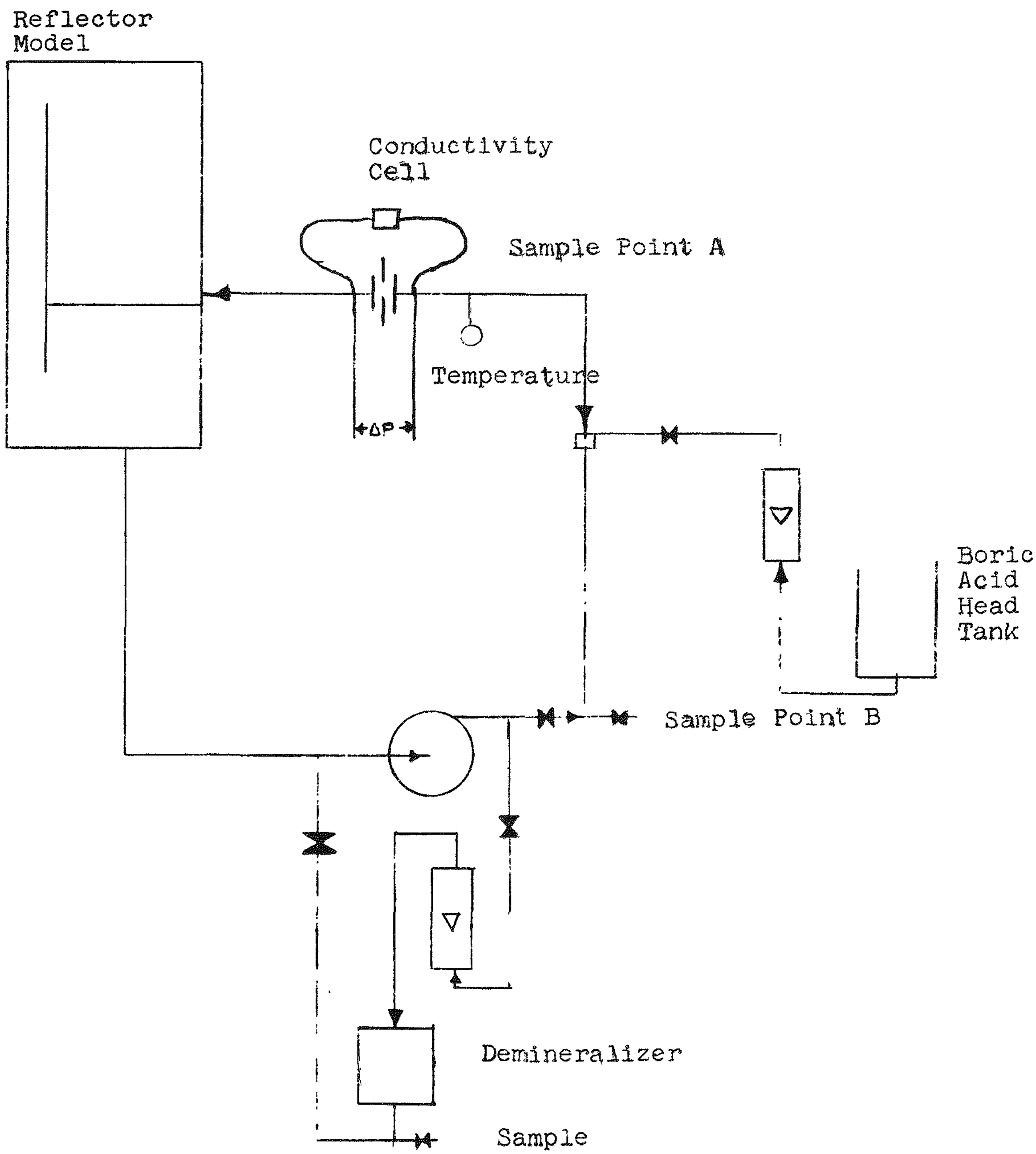
Throughout each run, water samples, resistivity and flow rate measurements were taken at three points. The first set of readings were taken from Point A (See Figure 4.A). At this point, the resistivity, temperature and flow rate of the water circulating through the model were taken. The resistivity measurements were made with a flow conductivity cell.

From Point B water samples were taken for dip cell resistivity measurements, temperature, and boric acid analysis. These samples are samples of the circulating water and should agree with measurements at Point A except when boric acid was being added to the system.

Samples of the effluent from the ion exchange column were taken at Point C. These samples were analyzed for resistivity, temperature, and boric acid concentration.

Figure 4.A

Boric Acid Injection Test Setup



Water samples which were to be analyzed for boric acid concentration were analyzed both by Internuclear Company personnel and by the Saint Louis Testing Laboratory. For details, see Appendix 9.0.

4.6 Experimental Results - Safety Reflector Drop Time

Safety reflector drop time experiments were conducted with three basic variable parameters; scram line size (area ratio), main circulating system pipe arrangement, and flow rate of the water in the main circulating system. Since scram line size is by far the most important parameter involved in the safety reflector drop time, the experimental results reported here were chosen as being typical of the particular scram line size group they represented. The data in this section is presented as a plot of displacement versus time, based on the "averaged" data, and showing the data spread. Complete primary time-displacement data is presented in Appendix 4.0 and complete "averaged" time-displacement data is presented in Appendix 5.0. In both cases, all data in the Appendix is in numerical form.

The drop of the water in the safety reflector column with a 1 inch nominal diameter, closed circuit scram line and a 1 inch solenoid valve is represented graphically in Figures 4.B and 4.C.* Figure 4.B is a plot of the time displacement data from safety reflector drop test number 4 and Figure 4.C is a plot of the time-displacement data from safety reflector drop test number 19. Additional details on the test conditions obtaining in these two tests may be found in Table A2.a of Appendix 2.0.

The drop of the water in the safety reflector column with a 2 inch nominal diameter, closed circuit scram line and a 2 inch solenoid valve is represented graphically in Figures 4.D and 4.E. Figure 4.D is a plot of the time-displacement data from safety reflector drop test numbers 25 and 36 and Figure 4.E is a plot of the time-displacement data from safety reflector drop test numbers 33 and 39. Additional details on the test conditions obtaining in these four tests may be found in Table A2.a of Appendix 2.0.

The drop of the water in the safety reflector column with a 1 inch nominal diameter, open circuit scram line and a 1 inch solenoid valve is represented graphically in Figures 4.F and 4.G. Figure 4.F is a plot of the time-displacement data from safety reflector drop test numbers 202 and 205, and Figure 4.G is a plot of the time-displacement data from safety reflector drop test numbers 203 and 206. Additional details on the test conditions maintained in these four tests may be found in Table A2.a of Appendix 2.0.

* Note: All figures presenting results from Section 4.0 will be found at the end of the Section.

The drop of the water in the safety reflector column with a 2 inch nominal diameter, open circuit scram line and a 2 inch solenoid valve is represented graphically in Figures 4.H and 4.I. Figure 4.H is a plot of the time-displacement data from safety reflector drop test numbers 301 and 304 and Figure 4.I is a plot of the time-displacement data from safety reflector drop test number 307 and 310. Additional details on the test conditions obtaining in these four tests may be found in Table A2.a of Appendix 2.0.

The drop of the water in the safety reflector column with a 2 inch nominal diameter scram line and both a 1 inch and a 2 inch solenoid valve, in parallel, is represented graphically in Figures 4.J and 4.K. Figure 4.J is a plot of the time-displacement data from safety reflector drop test numbers 401 and 404 and Figure 4.K is a plot of the time-displacement data from safety reflector drop test numbers 403 and 406. Additional details on the test conditions obtaining in these four tests may be found in Table A2.a of Appendix 2.0.

It should be pointed out that the basic data, from which all the results presented above in this section and in Appendices 4.0 and 5.0 were obtained, is contained on 13 one hundred foot rolls of 16 mm motion picture film. Thus the film is available for review of the original data.

Phenomena observed in the laboratory but not reported among the detailed numerical data presented are reported below.

A phenomenon observed in the laboratory indicated that safety reflector drop times (with a given area ratio) may be decreased somewhat by utilizing long radius elbows, instead of short radius elbows, wherever a change in scram line direction is desired. The observations leading to this conclusion follow. During reported drop tests it was noted that a discharge of water from the drop tank vent line was invariably associated with the shortest drop times. The highest water discharges were associated with the shortest drop times. For example, when the series 300 drop tests were conducted, no water was observed to shoot out of the drop tank vent line, but when the series 400 drop tests were conducted, water shot out of the drop tank vent line with sufficient force to hit the ceiling. After all drop tests reported here were completed, the 2 inch, 90° ell was removed from the short 2 inch nipple extending vertically out of nozzle 1 and the 2 inch solenoid valve was screwed directly onto this nipple such that it was also mounted vertically, a position that is not recommended for operation. The valve operated well in this position, however, and it was noted that water would shoot out of the drop tank vent line, almost to the ceiling, when the model was scrammed with the 2 inch solenoid mounted in this position. Therefore, it is concluded that the drop time is adversely affected by the short-radius elbows used in the scram line in all drop tests and that the use of long-radius elbow would shorten the drop times achieved as would be expected considering the decreased resistance to gas flow offered by the long-radius elbows.

As noted in detail in Appendix 6.0, the water jet eductor performed both reliably and adequately to raise the water in the safety reflector column. Ordinarily, the water column rises with a smooth, steady motion. Occasionally in every rise, however, the water column appears to hesitate momentarily and then rise again, very rapidly, for a total displacement of between 2 and 3 inches. Whether the magnitude of this jerking motion is sufficient to reflect on the overall safety of the concept can only be determined by analytical studies. Whether or not it can be elminated by design is questionable.

As the reflector model was originally designed, water from the water jet eductor pump was supposed to enter the drop tank through nozzle 8 (shown in Figure 3.A). In the first test of raising the water in the safety reflector after the model was piped up it was apparent that this arrangement was not appropriate. The water would shoot horizontally out of nozzle 8 across the drop tank and strike the water in the drop tank just short of the partition between the drop tank and the safety reflector. This would carry many large air bubbles through the bottom weir into the safety reflector such that the water jet eductor was never able to completely evacuate the air from the safety reflector. As a result, the piping was changed to make nozzle 7 the inlet from the water jet eductor pump. This arrangement worked excellently.

Whenever the main circulating system pump was causing flow in excess of about 80 gpm a vortex would appear in the water of the drop tank. This vortex would never quite reach the water outlet but it definitely indicates that care must be taken in design to provide either a sufficient number of outlets or outlets of sufficient size to insure that air from the drop tank is not drawn into the pump suction line through the formation of a vortex. Some type of shield, to act as a vortex breaker, might also be provided over each outlet.

4.7 Experimental Results - Conductivity of Boric Acid Solutions

The conductivity of boric acid solutions was determined by measuring the resistivity of the solution. The results of these measurements are presented in Figure 4.L.

The resistivities of a number of other solutions were measured to determine what effect corrosion products have on the resistivity of boric acid solutions. The results of these measurements are shown in Figure 4.M. In this figure, the solution resistivity is plotted as a function of the boric acid concentration in the solution. The boric acid concentration of the boric oxide solutions was taken as that concentration of acid which would be formed by the boric oxide.

$$B_2O_3 + 3H_2O = 2H_3BO_3$$

All primary data are presented in Section A8.1.a of Appendix 8.0.

4.8 Experimental Results - Ion Exchange Resin Capacity for Boric Acid

The ion exchange resins behaved as expected - they removed boric acid easily and completely. The results are summarized in Table 4.a. The resin removed from 0.09 to 0.15 grams of boric acid per milliliter of wet resin. In all runs the point of breakthrough was quite sharp and resulted in an abrupt decrease in the effluent resistivity.

The velocity at which the boric acid solution passed through the column had a marked effect upon the effluent resistivity and the ion exchange capacity. At very low flow rates, about 0.2 mℓ/sec, the indicated resistivity was quite low (See Figure A8.a). When the velocity was increased, the indicated resistivity increased about 50%. However, as the flow rate was further increased, to about 2.5 mℓ/sec the ion exchange capacity decreased.

Table 4.a

Resin Performance

Run	A	B	C		D		E	F
Resin	MB-1	MB-1	MB-1 24.8%	IRA-400 (in Cl^- form) 75.2%	MB-1 19.4%	IRA-400 (in OH^- form) 80.5%	MB-1	MB-1
Solution gmH_3BO_3/ℓ	20	20	20		20		20	20+ 1 gm Al_2O_3/ℓ
Capacity (gmH_3BO_3/gm Wet Resin)	0.151	0.114	0.148* 0.037**		0.125**		0.096	0.088
Liquid Velocity ($m\ell$/sec)	0.2-0.6	2	1.4-1.5		1.2		2.3	2.5
Effluent Resistivity Before Breakthru (megohm-cm)	6-7	6-7	3		2-4		4	9
Bed Shrinkage (percent)	5.1	5.8	21	-3	2.6	3.0	7	8.8

* Based upon MB-1 only as IRA-400 was in $C\ell^-$ form
** Capacity based upon weight of both IRA-400 and MB-1

4.9 Experimental Results - Dye Injection Experiments

All the experimental results of the dye injection experiments conducted in the shim reflector portion of the reflector model are presented in this section. Table 4.b outlines the test conditions maintained during each of the four runs comprising the different dye injection tests.

Table 4.b

Test Conditions in the Dye Injection Experiments

Test Number	Flow Rate Main Circulating Stream gpm	Flow Rate Dye Injection Stream gpm	Water Temperature °F.
101-A	80	5.0	86-90
102-A	80	1.8	85
103-B	80	3.5	85
104-B	100	2.5	84-85
105-A	100	1.6	85
106-A	100	2.1	82-84

Table 4.c presents the primary time-area covered data obtained from the enlargements made of individual frames in the motion picture films taken of the dye diffusion. The position of the camera relative to the model was such that only about 70% of the total shim reflector area appeared on the film. Also, with the 26x lens used in the Thermo-Fax Microfilm Reader-Printer to enlarge the films, only about 85% of the picture on the motion picture film could be enlarged. As a result, only about 60% of the total shim reflector area appeared in the enlargement. This necessitated an adjustment in the primary data in order to present a valid representation of the diffusion of the dye solution in the shim reflector. The adjusted diffusion data is presented in Table 4.d and the adjustment is explained in Section 5.4.

Table 4.c

Primary Time-Area Covered Data from Dye Injection Experiments

Test and Run Number	Time, Seconds, After Dye Injection Initiated 5	10	15	20	25	30
	Area Covered (sq.ft.)					
101-A						
1	1.19	3.18	4.66	5.45	6.72	7.72
2	1.04	4.97	5.28	6.27	6.59	7.72
3	1.42	4.16	5.06	5.60	6.31	7.72
4	0.95	3.97	4.63	5.63	6.59	7.72
Ave.	1.15	4.07	4.91	5.74	6.55	7.72
102-A						
1	0.34	2.48	--	3.86	4.11	4.39
2	0.31	2.08	3.45	3.97	4.11	4.13
3	0.47	2.47	3.45	3.97	4.11	4.69
4	0.38	2.59	3.41	3.97	4.11	5.45
Ave.	0.38	2.41	3.44	3.94	4.11	4.67
103-B						
1	0.89	3.59	4.80	6.31	7.72	--
2	0.31	3.06	5.31	6.17	7.72	--
3	0.38	3.25	5.14	6.61	7.72	--
4	0.28	3.38	5.53	5.89	7.72	--
Ave.	0.47	3.32	5.20	6.25	7.72	--
104-B						
1	0.84	3.91	4.88	6.84	7.72	--
2	1.55	2.56	5.54	7.03	7.72	--
3	1.05	2.39	5.13	6.03	7.37	7.72
4	0.50	2.77	3.30	5.35	7.11	7.72
Ave.	0.98	2.91	4.81	6.31	7.48	7.72
105-A						
1	0.96	3.03	3.83	5.75	6.67	7.72
2	1.75	3.70	4.28	6.39	7.22	7.72
3	1.34	3.22	4.49	5.27	7.72	--
4	1.47	4.72	--	--	7.72	--
Ave.	1.38	3.67	4.20	5.80	7.33	7.72
106-A						
1	0.66	2.50	3.45	4.91	6.86	7.72
2	1.19	3.34	4.63	6.19	7.72	--
3	0.56	1.38*	3.56	--	7.72	--
4	0.38	3.50	5.38	5.84	7.72	--
Ave.	0.70	3.11	4.25	5.65	7.51	7.72

*Assumed to be spurious - not averaged.

Table 4.d

Adjusted Time-Fraction Area Covered Data
From Dye Injection Tests

Test Number	Time, Seconds, After Dye Injection Initiated 5	10	15	20	25	30
	Fraction of Area Covered					
101-A	0.089	0.326	0.538	0.720	0.875	1.000
102-A	0.029	0.177	0.350	0.515	0.670	0.819
103-B	0.036	0.255	0.500	0.750	1.000	
104-B	0.075	0.302	0.510	0.693	0.857	1.000
105-A	0.106	0.282	0.465	0.635	0.818	1.000
106-A	0.054	0.268	0.470	0.662	0.830	1.000

4.10 Experimental Results - Shim Reflector Experiment with Boric Acid Injection, Measurement and Removal

Operation of the shim reflector model with boric acid injection, measurement, and removal was completely successful in one run (Run 2) and only moderately successful in the other (Run 1). Therefore, only the results of Run 2 are presented in this section. All data taken from both runs is presented in Appendix 9.0

The first objective of these runs was to remove the ionic matter from the water in the shim reflector model. The results of this operation are shown in Figure 4.N. With a flow rate of 90 gpm through the model, 2.6 gpm through the resin column and when the water resistivity was below one megohm-cm, the impurities were removed at a rate such that the resistivity of the water increased exponentially with a half life of 36 minutes. The maximum purity obtained was about three megohm-cm. A total of about 5 hours was required to perform this operation.

The second objective of these runs was to inject and then remove boric acid in the shim reflector model. The results of these operations are shown in Figure 4.O. In this figure, the continuous curve is the resistivity of the circulating water as measured at point A with the flow type conductivity cell. The bars in the figure are the boric acid concentrations as analyzed in samples taken from point B. The rate at which boric acid was removed from the system by the ion exchange resins was exponential. The half life of the first batch of resin was 72 minutes and the half life of the second batch of resin was about 84 minutes.

A detailed plot of the water resistivity at point A, uncorrected for temperature changes, during boric acid injection is shown in Figure 4.P.

The third objective of this series of tests was to test the conductivity method of measuring boric acid in a dynamic system. These results are shown in Table 4.e in which the boric acid concentration of a number of samples is presented 1) as analyzed by St. Louis Testing Laboratory and 2) as measured by use of resistivity and the calibration curve presented in Figure 4.L.

Table 4.e

Boric Acid Measurement

Sample Number	Boric Acid Concentration By Chemical Analysis (gms/ℓ)	Boric Acid Concentration By Conductivity (gms/ℓ)
100	None*	Less than 0.1
101	5.79	6.4
102	30.80	27.2
103	3.91	4.2
104	3.91	Less than 0.1
105	3.91	3.7
106	3.91	Less than 0.1
107	3.91	3.7
119	3.91	3.25
134	3.91	3.4
200	9.64	10.5
201	0.03	Less than 0.1
202	2.19	1.3
203	Less than 0.01	Less than 0.1
204	0.985	1.0
205	1.02	0.33
206	1.02	0.28
207	1.03	0.33
208	Less than 0.01	Less than 0.1
209	0.57	Less than 0.1
211	0.18	Less than 0.1
212	0.07	Less than 0.1
213	0.15	Less than 0.1
214	0.15	Less than 0.1
215	0.15	Less than 0.1
216	0.15	Less than 0.1
217	0.15	Less than 0.1
218	0.16	Less than 0.1
219	0.15	Less than 0.1
220	0.16	Less than 0.1

* This sample was taken as a "blank" and arbitrarily assigned a 0.0 boric acid concentration

Figure 4.B
Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Number 4

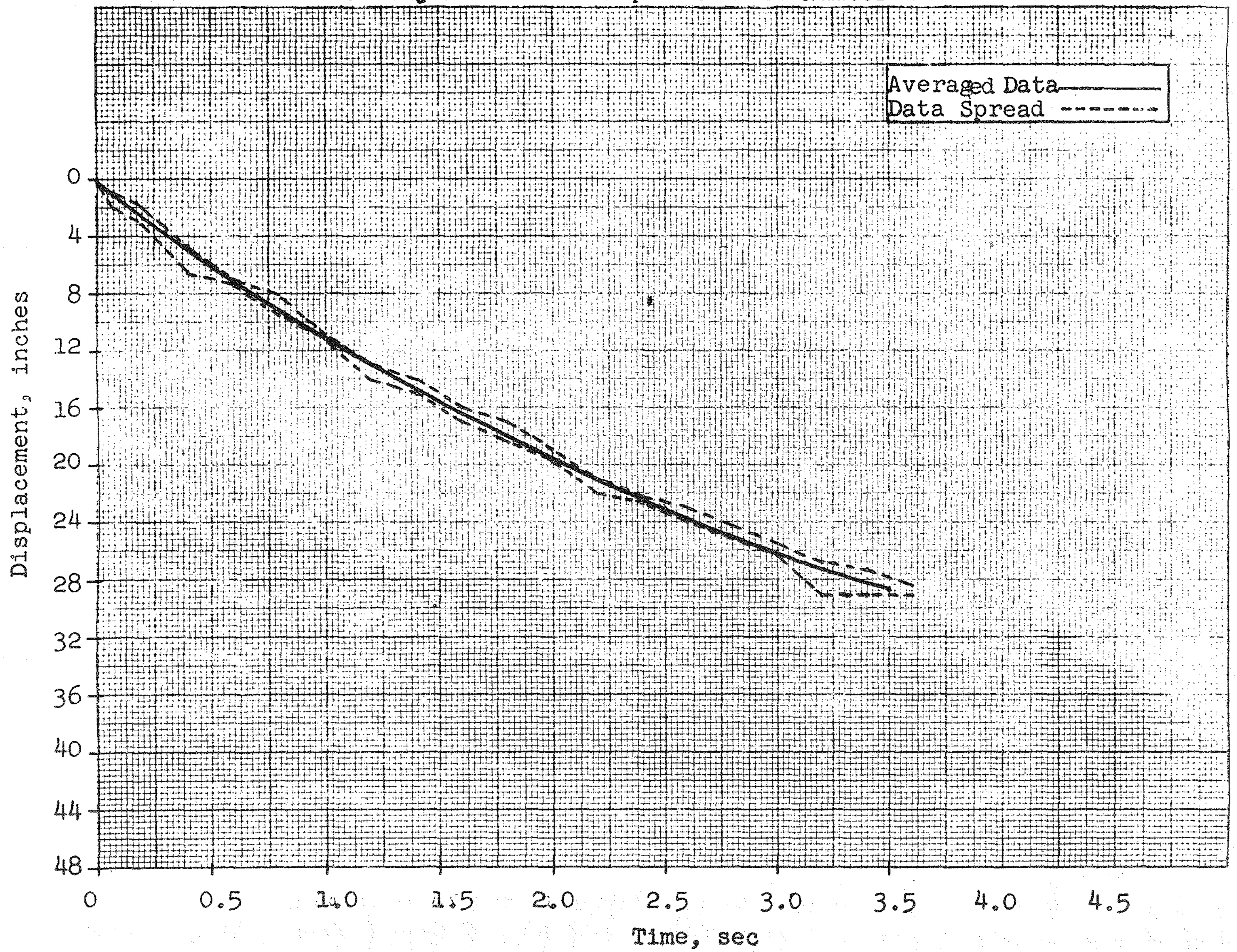


Figure 4.C
Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Number 19

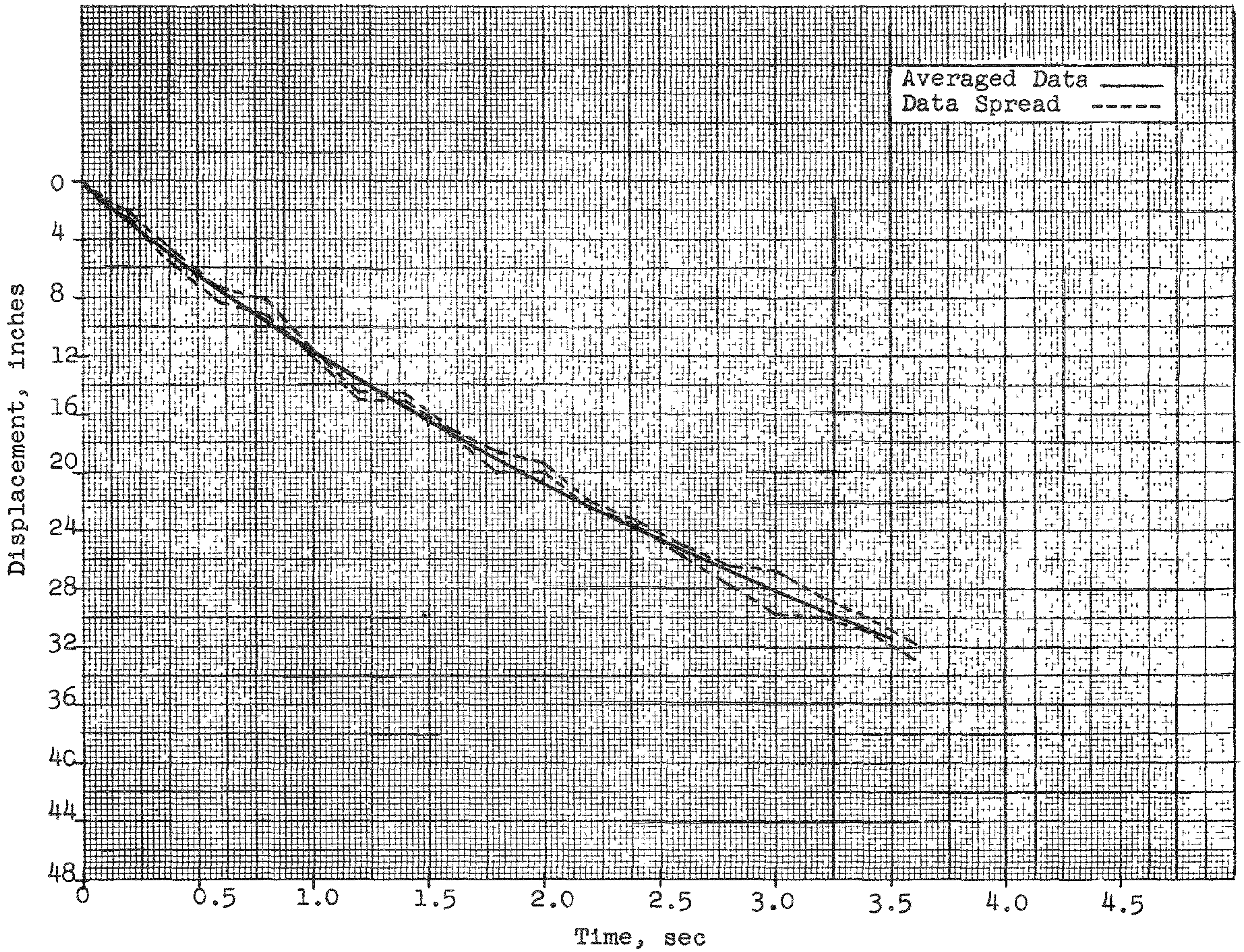


Figure 4.D

Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Numbers 25 & 36

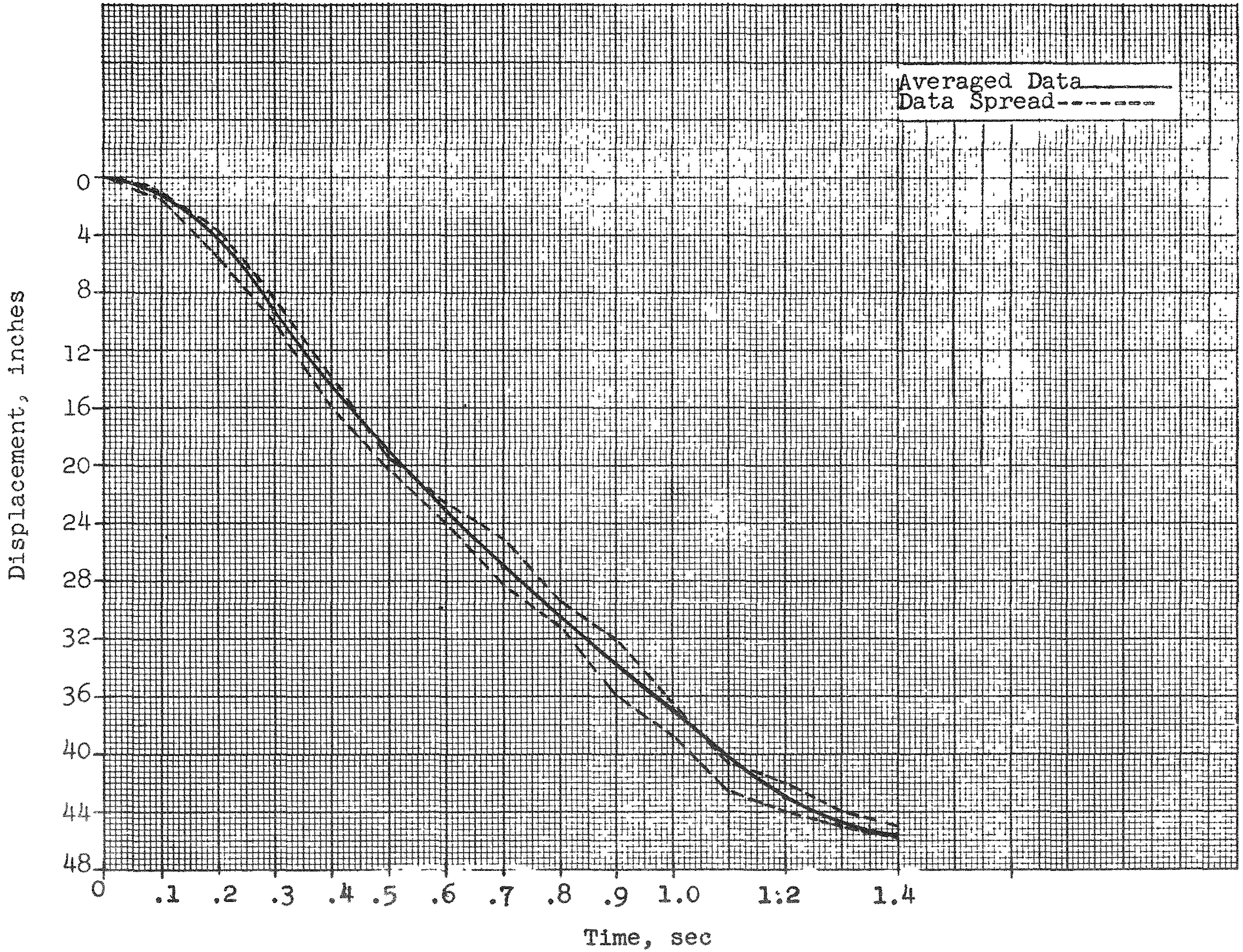


Figure 4.E
Plot of Averaged Time-Displacement Data and Data Spread for
Safety Reflector Drop-Time Test Numbers 33 & 39

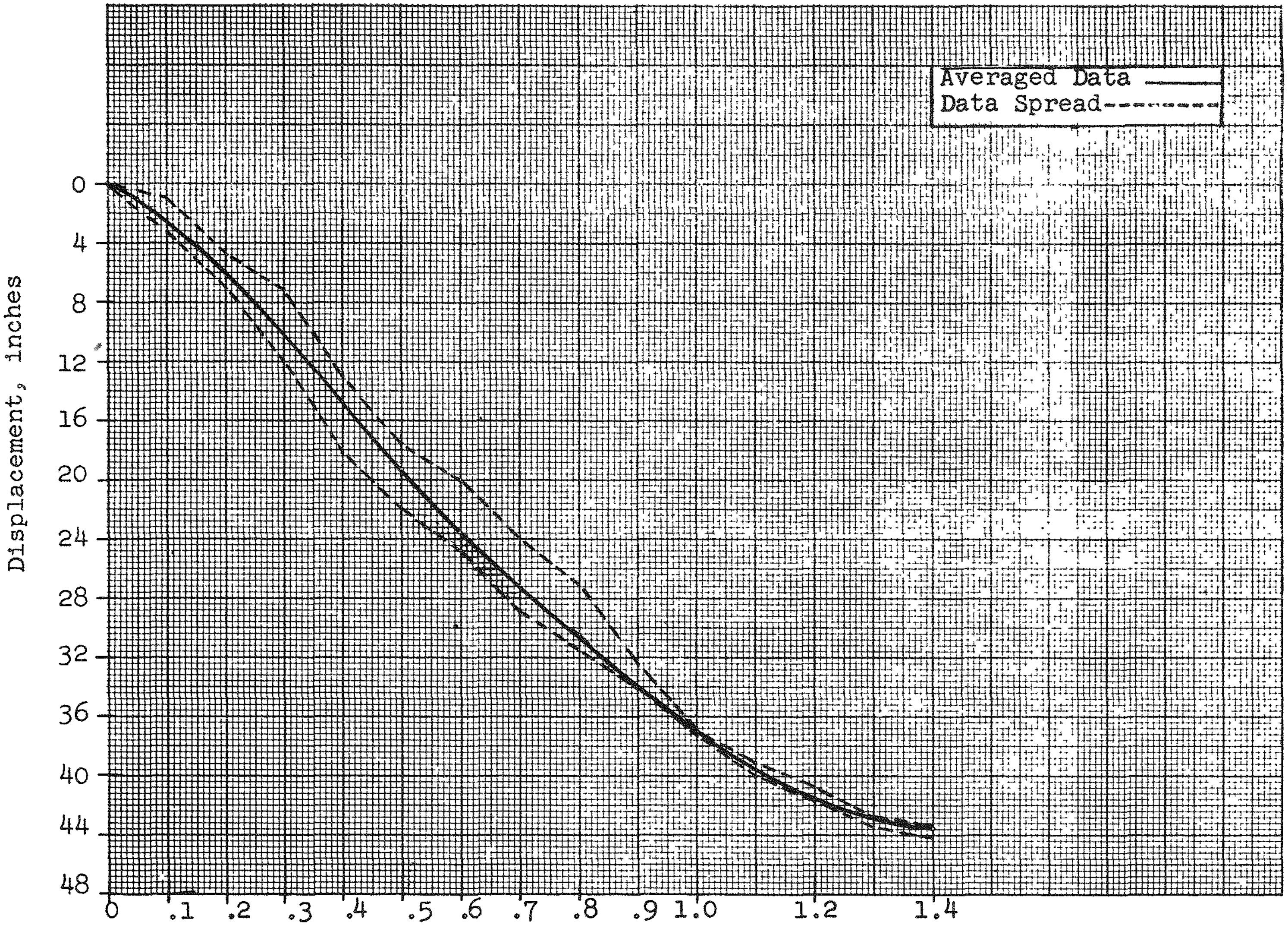


Figure 4.F

Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Numbers 202 & 205

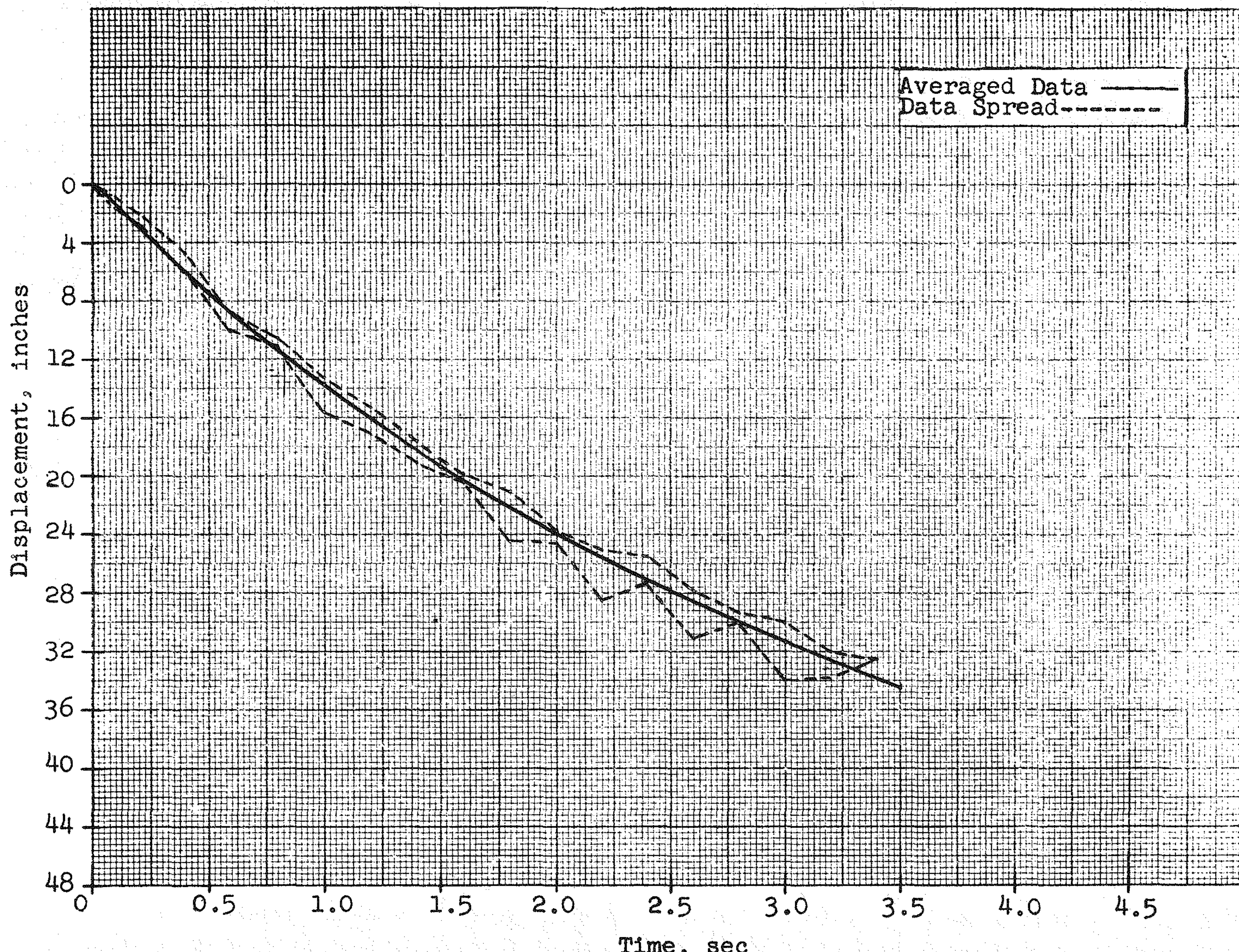


Figure 4.G
Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Numbers 203 & 206

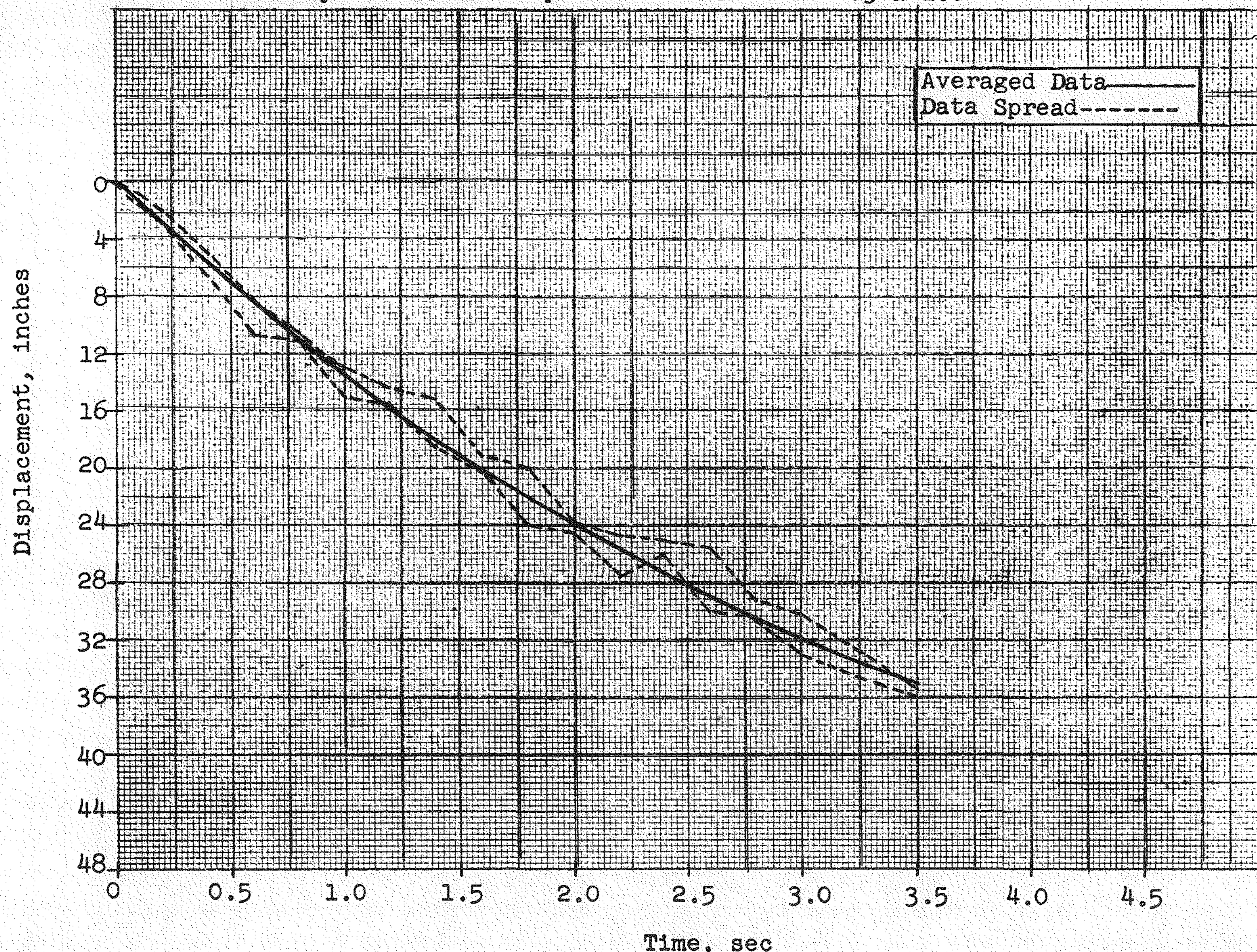


Figure 4.H
Plot of Averaged Time-Displacement Data and Data Spread for
Safety Reflector Drop-Time Test Numbers 301 & 304

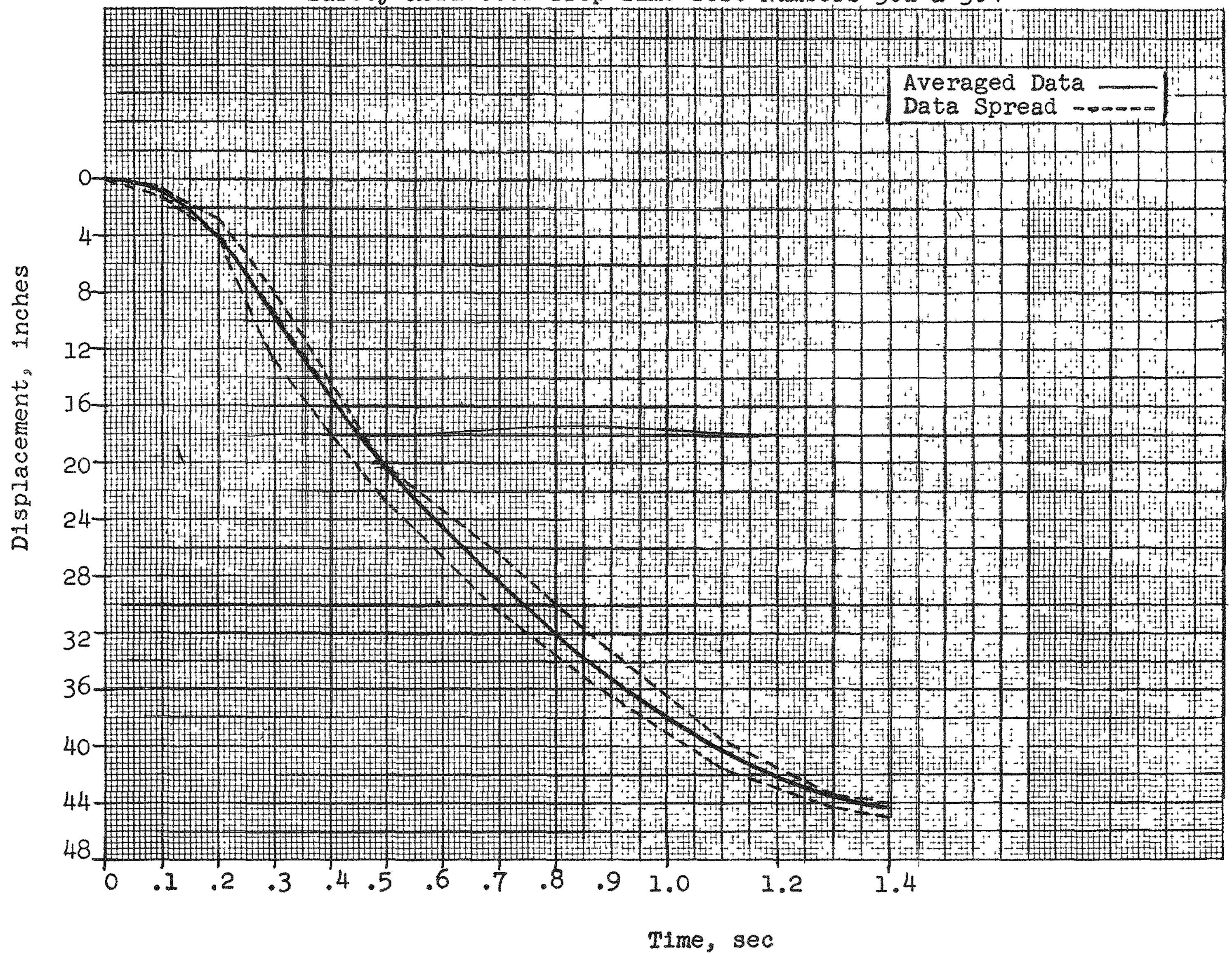


Figure 4.I

Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Number 307 & 310

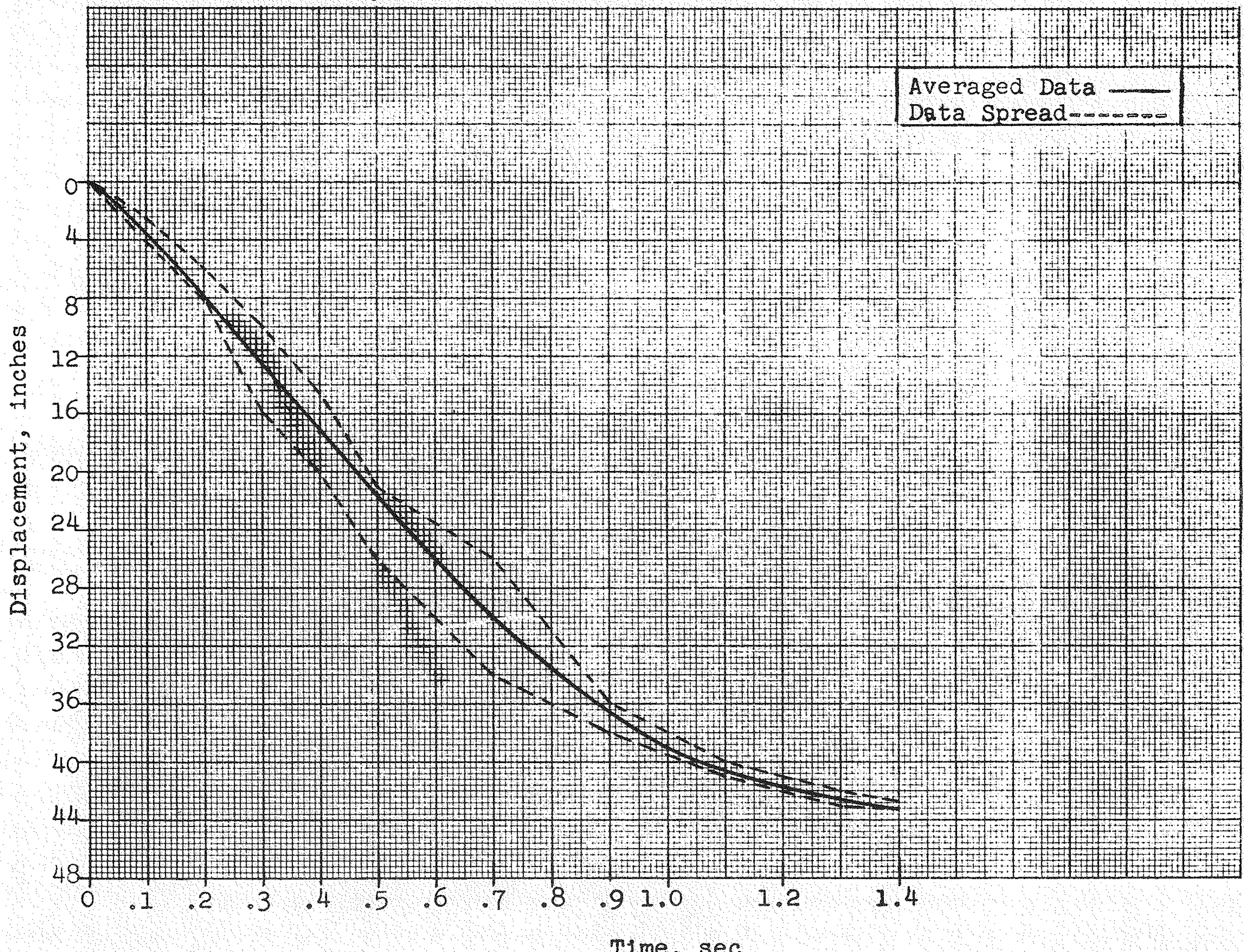


Figure 4.J
Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Numbers 401 & 404

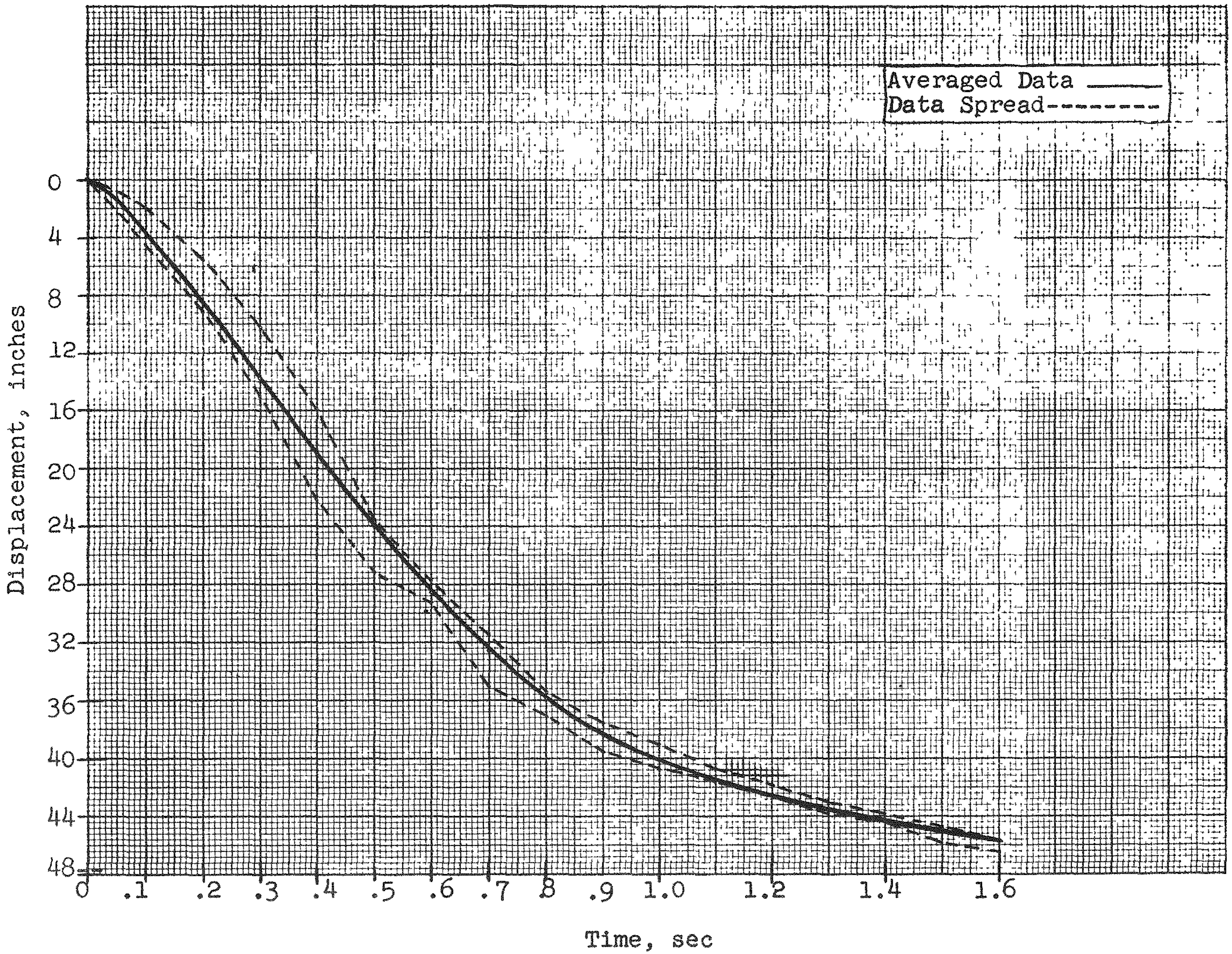


Figure 4.K
Plot of Averaged Time-Displacement Data and Data Spread for Safety Reflector Drop-Time Test Number 403 & 406

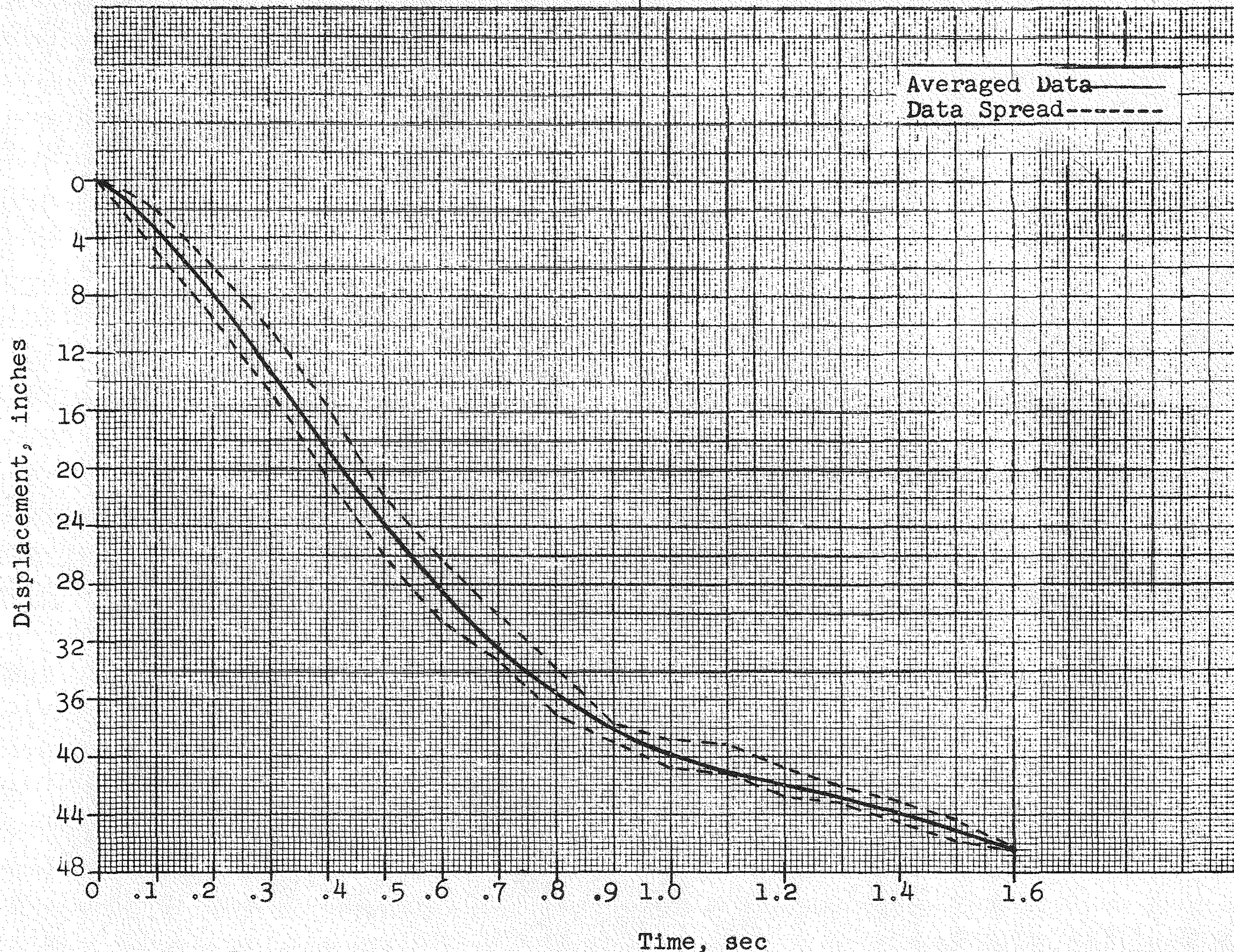


Figure 4.L

Resistivity of Boric Acid Solutions

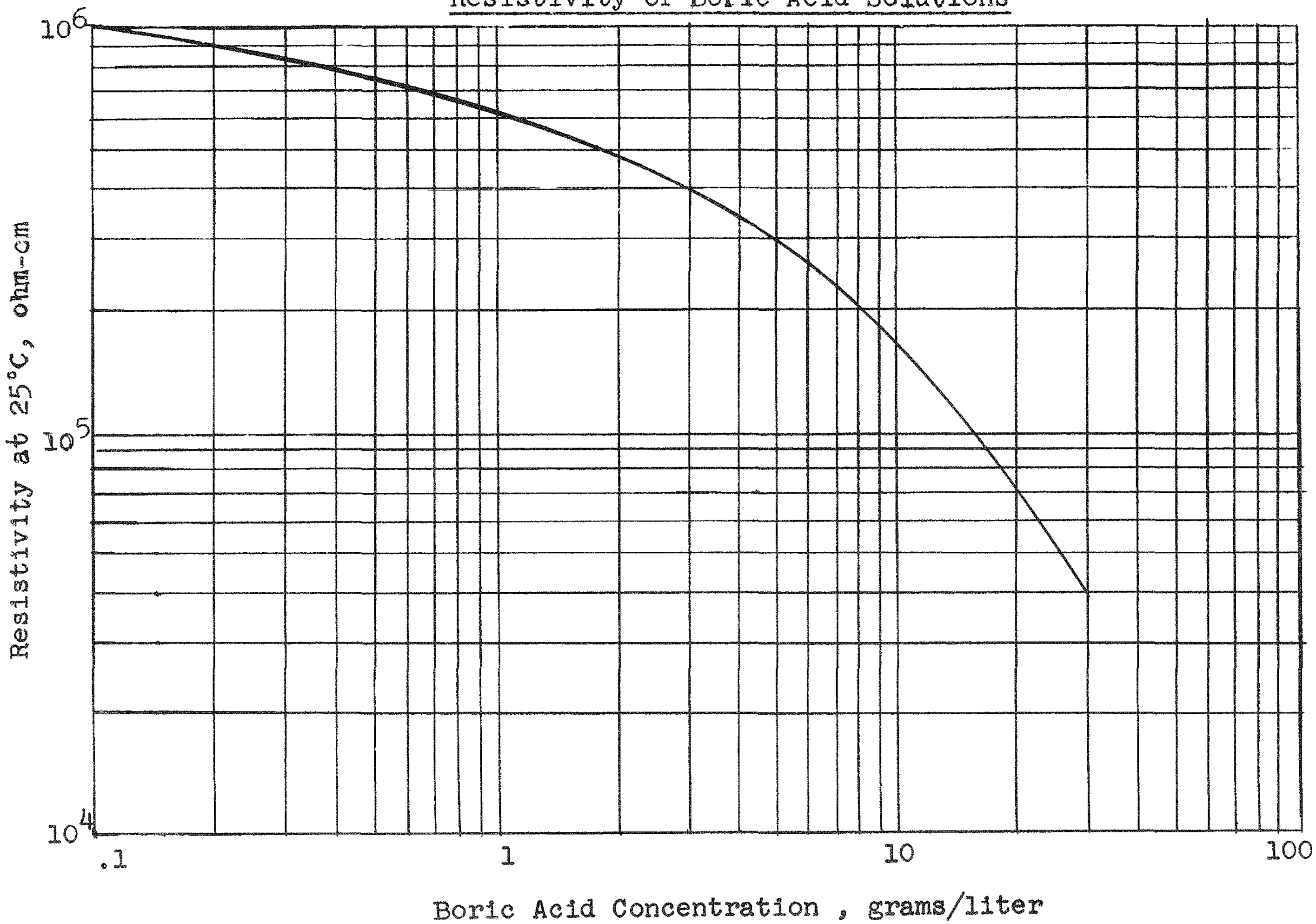


Figure 4.M

Resistivity of Solutions

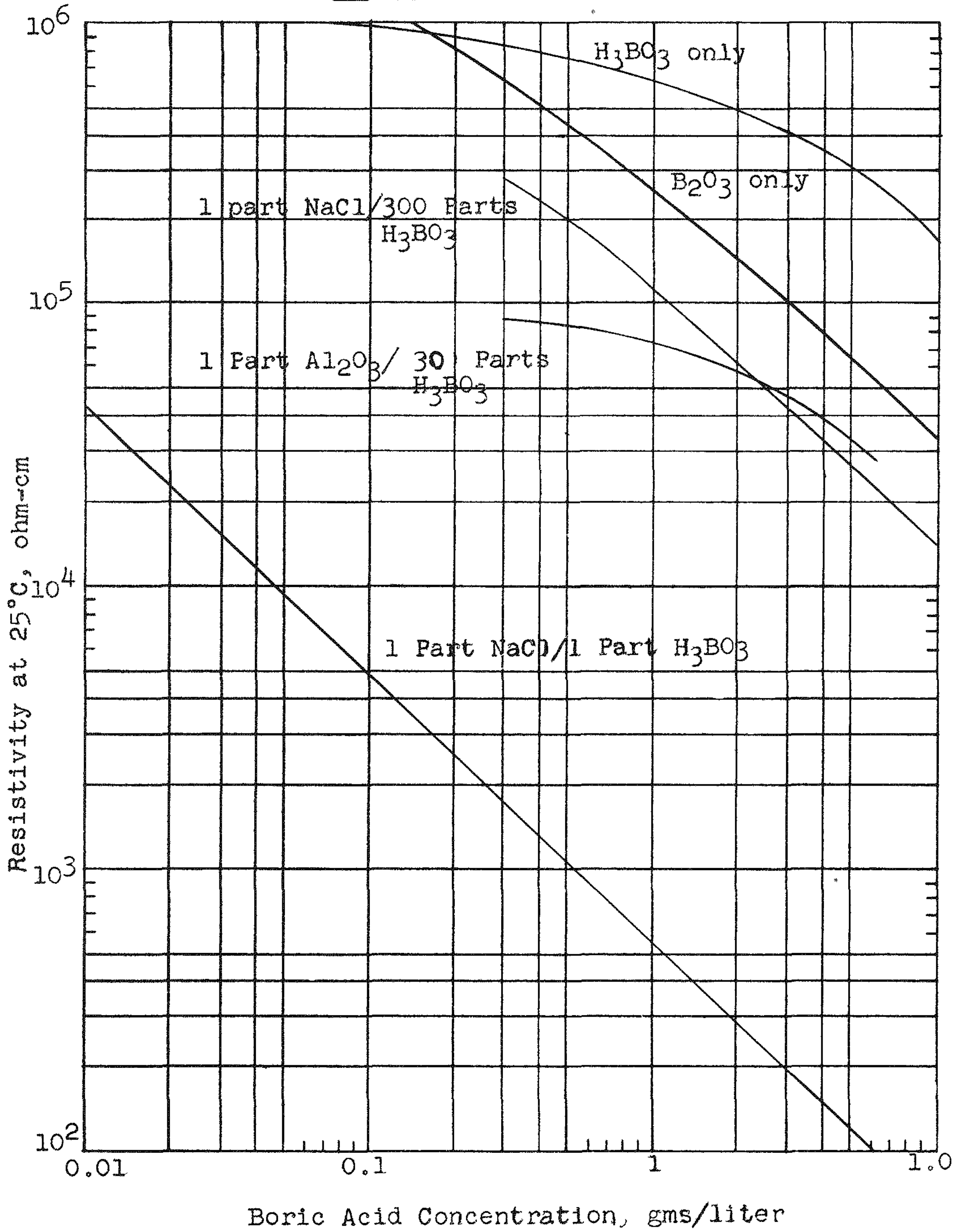


Figure 4.N

System Cleanup-Run 2

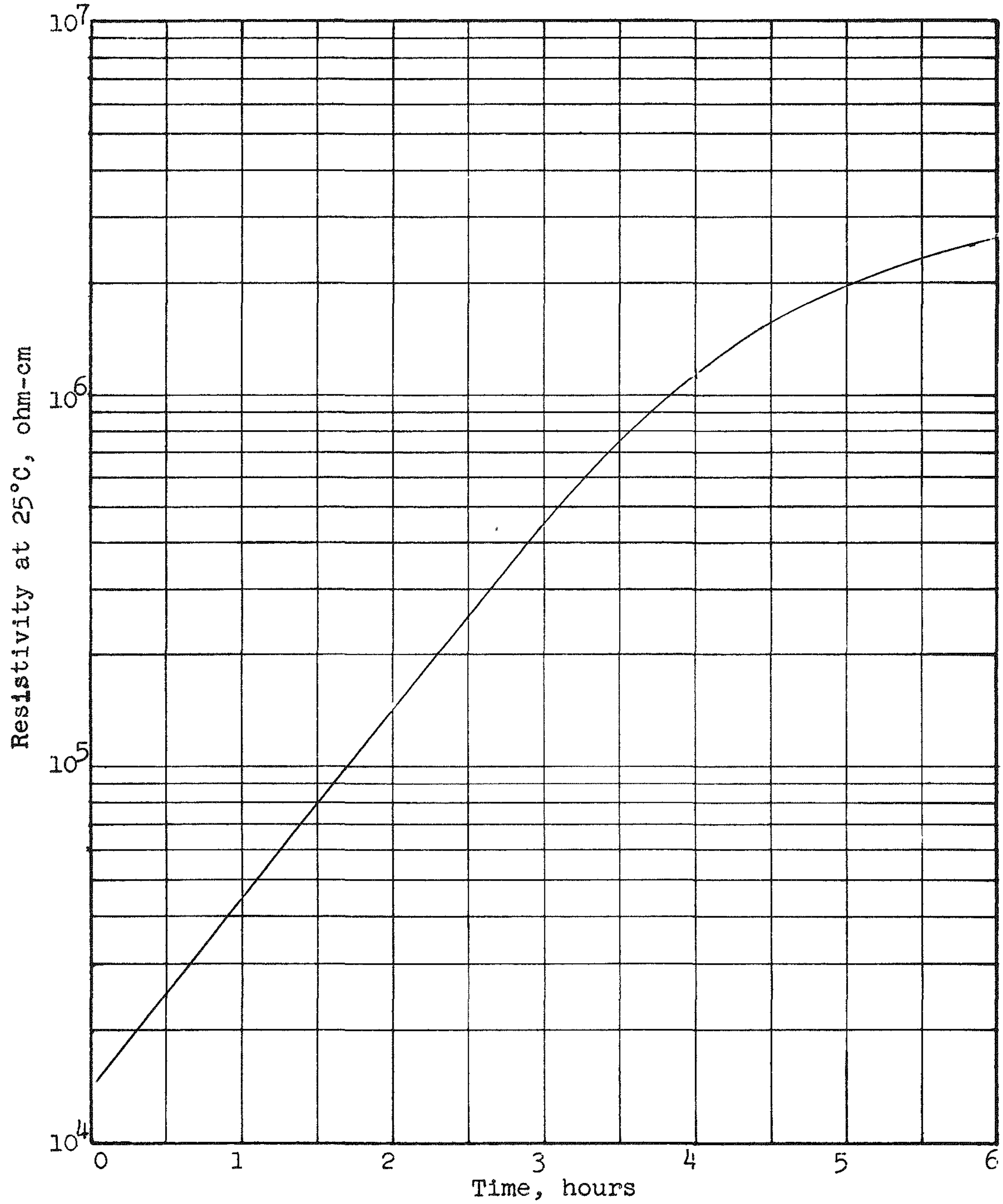


Figure 4.0

Boric Acid Injection and Cleanup-Run 2

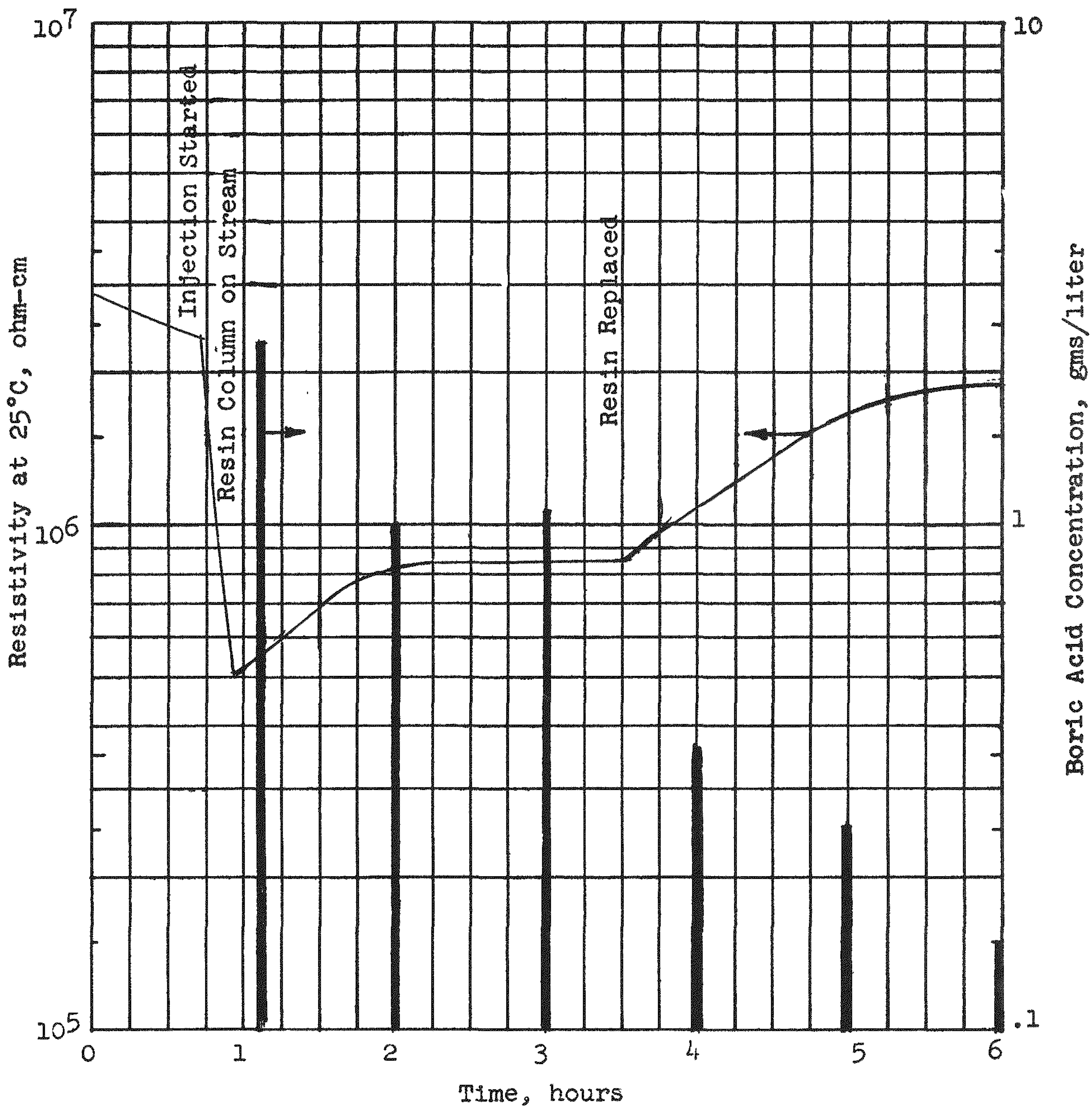
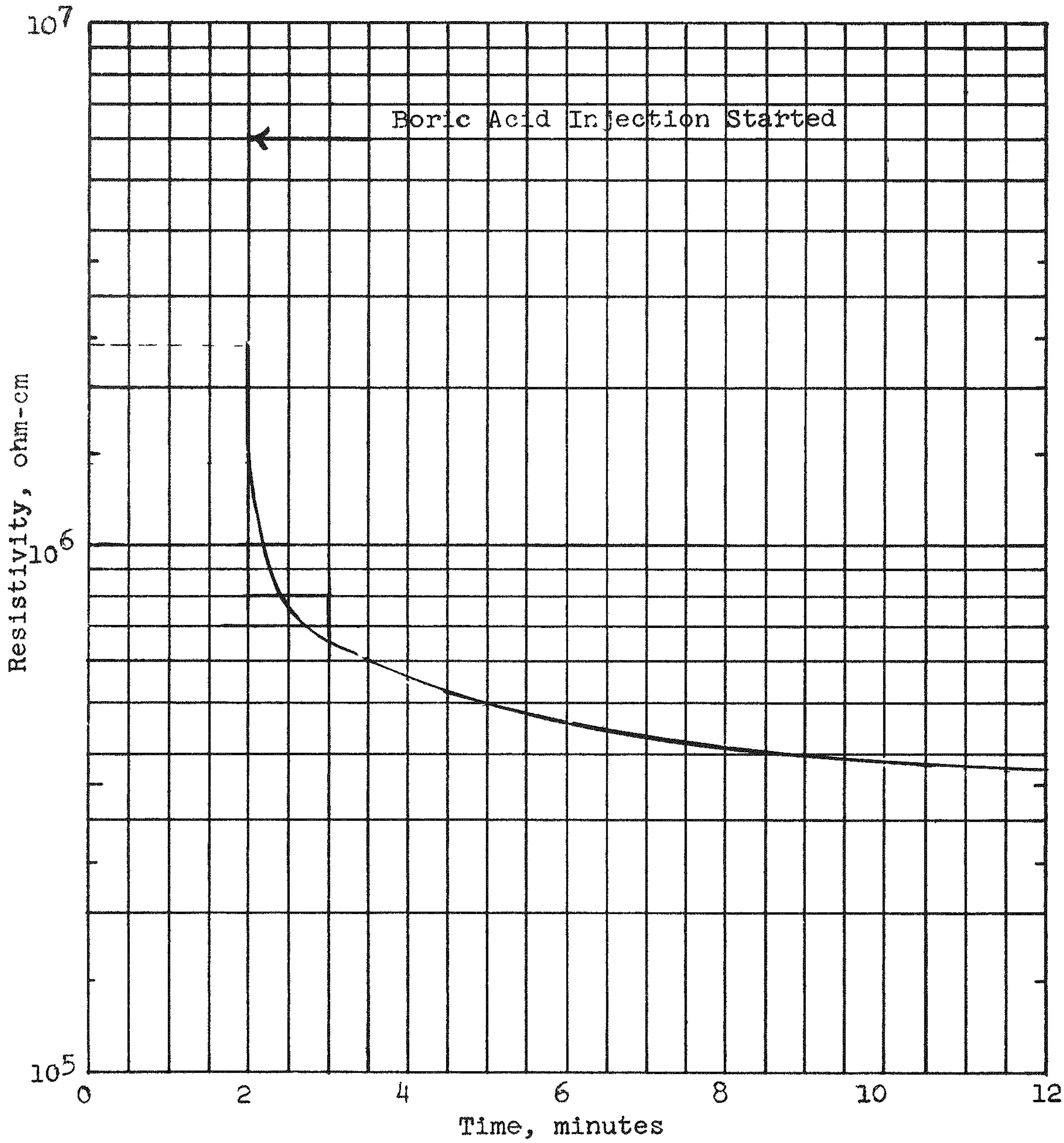


Figure 4.P

Boric Acid Injection Detail-Run 2



5.0 DISCUSSION OF RESULTS

This section interprets and analyzes the data and some of the problems encountered in collecting the data in order to provide a better understanding of the data and its significance.

5.1 Safety Reflector Drop Time

The primary objective of the safety reflector drop tests was to determine a definite time-displacement curve for the dropping column of water in the safety reflector portion of a model of the reflector control system presented in INTERNUC-23. Additional objectives were to demonstrate the reliability of the concept and to determine the overall practicality of the system. As noted in the Introduction, these initial primary objectives were perturbed somewhat by the fact that the reflector control system model was ultimately designed to simulate, as nearly as possible, the safety and shim reflector actions of the original INTERNUC-23 reflector control concept and three variations of this concept, as outlined in Part B of this report. Therefore, in addition to the initial objectives for the safety reflector drop tests, the following objectives were added: 1) determine the relative effect, if any, of piping arrangement on drop time; 2) determine the relative effect, if any, of flow rate on drop time; 3) determine the effect of area ratio (scram line size) on drop time. As a result, a series of tests designed to accomplish all of these objectives was initiated.

The primary time-displacement data from the above series of tests was recorded on 16 mm motion picutre film as described in detail in Appendix 2.0. The methods of extracting this data from the motion picture film and the problems involved in extracting the data are described in detail in Appendix 3.0. The major objective of this section is to interpret and analyse the extracted data in relation to its significance in the actual safety reflector control system.

The reactivity effects of the dropping water column and the rate at which reactivity is removed are of primary importance to this investigation. In INTERNUC-23, reactivity removal rates, based on safety reflector water drop times predicted by an analytical expression, were presented. A comparison of the drop times observed for the water in the safety reflector of the model with those predicted by the analytical expression used in INTERNUC-23 is presented in Figures 5.A and 5.B. Figure 5.A compares the drop time observed in

Figure 5.A

Comparison of Time-Displacement Data from Drop Tests 25 and 36 with that Predicted by Analytical Expression Used in Internuc-23

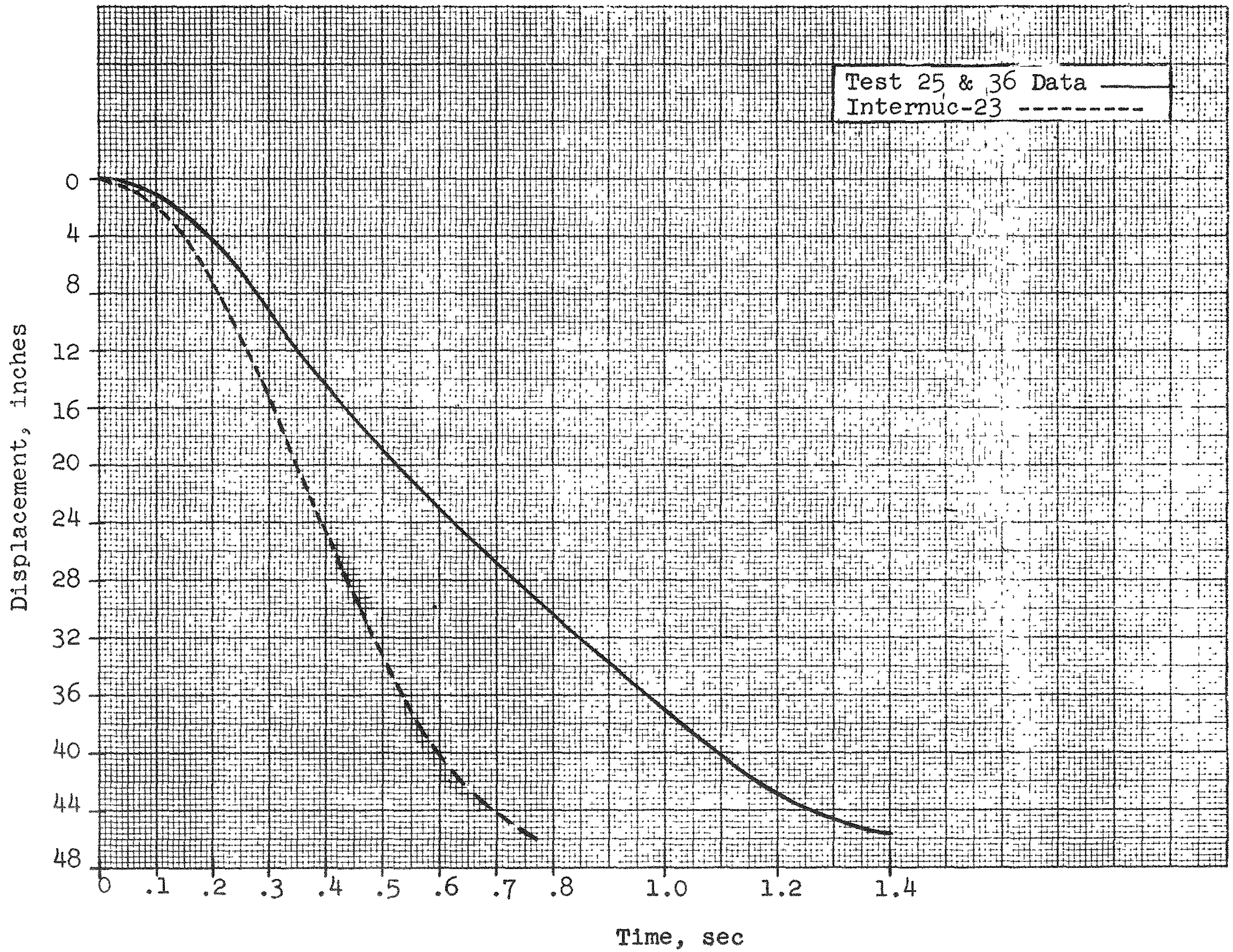
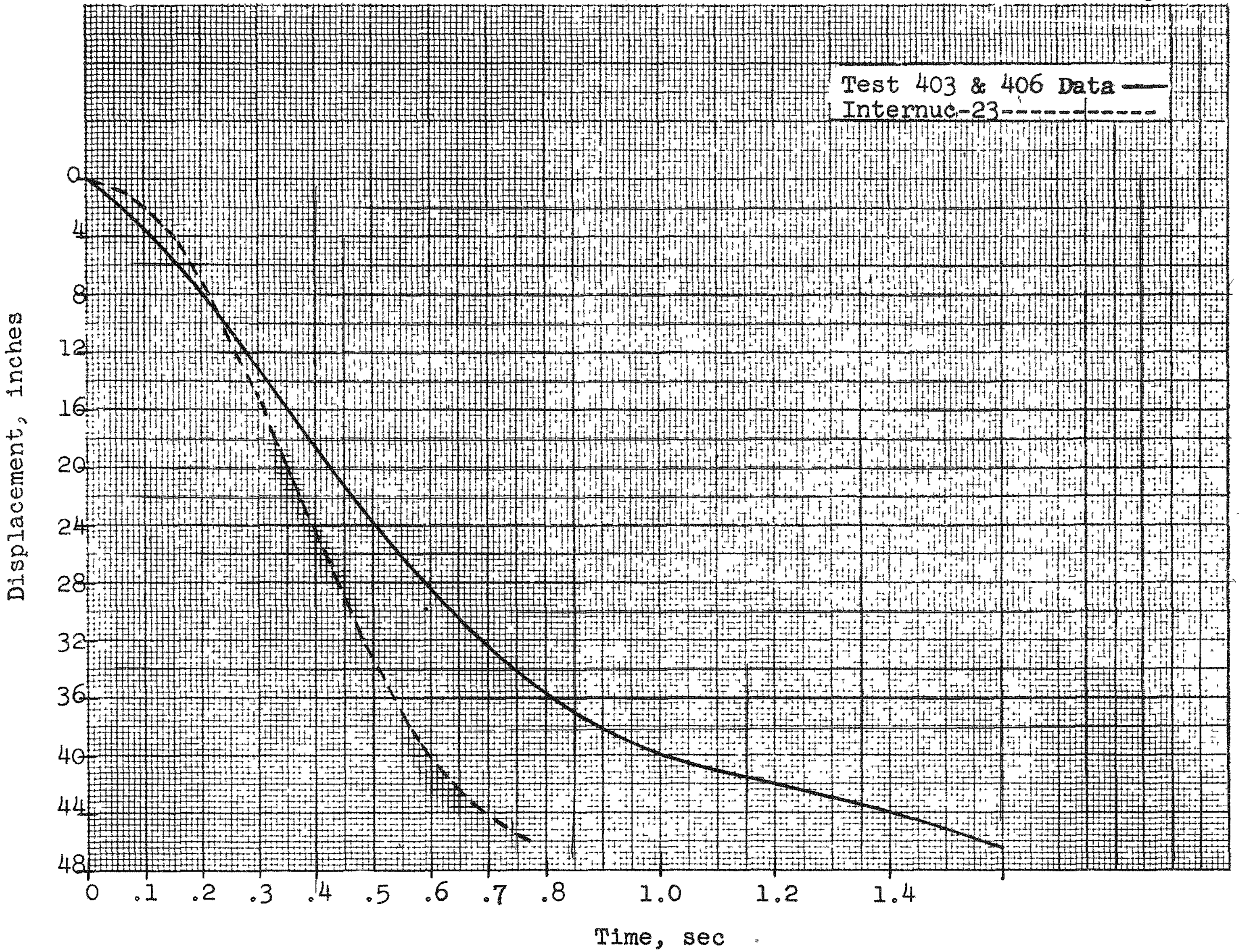


Figure 5.B

Comparison of Time-Displacement Data from Drop Test 403 and 406 with that Predicted by Analytical Expression Used in Internuc 23



in tests 25 and 36 with those predicted by the analytical expression of INTERNUC-23. Figure 5.B compares the drop times observed in drop tests 403 and 406 with those predicted by the analytical expression in INTERNUC-23. In Figure 5.A it will be noted that the experimental drop times were all longer than those predicted, where-as, in Figure 5.B it may be noted that the experimental drop times immediately after scram are shorter than those predicted and become longer than predicted about 0.23 seconds after scram is initiated. The predicted drop times in in both Figures 5.A and 5.B are based on an area ratio (scram line cross-sectional area: safety reflector cross-sectional area) of 0.0237, corresponding to a 1.5 inch nominal diameter scram line, where-as the experimental area ratios for the data plotted in these figures are 0.0389 and 0.049, respectively. It should be pointed out, however, that the analytical expression used to predict drop times could be solved numerically only for certain discrete values of the constant C and therefore, the selection of the area ratio that imparted a particular value to the constant was of necessity a somewhat arbitrary one. The analytical expression predicted the basic form of the time-displacement curve reasonably accurately and might also have predicted experimental drop times much more accurately if long radius elbows and a different type solenoid valve had been used in the scram line. (See Section 6.1, Recommendations).

The fraction of total reactivity removed versus time with safety reflector control is compared with that removed by the mechanical safety rods of the ETR[2] in Figures 5.C and 5.D. These figures show that reactivity removal rates of the safety reflector system are better than those of the mechanical safety rods with no flow and worse than those of the mechanical safety rods with full flow. It should be noted, however, that the four ETR safety control rods, besides being spring loaded for high initial acceleration, will only overcome an excess reactivity of 14.4 percent[3] where-as the safety reflector of the model, based on the core and reflector designs presented in INTERNUC-23, will overcome an excess reactivity of 30-50 percent. In addition, the initial rate of reactivity removal with a safety reflector may be increased by moving the mid-plane of the core closer to the point at which the void initiates in the safety reflector. The calculations for the reactivity removal rates of the safety reflectors represented in Figures 5.C and 5.D were based on the void initiating one foot above the mid-plane of a core three feet in length and are therefore considered conservative.

On the basis of the comparisons made above, it may be concluded that some of the experimental safety reflector drop times observed during the drop tests reported are adequate

Figure 5.C

Comparison of Reactivity Removal Rates with a Safety Reflector System to Those of the Mechanical Safety Rods of the ETR

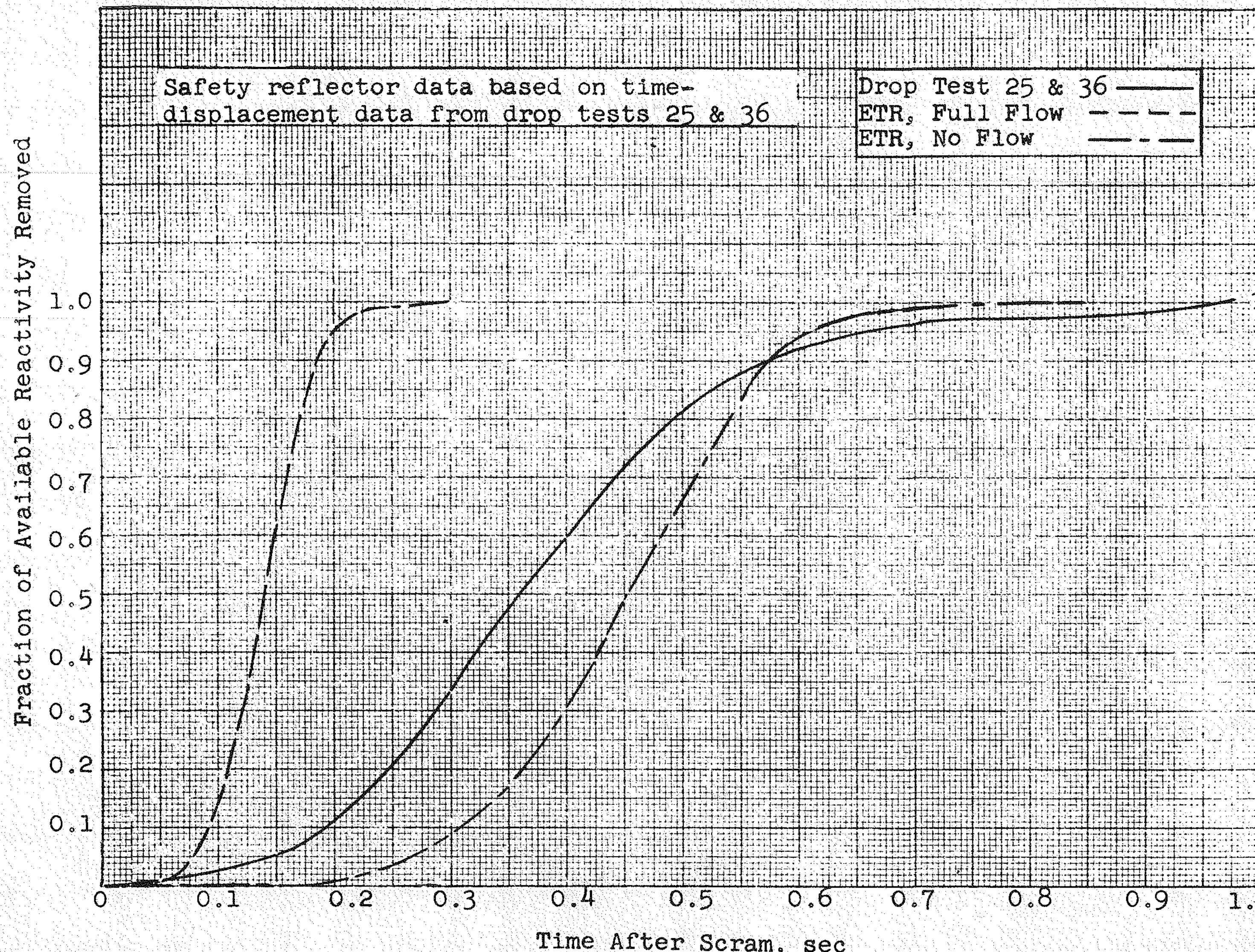
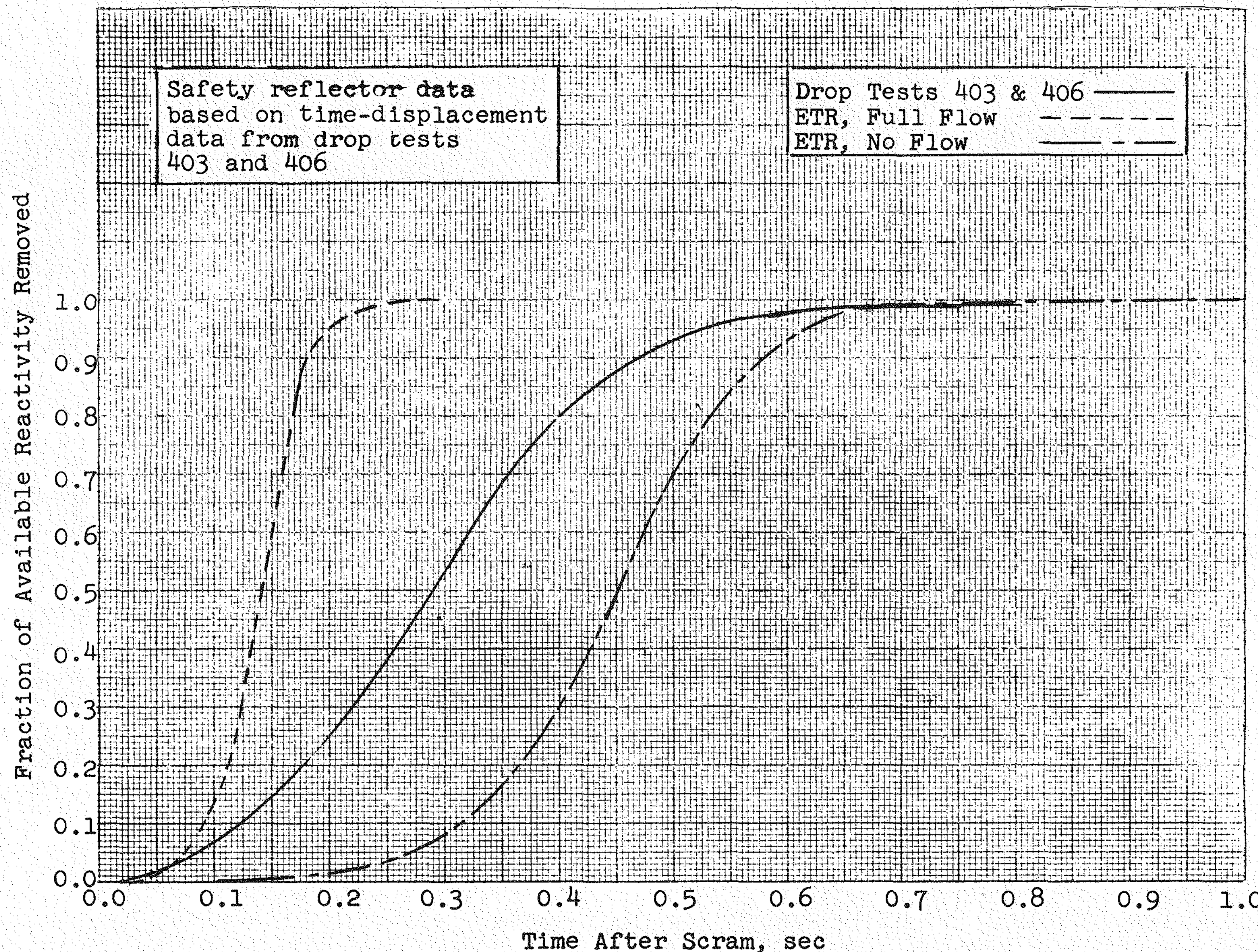


Figure 5.D

Comparison of Reactivity Removal Rates, with a Safety Reflector System, to Those of the Mechanical Safety Rods of the ETR.



to warrant the use of safety reflector control for the flux trap type reactor designs presented in INTERNUC-23. If further decreases in safety reflector water drop times (with a given area ratio) are effected by the design improvements suggested here-in, safety reflector control for flux trap type reactors would appear even more promising than at present. Even though drop times might not be decreased for a given area ratio by the suggested design improvements, it is certain that shorter drop times may be achieved by using larger area ratios or gas pressure above the safety reflector. Thus safety reflector control appears a very promising method of safety control for any reactor having a substantial amount of reactivity associated with a fluid reflector.

One of the complications of interpreting the position of the air-water interface, as noted in Appendix 3.0, was the fact that the initial interface formed as a bubble during the first few tenths of a second after "scram". Subject to the limitations of the field of vision of the camera, the method used to interpret the position of the interface immediately after "scram" is felt to be a conservative one from the standpoint of effect on reactivity in a flux-trap type reacotr with an annular safety reflector control. In the annulus of the actual safety reflector, where the "scram" air is introduced at three or more discrete intervals around the core, the bubble forming under each inlet will produce a void much closer to the mid-plane of the core, where the reactivity worth of the void is greater, than would be the case if a horizontal, flat plane interface formed immediately.

Shortly after a flat plane interface formed in the safety reflector of the model the plane of the interface appeared to wobble about a vertical axis through the center of the safety reflector column (described in detail in Appendix 3.0). The effects of this wobble on the interpretation of the position of the interface are also discussed in Appendix 3.0. In the annulus of an actual safety reflector it may be postulated that the wobble, noted in the model, would become a series of waves traveling around the annulus in one direction or the other or oscillating back and forth between a series of nodes around the annulus. If this is the case, and as long as the plane of the air-water interface is above the mid-plane of the core, the interpretation of the interface as a flat, horizontal plane would be a conservative one since the troughs of the waves would produce a fraction of voids closer to the midplane of the core where the reactivity worth of the void is greater. On the other hand, if the wobble in the model should appear in the actual safety reflector annulus as a wave traveling radially back and forth across the annulus, the interpretation of the interface as a flat, horizontal plane would be either conservative or optimistic depending on whether the crest of the wave was far from the core or near the core, respectively. In either case it is expected that the magnitude of the wave that might develop would not be great enough to significantly perturb the reactivity effects predicted on the basis of a falling flat, horizontal plane interface. The reactivity effects of such movements of the falling safety reflector water will be studied in more detail in the nuclear mockup.

From the beginning it was recognized that details of piping arrangement or main circulating water flow rate would have relatively minor effects on the drop time of the safety reflector water column. However, since it was fairly easy to set up test conditions to check this premise, it was considered appropriate to do so. Close inspection of Tables A5.a, A5.b and A5.c indicates that piping arrangement might have some slight effect on drop time and that main circulating water flow rate probably does have an effect on drop time. First and second differentials of the data indicate that(in the case of the 2 inch scram-line only) the water appears to drop with an initial velocity between 1.0 and 2.5 ft/sec and with an initial acceleration very near to the acceleration of gravity. If the water does drop with an initial velocity, it is felt that it is due to the downward flow of water in the safety reflector. Regardless of the phenomena responsible for the apparent initial velocity of the dropping water in the safety reflector column, the magnitude of the effect is so small in relation to the effect of scram line size that it may be disregarded. Any effect on the drop time that might remotely be ascribed to piping arrangement is so minute that it may be completely ignored.

The stair-step irregularities noted in plots of time-displacement data from the tests conducted with the 1 inch scram line are believed to be a relatively true representation of the action of the interface. They could be caused by the interface wobble (described in Appendix 3.0), of course, provided that the plane of the interface always had the same position relative to the line of sight of the camera in all five runs of the test, but this is considered to be highly improbable. Also, when the films are viewed as motion pictures, the air-water interface definitely appears to fall with a jerking motion that could not be attributed to interface wobble. It is felt that this phenomenon may be due to the wide disparity between the dynamic response of the air in the scram line and that of the water in the safety reflector column.

Comparison of the drop time data in Table A5.a with that in Table A5.b indicates a large decrease in drop time is achieved by replacing the 1 inch scram line with a 2 inch scram line. In an effort to determine what effect the frictional resistance in the scram line had relative to the frictional resistance in the scram solenoid valve, drop time tests were conducted with extremely short scram lines and the solenoid valves open to the atmosphere. These were the series 200 tests, for the 1 inch scram solenoid, and the series 300 tests for the 2 inch scram solenoid. Comparison of the data from these tests with that from the corresponding tests with a full length scram line indicate that there is very little, if any, difference in drop time. Assuming that the highly transient and very likely low level pressure build-up in the drop tank does not compensate for the friction loss in the long scram line cases leads to the conclusion that frictional resistance in the scram line itself is quite unimportant relative to that encountered in the scram solenoid valve. Comparison of the data from series 400 tests, conducted with the 2 inch and 1 inch solenoid valves in parallel and open to the atmosphere, with that of the series 300 tests tends to confirm the conclusion that frictional resistance in the lines is quite unimportant relative to that in the solenoid valves.

5.2 Conductivity of Boric Acid Solutions

The calibration curve of resistivity versus boric acid concentration was as would be expected for a weakly ionized acid (dissociation constant for the first hydrogen is 6.4×10^{-10} at 25°C).[4] At high concentrations of boric acid, the change in resistivity per unit change in concentration was small, due to the very small dissociation constant. However, at low concentrations, the change in resistivity per unit change in concentration was quite large as a relatively large change in ion concentration occurs.

As the boric acid solutions became very dilute, the resistivity approached an asymptotic value of one megohm-cm. This was due primarily to the diluent resistivity. With the dilutions which were necessary to obtain concentrations as low as 0.1 gram of boric acid per liter, the diluent water was in contact with glass and the atmosphere for relatively long periods of time. Thus, the water leached ionic material from the glass and absorbed gases from the atmosphere which kept the diluent resistivity below 2 megohm-cm. Diluent fresh from an ion exchange column was alwyas 6 to 10 megohm-cm purity or better.

As the AETR shim reflector is to contain heavy water, the resistivity of boric acid solutions made from boric oxide was investigated. Boric oxide is of interest as it may be used to prepare deuterated boric acid by the reaction:

$$B_2O_3 + 3D_2O = 2D_3BO_3$$

In these investigations light water, not heavy water was used. The calibration curve for resistivity versus boric acid concentration prepared from boric oxide is shown in Figure 4.M. As can be seen the shape of the curve is quite different from that for solutions produced from solid boric acid. The reason for this difference is not clear but mav be due to impurities in the boric oxide. The solutions made with boric oxide were quite murky and those made with boric acid were clear.

The effect of corrosion products on the boric acid calibration curve was investigated. Corrosion products were simulated by sodium chloride and aluminum oxide; the sodium chloride to simulate ionic constitutents and the aluminum oxide to simulate the metal oxide. As is shown in Figure 4.M, these chemicals have a major influence on the boric acid calibration curve, with sodium chloride exerting the strongest influence. One part of sodium chloride for 300 parts of boric acid results in resistivity decreasing by a factor of ten. Ten parts of aluminum oxide per 300 parts of boric acid were required to give a corresponding resistivity decrease. Although these concentrations of corrosion products are higher than would be expected to be encountered in most systems, they indicate that caution must be exercised in interpreting boric acid concentration by electrical conductivity measurements.

One of the first characteristics of boric acid and boric oxide solutions observed was the difficulty with which they were dissolved. To completely dissolve boric acid, some heating was required. Even with dilute solutions, violent mixing and standing for 24 hours was not sufficient to obtain complete dissolution. However, with vigorous heating the boric acid was easily dissolved. When a small amount of water is added to boric oxide, a moderate amount of heat is liberated as the boric oxide converts to boric acid. Thereafter, the converted boric oxide behaves the same as boric acid when attempting to dissolve it.

In preparation of boric acid solutions for conductivity measurements, great care had to be exercised in the dilution technique as most errors encountered were errors in dilution. Preliminary experiments indicated errors as large as 100 percent. However, these errors were eliminated with careful techniques.

The solutions used for conductivity measurements were prepared in volumetric equipment which was calibrated for use at 20°C. As the temperature of the solutions varied between 24 and 27°C, some error was introduced by this temperature variation.

Resistivity measurements are temperature sensitive. Therefore, all readings must be corrected to a common temperature. The Operating Manual[5] which accompanied the conductivity bridge recommended correcting readings to 25°C by use of the equation:

$$R_{25} = R_t\left[1 + 0.025(t-25)\right]$$

where

R_{25} = solution resistivity at 25°C

R_t = solution resistivity measured at temperature t

t = temperature of solution (°C)

This equation was experimentally checked (See Table A8.a) and found to be valid over the temperature range of 23 to 60°C. Above 60°C, the results were erratic. Over the range of 23 to 60°C, the maximum variation noted was about ± 1.4%. Thus, the relationship was used to correct all resistivity measurements to a common temperature of 25°C.

It may be concluded from these experiments that, although electrical conductivity appears to be a fair semi-quantitative method of determining boric acid concentrations in otherwise pure solutions, at constant temperature, the magnitude of the effects of impurities and temperature changes on the conductivity of boric acid solutions is sufficient that the use of electrical conductivity should probably be confined to determining gross qualitative changes of boric acid concentration in shim reflector solutions. When properly used in this manner, it is felt that electrical conductivity measurements may prove useful in determining the dynamic response of a shim reflector control system to gross changes in boric acid concentration. However, this possible use of the electrical conductivity method of determining boric acid concentration does not warrant further investigation of the method at this time. If analytical studies indicate a need for determining gross changes in boric acid concentration in a dynamic shim reflector system, the data presented here may be sufficient to serve the need, if not, adequate data could readily be developed.

5.3 Ion Exchange Resin Capacity for Boric Acid

The ion exchange resins performed as was expected. Boric acid was easily removed prior to breakthrough and the latter was sharp and easily detected by a change in solution conductivity. Only one exception was found. In run D, the resin column used was made up of Amberlite IRA-400 anion resin in the hydroxide form followed by a short polishing section of Amberlite MB-1 monobed resin. This, it was felt would increase the capacity of the column for boric acid by about 50 percent. This was not the case; the capacity of the column was unchanged.

5.4 Dye Injection Experiments

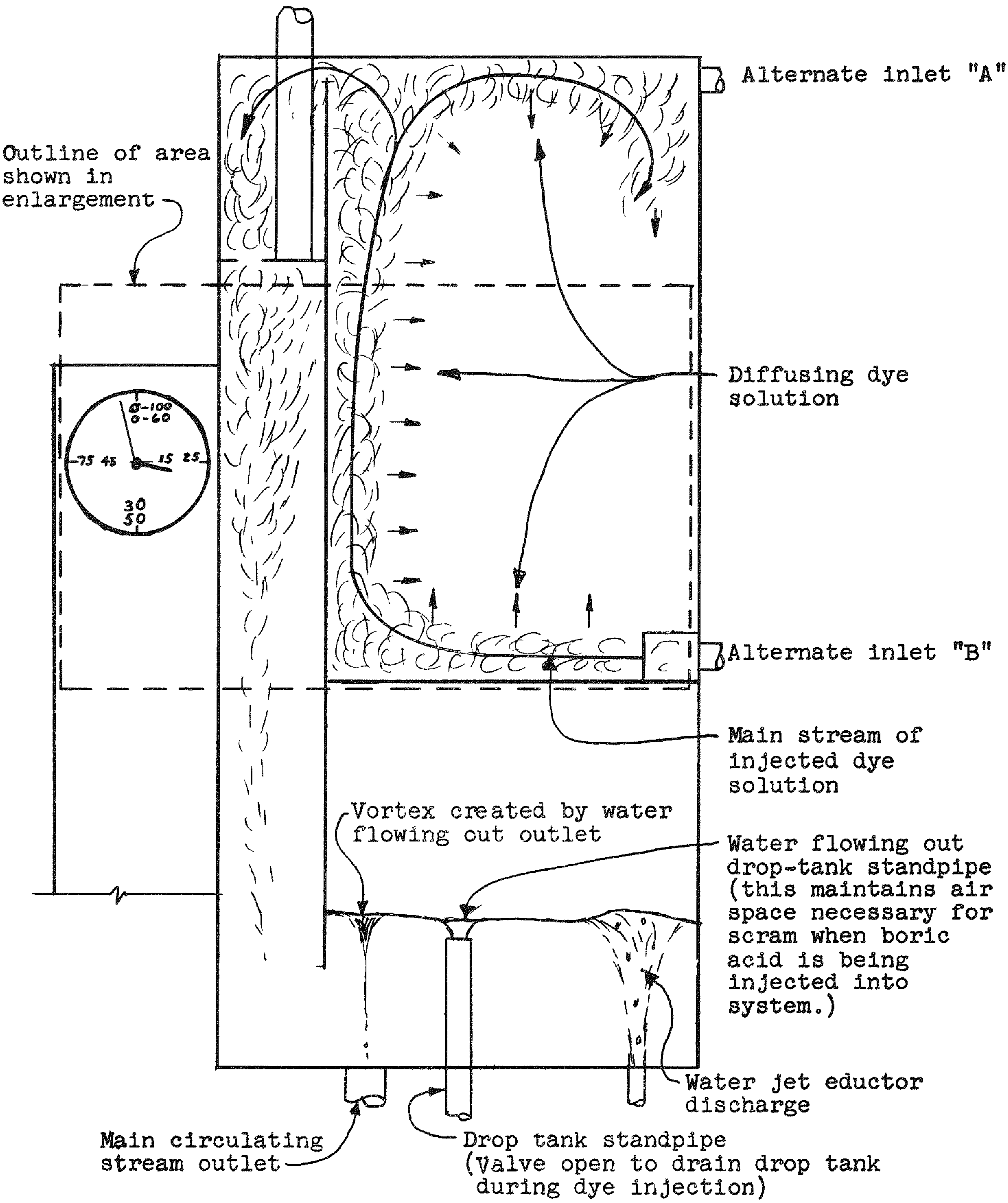
The major objectives of the dye injection experiments were to provide some information as to how rapidly the boric acid might diffuse in the shim reflector after boric acid injection was started and any tendency toward channeling or pocketing that might be exhibited with the inlet plenum arrangement provided in the model. The dye injection experiments were conducted primarily to determine the possible ability of the shim reflector to accomplish power regulation as well as shim control.

It should be pointed out that it is not true diffusion but a combination of diffusion and turbulent mixing that is represented by the dye diffusion data presented in this report. Since it is felt that turbulent mixing will be far more prominent in distributing chemical poison in the shim reflector than diffusion, an attempt to determine true diffusion rates separately from true turbulent mixing is not warranted.

The dye injection tests definitely indicated a channeling tendency. As indicated in Figure 5.E, the dye solution would spread evenly across the bottom of the shim reflector after leaving the plurality of openings in the inlet plenum. It would then flow steadily and uniformly from right to left across the bottom of the shim reflector, up along the left side and then from left to right across the top of the shim reflector - all with relatively little tendency to either vertical or horizontal diffusion away from the main dye stream. As the main dye stream reached the top of the shim reflector, part of the stream would start flowing through the weir separating the shim and safety reflectors. This stream would color all the solution in both sections of the safety reflector and in the drop tank before all the solution in the shim reflector became colored with dye solution. In spite of this, the splitting of the main dye solution stream at the top of the shim reflector did not appear to slow down the dye diffusion rate in the shim reflector to any appreciable extent.

Figure 5.E

Diffusion of Dye Solution in Shim Reflector



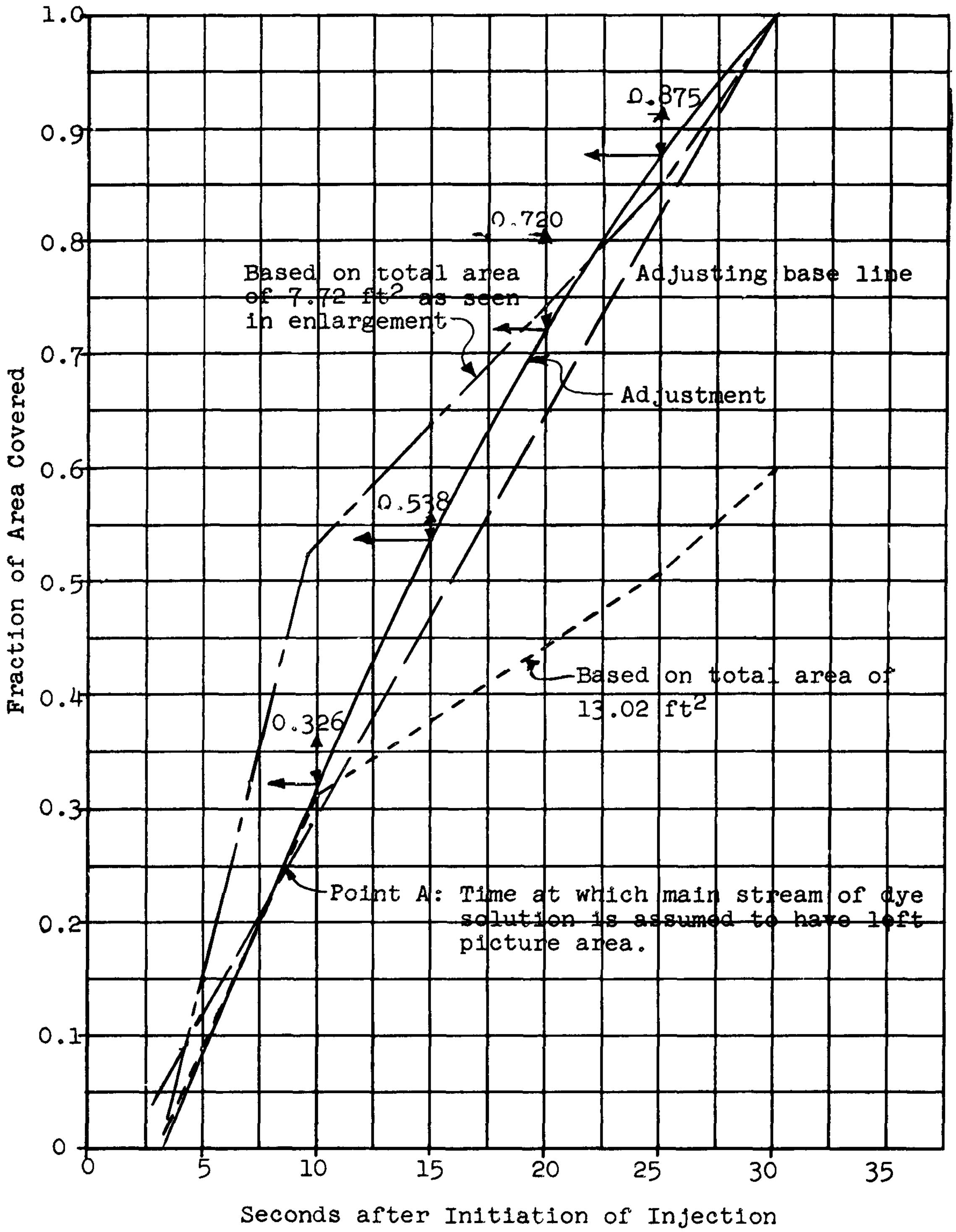
The major significance of the dye injection tests is that they demonstrate the necessity of good inlet plenum design to achieve uniform distribution of control solutions throughout the entire area of a large shim reflector. The ideal conditions for good chemical regulation control would be complete mixing in the lines leading to the shim reflector followed by slug flow in the shim reflector. The latter is probably much harder of attainment than the former and design of a good inlet plenum to approach the ideal of slug flow in the shim reflector would undoubtedly require some development. Also, the response time of the shim reflector design investigated with the model is felt to be much too long to ever be practical for regulation of reactor power. However, uitlization of the shim reflector for power regulation as well as shim control should not arbitrarily be ruled out on the basis of the results from the tests reported here. The reflector size in the "three-reflector" control system design is small enough that much shorter response times undoubtedly could be achieved. Whether they would be short enough to warrant attempting power regulation should be investigated analytically or determined by experiments with the nuclear mock-up.

Since the enlargements of the dye injection test films showed only the bottom 60% of the shim reflector area, as indicated in Figure 5.E, the dye diffusion rates indicated by the primary dye diffusion data presented in Table 4.c of Section 4.9, would rapidly decrease as soon as the main stream of the dye solution passed out of the area shown in the enlargement as it traveled up the left side of the shim reflector. From that instant until the dye started diffusing back down into the area shown in the enlargement, the dye diffusion rates indicated by the primary data are only those of the horizontal and vertical diffusion of dye solution away from the main dye stream. As soon as the dye starts diffusing down from above the picture area, the diffusion rate indicated by the primary data again approached that of the total diffusion rate for the entire shim reflector. When all the shim reflector area not colored by dye solution appears in the picture area, the diffusion rates indicated by the primary data are again the total diffusion rate (as interpreted in these experiments).

In order to obtain the data presented in Table 4.d, the average primary data was first converted to both fraction of area (7.72 ft^2) seen in enlargement colored by dye and fraction of total shim reflector area (13.02 ft^2) colored by dye. Both these conversions were plotted against time, as shown in Figure 5.F. Then, since it was known that the dye solution had to be coloring the entire shim reflector area if it colored all the area shown in the enlargement, an adjusting base line was drawn as shown in Figure 5.F. A french curve,

Figure 5.F

Primary Dye Diffusion Test 101-A
Data Adjustment



fitted to approximate the slope of the dye diffusion rate (based on the total area of the shim reflector) up to Point A in Figure 5.F and terminating at point (30, 1.0) as shown in the figure, was then used to draw in the adjustment line. (In a few cases, the adjusting base line also served as the adjustment line. This was only done when the slope of the adjusting base line was almost identical to that of the fraction of total area colored line up to Point A). The data for Table 4.d was then taken off the adjustment line as indicated in Figure 5.F.

The utility of the data obtained in the dye injection experiments for determining the effects of main circulating stream flow rate and dye solution injection rate on diffusion rates in the shim reflector are questionable for the following reasons. First, it was necessary to experiment with initial dye solution intensities, type of film, type of light filter and lighting before arriving at a combination that would show up well in the enlargements made by the Thermo-Fax Microfilm Reader Printer. Since each dye injection test required almost a full day to complete, it was not possible to run all the dye injection tests on the basis of common dye solution intensities, lighting, type of light filter used, and type of film used. As a result, the data presented in Table 4.c was extracted from enlargements made from both color film (positive) and black and white film (negative) such that the intensity with which the dye solution showed up on the enlargement did not necessarily bear any relation to the actual intensity of the dye in the model. Also, the exposure times used in making the enlargements on the Microfilm Reader Printer are known to have varied considerably. This also makes a considerable difference in the intensity exhibited by the dye solution in the enlargement. With all these factors influencing the interpretation as to whether dye solution had diffused into a given area or not, it is not considered appropriate to base conclusions (as to the relative effects of the parameters on the rate of diffusion) on the data presented here.

5.5 Shim Reflector Experiment with Boric Acid Injection and Measurement

Originally only one run was planned in which boric acid would be injected into and removed from the shim reflector model. However, difficulties were experienced in the first run which made a second run desirable. These difficulties were primarily due to injection of too much boric acid into the model.

The water in the reflector model was cleaned up by use of the ion exchange resin column prior to boric acid injection. This operation was easily and quickly accomplished. In both runs, the resistivity of the water in the model increased exponentially with a period of 36 minutes. An attempt was made to decrease the flow rate through the resin column in Run 2. However, the existing piping and valves were such that no stable flow rate could be set except full flow.

During cleanup of the water in the system for Run 2, an interesting phenomena was noticed. The resistivity of the water increased but the boric acid concentration also increased. The only known source of boric acid was the ion exchange resin, which had had part of its ion exchange capacity used up by boric acid. Thus, for Run 2, the model was drained and refilled with tap water and the resin replaced.

Throughout all of Run 1 and in the early parts of Run 2, a strong odor of ethanol was noticed when ever a sample was taken. The only sources of the ethonal were the ion exchange resin and/or the food dye used in the dye injection tests. As the resin consisted of a quaternary amine and a sulfuric acid type resin, the resin does not seem to be a likely suspect. Therefore, the alcohol must have been due to some food dye which was not flushed out even though the water in the model was changed several times between the two test series. Just what effect the ethanol had, if any, on the ion exchange capacity of the resin is unknown.

In determining the resin capacity for boric acid, some difficulty was experienced as material balances could not be made on the system. The determination of capacity was also complicated by not knowing when initial break through occured. This was further confused by the disagreement between resistivity measurements and chemical analyses performed by St.Louis Testing Laboratory. In the second resin bed of Run 2, the effluent from the resin column was of 1.8 megohm-cm purity but was analyzed as 0.15 grams boric acid per liter. At this point the resin bed had absorbed about 2 pounds of boric acid per cubic foot. In Run 1, after the resin had removed 4.2 pounds of boric acid per cubic foot of resin, the effluent boric acid concentration was 3.91 grams per liter and the resistivity was about 370,000 ohm-cm.

Based upon this experience, it appears that the most economic means of resin bed usage in a dynamic system is to use two beds in series. The upstream bed could then be used to remove about 4 pounds of boric acid per cubic foot of resin and the downstream bed could remove about 2 pounds per cubic foot while yielding water of about 2 megohm-cm purity. By replacing the upstream resin and reversing flow direction, the ultimate capacity of the resins may be utilized.

Operation of the shim reflector system of the model proved that the system easily and reliably performed all the basic design functions required of it. It further indicated possible methods of increasing the capacity of demineralizing resins for boric acid in shim reflector systems. The feasibility of nuclear shim control by means of a shim reflector must ultimately be determined by operation of the nuclear mockup. However, since the response times required for nuclear shim control are ordinarily several orders of magnitude greater than those required for power regulation, it is felt that chemical shim reflector control is far more practical than power regulation with a chemical shim reflector system.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This section briefly presents the conclusions and recommendations reached as a result of the operational experience gained with the reflector model and the analysis of the data obtained in the experiments conducted.

6.1 Safety Reflector Drop Time

Conclusions

The safety reflector design presented in INTERNUC-23 and the three variations of it, developed by studies conducted under this contract, have proven to be practical and reliable from both functional and operational standpoints, by the construction and test operation of the reflector control system model. The nuclear worth of the functions performed has yet to be proved by operation of the nuclear mockup.

Based on the experiments conducted with the safety reflector portion of the reflector control system model, the safety reflector water drop times predicted in INTERNUC-23 were optimistic. However, the drop times achieved in test operation of the model appear to be entirely adequate for this method of "scram" control to be considered for use with the flux-trap type test reactor design presented in INTERNUC-23.

With the area ratios investigated, the parameter having by far the greatest effect on water drop times is the resistance to air flow in the scram line. This, in turn, is primarily a function of the area ratio (scram line cross-sectional area: safety reflector cross-sectional area) which determines the velocity of the air in the scram line relative to that of the water in the safety reflector. Main circulating system water flow rate appears to have a slight effect on water drop times but this effect is negligible with respect to the effect of scram line size. The results of these experiments do not definitiely prove that piping arrangements have no effect what-so-ever on water drop times but they do indicate that any such effects are so small that they may safely be disregarded.

The utility of a water jet eductor to raise and maintain a column of water in the safety reflector portion of a reflector control system has been definitely established through operation of the reflector control system model. The only precautionary note is that maximum water temperatures in the safety reflector must be maintained at reasonably low values to preclude the possibility of vapor voids in the safety reflector column causing power transients or an unscheduled scram.

Recommendations

It is believed that the drop time achieved with a given area ratio could be reduced considerably by: a) utilizing a scram solenoid valve of different design than those used in the drop time tests reported here, b) by utilizing long radius elbows (or pipe bends) rather than short radius elbows where-ever a change in direction of the scram line is desired, and c) utilizing air (or gas) pressure rather than the acceleration of gravity to force the water column down.

It is also believed that experimental information concerning the relative effects on drop time of scram line friction, pipe bend radius, and type of solenoid valve would be extremely valuable in the design of an operational safety reflector control system.

Therefore, it is recommended that a series of experiments, designed to obtain substantial evidence in confirmation or denial of the above considerations be performed with the present reflector system model.

6.2 Conductivity of Boric Acid Solutions

Conclusions

Based upon the work reported, it may be concluded that electrical conductivity is not a universally reliable method of measuring boric acid. Conductivity indicates the total ionic concentration in the solution and gives no specific information about boric acid. However, conductivity is suitable for following the course of additions and removals of boric acid from a system if an accurate knowledge of the boric acid concentration is unnecessary.

As a laboratory method of measuring boric acid concentration, conductivity is unsuitable if any chemicals other than boric acid may be present.

Recommendations

Therefore, it is recommended that no further study be made of the electrical conductivity method of measuring boric acid concentration. A device which measures the neutron absorption of the shim reflector solution (see Section A7.1.1 of Appendix 7) would probably give much more reliable information about boric acid concentration to a reactor operator. For laboratory work titration with standard sodium hydroxide by the method described in Section A7.1.3 of Appendix 7 is most suitable.

6.3 Ion Exchange Resin Capacity for Boric Acid

Conclusions

From the break thru curves obtained with the Amberlite MB-1 ion exchange resin, it may be concluded that this resin is quite adequate for removing boric acid from water. The ion exchange capacity of this resin for boric acid is about 4 pounds per cubic foot of resin.

6.4 Dye Injection Experiments

Conclusions

The dye injection experiments conducted in the shim portion of the reflector model indicate that there is definite channeling of injected fluids with the inlet plenum design tested. Also, these experiments indicate diffusion rates are slow and relatively constant throughout the injection period with the shim reflector and inlet plenum designs studied. Conclusions as to the effect of main circulating system flow rate and dye solution injection rates on diffusion rates in the shim reflector are probably not warranted on the basis of the tests reported.

Diffusion rates and dispersion of injected fluids are considered adequate to warrant shim reflector control of an operating reactor. However, they do not warrant use of the shim reflector and inlet plenum designs tested for power regulation.

Recommendations

If analytical studies of the reactivity effects of channeling and/or pocketing of chemical shim solution in the shim reflector annulus show that such phenomena would be deleterious to the safety or operability of a test reactor, it is recommended that an annular model of a shim reflector system be built and test operated to determine the best methods of achieving the ideal distribution desired in a chemical shim control system.

The results of these tests probably eliminate consideration of power regulation as a concurrent use for a chemical shim control system in a large control volume. The dynamic nuclear response of the reactor and the dynamic functional response of a small shim control system should be investigated analytically, however, to determine whether or not power regulation might be feasible. Based on the results and conclusions of this analytic study, experiments to determine feasibility of power regulation with a chemical shim control system could be conducted in the nuclear mockup.

6.5 Shim Reflector Experiment with Boric Acid Injection and Measurement

Conclusions

Operation of the shim reflector model with boric acid injection, measurement, and cleanup was satisfactory in all respects, indicating that the system is workable. The demineralizer was also adequate for removing boric acid and has a capacity of about two pounds of boric acid per cubic foot of wet resin at initial breakthrough and an ultimate capacity of four pounds per cubic foot.

From the performance of the conductivity measurement method, it may be concluded that, in the absence of corrosion products, the method is suitable for approximate measurement of boric acid concentrations. However, at low concentrations the method is not reliable.

Recommendations

The utility of reflector shim control for a flux trap type test reactor may ultimately be determined only by operation of a nuclear mockup of the system. The advantages to be achieved with reflector shim control seem sufficient to warrant the expense of such an investigation. Therefore, it is recommended that a nuclear mockup, incorporating a reflector shim control system, be built and test operated.

7.0 REFERENCES, PART A

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PART B

ANALYTICAL STUDIES OF REFLECTOR CONTROL

1.0 INTRODUCTION

A study of reflector control concepts was made in order to evaluate those which appeared promising for AETR application. Selected concepts then could be studied experimentally in the reflector model and nuclear mockup before a final selection would be made for use in an AETR. The experimental information obtained, of course, would be generally applicable to any similar reactor system employing reflector control.

It is recognized that a reflector control system can be augmented with other means such as burnable poison in the fuel elements, soluble poison in the coolant, etc. These have not been considered in this report and they may alter somewhat the optimum control schemes. Nevertheless, it is felt that these additional methods of control will not seriously affect a reflector control experimental study since they will tend to reduce the shim control requirements of the reflector and reduced shim control requirements will necessarily be included in any experimental study.

2.0 SUMMARY

Two reflector control schemes appear most promising and they should be considered first in experimental studies: 1) a single-region reflector control scheme and 2) a three-region reflector scheme. For the nuclear mockup the three-region reflector is selected for fabrication (See Figure 1) since with proper design of piping, valves, etc., both schemes can be simulated as well as the other control schemes considered in this report.

The single-region reflector control would incorporate both shim and safety control into a single-region next to the core with boron concentration adjusted so that maximum shim and minimum safety worths are about equal. Only a small portion of the reflector would be used for control. Dynamic response of this shim control should be good since the boron concentration and the volume of poisoned D_2O are both low making it possible to change reactivity significantly and relatively rapidly by removing or adding only small amounts of boron.

The three-region reflector control consists of a pure D_2O annulus next to the core for safety control. Approximately 3 - 4 inches from the core, a shim control region is provided. The thickness of the shim region is such that approximately a 50% saturated boron solution is adequate to provide all the shim control desired. The outer region of the reflector contains pure D_2O. The dynamic response of the three-region reflector control is approximately as good as that for the single-region case and a fast safety control is always provided regardless of the boron concentration in the shim control region.

A separate two reflector scheme and a connected two reflector scheme also were considered for control. However, they were similar in concept to the above schemes but had additional disadvantages. Nevertheless, they may warrant consideration in an experimental program.

Calculations were made of shim and safety reflector worth for a variety of shim and safety reflector parameters. Safety reflector thickness was varied from 7.75 to 0 inches, with and without boron. Boric acid concentration was varied from 100% to 2% of saturation in the shim reflectors. Neutron flux plots also were obtained from these calculations.

A number of general conclusions can be made as a result of this study:

1. The worth of the reflector is generally very large, exceeding 50% $\Delta k/k$ for the geometry considered herein. This indicates the importance of the reflector for moderating neutrons and reflecting them back into the core.

2. The total reactivity worth of the reflector for a given core geometry and reflector material is essentially fixed. Thus the worth of the reflector shim control can be increased only at the expense of the worth of the safety reflector.

3. There is a shift in the radial power distribution of the core as the poison content in the shim control reflector is varied. The magnitude of the change in maximum-to-average power distribution is primarily a function of total reactivity variation.

3.0 GENERAL REFLECTOR CONTROL CONSIDERATIONS

In a small reactor such as the AETR where the ratio of core surface-to-volume is high, the leakage of neutrons from the core is large resulting in a greater than normal reactivity worth in the reflector. Reflector control is enhanced and it offers the potential for minimum perturbation of the axial power distribution in the core and neutron flux in the central test region. Also the fabrication of the reactor is greatly simplified since no control rod drives are necessary and no provisions for moving fuel or poison in the core need be made.

In order to take full advantage of a reflector control, a heavy water reflector was chosen early in the AETR work.[2] This has several important advantages over solid reflector materials for control such as mechanical simplicity, simple cooling, lower critical mass, and greater ease of inserting experiments.

3.1 Reflector Control Methods

There are two basic methods which can be employed in reflector control: 1) varying the effective density of the reflector and 2) varying the poison content in the reflector. Both control methods can be used in a single reflector region or in a number of regions; they can be used simultaneously in any region or used separately in different regions.

For safety control, the reflector can simply be dropped away from the core. Only a small portion of the reflector, next to the core need be dropped since the reflector past approximately 8 inches from the core is worth little in reactivity.

For shim control, both basic methods can be used. For example, the height of a D_2O annulus surrounding the core can be varied (resulting in a varying void region), a soluble poison can be introduced into all or certain regions of the reflector, or a combination of the two schemes can be used.

3.2 AETR Control Requirements

3.2.1 Shim Control

The excess reactivity anticipated for an operating cycle of the AETR is approximately 16% $\Delta k/k$. In addition, it is planned to be able to supply enough shim control so as to be 4% subcritical with the safety reflector in its most reactive position. Hence the minimum worth of the shim control should be approximately 20% $\Delta k/k$.

Normally startup requirements dictate the maximum rate of reactivity addition. Reactivity addition rates are limited so that period or high flux level serves to terminate power before some dangerous limiting condition in the core is reached. Detailed calculations are required and it is hoped, because of some beneficial effects of the D_2O reflector, that reactivity addition rates can be permitted which will be high enough to override xenon for any shutdown situation.

3.2.2 Regulating Rod

It may be possible to use the reflector shim control in a dual capacity, both for shim and regulating control. This will depend on possible rates of poison addition and removal. It is expected that the nuclear mockup will provide experimental information on this possibility.

A mechanical regulating rod is proposed both for the nuclear mockup and the AETR at present. This is an aluminum clad cadmium tube located in the heavy water safety reflector for maximum worth. The maximum worth of the rod is approximately 0.5% $\Delta k/k$, but since it is normally at its midpoint of travel, its operating worth is usually 0.2-0.3% $\Delta k/k$.

3.2.3 Safety Control

The worth of the safety reflector in the AETR depends on the core geometry, being greater for cores with larger core surface-to-volume ratios. In the core designs presented in Internuc-23[2] there appears to be ample total reactivity within the reflector so as to provide safety control at least equivalent to shim control. On this basis the safety reflector could be designed so as to be worth at least 20% $\Delta k/k$, thus always overriding shim control for any of the control schemes discussed.

It is desirable to remove reactivity with the safety control as quickly as possible. Reactivity removal rates equal to or greater than those of the safety rods in the ETR can be attained as demonstrated by the experimental data reported in Section A of this report. The reactivity removal rates are shown in Figure 5.E and it is noted that for smaller total worth, these rates can be further increased by commencing safety reflector drop closer to the midplane of the core.

4.0 REFLECTOR CONTROL SCHEMES

Four possible reflector control schemes are considered. These schemes differ principally in the number of control regions and the function of each region.

4.1 Two Separate Reflectors

The two separate reflectors are composed of two concentric annuli of D_2O surrounding the core as illustrated in Figure 2. The pure inner reflector serves as a safety control and can be dropped quickly into its reservoir. The outer reflector, serving as a shim control, is poisoned with boric acid. The two regions are separated functionally and mechanically.

4.2 Two Connected Reflectors

The two connected reflectors are also formed by two concentric annuli but in this case the separating wall is open at the top of the reflector so as to permit heavy water circulation between regions (Figure 3). Thus both regions are poisoned for shim control but the inner region can be dropped for safety control. A common circulating system, as shown in Figure 3, is used for cooling and poison removal.

The worths of the shim and safety controls can be adjusted by varying the thicknesses of the two regions. Even with a saturated boron solution, the region next to the core has sufficient reactivity worth for safety control. The disadvantages inherent in a connected reflector system include a slower response time and larger resin bed size because of the large shim reflector volume.

4.3 Single Reflector Control

This scheme also provides both safety and shim control in the same region but uses only the inner portion of the reflector (Figure 4). The outer (lower worth) region contains pure D_2O which is not to be dropped for safety. By using less than 8 inches of the reflector for control, essentially the same reactivity worth can be attained as by using the entire reflector. This is discussed in Section 6.1.

In this arrangement, the minimum safety control may not need to be as great as the maximum shim control since reactivity should always be reduced by dropping the single reflector control region even if poison is completly removed from it. This permits greater flexibility in control.

4.4 Three Separate Reflectors

The reflector region is divided into three annuli as shown in Figure 1. The inner region provides safety control and the intermediate region shim control. The other region is pure D_2O ordinarily left in place.

This scheme is advantageous in that both safety and shim reflector volumes can be relatively small, separated, and still provide sufficient control. The response time of the shim control should be good and the rate of reactivity removal by the safety control should be high. A disadvantage is the probable need to provide a separate auxiliary system for each of the three reflector region, although one system might be adequate for the safety and outer reflector region which contain only pure D_2O.

5.0 NUCLEAR CALCULATIONS

WANDA[3], a one-dimensional IBM 704 code based on diffusion theory, was used to perform the nuclear calculations. The type "A" core as shown in Figure 3C of Internuc 23[4] was used as the reference reactor. The physical arrangements of the reflector schemes are shown in Figures 1 through 4 of this report.

5.1 Reflector Reactivity Worth

Reactivity worths of the safety and shim reflectors were calculated for a number of different reflector arrangements. WANDA, the one-dimensional diffusion code, should give reasonable results except for calculating the worth of the safety reflector where an annular reflector void must be introduced. As a result the axial leakage term, $D\beta_{\perp}^2$, goes to infinity and thus overestimates the worth of the void.

In order to avoid an infinite leakage term, safety worth was calculated by varying the D_2O density stepwise to 50% and 25% of actual density. To obtain the reflector worth at zero density, a linear extrapolation from the 50% and 25% densities was used. Although this may not give an exact value, for comparison purposes the error is acceptable and a more refined calculation was not justified for this study.

The direction of the error can be estimated from the total worth of the reflector and the worth of portions of the reflector. In Figure 6, which gives a plot of shim reflector worth as a function of safety reflector thickness and boron concentration, the worth of the remaining reflector saturated with boric acid is approximately 10% $\Delta k/k$ for the 7.75 inch safety reflector. For the same reflector, the total reflector worth is probably greater than 55% $\Delta k/k$. Assuming that the reflector past 7.75 inches is not worth more than 16% in reactivity (a reasonable assumption), then the safety reflector is worth more than 39% $\Delta k/k$. This indicates that the value of 36% $\Delta k/k$ obtained from the WANDA calculation is conservative.

Figure 13 shows a typical safety reflector worth as obtained by extrapolating the WANDA calculations to zero density. The results of the safety reflector calculations are shown in Figure 5.

Shim reflector worths were obtained for a variety of reflector arrangements. Boric acid concentration was varied from 100% of saturation to 2% of saturation at 68°F. Input data to the WANDA code are shown in Appendix A2.0 of Internuc-23[2]. Figures 5, 6, 7, and 8 summarize the results of the shim worth calculations.

5.2 Neutron Flux Calculations

Neutron flux plots through the reflector, core and test region also were obtained from many of the WANDA calculations. Generally only the thermal neutron flux was affected by poison in the reflector. Figures 9 through 12 show thermal neutron flux plots as a function of boric acid concentration for the different reflector control schemes.

6.0 COMPARISON AND SELECTION

Each of the four reflector control schemes was compared on the basis of control worth, mechanical feasibility and flexibility, operational simplicity and neutron flux requirements. From the comparison the most promising control schemes were selected for possible use in the AETR.

6.1 Control Worth

The total reflector worth is fixed for a given core size. Safety and shim control worths can be adjusted by varying the poison concentration in the shim region and by varying the thicknesses of the shim and safety control regions. Table 6.1 shows the maximum safety reflector worths for the four schemes proposed with the safety reflector thickness chosen so as to obtain approximately equal safety and shim control.

Table 6.a

Maximum Safety Reflector Worth
(No Poison in Reflector)

Control Scheme	Reflector Thickness, inches Safety	Shim	Maximum Reactivity Worth % Δk/k
Two Separate Reflectors	4	Remainder	19
Two Connected Reflectors	7.75	Total-Reflector	36.5
Single Reflector Control	7.75	Same Region	36.9
Three Separate Reflectors	4	3 (Following Region)	19

For the same reflector dimensions, the worth of the shim control as a function of boric acid concentration is shown in Table 6.0b.

Table 6 b

Shim Reflector Worth

Control Scheme	Reactivity Worth, % Δk/k Boric Acid Concentration, % of Saturation		
	10 %	50 %	100 %
Two Separate Reflectors	13	18	19.5
Two Connected Reflectors	24.5	39	41
Single Reflector Control	24	38	41
Three Separate Reflectors	11	16	18

It is apparent that the separated reflector control schemes do not have the flexibility to vary the worth of the shim and safety reflectors as do the connected and single region schemes. Even with different dimensions flexibility in control is limited. However, this may not be too great a disadvantage since the maximum shim control may be limited in any case by its effect on power distribution in the core. It is expected that for all control schemes boric acid concentration will be adjusted so that shim control will not exceed safety control.

It should be noted that even with a saturated boric acid solution, the minimum safety reflector for the single reflector control or connected reflector schemes is appreciable, being approximately 14% Δk/k.

6.2 Neutron Flux

The maximum-to-average power ratio in the core must be maintained nearly constant over the operating life of the fuel. The power ratio is primarily dependent on the thermal energy neutron flux distribution in the core, and to a lesser extent on the intermediate energy neutrons. Fortunately, both fast and intermediate neutron fluxes are not affected significantly by the poison in the reflector. However, the thermal neutron flux is.

Figure 9 shows the thermal fluxes as a function of boric acid concentration. Since the maximum shim control reported in the figure is 10% Δk/k and a 20% Δk/k is desired, the boric acid concentration must be increased which will result in a thermal neutron flux lower by approximately a factor of three over the reflector region. The neutron flux in the core will not change by an equivalent factor. Nevertheless, a significant change will occur being perhaps greater than 20%, but the power distribution should change by a lesser amount.

A similar situation occurs in Figure 10 for the case of a 7.75-inch safety reflector in a connected reflector control scheme. Again the boric acid concentration must be increased to attain the desired shim control, resulting in a large perturbation of the thermal flux. However, in this case the power distribution may be affected to a lesser degree than in the previous case.

Figure 11 shows the thermal neutron fluxes for a single region reflector control (7.75 inches thick). In this case the boric acid concentrations shown are greater than for the previous two figures. It is expected that for the desired 20% $\Delta k/k$ shim control, the power distribution in the core is affected to about the same degree as for the connected reflector and two-region reflector control schemes shown in Figures 9 and 10. Figure 11 is significant in that it shows the shim control may be limited to about 20% $\Delta k/k$ in all reflector schemes unless large changes in thermal neutron fluxes can be tolerated in the core.

Figure 12 shows the thermal neutron fluxes for the three region reflector control scheme. Here also the power distribution in the core changes with boron concentration. A 10% change in core maximum-to-average power ratio is estimated in going from a clean shim reflector to a fully saturated boric acid solution (18% $\Delta k/k$).

6.3 Operational and Fabrication Considerations

In the operation of a chemical shim control, the system of smallest volume has important advantages in requiring a smaller purification system and faster response time. On this basis, the single-reflector control and the three region reflector schemes are preferred.

Scram times for the four schemes is expected to be nearly the same if the ratio of scram line area to safely reflector flow area is the same. It appears, however, that the smaller safety reflectors may have a mechanical advantage in requiring smaller scram line area.

The number of cooling and purification loops are a minimum for the two connected reflector control scheme and maximum for the three separate reflector scheme.

6.4 Selection

On the basis of nuclear considerations, the two separate reflector scheme is comparable to the three region scheme. The two separate reflector scheme has the disadvantage of a large shim volume requiring high poison concentration and resulting in poor response time. It has the advantage of requiring only two auxiliary systems as compared to three for the three region core (although the auxiliary loops might be reduced to two). This advantage is not sufficient to prefer the two separate reflector scheme over the three separate reflector scheme.

The two connected reflectors have certain attractive control features in that a large amount of shim control can be obtained while still providing safety control. The amount of shim and safety control can be adjusted over a wide range although this range may be limited by an adverse effect on power distribution in the core. There is a disadvantage in that a more complicated system results if the shim reflector is to be prevented from draining into and filling the safety reflector region following a scram. A large purification system is required and the response time of the shim control is as slow as the two separate reflector scheme. Because the two connected reflector scheme is similar to the single reflector scheme and has several additional disadvantages, this system is not considered as promising as the latter.

The single reflector control scheme is very attractive in that it offers the maximum amount of shim and safety control in a reasonably small volume and safety control is still always available. The auxiliary systems are as simple or simpler than those for the other schemes.

The three separate reflector scheme has the advantage of small volume, fast response time and possibly less perturbation of the power distribution in the core than the single reflector control scheme. It has the disadvantage of requiring a more complicated auxiliary system.

It is difficult at the present time to choose between the single reflector control and the three separate reflector schemes. Since, however, the latter is more flexible in that with proper piping design all the other control schemes can be simulated, the three separate reflector scheme was chosen for the nuclear mockup.

7.0 REFERENCES, PART B

1. S. Glasstone and M. C. Edlund, "The Elements of Nuclear Reactor Theory," D. Van Nostrand Company, Inc., New York (1952)

2. C. F. Leyse, et al, "An Advanced Engineering Test Reactor", Report INTERNUC-23, AECU 3775, Office of Technical Services, Dept. of Commerce, (1958)

3. Marlowe, O. J., et al, Report WAPD-TM-28, "WANDA-A One-Dimensional Few Group Diffusion Equation Code for the IBM-704", (1956)

Figure 1

Reflector Control with Three Separate Reflectors

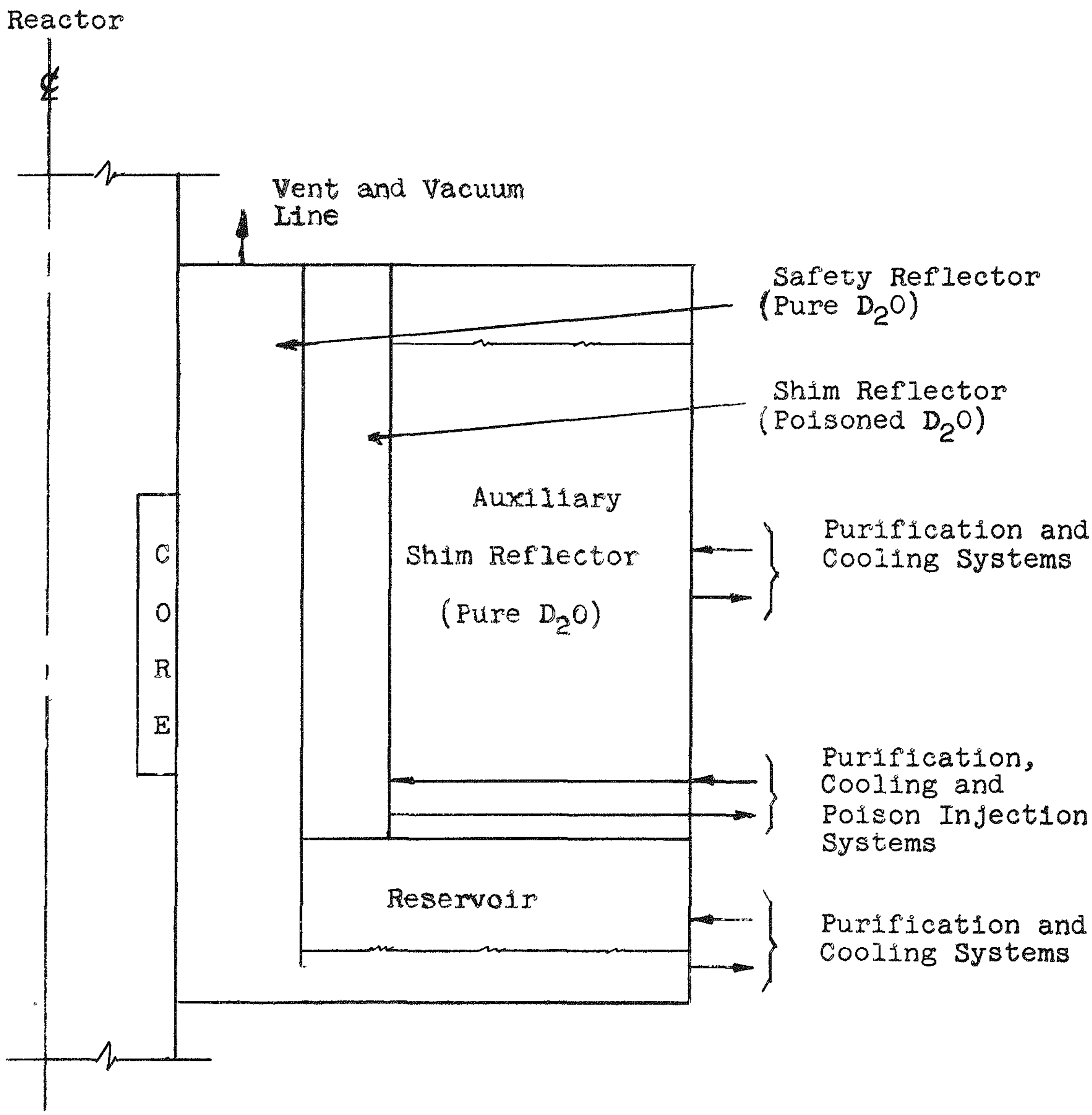


Figure 2

Reflector Control with Two Separate Reflectors

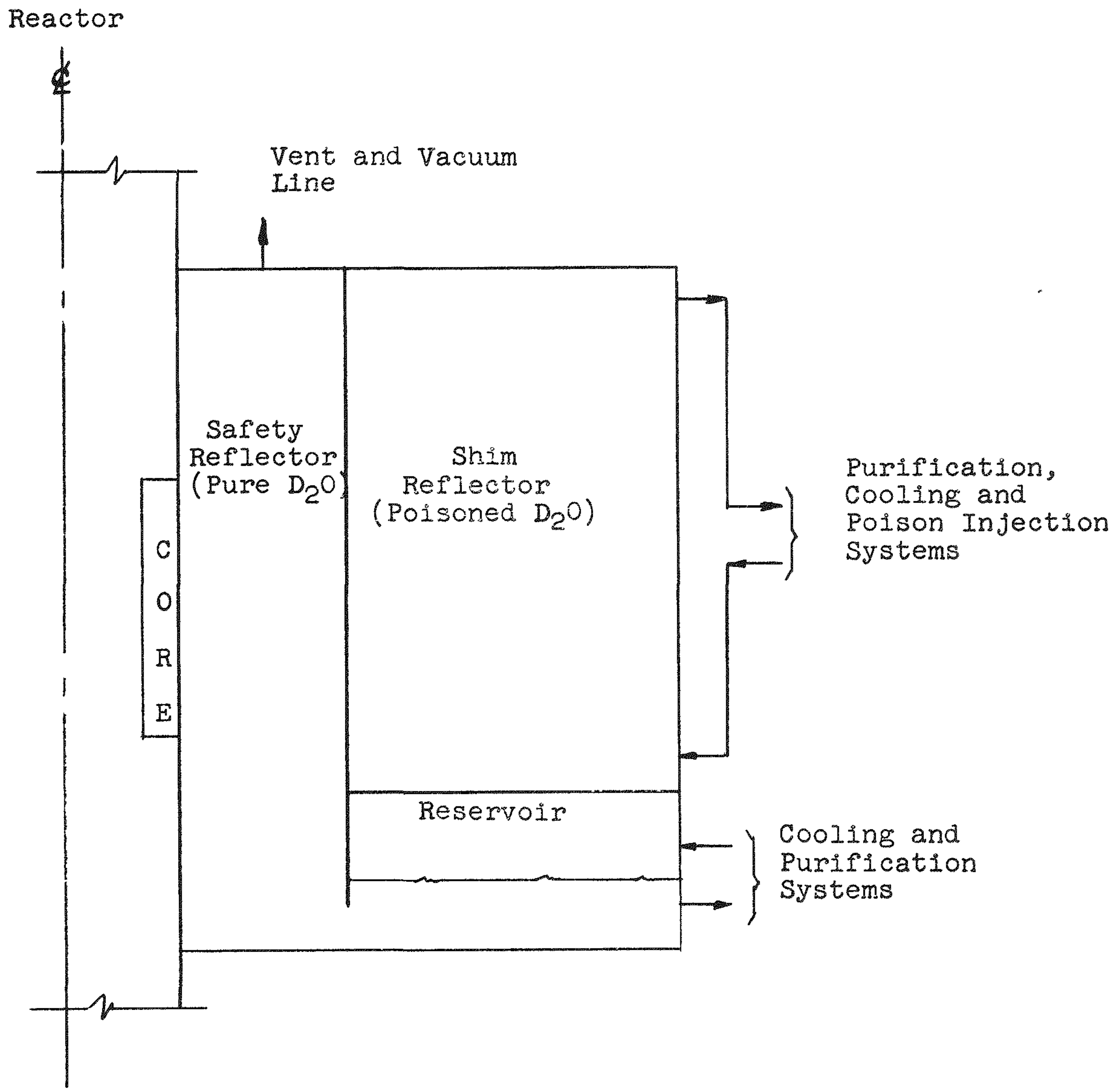


Figure 5

Worth of Safety Reflector as a Function of Thickness (Clean Shim Reflector)

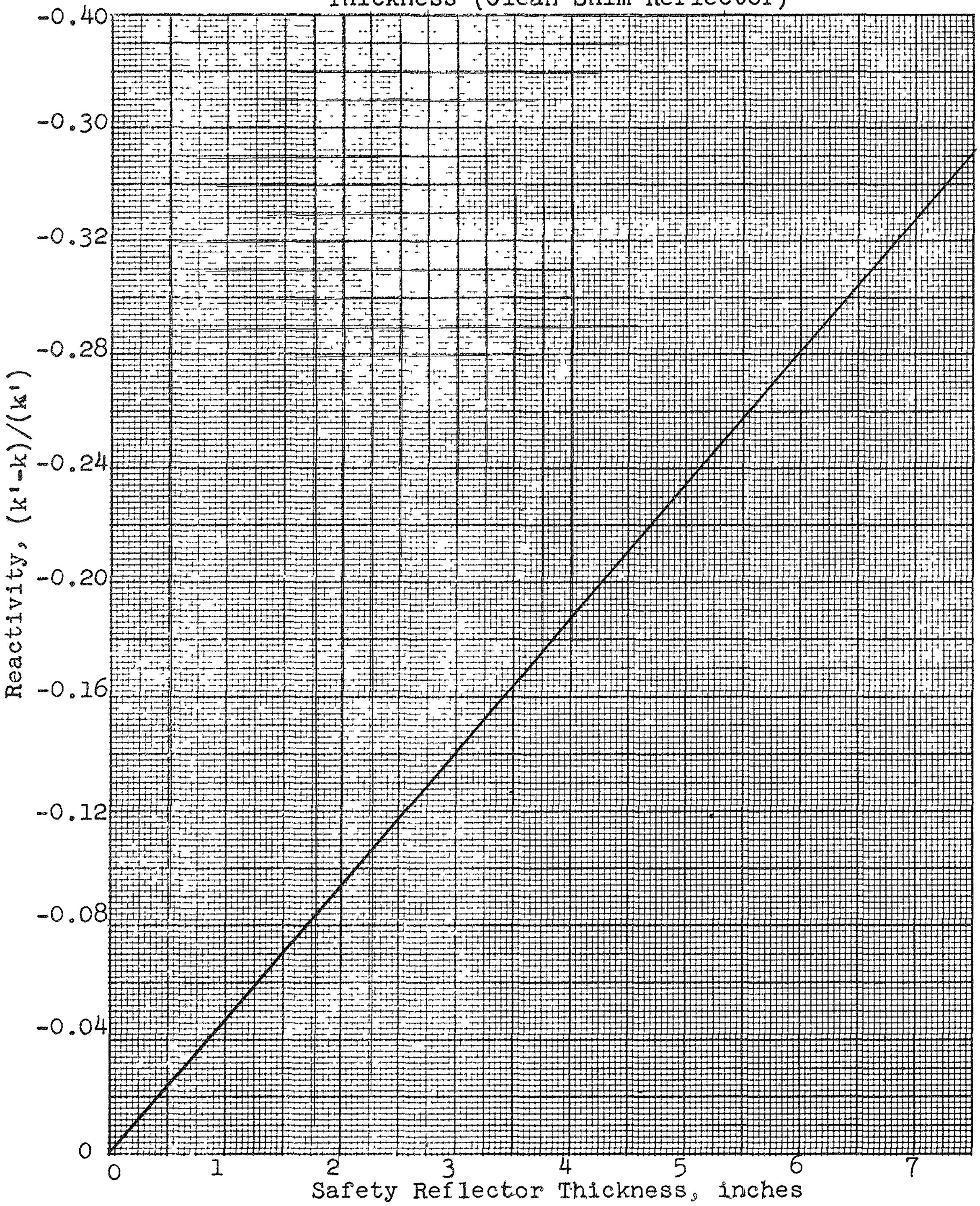


Figure 4

Single Region Reflector Control

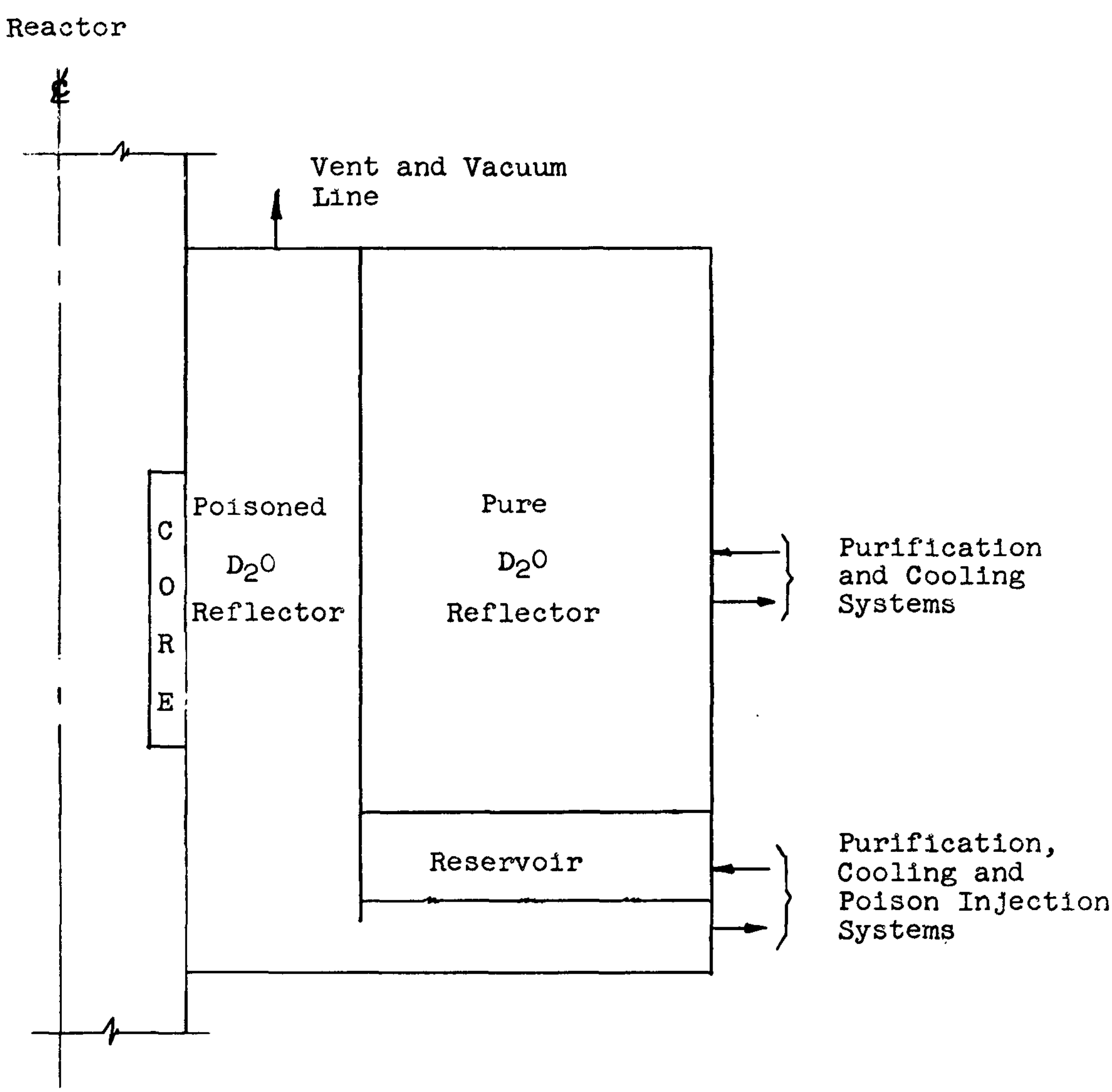


Figure 5

Worth of Safety Reflector as a Function of Thickness (Clean Shim Reflector)

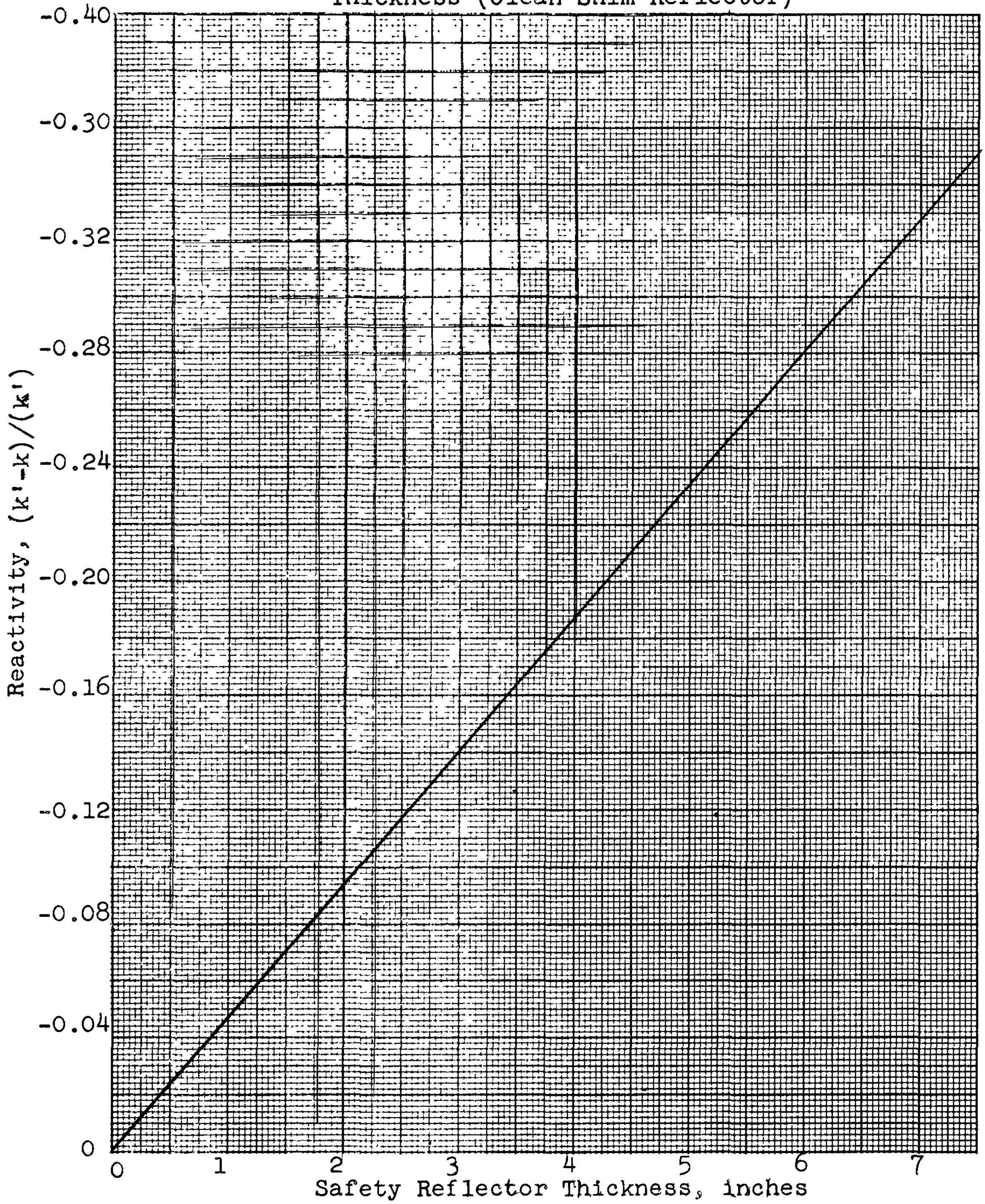


Figure 6

Worth of Shim Reflector for Various Reflector Thickness (Clean Safety Reflector)

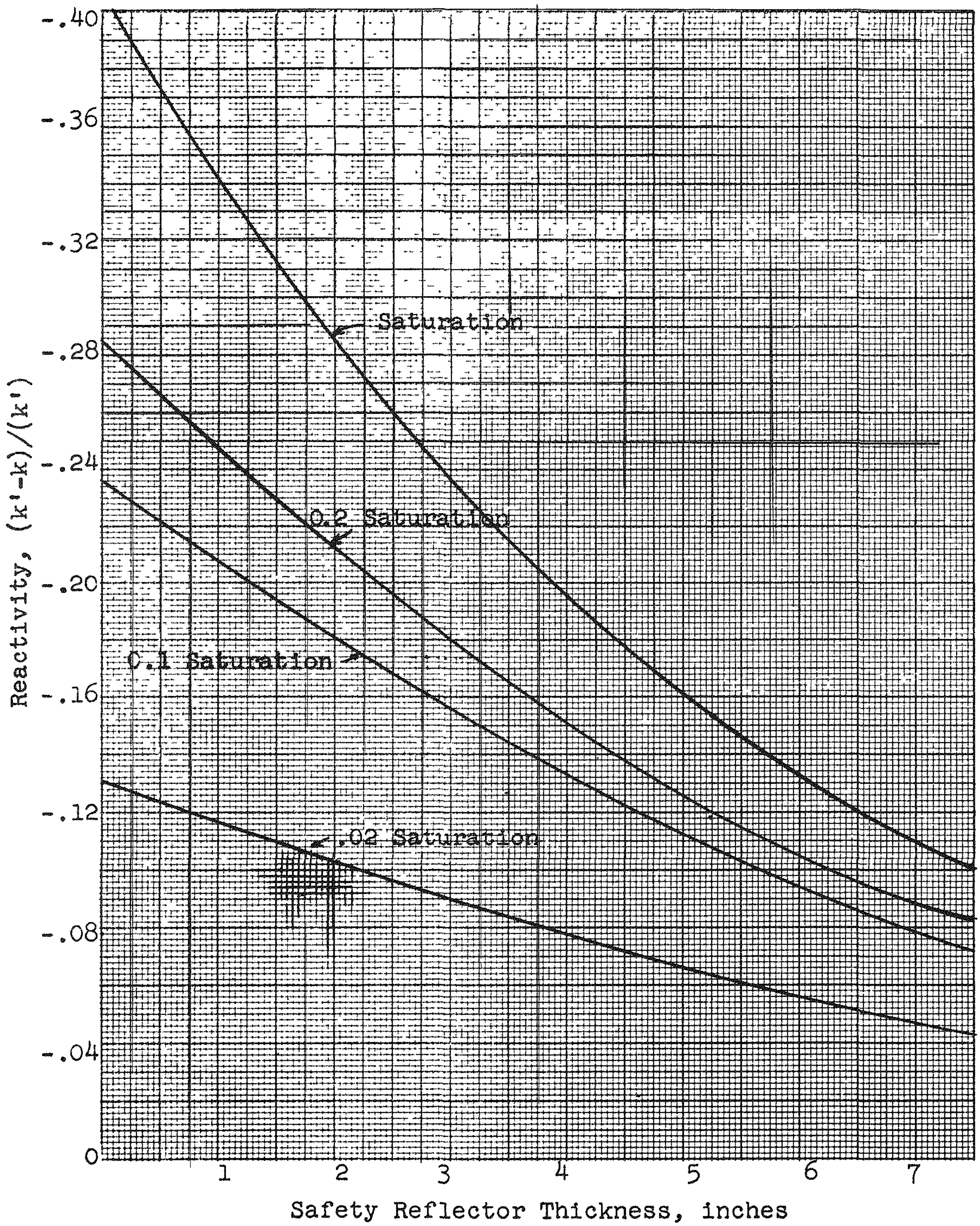


Figure 7

Comparison of Reactivity Controlled by Poisoning 7.75-inch Safety with Reactivity Controlled by Poisoning Entire Reflector

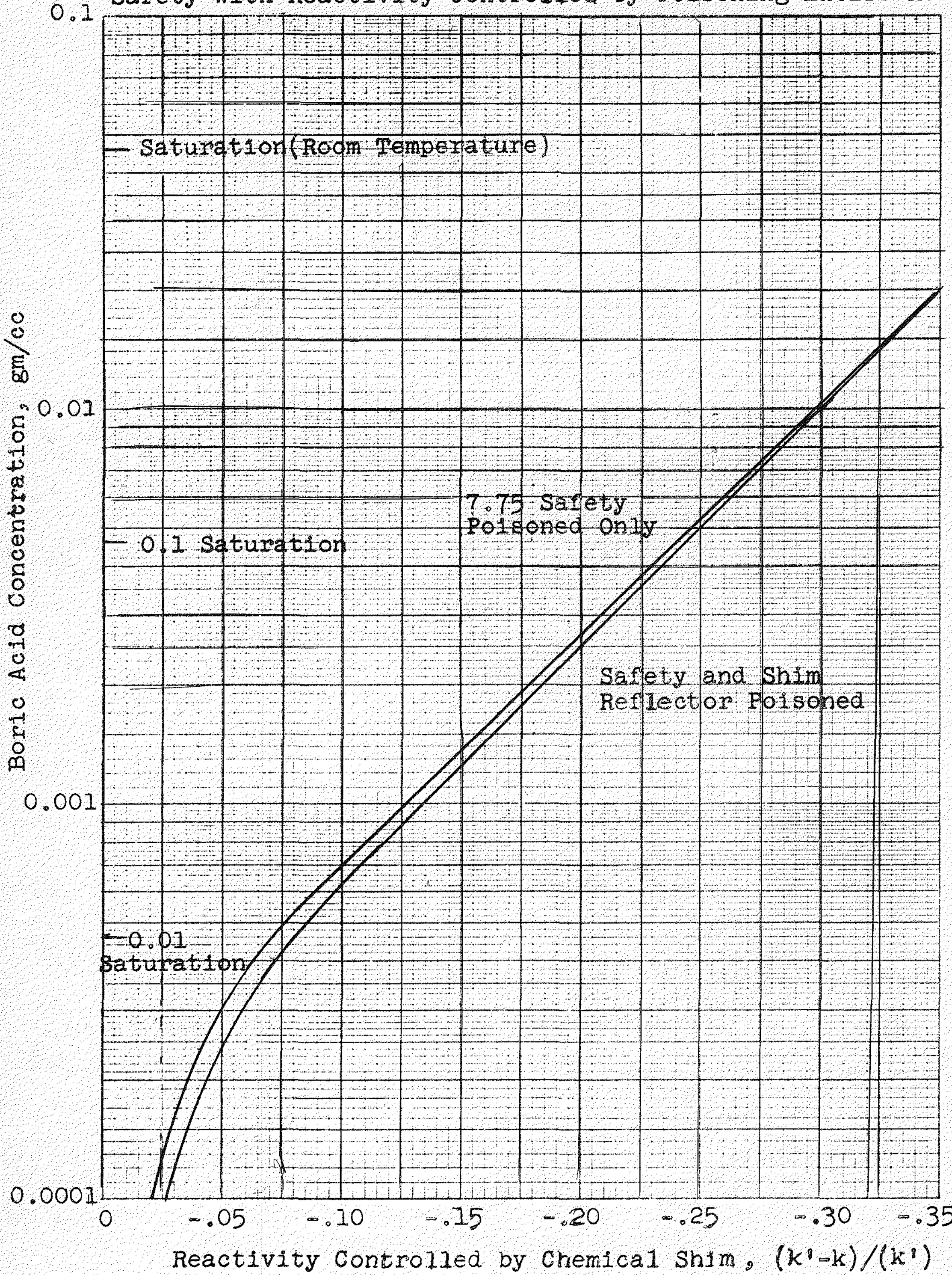


Figure 8

Variation of Reactivity with Shim Annulus Thickness for Various Poison Concentrations

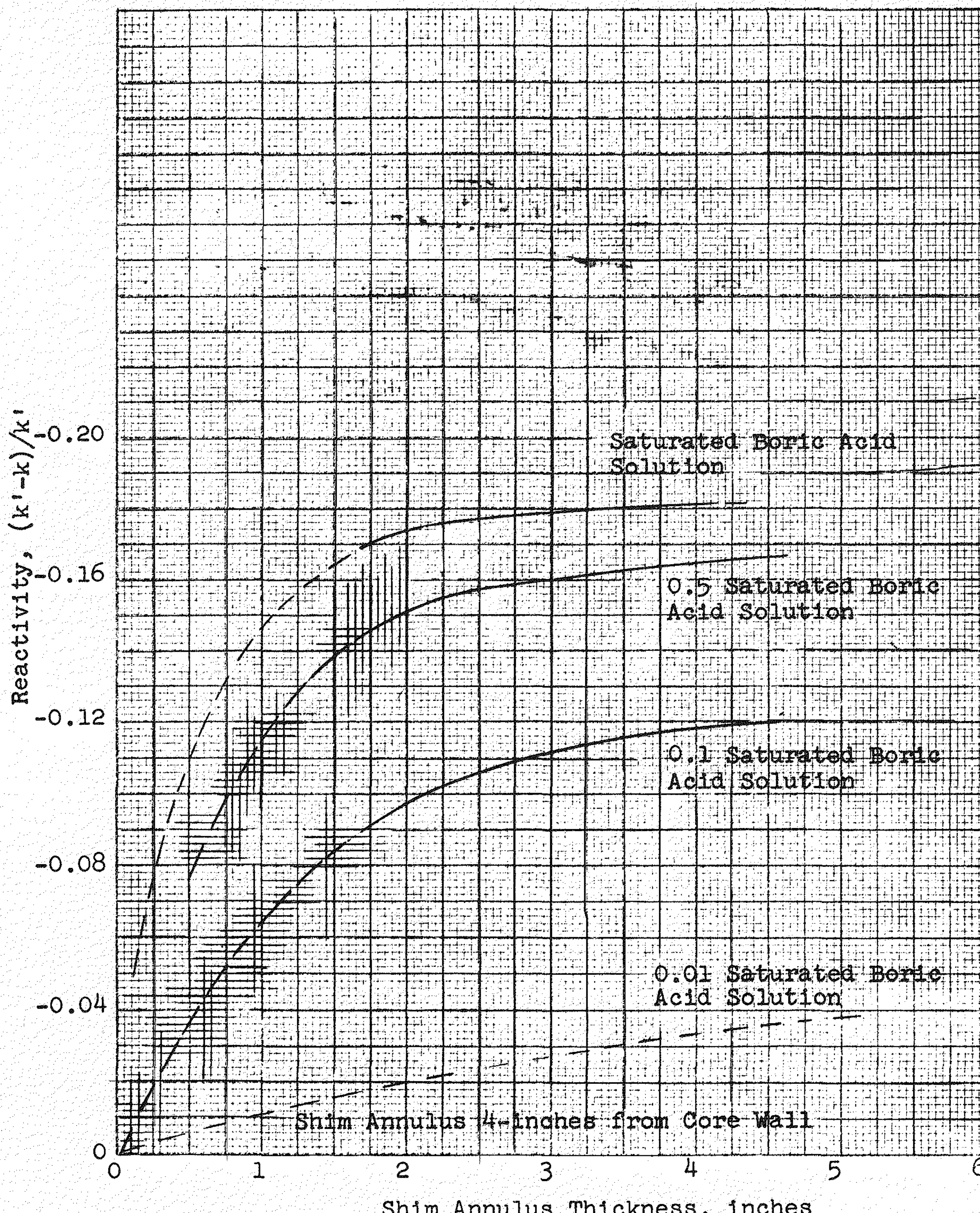
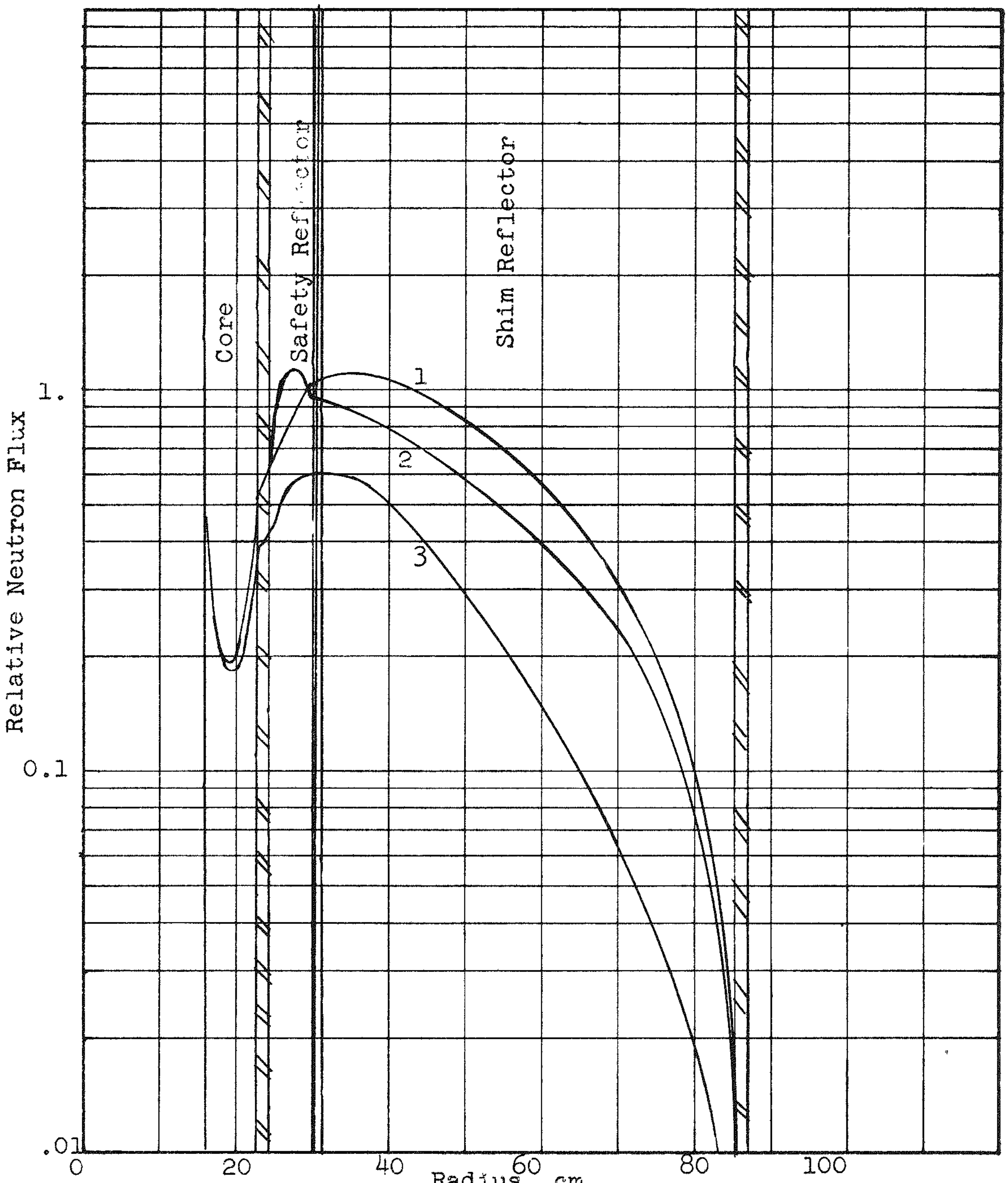


Figure 9

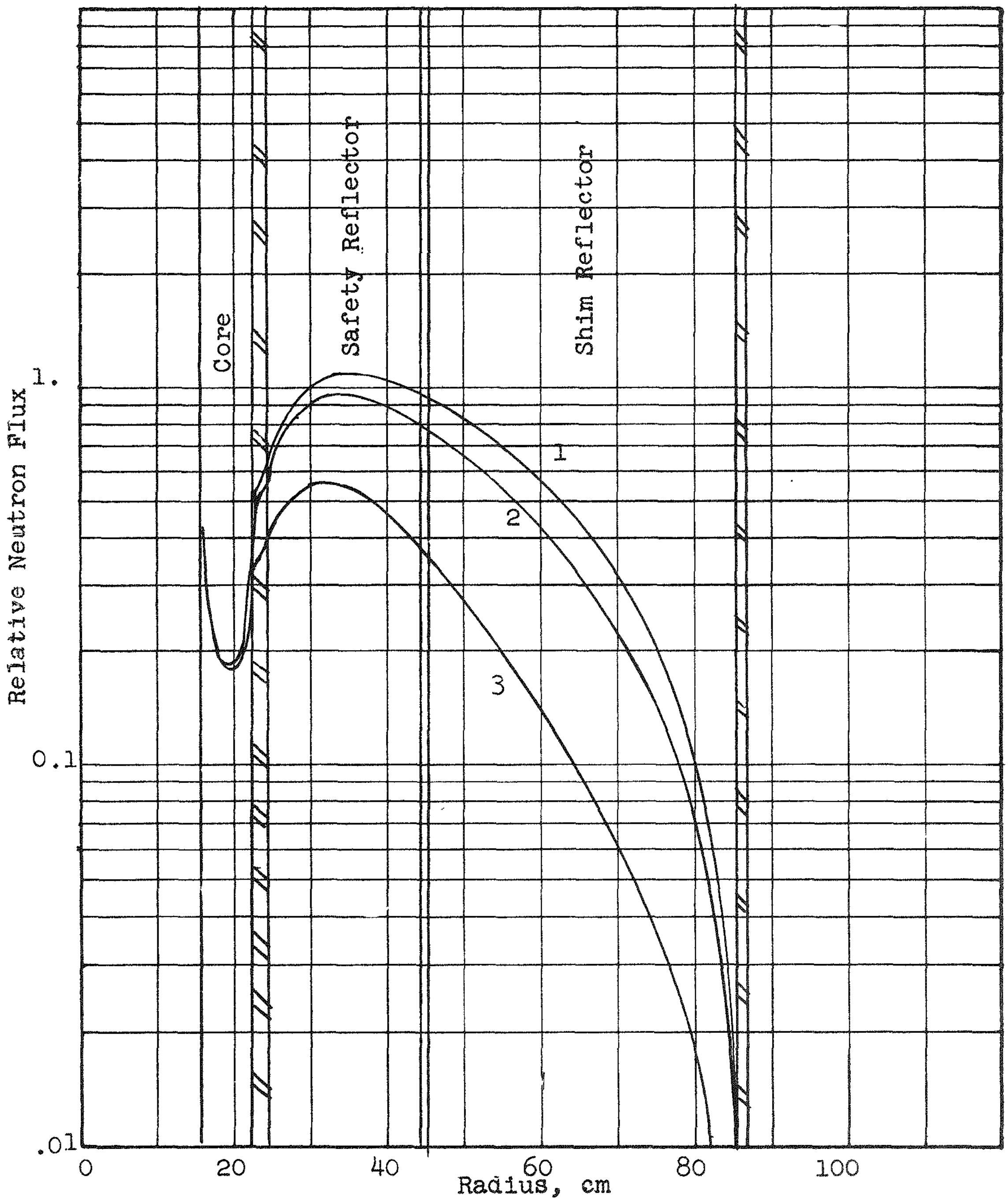
Relative Neutron Flux: Poison in Outer Reflector Only
(2-in Safety Reflector)



Note: Problem 1 - Clean Reflector (0.9% $\Delta k/k$)
Problem 2 - 0.00305 Saturated Boric Acid (2.97% $\Delta k/k$)
Problem 3 - 0.01845 Saturated Boric Acid (10% $\Delta k/k$)

Figure 10

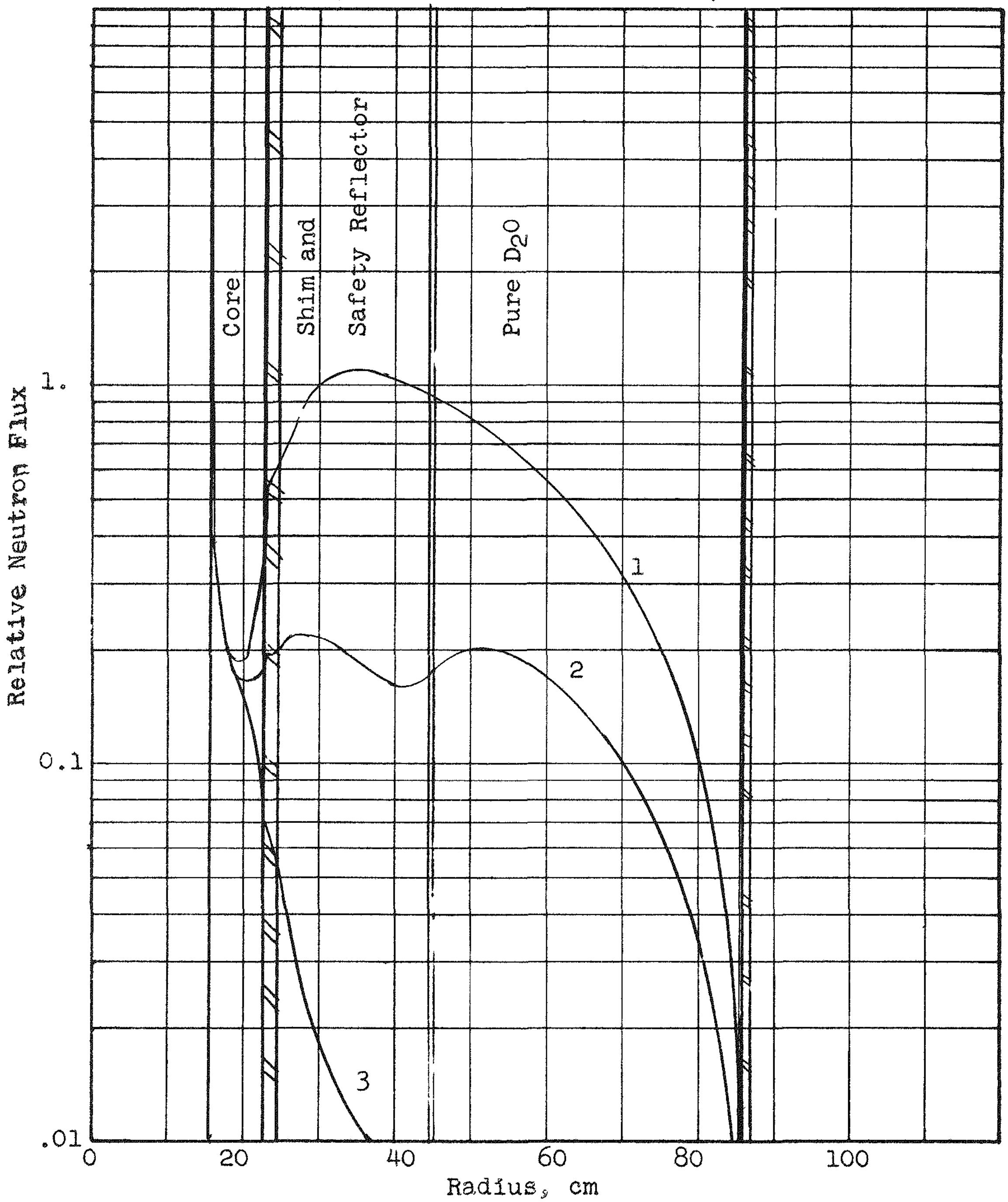
Relative Neutron Flux: Poison in Both Reflectors
(7.75-in Safety Reflector)



Note: Problem 1 - Clean Reflector (0.9% Δk/k)
Problem 2 - 0.003075 Saturated Boric Acid (3.4% Δk/k)
Problem 3 - 0.01845 Saturated Boric Acid (12.3% Δk/k)

Figure 11

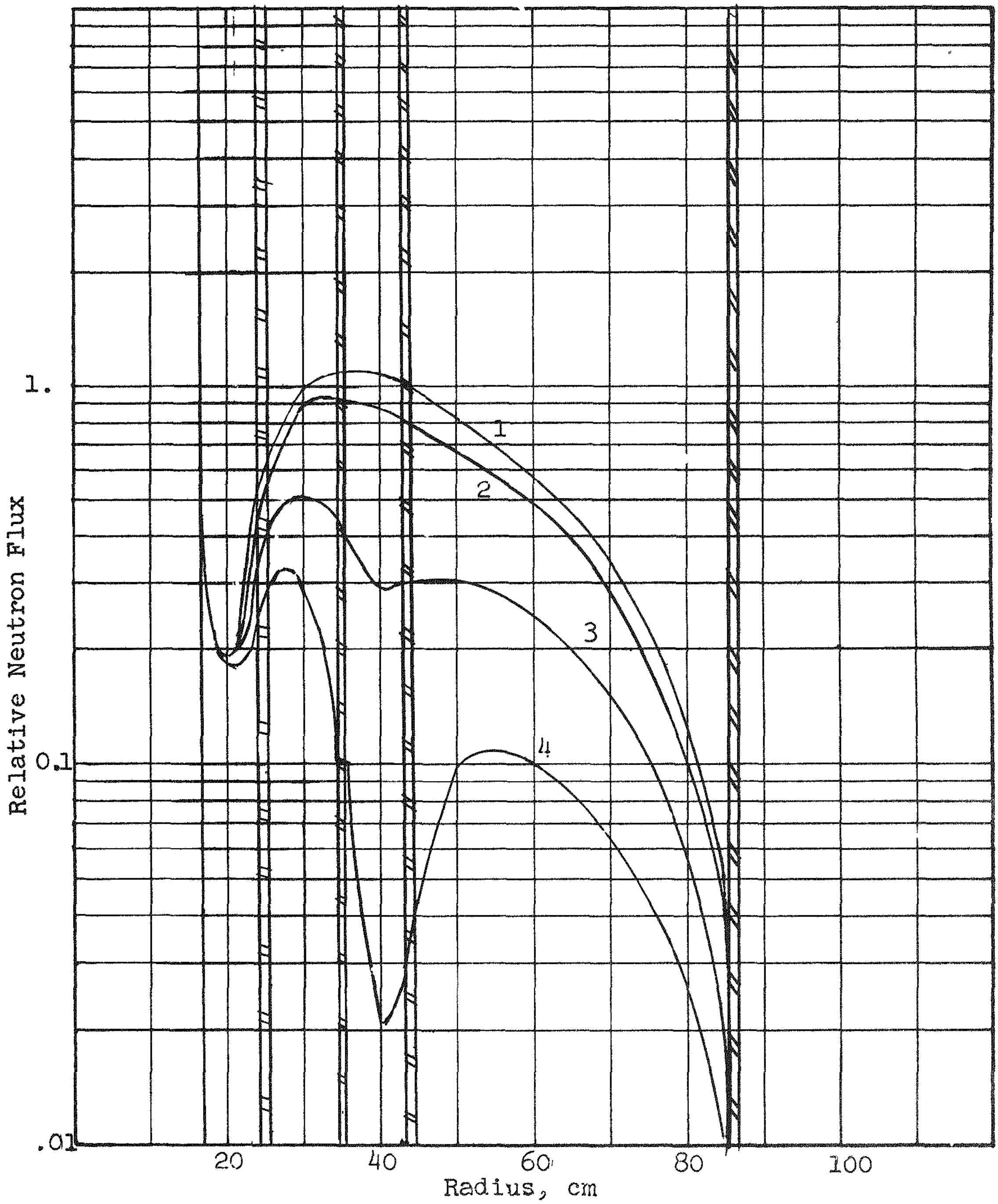
Relative Neutron Flux: Poison in Inner Reflector Only
(7.75-in Safety Reflector)



Note: Problem 1 - Clean Reflector (0.9% $\Delta k/k$)
Problem 2 - 0.1 Saturation Boric Acid (24% $\Delta k/k$)
Problem 3 - Saturated Boric Acid (41% $\Delta k/k$)

Figure 12

Relative Neutron Flux: Poison in Intermediate Shim Reflector Only (4-in Safety Reflector, 3-in Shim Reflector)



Note: Problem 1 - Clean Shim Reflector
Problem 2 - 0.01 Saturation Boric Acid (2.6% k/k)
Problem 3 - 0.1 Saturation Boric Acid (11.4% k/k)
Problem 4 - Saturated Boric Acid (18.2% k/k)

Figure 13

Estimation of Multiplication Factor For Reactor With 7.75-inch Safety Reflector of Pure D_2O

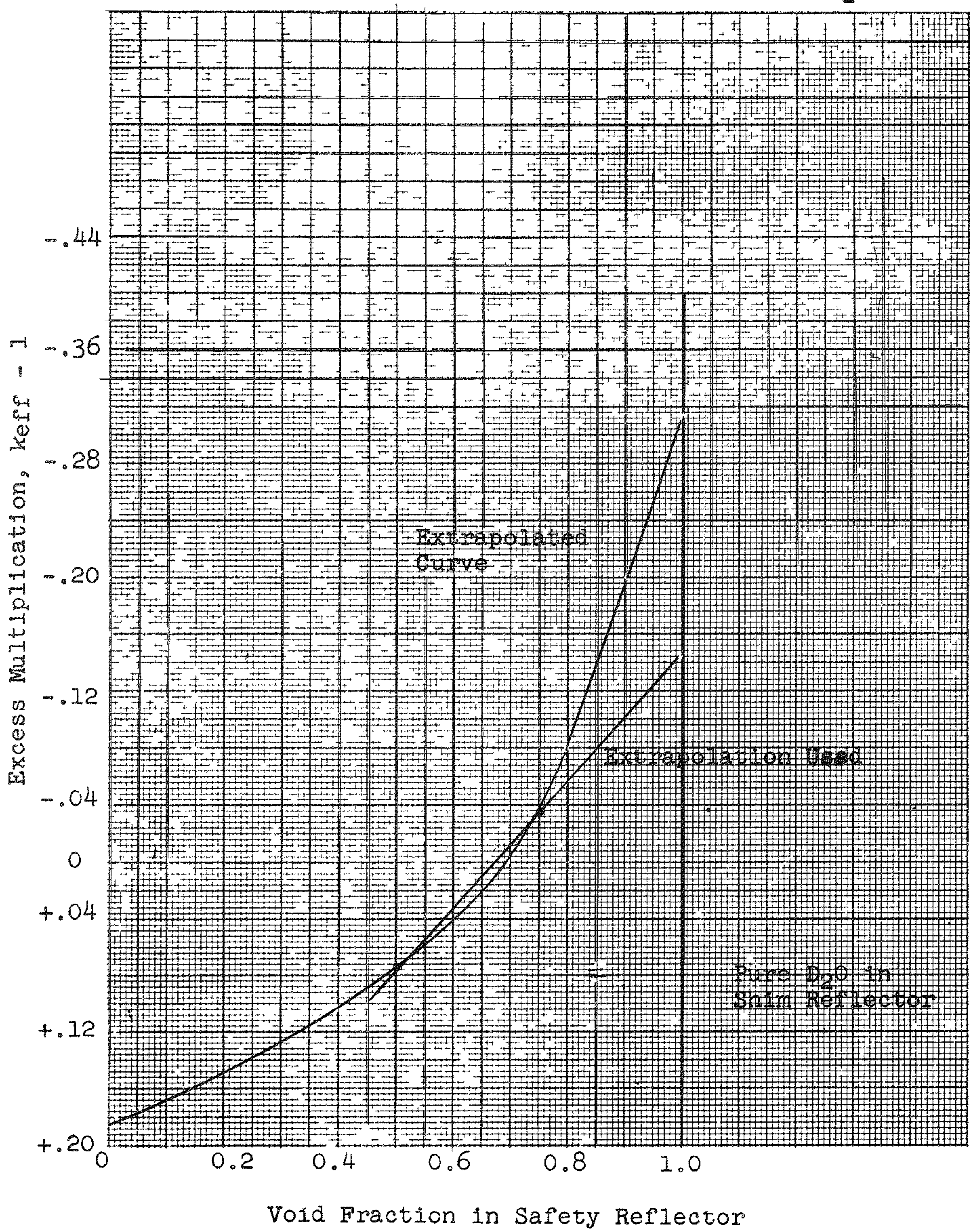
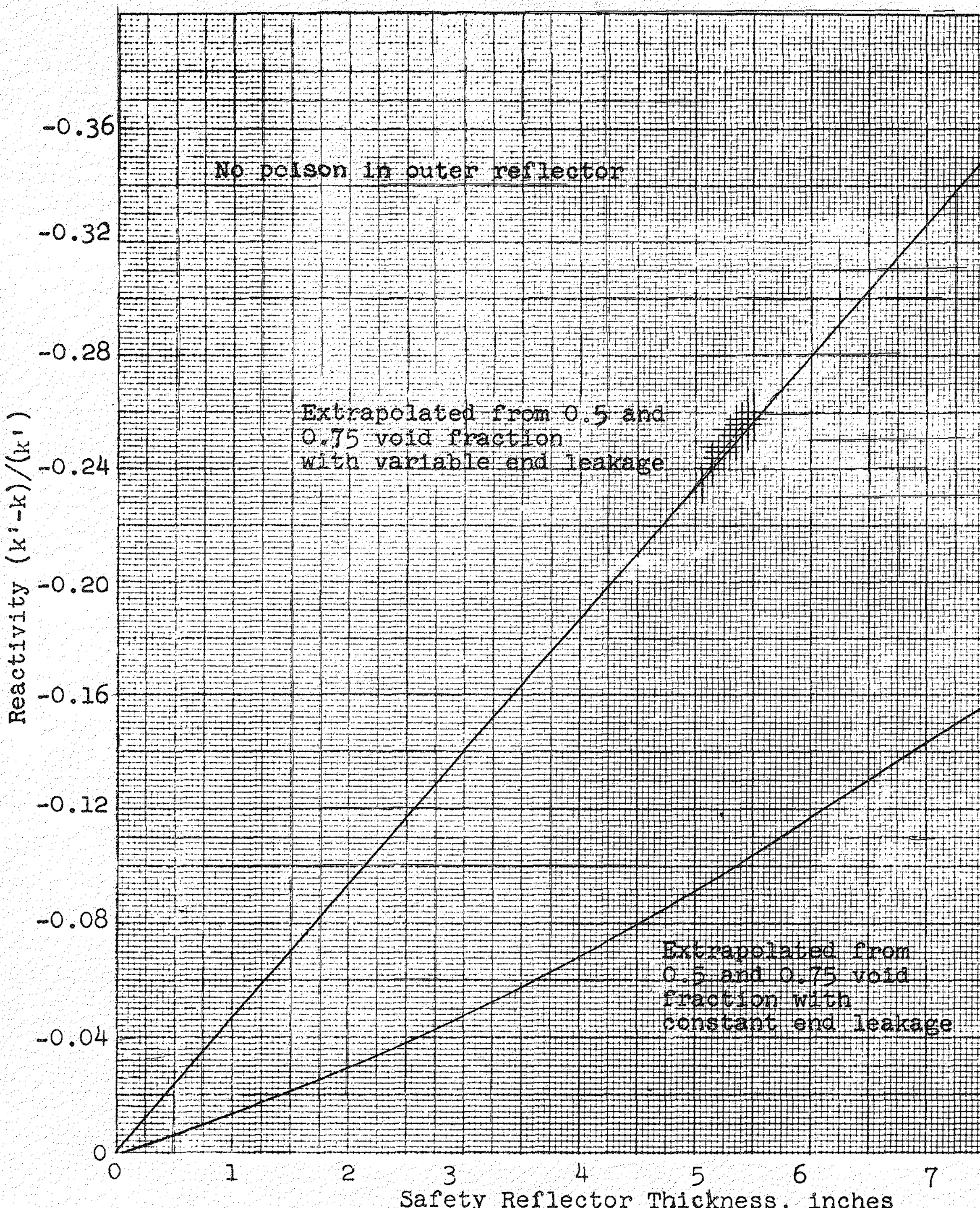


Figure 14

Worth of Safety Reflector as a Function of Thickness



APPENDICES

APPENDIX 1.0

RESEARCH AND DEVELOPMENT OBJECTIVES

The research and development objectives, as outlined in Contract AT(11-1)688, are as follows:

Construct and test operate pilot plant models of the reflector control systems. These systems will utilize H_2O rather than D_2O as test fluid.

a. Design and construct a scale model of the safety reflector system.

b. Determine operational characteristics of the safety reflector system.

   1) Determine suitability of the eductor system for raising water level and circulating water in the safety reflector.

   2) Determine position of reflector versus time curve after scram valves are opened.

c. Design and construct a scale model of the shim reflector system.

d. Test operation of scale model of shim reflector system.

   1) Determine practical rates of addition and removal of boron poison.

   2) Test conductivity method of measuring boron concentration in shim control system.

   3) Test operation and analysis of resin system.

APPENDIX 2.0

SUMMARY OF SAFETY REFLECTOR DROP TIME TEST CONDITIONS AND METHODS OF MEASUREMENT

The test conditions under which safety reflector drop time tests were conducted are described here in detail, summarized for quick reference in Table A2.a and illustrated with the drawings that complete this Appendix. Methods of measurement are also described in detail.

A2.1 Scram Line and Solenoid Valve Description

Two different scram line and solenoid valve sizes were used to obtain the drop-time data presented in this report. Both 1-inch and 2-inch, nominal diameter, schedule 40 aluminum pipes and fittings were used in the line connecting the drop tank nozzle to the safety reflector nozzle. A 1-inch, type 18 GR 24 Magnatrol solenoid valve and a 2-inch, type 33 GR 27 Magnatrol solenoid valve were used in connection with the 1-inch and 2-inch scram lines, respectively.

Nozzle 2, which connects the scram line to the drop tank, is a horizontal, 6-inch long, nominal 3-inch diameter, schedule 40 pipe welded into the side of the reflector model. Nozzle 1, which connects the scram line to the section of the safety reflector lying below the safety reflector partition, is a vertical, 24-inch long, nominal 3-inch diameter, schedule 40 pipe, penetrating both the top and the safety reflector partition of the reflector model and seal-welded at both penetrations.

A2.1.1 Piping and Valve Arrangements for Tests 1 Through 19

Figure A2.A is a simplified line drawing of the scram line and solenoid valve arrangements for safety reflector drop time tests 1 through 19. The scram line arrangement for this series of tests is considered as a "CLOSED CIRCUIT" scram line. A 3-inch coupling, reduced in two steps by a 3" x 2" reducing bushing and a 2" x 1" reducing bushing, connected the upstream end of the 1-inch scram line into the drop tank through nozzle 2. Another 3-inch coupling, reduced in a like manner, connected the downstream end of the 1-inch scram line into the safety reflector through nozzle 1. The dimensions in figure A2.A indicate exact field measurements (to the nearest 1/8 inch) of the 1-inch scram line used. Face to face measurements along the center line of the three 1-inch 90 degree ells used indicated them each to be 2 5/8 inches long. The total length of 1-inch scram line used in tests 1 through 19, including all 1-inch pipe, valves and fittings, was taken to be 11' - 2 3/4". It should be noted that all scram line piping lies in one plane for all safety reflector drop time tests. It should also be noted that the drop tank was always vented to the atmosphere through nozzle 8, a 3/4-inch, 90 degree pipe ell, a 6-inch long 3/4-inch nominal diameter pipe nipple, a 3/4-inch, 45 degree pipe ell and a 12-inch long, 3/4-inch nominal diameter pipe nipple for all safety reflector drop time tests except as noted in Table A2.a.

A2.1.2 Piping and Valve Arrangements for Tests 20 Through 40

Figure A2.B is a simplified line drawing of the scram line and solenoid valve arrangements for safety reflector drop time tests 20 through 40. The scram line arrangement for this series of tests is also a "CLOSED CIRCUIT" scram line. A 3-inch coupling, reduced by a 3" x 2" reducing bushing, connected the upstream end of the 2 inch scram line into the drop tank through nozzle 2. Another 3-inch coupling, reduced in a like manner, connected the downstream end of the 2-inch scram line into the safety reflector through nozzle 1. The dimensions in Figure A2.B indicate exact field measurements (to the nearest 1/8 inch) of the 1-inch scram line used. Face to face measurements along the center line of the three 2-inch, 90 degree ells used indicated them each to be 4 inches long. The total length of 2-inch scram line used in tests 20 through 40, including all 2-inch pipe, valves and fittings, was taken to be 11' - 4 3/4".

A2.1.3 Piping and Valve Arrangements for Test Series 200

Figure A2.C is a simplified line drawing of the scram line and solenoid valve arrangements for safety reflector drop time test series 200. The scram line arrangement for this series of tests is considered an "OPEN CIRCUIT" scram line. A 3-inch coupling, reduced by a 3" x 2" bushing, connected the downstream end of the 1-inch scram solenoid into the safety reflector through nozzle 1. A 2-inch long, 2-inch nominal diameter pipe nipple and a 2-inch, 90° ell, reduced by a 2" x 1" reducing bushing completed the 2-inch pipe used in this series of tests. A 6-inch long, 1-inch nominal diameter pipe nipple connected the 1-inch scram solenoid valve to the 2" x 1" reducing bushing in the 2-inch pipe ell. The upstream end of the 1-inch scram solenoid valve was open to the atmosphere. For all series 200 tests, the drop tank was vented to the atmosphere through the section of 2-inch scram line, as shown in Figure A2.B, from nozzle 2 to the bottom half of the pipe union in addition to being vented through the normal vent from nozzle 8. This alternate vent constituted a total length of 23 3/4 inches of 2-inch pipe.

A2.1.4 Piping and Valve Arrangements for Test Series 300

Figure A2.D is a simplified isometric line drawing of the scram line and solenoid valve arrangements for safety reflector drop time test series 300. The scram line arrangement for this series of tests is considered an "OPEN CIRCUIT" scramline. A 3-inch coupling, reduced by a 3"x2" reducing bushing, connected the downstream end of the 1-inch scram solenoid into the safety reflector through nozzle 1. A vertical, 2-inch long 2-inch diameter pipe nipple, a 2-inch 90°ell and a horizontal 3-inch long 2 inch diameter pipe nipple complete the circuit between nozzle 1 and the 2 inch scram solenoid valve. The upstream end of the 2-inch solenoid valve was open to the atmosphere. For all series 300 tests, the drop tank was vented to the atmosphere through the same section of 2-inch scram line described in Section A2.1.3, as well as through the normal 3/4-inch vent from nozzle 8.

A2.1.5 Piping and Valve Arrangements for Test Series 400

Figure A2.E is a simplified isometric line drawing of the scram line and solenoid valve arrangements for safety reflector drop time test series 400. The scram line arrangement for this series of tests is considered an "OPEN CIRCUIT" scram line. This test series utilized both the 1-inch and the 2-inch scram solenoid valves, in parallel and open to the atmosphere, to supply air to scram the safety reflector. A 3-inch coupling reduced by a 3"x2" bushing and connected by a 2-inch long 2-inch diameter pipe nipple to a 2-inch pipe tee, provided the arrangement whereby both the 1-inch and 2-inch solenoid valves were connected to nozzle 1. One arm of the 2-inch tee was connected to the 2-inch solenoid valve through a 3-inch long pipe nipple while the other arm of the 2-inch tee was connected to the 1-inch solenoid valve through a 2"x1" reducing bushing and a 3-inch long 1-inch diameter pipe nipple. For all series 400 tests, the drop tank was vented to the atmosphere through the same section of 2-inch scram line described in Section A2.1.3, as well as through the normal 3/4 inch vent from nozzle 8.

A2.2 Circulating System Alternative Pipe Arrangements

A total of four different arrangements of circulating water was provided in the reflector model piping system. The reason for this versatility was primarily to demonstrate whether or not the method of circulating water inside the reflector model would have any significant effect on the safety reflector drop time.

A2.2.1 Piping Arrangement A

Figure A2.F is a simplified line drawing demonstrating piping arrangement A. In this arrangement, water enters the shim reflector near the top in a stream directed at the weir separating the shim reflector from the safety reflector.

Actually, there is considerable mixing of the inlet stream with the bulk of the water in the shim reflector, as shown by a few preliminary (and unreported) dye injection tests, before the water flows over the weir separating the shim and safety reflectors.

A2.2.2 Piping Arrangement B

Figure A2.G is a simplified line drawing demonstrating piping arrangement B. In this arrangement, water enters the bottom of the shim reflector through a flow distributing plenum chamber. This arrangement is much more typical of what might actually be used than is piping arrangement A.

Since no check valve was provided anywhere in the circulating water piping system, piping arrangement B-1 evolved as the result of some preliminary safety reflector drop tests with the 1-inch scram line. It was noted that, when utilizing piping arrangement B, the water-air interface would actually start traveling back up the safety reflector after it had first dropped to about 40 inches below the safety reflector partition. It would quickly rise to a level only about 24 inches below the safety reflector partition if valve V-5 was not shut off immediately. Therefore, piping arrangement B-1 merely consisted of piping arrangement B, accompanied by a rapid closing of valve V-5 as soon as possible after pushing the scram button. This simulated the action of a check valve in the circulating water circuit.

A2.2.3 Piping Arrangement C

Figure A2.H is a simplified line drawing demonstrating piping arrangement C. In this arrangement, water enters the safety reflector immediately below the partition separating the safety reflector into an upper and lower portion. This arrangement simulates the action of a full length safety reflector, partitioned to start the safety reflector void growth below the top of the active core.

A2.2.4 Piping Arrangement D

Figure A2.I is a simplified line drawing demonstrating piping arrangement D This arrangement is exactly the same as pipe arrangement C except that the flow restricting weir in the safety reflector partition is blanked off. This arrangement simulates the action of a part length safety reflector that provides only a partial void next to the core.

A2.3 Circulating Water Flow Rates and Directions

A total of four different circulating water flow rates, 120, 100, 80 and 0 gpm were used to demonstrate whether or not initial velocity in the safety reflector column would have any significant effect on the safety reflector drop time. The flow direction in the safety reflector was always downward since it was felt that this would be the most favorable flow direction for short drop times.

Water flow rate was measured from the pressure drop across an orifice plate by a 12 inch Meriam Model 30 EB 25 WM well type mercury manometer. Both the manometer, orifice plates and flanges were supplied by the Meriam Instrument Company and the combination was calibrated at the factory for a boric acid solution of 1.04 specific gravity and a temperature of 80°F. The mercury manometer is direct reading in gpm and the flow rates reported herein are those taken directly from the manometer, with no attempt made to correct for specific gravity or temperature variations.

A2.4 Water Temperature Measurement

The initial drop tests (tests 1 through 7) were conducted with no means for measuring the temperature of the circulating water. The (E) in the column for water temperature in Table A2.a indicates that these temperatures are estimates. Water temperatures for subsequent tests were measured by a Taylor meat thermometer, cemented to a 90° ell in the 2-inch circulating system with Duco Aluminum Cement and heavily insulated with wrappings of paper and friction tape. The relative accuracy of this thermometer was demonstrated by taking simultaneous readings on it and tapping water from the system, the temperature of which was subsequently taken with a laboratory type mercury thermometer. Although the Taylor meat thermometer was calibrated in 5° divisions, the readings taken from it never varied more than 1° (Fahrenheit) from the readings taken by the laboratory thermometer on the water withdrawn from the system.

A2.5 Timing of Scram and Electrical Scram Circuits

Timing of the safety reflector drop was accomplished with a Standard Electric Time Co., surface mounted, Model SW-1 timer. This timer has a 10-inch diameter face, one sweephand that makes one revolution a second, measuring time in hundredths of seconds, and another, shorter, sweephand that makes one revolution a minute, measuring time in seconds. The timer motor runs continuously and the hands are magnetically engaged when the timer start circuit is energized, resulting in an absolute minimum of time lag in starting.

The timer was mounted next to the safety reflector where it could be photographed simultaneously with the dropping water column. The timer is energized and the scram solenoid valve and both the circulating and water jet eductor pumps are de-energized, via magnetic switches, when the scram switch "stop" button is depressed. This combination accomplishes nearly simultanteous initiation of all the desired action, such that there is the least possible error due to time lapse in initiating different events.

A2.6 Pertinent Photography Data

The cameras used to photograph the action were all Paillard-Bolex H16 (16 mm) movie cameras with a frame speed selection ranging from 8 frames per second to 64 frames per second. A majority of the safety reflector drop time films were taken at a nominal frame speed of 64 frames per second. However, approximately one quarter of the 1-inch scram line drop time tests were taken at a nominal frame speed of 32 frames per second to conserve film.

The lens used to film a majority of the safety reflector drop tests was a Bolex Lytar (1:1.9) F 25mm(normal) lens with a Walz Series daylight filter. In order to get adequate detail and clarity of the timer scale divisions in the films, it was necessary to place the camera such that the nominal perpendicular distance between the face of the model and the lens was 10' 8". At this short distance, the lens field was not wide enough to take more than about 30 inches of the initial reflector drop in one test series. Also, the safety reflector displacement scale was about 1 1/2 inches nearer the camera than the front plexiglass face of the reflector model so that a larger field than this was undesirable from the standpoint of increasing difficulty with parallax. Figure A2.J illustrates the normal relative positions of camera and reflector model used in most of the reflector drop time tests. Figure A2.K illustrates the error due to parallax.

The inability of the camera to take more than 30 inches of the reflector drop in one set-up made it necessary to have two different camera set-ups and two different tests to get the entire drop of the safety reflector water column on film. This accounts for the fact that Table A2.a, in several places, has dual test numbers listed opposite the same row of safety reflector drop time test conditions. Also for the fact that these dual tests have dual listings for water temperatures and the number of the film roll on which they were recorded. In all of these cases, the first test number listed represents the top half of the drop and the second test number listed represents the bottom half of the drop.

The majority of the safety reflector drop tests were recorded on Kodak Plus X Negative (PXN449) film so as to give a positive reproduction. A relatively "fast" film, such as Plux X, was also necessary to reduce the lighting requirements.

Table A2.a

Summary of Safety Reflector Drop Time Test Conditions

Test No.	Piping Arrangements	Water Temperature °F	Circulating Flow Rate GPM	Nominal Scram Line Diameter, in.	Scram Line Length ft-in	Circuit	Scram Solenoid Size and Arrangement	Recorded on Film Roll
1	A	70-est	120	1	11-2 3/4	Closed	1" - in-line	1
2	A	75-est	100	1	11-2 3/4	Closed	1" - in-line	1
3	A	80-est	80	1	11-2 3/4	Closed	1" - in-line	1
4 ①	A	80-est	0	1	11-2 3/4	Closed	1" - in-line	2
5	B	80-est	120	1	11-2 3/4	Closed	1" - in-line	2
6	B	80-est	100	1	11-2 3/4	Closed	1" - in-line	2
7	B	80-est	80	1	11-2 3/4	Closed	1" - in-line	2
8	C	84	120	1	11-2 3/4	Closed	1" - in-line	3
9	C	91	100	1	11-2 3/4	Closed	1" - in-line	3
10	C	94	80	1	11-2 3/4	Closed	1" - in-line	3
11 ②	C	94	0	1	11-2 3/4	Closed	1" - in-line	3
12 ③	B-1	86	120	1	11-2 3/4	Closed	1" - in-line	4
13 ③	B-1	89	100	1	11-2 3/4	Closed	1" - in-line	4
14 ③	B-1	91	80	1	11-2 3/4	Closed	1" - in-line	4
15 ④	A	93	100	1	11-2 3/4	Closed	1" - in-line	4
16	D	84	120	1	11-2 3/4	Closed	1" - in-line	5
17	D	88	100	1	11-2 3/4	Closed	1" - in-line	5
18	D	90	80	1	11-2 3/4	Closed	1" - in-line	5
19	D	90	0	1	11-2 3/4	Closed	1" - in-line	5

Table A2.a (Continued-Page 2)

Test No.	Piping Arrangements	Water Temperature °F	Circulating Flow Rate GPM	Nominal Scram Line Diameter, in.	Scram Line Length ft-in	Circuit	Scram Solenoid Size and Arrangement	Recorded on Film Roll
20	D	86	120	2	11-4 3/4	Closed	2" - in-line	6
21	D	90	100	2	11-4 3/4	Closec	2" - in-line	6
22	D	93	80	2	11-4 3/4	Closed	2" - in-line	6
23	D	92	0	2	11-4 3/4	Closed	2" - in-line	6
24-35	A	92-93	120	2	11-4 3/4	Closed	2" - in-line	6-7
25-36	A	94-95	100	2	11-4 3/4	Closed	2" - in-line	6-8
26-37	A	90-96	80	2	11-4 3/4	Closed	2" - in-line	6-8
27 (1)	A	90	0	2	11-4 3/4	Closed	2" - in-line	6
28 (2)	A	90	0	2	11-4 3/4	Closed	2" - in-line	6
29	B	92	120	2	11-4 3/4	Closed	2" - in-line	7
30	B	94	100	2	11-4 3/4	Closed	2" - in-line	7
31	B	95	80	2	11-4 3/4	Closed	2" - in-line	7
32-38	C	98-97	80	2	11-4 3/4	Closed	2" - in-line	7-8
33-39	C	100-99	100	2	11-4 3/4	Closed	2" - in-line	7-8
34-40	C	104-100	120	2	11-4 3/4	Closed	2" - in-line	7-8
201-204	A	91-97	120	1	2 -1	Open	1" -to atmos.	16-16
202-205	A	94-99	100	1	2 -1	Open	1" -to atmos.	16-16
203-206	A	96-99	80	1	2 -1	Open	1" -to atmos.	16-17

Table A2.a (Continued-Page 3)

Test No.	Piping Arrangement	Water Temperature °F	Circulating Flow Rate GPM	Nominal Scram Line Diameter, in.	Scram Line Length ft-in	Circuit	Scram Solenoid Size and Arrangement	Recorded on Film Roll
301-304	A	101-91	120	2	2 - 7	Open	2" - to atmos.	17-17
302-305	A	89-93	100	2	2 - 7	Open	2" - to atmos.	17-17
303-306	A	90-95	80	2	2 - 7	Open	2" - to atmos.	17-18
307-310	B	95-100	120	2	2 - 7	Open	2" - to atmos.	18-18
308-311	B	98-101	100	2	2 - 7	Open	2" - to atmos.	18-18
309-312	B	99-103	80	2	2 - 7	Open	2" - to atmos.	18-18
401-404	A	89-93	120	2	2 - 7	Open	2" & 1" - to atmos.	19-19
402-405	A	90-94	100	2	2 - 7	Open	2" & 1" - to atmos.	19-19
403-406	A	92-95	80	2	2 - 7	Open	2" & 1" - to atmos.	19-19
407-410	(5) B	95-90	120	2	2 - 7	Open	2" & 1" - to atmos.	19-19
408-411	(5) B	95-90	100	2	2 - 7	Open	2" & 1" - to atmos.	19-20
409-412	(5) B	95-91	80	2	2 - 7	Open	2" & 1" - to atmos.	19-20
413-416	(5) C	92-95	120	2	2 - 7	Open	2" & 1" - to atmos.	19-20
414-417	(5) C	93-95	100	2	2 - 7	Open	2" & 1" - to atmos.	20-20
415	(5) C	93	80	2	2 - 7	Open	2" & 1" - to atmos.	20

(1) Water dropped from weir between shim and safety reflectors.
(2) Water dropped from safety reflector orifice plate.
(3) Inlet valve closed immediately after scram.
(4) Vent line capped off. Drop tank not vented to atmosphere.
(5) All frames on film roll 20 were double exposures so none of the tests recorded on this roll could be analyzed.

Figure A2.A

Sketch of Scram Line and Solenoid Valve Arrangements for Safety Reflector Drop Tests 1 Through 19

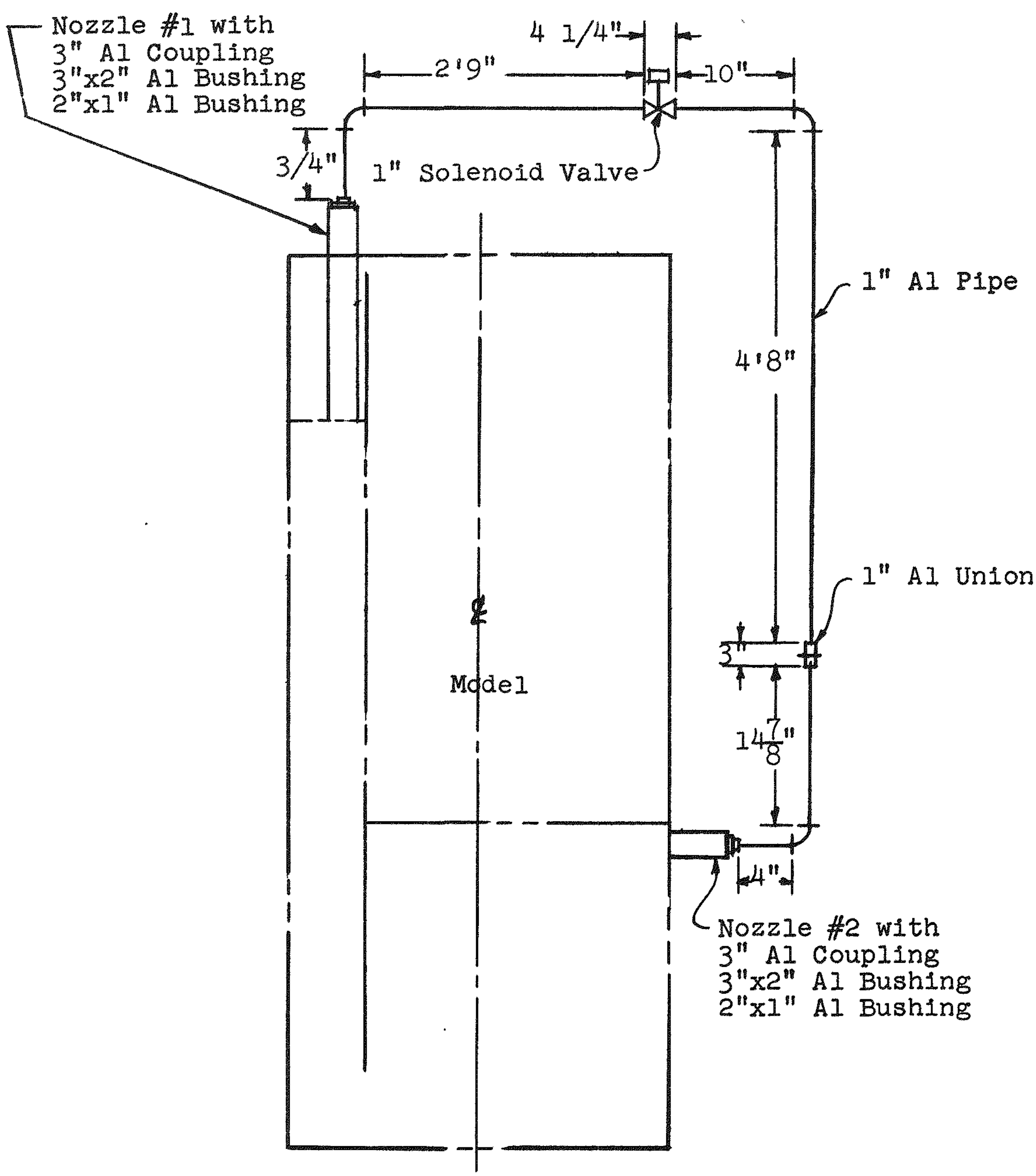


Figure A2.B

Sketch of Scram Line and Solenoid Valve Arrangements for Safety Reflector Drop Tests 20 Through 40

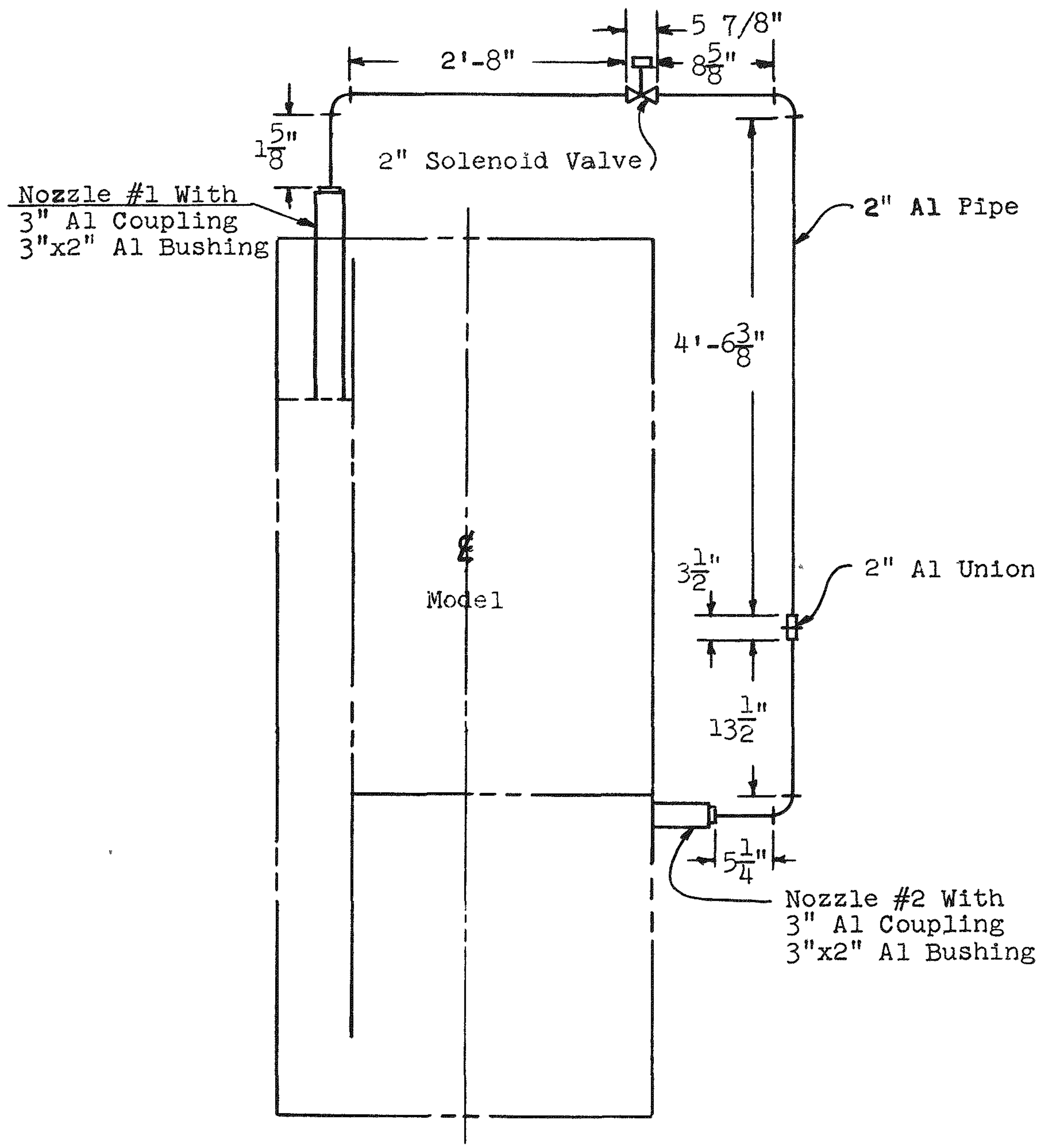


Figure A2.C

Sketch of Scram Line and Solenoid Valve Arrangements for Safety Reflector Drop Test Series 200

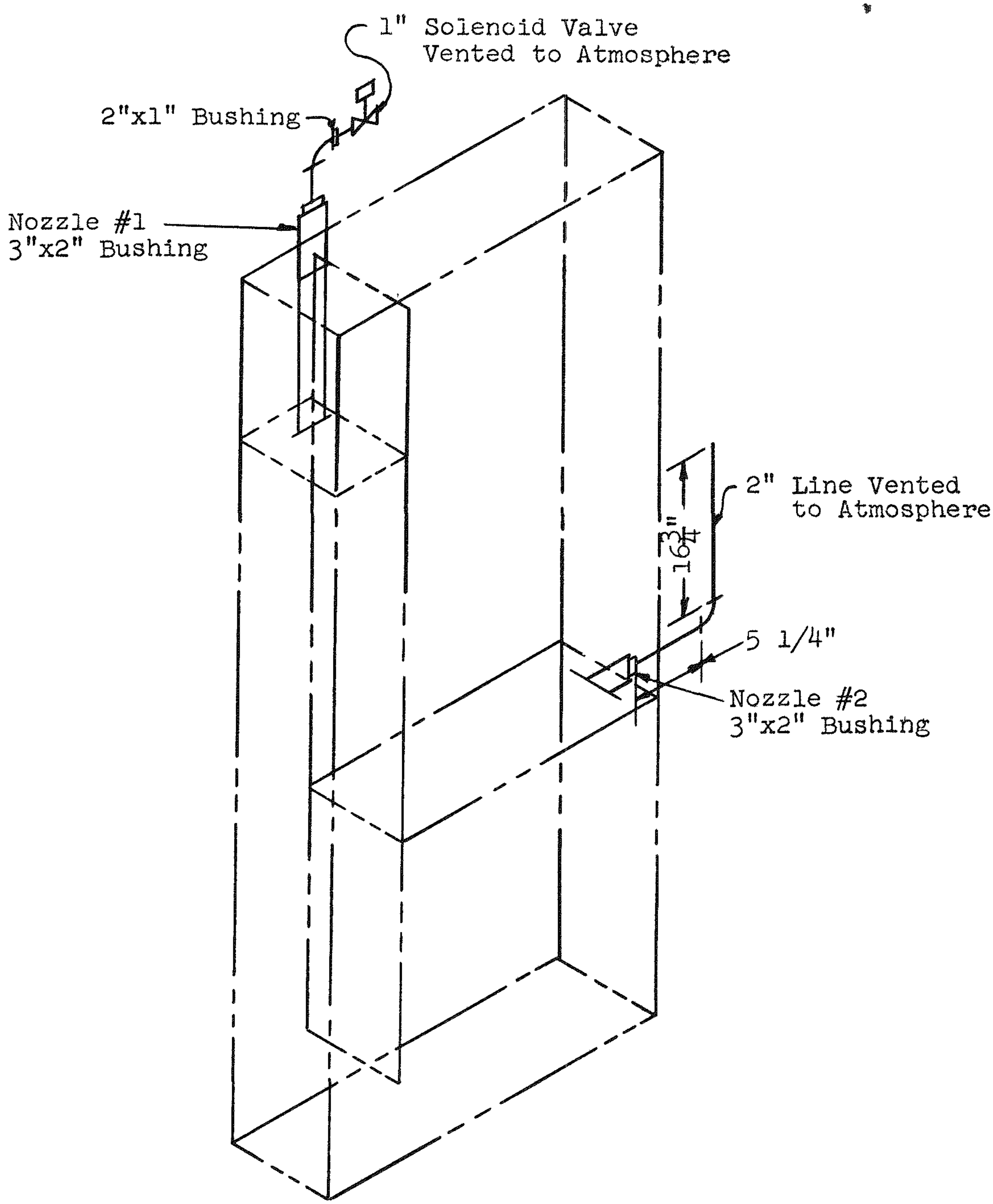


Figure A2.D

Sketch of Scram Line and Solenoid Valve Arrangements for Safety Reflector Drop Test Series 300

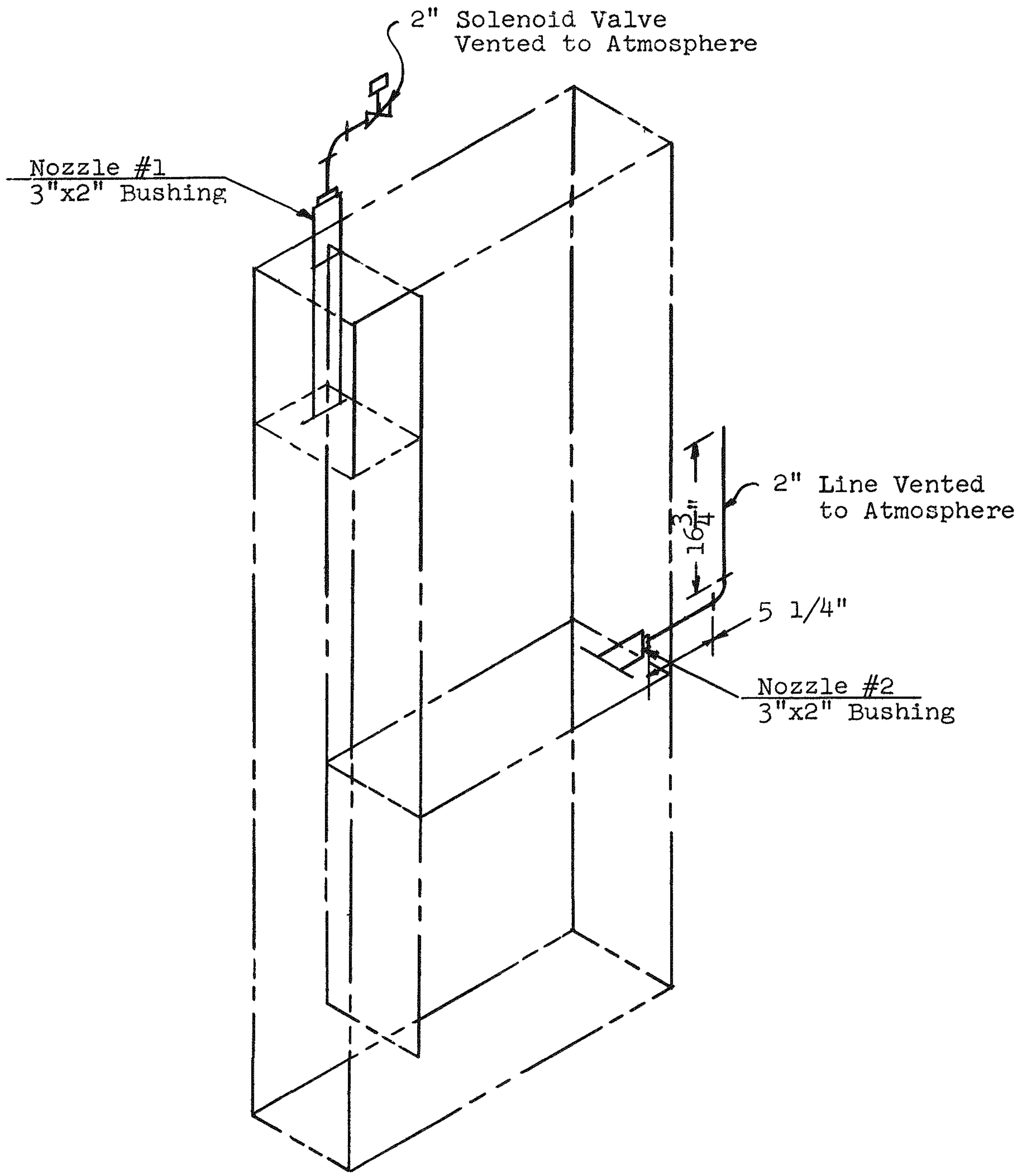


Figure A2.E

Sketch of Scram Line and Solenoid Valve Arrangements for Safety Reflector Drop Test Series 400

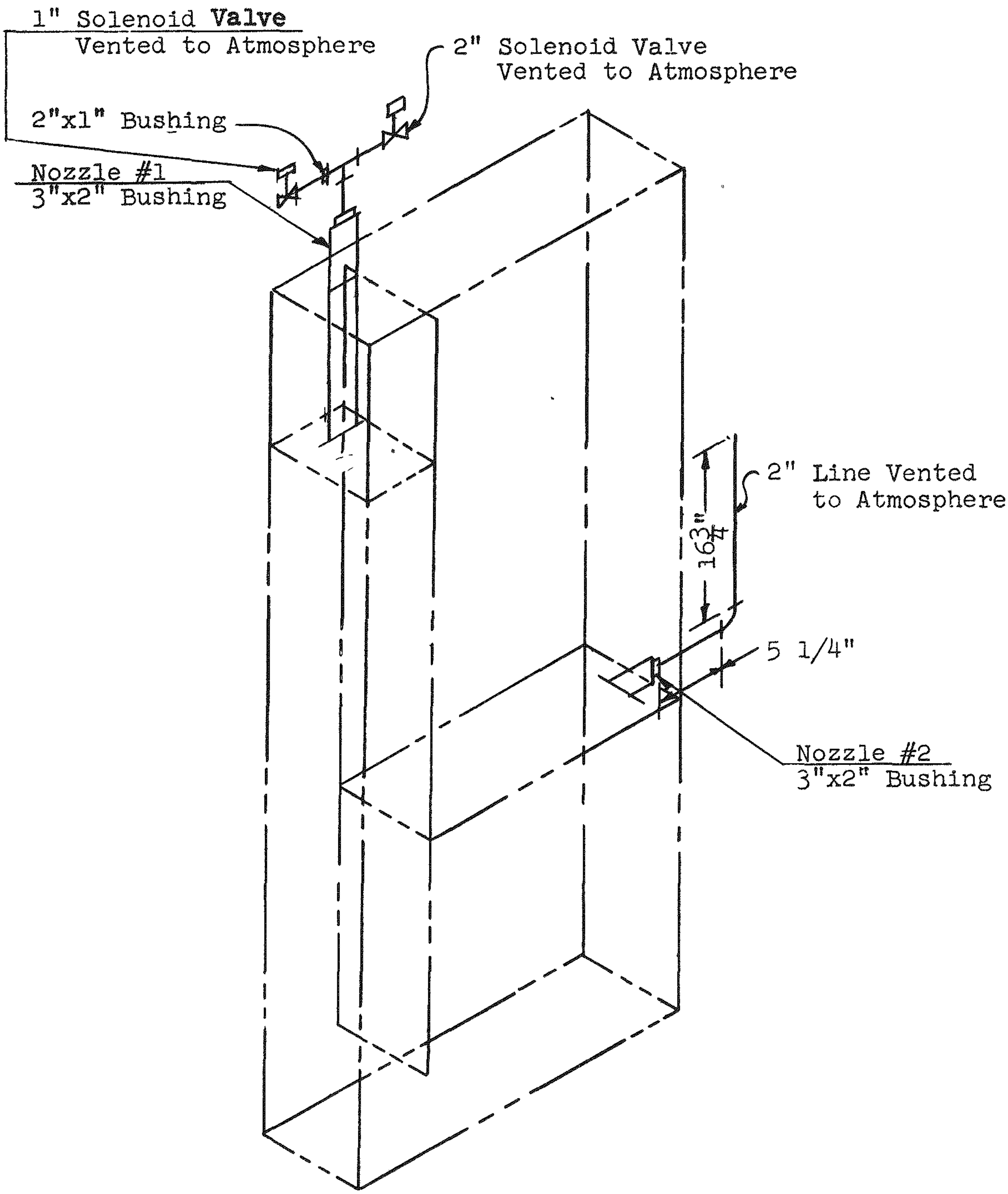


Figure A2.F

Schematic Diagram of Pipe Arrangement A

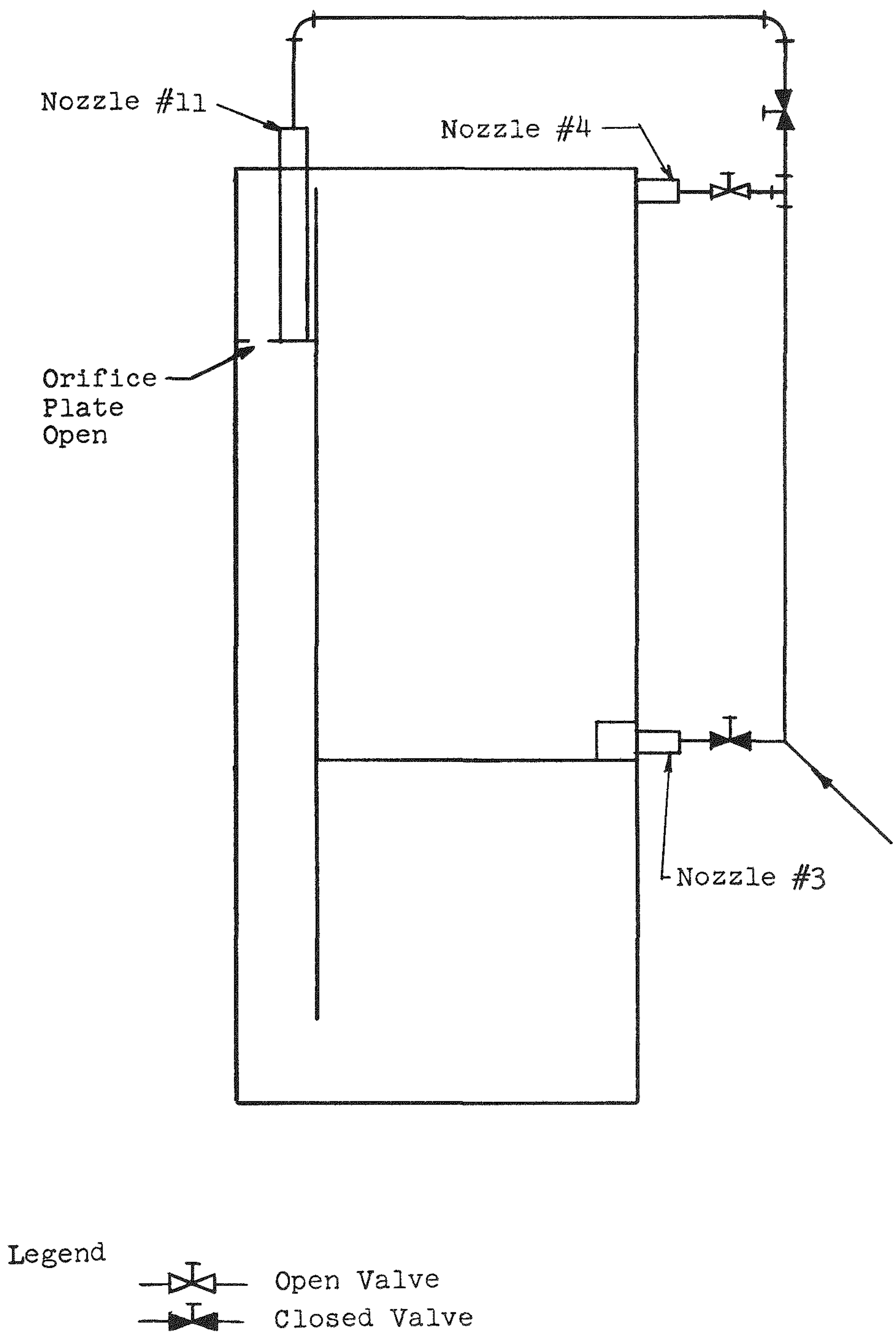
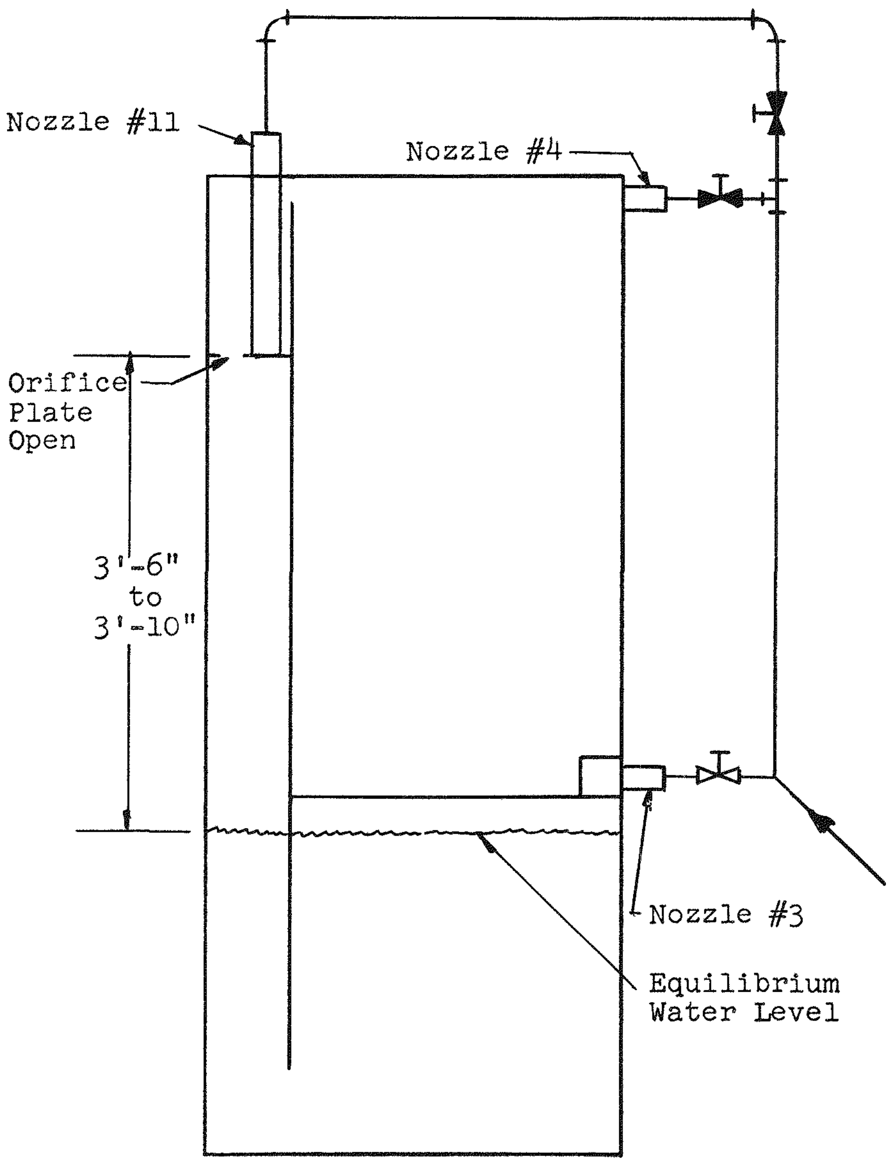


Figure A2.G

Schematic Diagram of Pipe Arrangement B



Legend

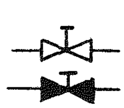


Figure A2.H

Schematic Diagram of Pipe Arrangement C

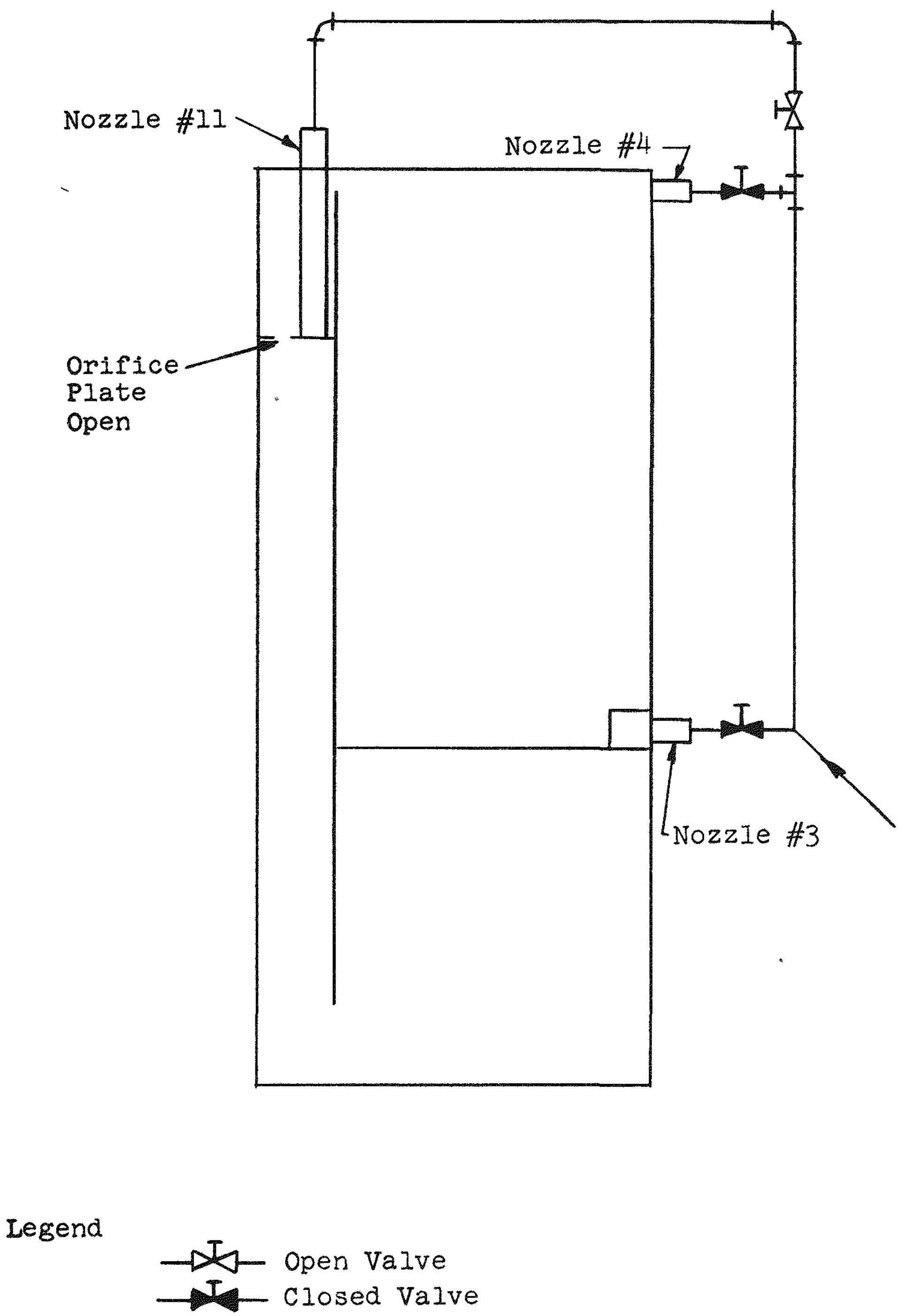


Figure A2.1

Schematic Diagram of Pipe Arrangement D

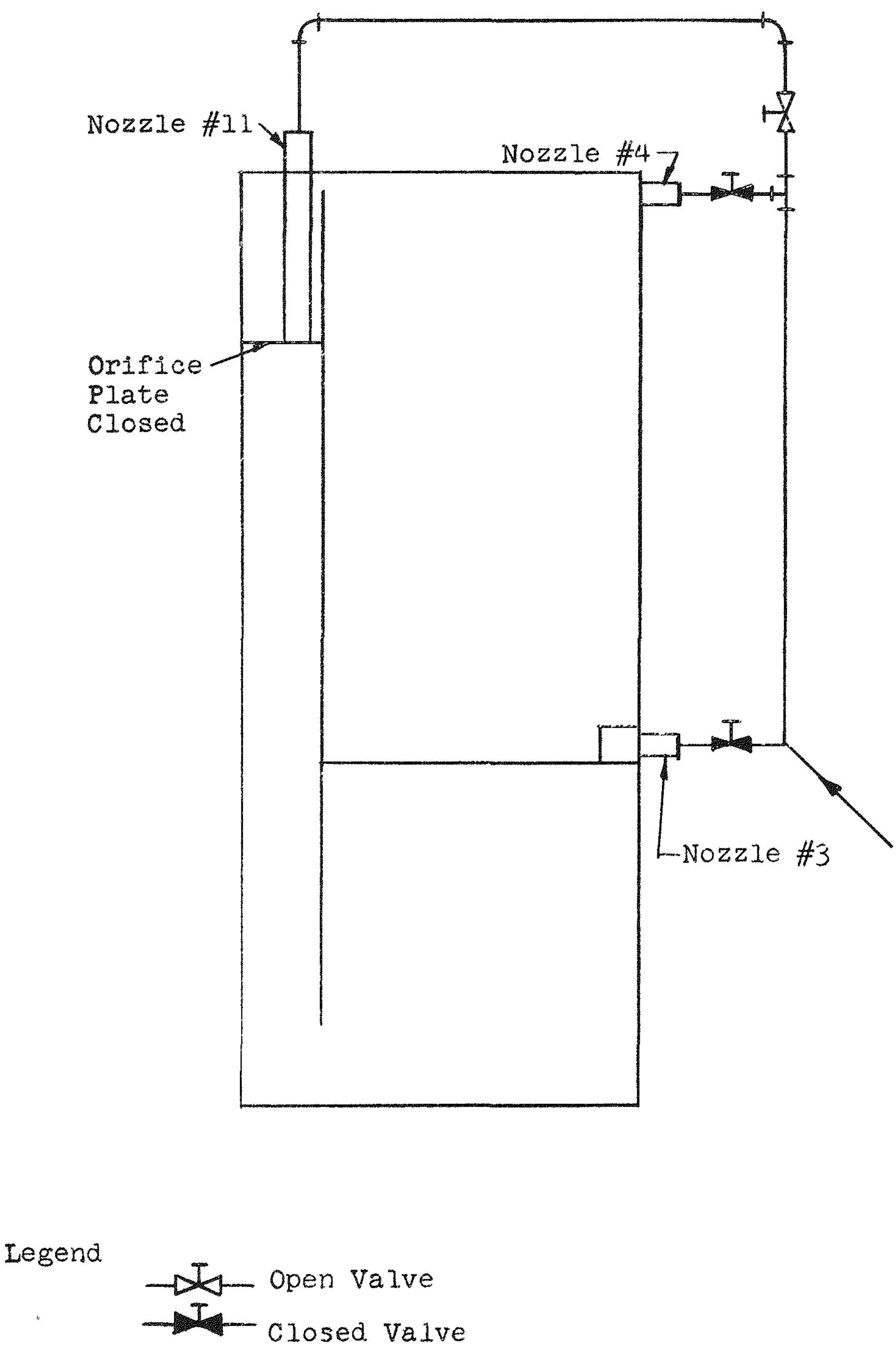
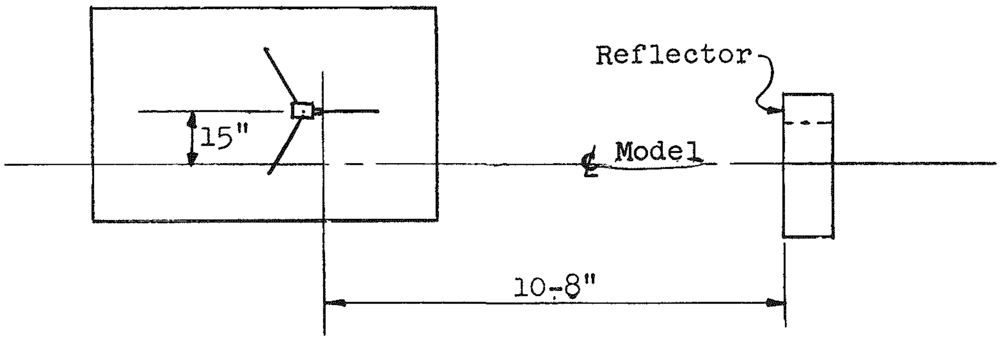
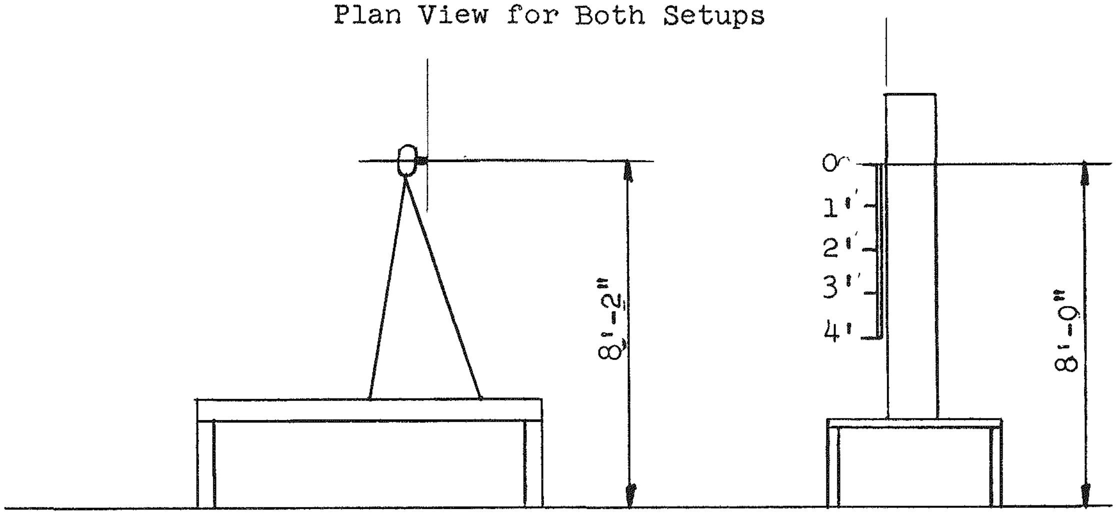


Figure A2.J

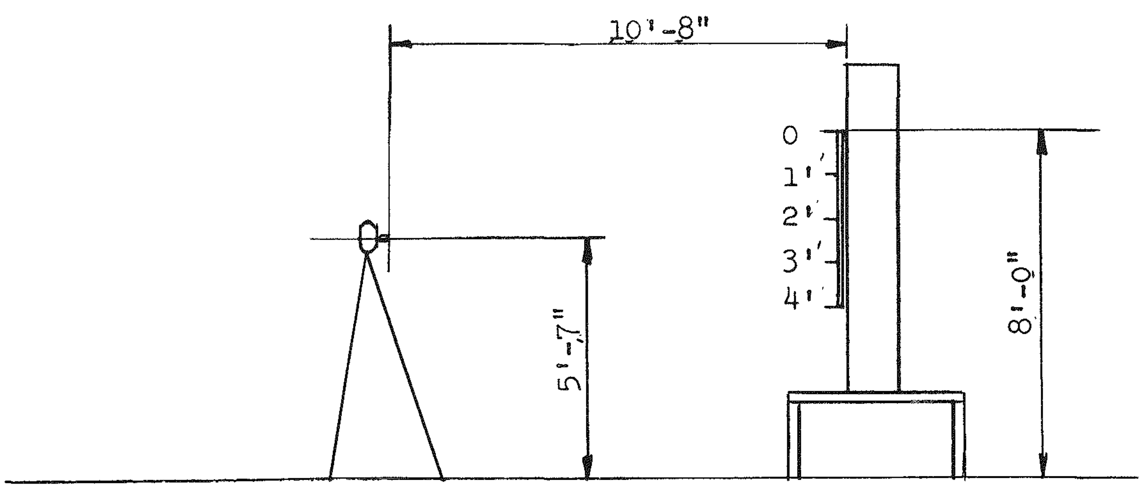
Sketch Showing Normal Position of Camera Relative to Reflector Model



Plan View for Both Setups



Setup for Top Half of Drop



Setup for Bottom Half of Drop

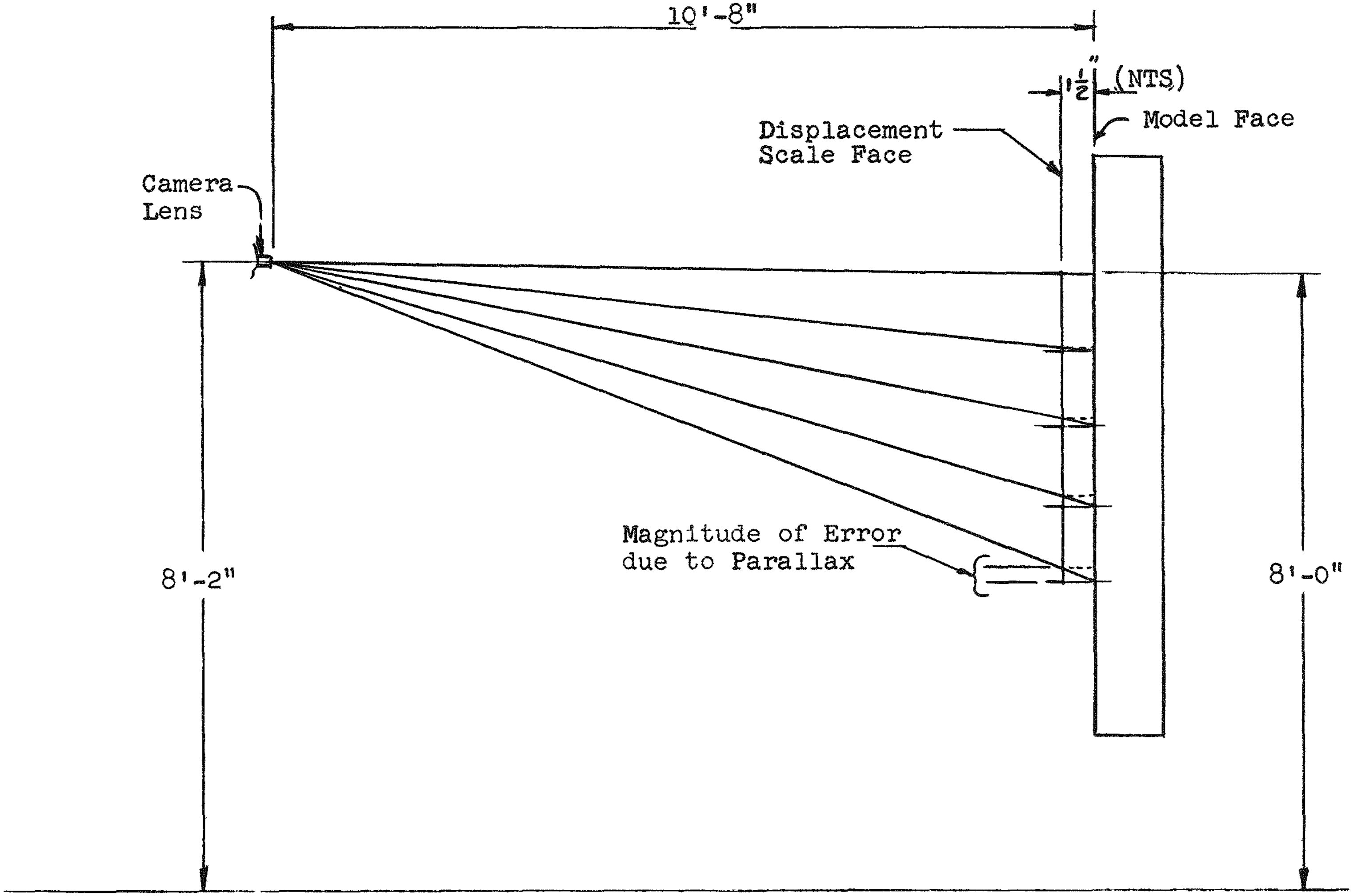


Figure A2.K

Sketch Illustrating Error Due to Parallax

APPENDIX 3.0

METHODS OF DATA ANALYSIS WITH TYPICAL ENLARGEMENTS OF INDIVIDUAL FRAMES FROM SAFETY REFLECTOR DROP TIME TEST FILMS

This appendix describes the methods used to obtain data and analyze the safety reflector drop time. The fundamental data were recorded on 16 mm film in the laboratory. Individual frames from these films were enlarged to expedite interpretation of the time and displacement data. The data from these enlargements were transferred, in numerical form, to tabular data sheets. These data were then fitted with a single, smooth curve.

A3.1 Safety Reflector Drop Time Tests

Each safety reflector drop time test consisted of five separate filmings of the reflector drop under a given set of test conditions. Every effort was made to keep test conditions identical for each of the five runs comprising a test. The temperature of the circulating water was the only condition it was impossible to control. The water temperature invariably increased, due to friction heating, as the runs progressed. Since the effect of water temperature on drop time is extremely small, it was not felt necessary to do more than record the water temperature at the time the test run was conducted. Figure A3.A is a reproduction of a typical test data sheet as recorded in the laboratory at the time of the test.

A3.2 Data Extraction from Drop Test Films

The method used to extract the time-displacement data from the 16 mm movie films was to enlarge individual frames from them and then read the time and displacement data from the enlargements. This provided a permanent, basic-data record for every data point used in subsequent analyses.

As nearly as possible, the enlargements were taken at equal time intervals, as shown by the timer in each frame of the 16 mm film. Although it was not always possible to obtain an enlargement at some exact time after scram (e.g., at 0.2 seconds) it was possible to get one sufficiently close to it (0.19 seconds or 0.21 seconds) to make the time difference negligible. A set of photographic enlargements from a typical test run is shown in Figures A3.B through A3.K.

The enlargements used in the actual data analysis were made with a Thermo-fax Microfilm Reader-Printer. These did not have the full clarity and detail seen in the photographic enlargements of Figures A3.B through A3.K but the detail and clarity were entirely adequate for good data interpretation. (In a few cases, due to poor lighting or erratic camera speed, it was necessary to read the time from the viewing screen prior to making the enlargement and then record the time on the enlargement after it was made. The view screen could bring out considerably more detail than could be obtained on the enlargement in any reasonable length of time). With the 26x lens used on the Microfilm Reader-Printer approximately 60 percent of the field covered by one 16mm frame was enlarged to a picture about 6.25 inches wide by 8.0 inches long.

A3.3 Interpretation of Data from the Enlargements

With the exceptions noted above, both the time and displacement data were read directly off the Thermo-Fax enlargement and recorded on the upper right-hand corner for later transfer to a time-displacement data sheet. No attempt was made to correct for the parallax inherent in reading the displacement scale, since the error introduced by parallax was considered to be of lesser magnitude than other possible interpretational errors.

The line the air-water interface made across the plexiglas face of the model nearest the camera was used as the interface position to determine displacement. This air-water interface was seldom a perfectly clear, narrow and horizontal line of demarcation. It was generally a relatively dark band, anywhere between 1 inch and 3 inches wide, and inclined at some angle with the horizontal (up to a maximum of about 45 degrees). Depending on the piping arrangement used, (pipe arrangement D was the worst offender) this line of demarcation between the air and water would be further distorted by water flowing down from either the alternate inlet pipe (C and D inlet), the section of the safety reflector above the partition, or from both. On the basis of these disturbances, it is unlikely that one can consistently interpret the position of the air-water interface much closer than about $\pm$ 2 inches.

Another difficulty of interpretation occured at the initiation of scram. At this time, the air void in the safety reflector column started and grew as a bubble. A bubble form, gradually distorting into a relatively flat plane interface, would persist until somewhere between 0.2 and 0.3 seconds after scram (in the case of the 2 inch scram line). During this period, the position of the air-water interface was more or less arbitrarily drawn where it appeared a flat plane interface would lie if the air in the bubble were spread uniformly across the entire cross-section of the safety reflector.

Still another factor that may have a considerable effect on the interpretation of the interface position is explained as follows. Shortly after the air bubble disappears, a relatively flat, plane interface (subject, of course, to the previously mentioned distortions) forms, apparently in a nearly horizontal position. As it travels down the safety reflector column, however, it appears to wobble about a vertical axis through the center of the reflector column, mush as a flat plate, spun on edge, wobbles as it comes to rest. This wobble is only apparent when viewing the films as a motion piciure and appears to be considerably more pronounced in some tests than in others. The action occurs rapidly so that at the relatively slow motion speed of 64 frames per second, it is a highly transitory phenomenon. It seldom was apparent in the enlargements of individual frames except as described below. At 0.5 seconds after scram in the cases of test 27 and 28 and to a somewhat lesser extent in test 20, it appeared that the plane of the interface was tilted directly toward the camera at an angle of between 30 and 45 degrees. A much more common tilt of the interface, as seen in the enlargements, is the one that occurs when a bisecting line through the plane of the interface is parallel with the line of sight of the camera. Whether or not these face-on and side-on tilts, respectively, are further proof of the existence of the interface wobble is questionable, although they would seem to be.

Again, primarily on the basis of viewing moving pictures of the water drop in the safety reflector, it appears that the magnitude of the wobble increases from a minimum immediately after the inital bubble converts to a plane interface, to a maximum somewhere between 0.5 and 0.8 seconds after scram and then decreases to almost no wobble at all near the bottom of the drop.

If this wobble actually exists, it can be seen that it would have a considerable effect on the interpretation of the position of the interface. The greatest perturbation would occur when the plane of the interface is tilted directly away from or directly toward, the line of sight of the camera. At intermediate positions, the tilt would have a progressively smaller effect on the interpretation of the position of the interface as it changed from a directly face-on or face-away position to a full side-on tilt with respect to the line of sight of the camera.

The magnitude of the effect this wobble would have on the interpretation of the position of the interface would be to make the interface appear to be about 5.5 inches higher or lower than it actually is depending on whether the plane of the interface is tilted at a 45 degree angle with a vertical axis through the safety reflector, directly away from the camera or directly toward the camera, respectively. It is felt that this phenomenan is probably the cause of some of the widest data spreads noted between different runs of some drop time tests. It might be possible to narrow the spread of data between runs of these tests by taking enlargements of individual frames at a different time sequence (e.g. at 0.05, 1.5, 2.5...etc. seconds, instead of 0.1, 0.2, 0.3...etc. seconds) than the one that was used. There was insufficient time remaining to do this for this report, however.

Regardless of the phenomena affecting the interpretation of the position of the interface, once the interpreter had established the position where he felt the interface to be, he would draw a horizontal line through this point on the enlargement. The intersection of this horizontal line with the displacement scale would then be read to the nearest 0.25 inch in the scale (minimum calibration, 1 inch).

A3.4 Fitting Primary Time-Displacement Data with a Smooth Curve

A 4th order, least squares, polynomial curve fitting routine was used to generate a smooth curve representing an average of the data obtained for each set of test conditions. However, wherever the polynomial did not fit the data, particularly at the beginning and end of the runs, these data were obtained from a smooth, hand-fit curve.

Figure A3.A

Typical Test Data Sheet

INTERNUCLEAR COMPANY DATA SHEET

PROJECT AETR-BB
TEST NO. 401 †
RUN NO. 1 THRU
DATE Aug 26, 1959
TIME 10:00

Photography Data

1. Camera Used PAILLARD BOLEX 119673
2. Film Used KODAK PLUS X NEG PXN 449
3. Number and Kind of Lights 3-500 W G.E. PHOTOFLOODS BEHIND MODEL
   1-500 W G.E. PHOTOSPOT IN FRONT
   FILTER WALZ SERIES V-1C (GREEN)
4. Lens Used BOLEX LYTAR (1:1.9) F25mm No. 62455
5. Lens to model distance 10 ft 8 in
6. Elevation of lens 8 ft 1 in
7. Distance of camera from perpendicular to model 1 ft 3 in WEST
8. Light meter readings
   1. F 1.8 1 FT BELOW S.R. PARTITION 2 F 1.5 AT CLOCK
   3 F 1.3 2 " " " " 4 F 1.8 AT REEL SIGN
   5 F 1.5 3 " " " " 6

10. Lens settings: Focal distance 13 ft Apeture. f 2.8
    FILM SPEED 64 FPS

Reflector Model Data

1. Water composition *Tap water ✓ pure water ____
   Boric acid solution ____ (specify conc)
2. Size scram ~~line~~ SOLENOID = 2 Nominal diameter 1 & 2 in
   Length of line 6 ft 6 in
3. Piping Arrangement
   A ✓ B ____ C ____ D ____

Test Data

Run No.	Circ. flow rate (gpm)	Boric acid inj. rate (gpm)	Water Temp. °F	Time Start	Time Finish	Film footage Initial	Final	Taken
1	118-122 120	0	89	10:03	10:04	0	3	3
2	119-121 120	0	89	10:11	10:12	3	5	2
3	119-121 120	0	89	10:17	10:18	5	8	3
4	119-121 120	0	89	10:23	10:24	8	10	2
5	119-121 120	0	89	10:30	10:31	10	12	2

* WITH RED SERIES

TOTAL TAKEN 12

† All 400 SERIES TESTS USE BOTH the 1" & the 2" solenoid valves in parallel - both open to the atmosphere & the drop tank vented to atmosphere thru a short section (25") of 2" pipe & (9") of 3" pipe.

Figure A3.B

Enlargement from Test 24 - Run 2

Time: 0.09 seconds after scram

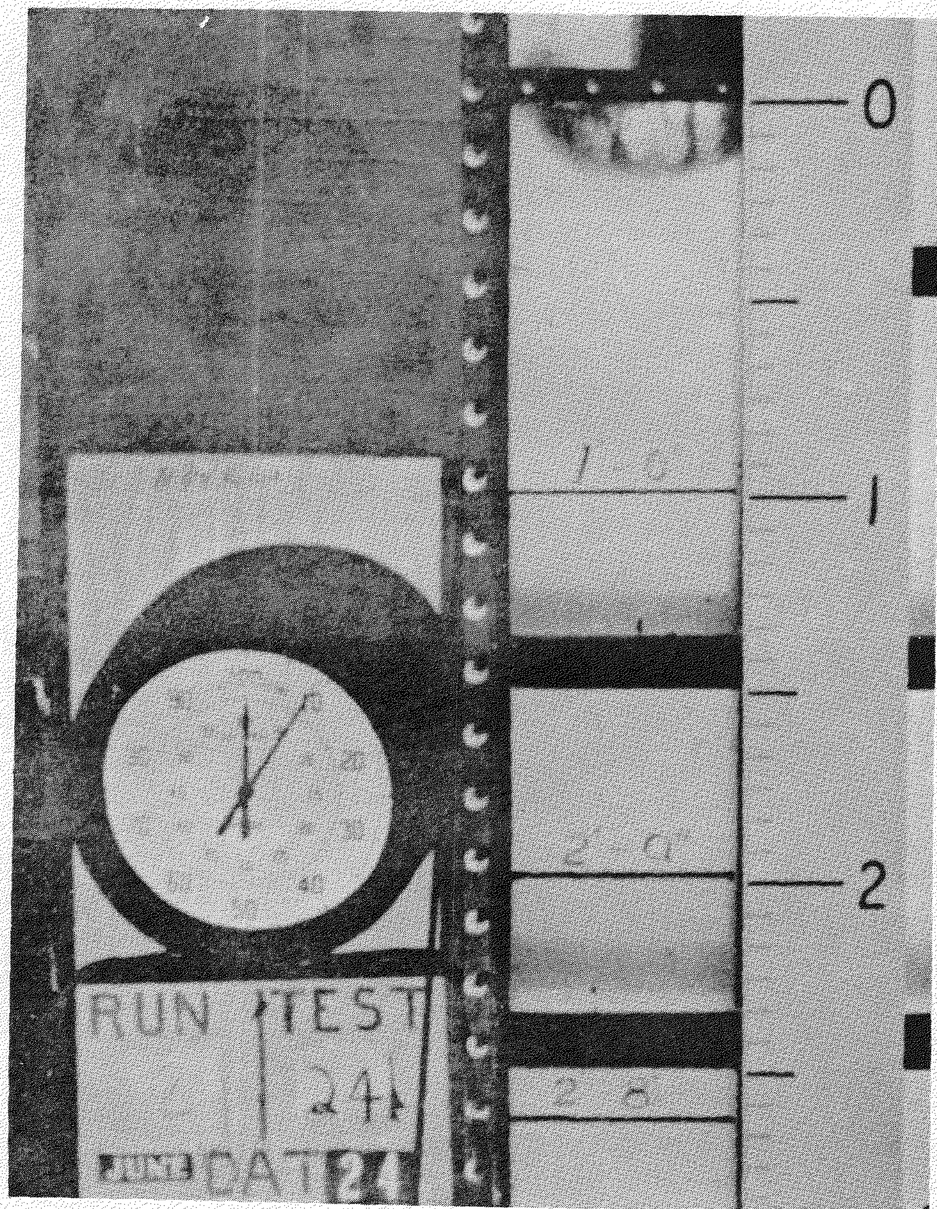


Figure A3.C

Enlargement from Test 24 - Run 2

Time: 0.19 seconds after scram

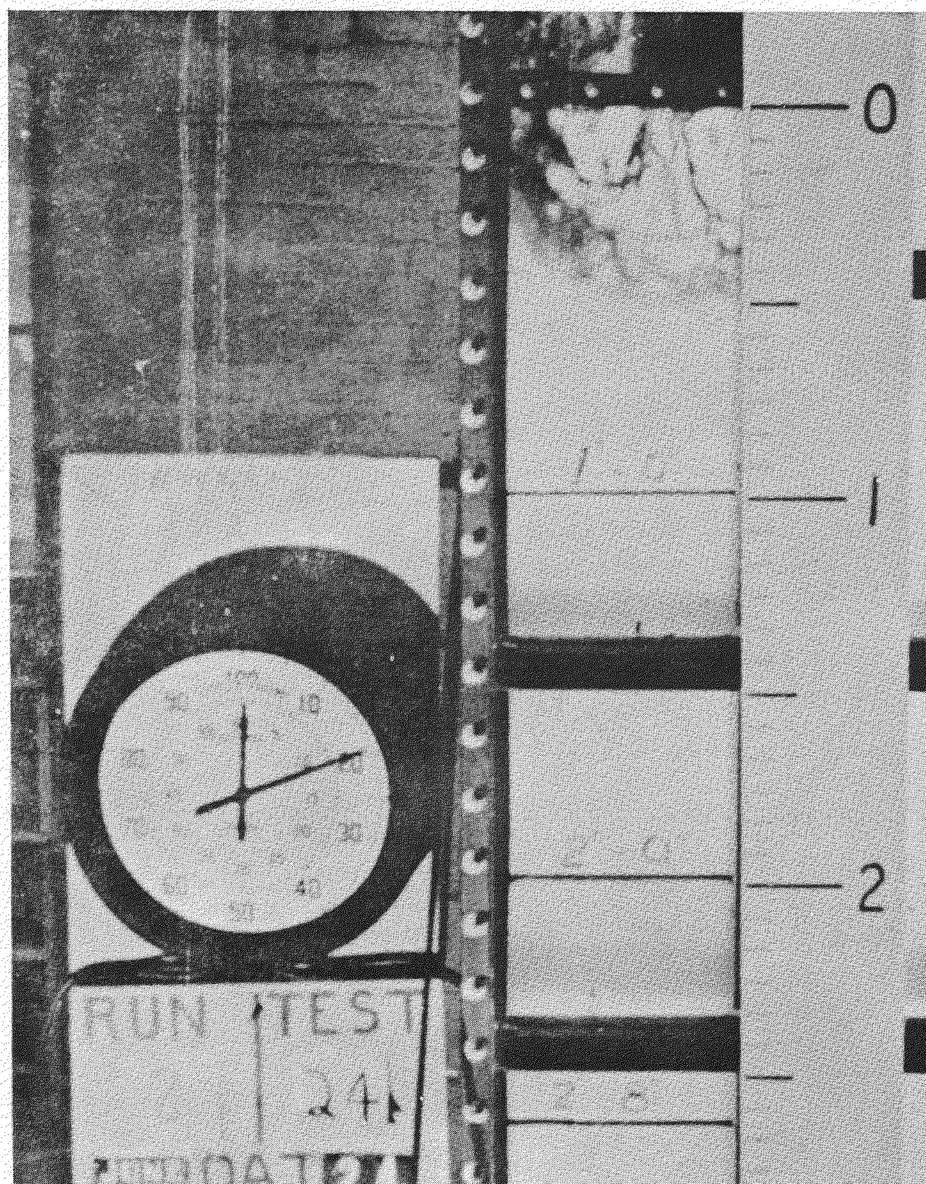


Figure A3.D

Enlargement from Test 24 - Run 2

Time: 0.31 seconds after scram

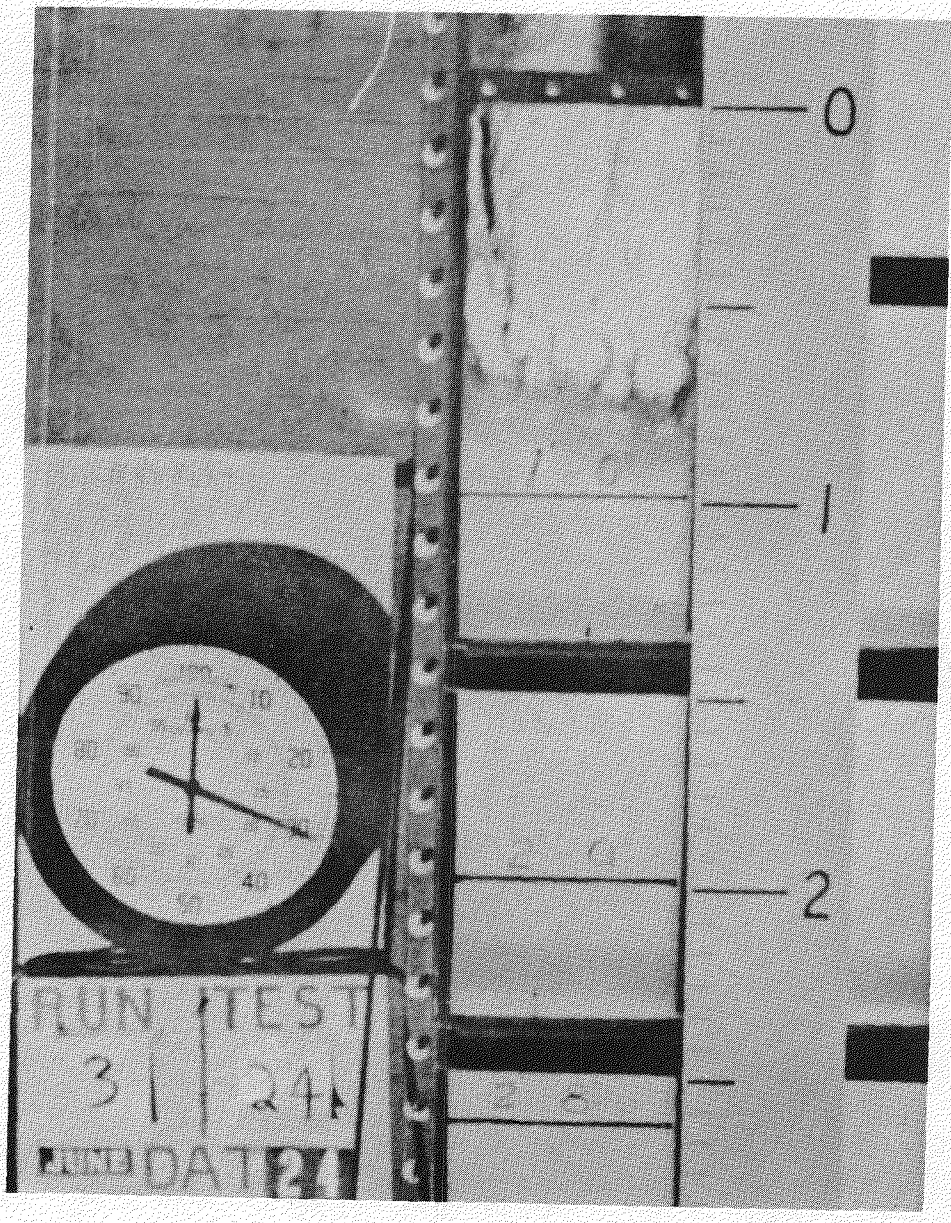


Figure A3.E

Enlargement from Test 24 - Run 2

Time: 0.39 seconds after scram

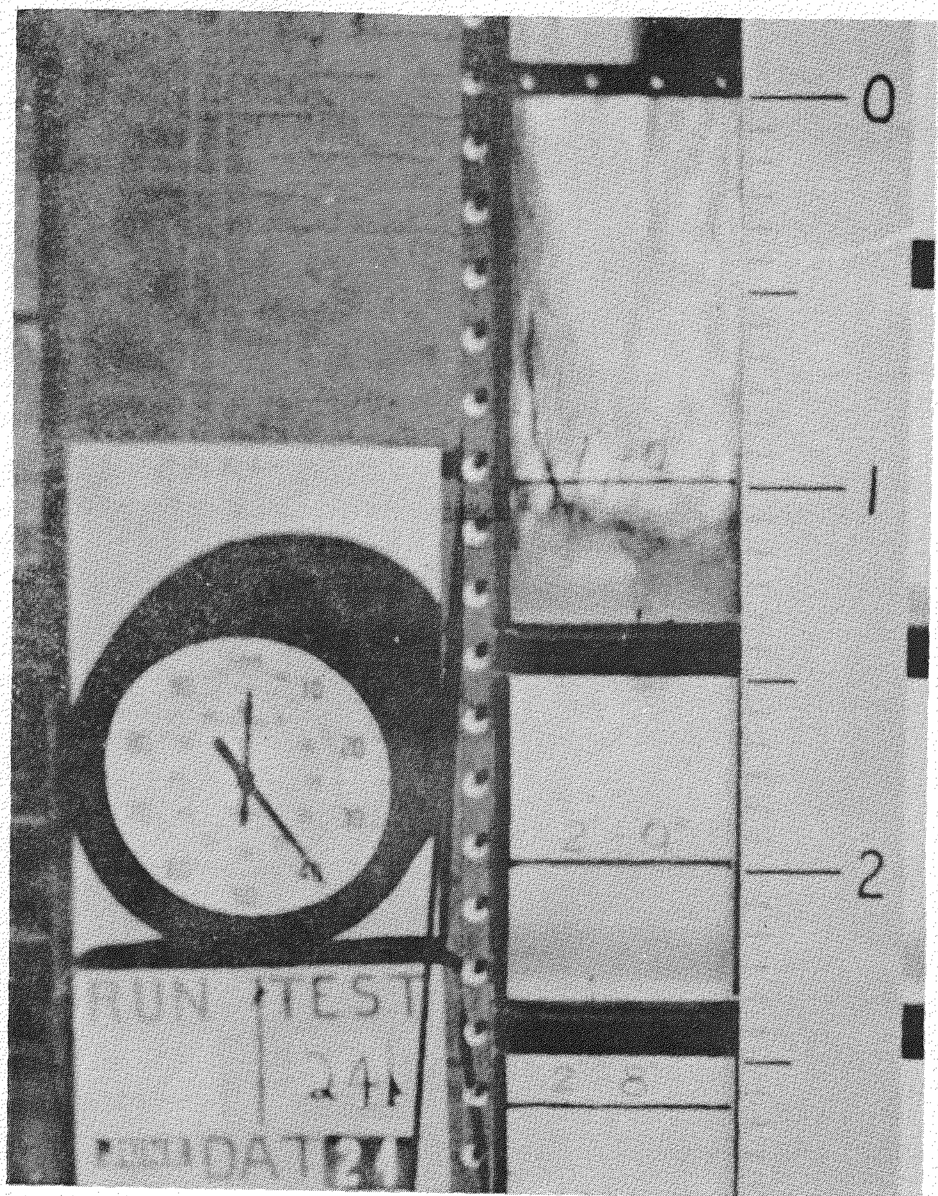


Figure A3.F

Enlargement from Test 24 - Run 2

Time: 0.50 seconds after scram

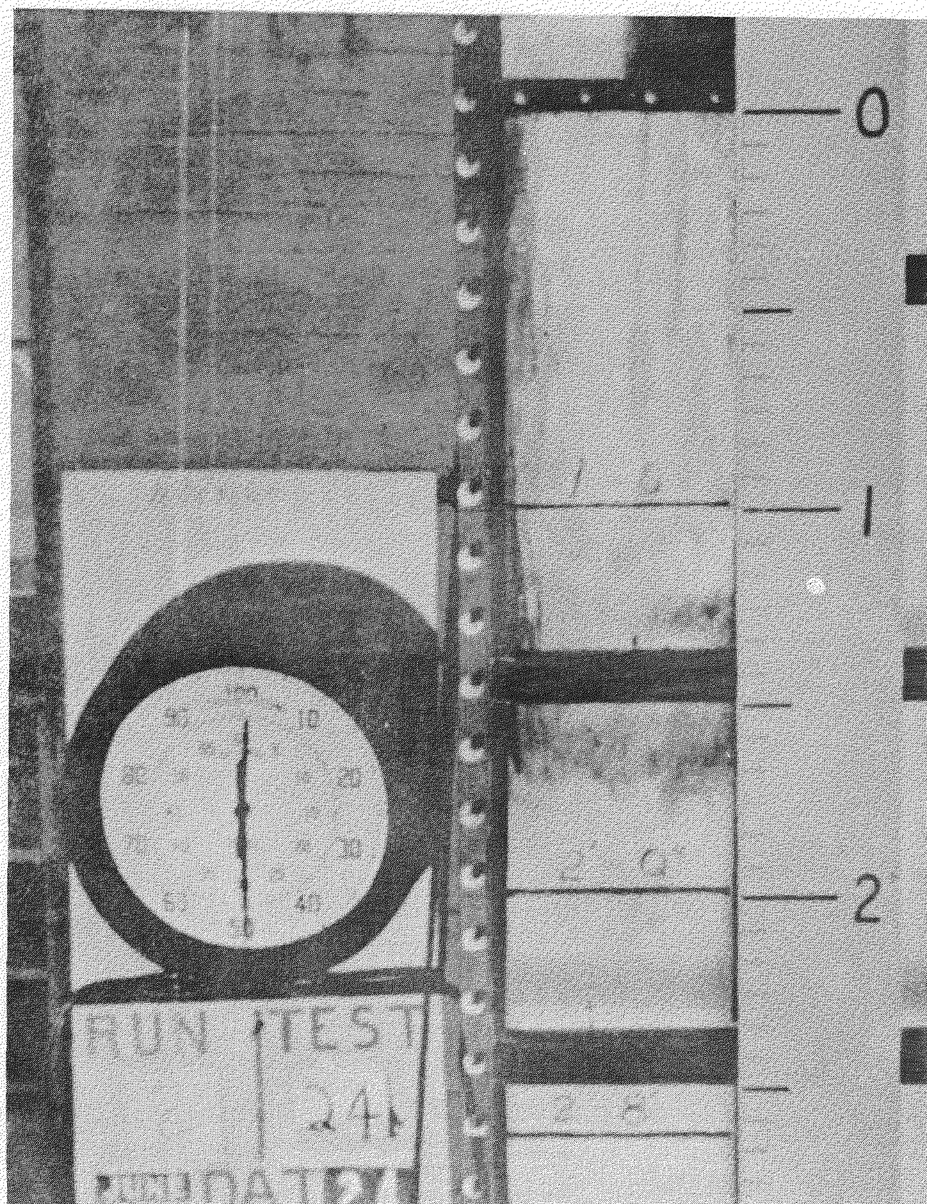


Figure A3.G

Enlargement from Test 24 - Run 2

Time: 0.61 seconds after scram

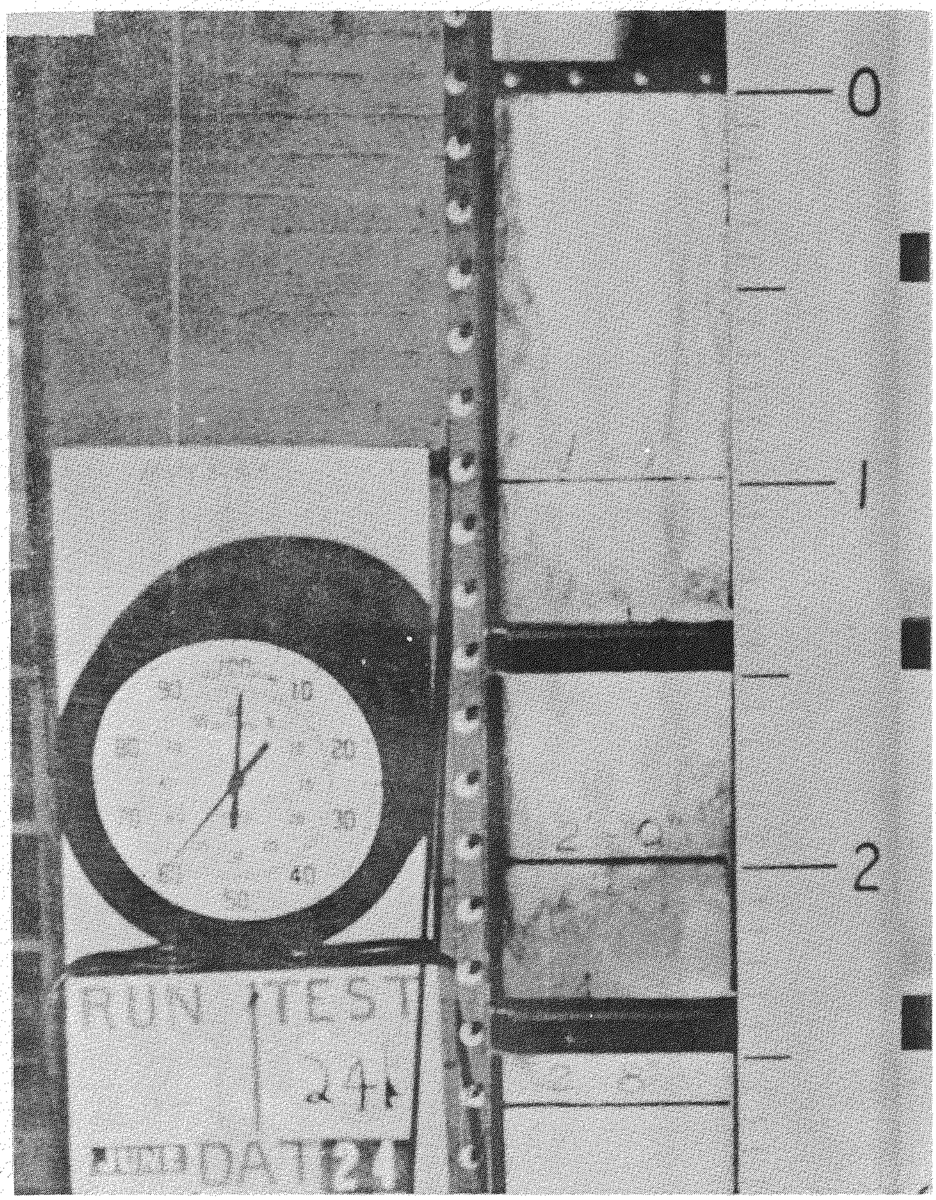


Figure A3.H

Enlargement from Test 24 - Run 2

Time: 0.70 seconds **after scram**

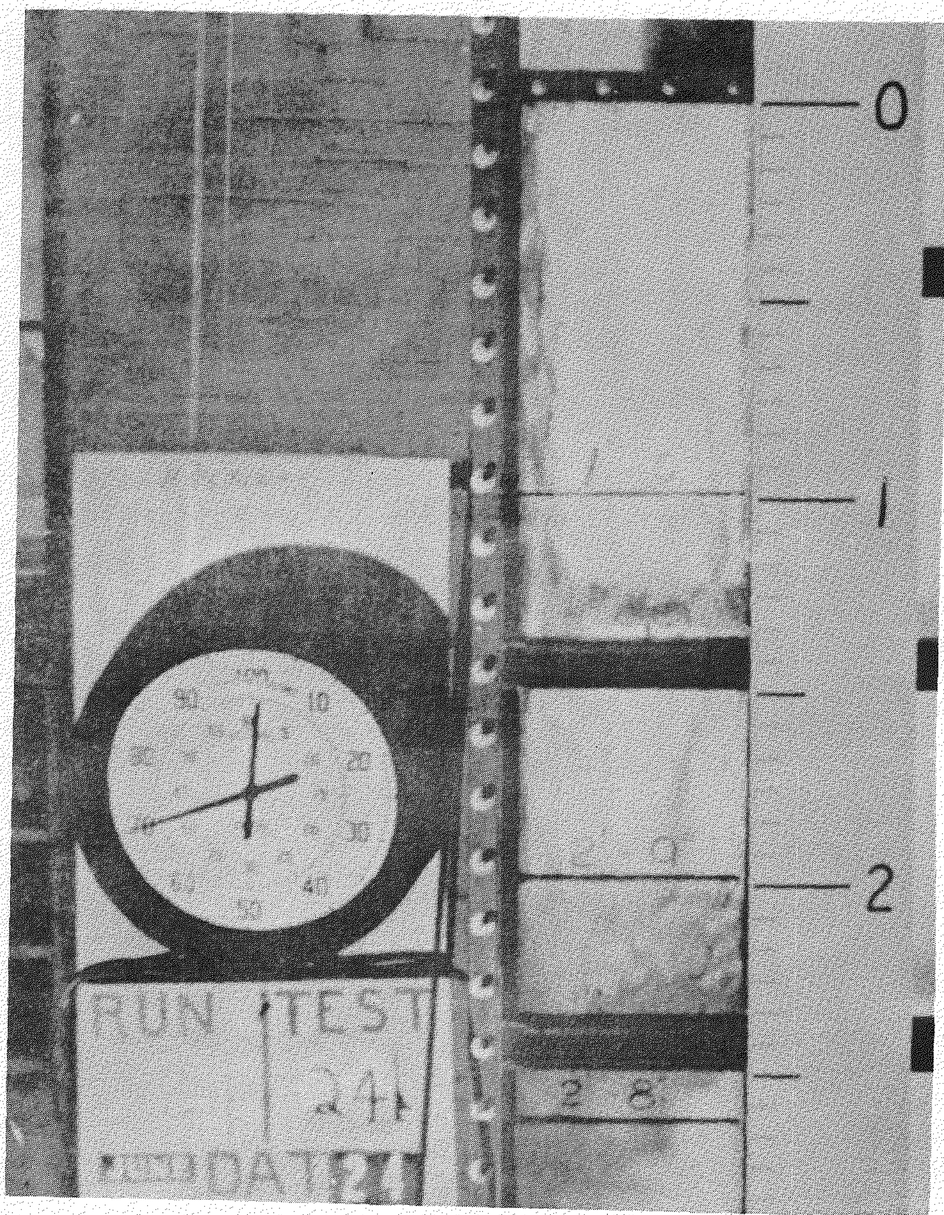


Figure A3.I

Enlargement from Test 24 - Run 2

Time: 0.80 seconds after scram

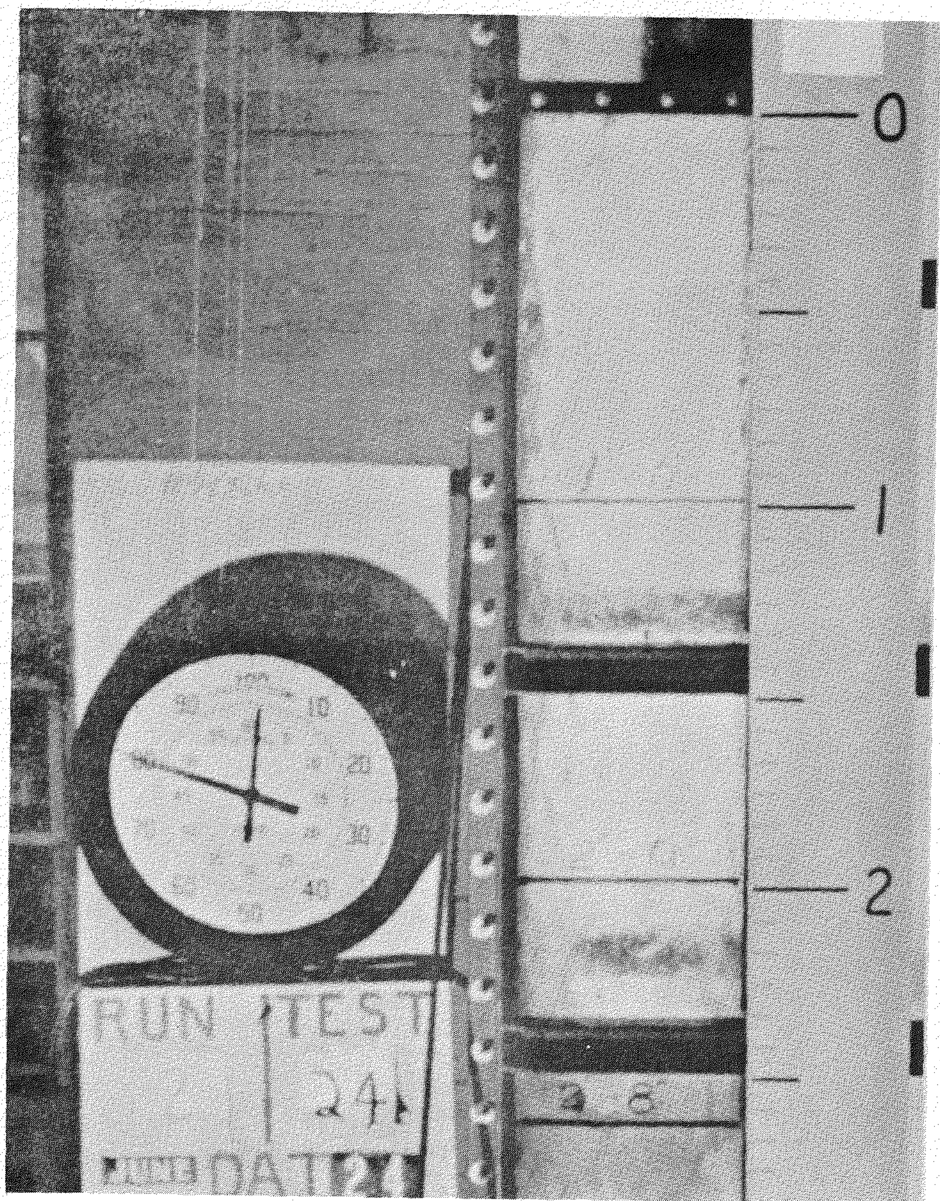


Figure A3.J

Enlargement from Test 24 - Run 3

Time: 0.10 seconds after scram

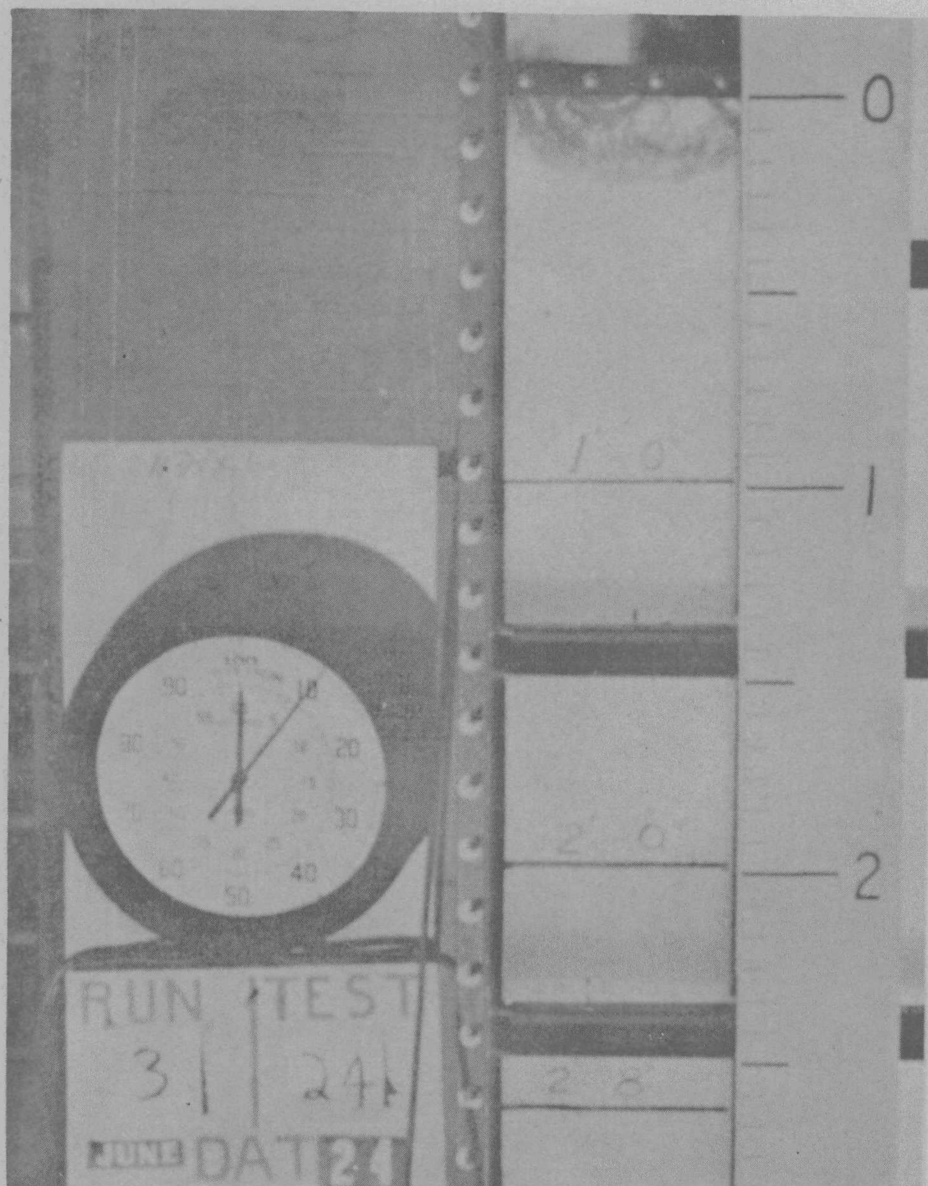
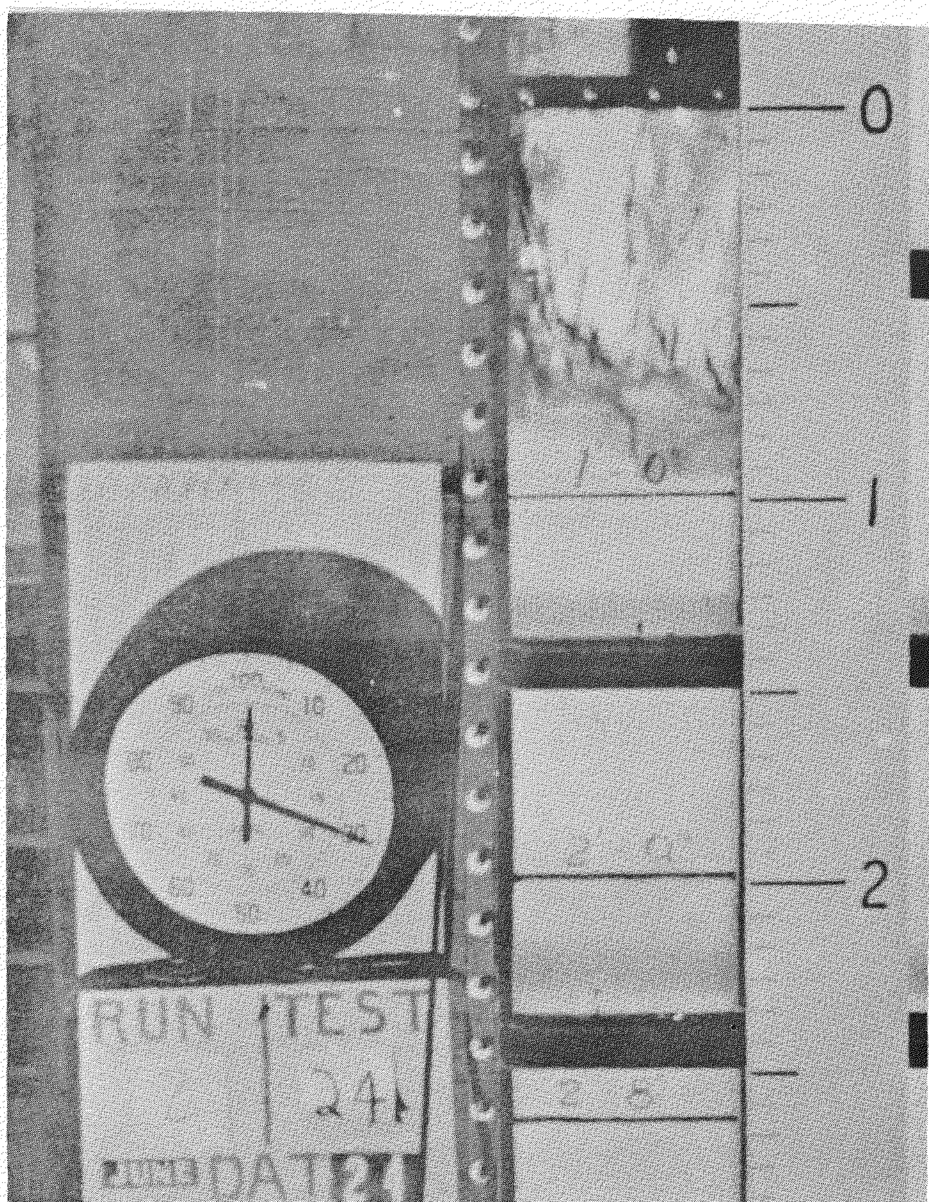


Figure A3.K

Enlargement from Test 24 - Run 3

Time: 0.31 seconds after scram



APPENDIX 4.0

PRIMARY TIME-DISPLACEMENT DATA FROM SAFETY REFLECTOR DROP-TIME TESTS

This appendix presents copies of all the primary numerical time-displacement data accumulated as described in Appendix 3.0.

Table A4.a

Primary Time-Displacement Data From Safety Reflector Drop-time Test 1

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	1.75	0.09	1.75	0.09	2.00	0.10	2.00	0.10	2.00		
0.21	3.00	0.20	2.75	0.20	2.75	0.19	2.50	0.20	2.50		
0.41	7.00	0.39	6.00	0.41	6.00	0.40	5.75	0.40	6.50		
0.59	8.75	0.59	8.25	0.59	8.25	0.60	8.00	0.59	8.00		
0.81	9.25	0.79	9.50	0.81	9.25	0.81	9.00	0.80	9.25		
0.99	13.00	0.99	12.50	1.00	13.00	1.00	12.50	1.00	12.75		
1.20	15.00	1.21	14.50	1.19	15.25	1.20	15.00	1.20	15.00		
1.41	15.75	1.41	16.25	1.40	15.50	1.40	15.75	1.40	15.75		
1.61	18.25	1.59	18.00	1.60	18.00	1.60	17.75	1.59	17.25		
1.80	21.00	1.80	20.25	1.81	20.50	1.80	20.50	1.80	20.50		
2.00	21.50	2.00	21.50	1.99	21.50	2.00	20.50	2.00	21.00		
2.22	24.00	2.20	23.00	2.20	23.25	2.20	23.75	2.21	24.00		
2.41	24.75	2.41	24.75	2.39	24.75	2.39	24.75	2.39	25.25		
2.58	26.25	2.59	25.00	2.60	25.50	2.60	25.25	2.61	26.00		
2.79	27.25	2.79	26.25	2.81	27.25	2.80	27.00	2.79	27.00		
3.00	28.25	2.99	27.25	3.00	27.75	2.99	27.75	3.00	27.50		
3.19	29.25	3.20	27.50	3.20	28.50	3.20	28.00	3.19	28.00		
3.40	30.00	3.40	29.50	3.40	29.25	3.40	30.50	3.39	30.50		
3.60	30.25	3.59	30.75	3.60	30.75	3.60	31.00	3.60	31.00		
3.80	31.25	3.80	31.00	3.80	31.25	3.81	31.50	3.79	31.00		
4.00	32.25	4.00	32.75	3.98	32.00	4.01	33.00	3.98	31.25		
4.20	33.00	4.19	34.00	4.21	33.00	4.19	34.00				
4.40	34.00	4.40	33.50	4.40	34.00	4.40	33.75				
		4.60	33.50	4.60	34.00						

Table A4.b

Primary Time-Displacement Data From Safety Reflector Drop-time Test 2

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

No Data Obtained from This Test

Table A4.c

Primary Time-Displacement Data From Safety Reflector Drop-time Test 3

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	1.25	0.11	1.00	0.10	1.00	0.11	1.50	0.09	1.00		
0.20	2.00	0.20	2.00	0.20	2.25	0.19	2.00	0.21	1.75		
0.39	6.00	0.39	5.75	0.41	6.00	0.41	6.00	0.41	6.00		
0.61	8.00	0.59	8.00	0.61	8.00	0.60	8.25	0.61	8.75		
0.80	9.25	0.80	9.00	0.80	9.00	0.81	8.75	0.81	9.00		
1.00	11.50	1.00	11.75	1.00	12.00	0.99	12.00	1.01	12.25		
1.19	14.25	1.20	14.50	1.21	15.00	1.20	15.25	1.21	15.00		
1.40	15.00	1.41	14.50	1.41	15.50	1.40	15.25	1.40	15.50		
1.60	17.50	1.60	18.00	1.61	17.75	1.60	17.50	1.60	18.00		
1.79	18.25	1.80	19.50	1.80	20.75	1.80	20.25	1.80	21.00		
2.00	20.75	1.99	21.50	2.00	21.25	2.01	20.75	2.00	21.25		
2.20	22.75	2.21	23.00	2.21	23.00	2.19	23.75	2.20	23.25		
2.41	24.25	2.40	24.25	2.40	25.25	2.40	25.75	2.40	25.50		
2.60	25.00	2.60	25.00	2.59	26.25	2.60	25.75	2.60	26.00		
2.80	26.50	2.80	26.50	2.80	27.75	2.79	27.00	2.79	27.00		
3.00	28.75	3.01	27.50	3.00	28.75	2.99	27.25	2.99	27.25		
						3.20	29.00	3.19	29.00		
								3.40	30.00		
								3.61	30.50		
								3.79	32.00		
								3.99	33.00		
								4.20	33.00		
								4.40	34.00		

Table A4 .d

Primary Time-Displacement Data From Safety Reflector Drop-time Test 4

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.25	0.09	2.00	0.10	1.75	0.10	1.75	0.11	1.75		
0.20	2.00	0.20	3.25	0.20	2.00	0.20	2.00	0.20	2.00		
0.39	4.75	0.40	6.50	0.40	5.0	0.40	5.00	0.41	5.00		
0.60	7.50	0.60	7.50	0.59	7.25	0.59	7.50	0.60	7.50		
0.81	9.00	0.80	8.00	0.80	9.00	0.80	9.50	0.80	9.25		
1.00	11.00	1.00	10.50	1.01	11.00	0.99	11.00	0.99	11.00		
1.19	13.00	1.21	13.00	1.19	13.00	1.20	14.00	1.20	13.00		
1.40	14.75	1.40	14.00	1.40	14.00	1.39	14.50	1.40	15.00		
1.60	16.00	1.60	16.00	1.59	16.00	1.60	17.00				
1.80	18.25	1.80	18.00	1.80	17.00	1.80	18.00	1.80	18.50		
2.00	19.00	2.00	19.00	2.00	19.00	2.00	19.50	2.01	19.75		
2.20	22.00	2.20	21.00	2.21	21.00	2.20	22.00	2.19	21.50		
2.40	22.50	2.40	22.25	2.40	22.50	2.41	22.50	2.41	22.75		
2.59	24.00	2.60	23.00	2.59	23.00	2.60	24.00	2.60	23.50		
2.80	24.50	2.80	24.25	2.80	25.00	2.81	25.00	2.81	25.25		
3.00	26.00	3.00	25.75	3.00	26.00	3.00	25.5	3.00	26.25		
3.20	26.75	3.21	27.0	3.20	28.00	3.20	27.00	3.19	29.00		
3.40	27.50	3.40	27.25	3.40	28.25	3.40	29.00				
		Bar	Bar	3.60	28.50	3.60	29.00				
		3.81	30.25	3.80	30.50						
				4.00	31.00						
				4.20	31.50						
				4.40	31.50						

Table A4.e

Primary Time-Displacement Data From Safety Reflector Drop-time Test 5

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.75	0.11	2.00	0.11	2.00	0.09	2.00	0.08	2.00		
0.20	3.00	0.20	3.25	0.20	3.00	0.19	2.75	0.21	3.25		
0.40	5.75	0.40	5.00	0.41	6.00	0.40	6.00	0.40	5.75		
0.58	8.00	0.59	7.75	0.60	8.00	0.60	8.00	0.59	8.25		
0.80	9.00	0.80	9.25	0.80	9.50	0.80	9.00	0.81	9.50		
1.00	12.00	1.00	12.50	1.00	12.25	1.00	12.25	0.98	12.50		
1.21	14.00	1.20	14.75	1.20	15.00	1.20	15.00	1.21	14.50		
1.40	15.75	1.40	16.00	1.40	16.50	1.40	15.50	1.40	15.75		
1.60	17.75	1.61	18.00	1.61	18.00	1.60	18.50	1.60	18.50		
1.79	19.00	1.80	19.50	1.81	19.25	1.80	19.50	1.79	20.50		
2.01	21.50	1.99	21.25	2.00	21.00	2.00	20.50	1.98	21.00		
2.20	22.50	2.21	23.00	2.19	23.00	2.19	22.50	2.21	23.00		
2.41	24.00	2.40	24.25	2.38	24.00	2.39	23.75	2.40	24.25		
2.60	25.75	2.60	25.00	2.61	25.00						
2.80	26.75	2.80	25.75	2.81	26.50	2.80	25.50	2.60	25.75		
		3.00	27.00			2.99	27.00	2.79	27.25		
		3.20	30.00								
		3.40	30.50	3.40	30.00			3.21	30.00		
		3.60	31.00	3.59	31.00			3.41	30.50		
								3.61	31.25		
								3.81	32.00		
								4.00			

Table A4 .f

Primary Time-Displacement Data From Safety Reflector Drop-time Test 6

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	2.00	0.11	2.25	0.10	2.00	0.11	2.50	0.11	2.00		
0.21	3.00	0.20	3.75	0.19	3.75	0.19	3.25	0.20	3.00		
0.38	6.00	0.40	6.00	0.40	6.00	0.41	6.50	0.40	6.00		
0.60	8.75	0.60	8.00	0.60	8.25	0.60	8.75	0.60	7.75		
0.82	9.50	0.79	9.00	0.82	9.00	0.80	9.00	0.81	8.75		
1.00	13.00	0.98	12.50	0.98	12.25	1.00	13.50	1.00	12.00		
1.21	15.00	1.20	15.25	1.21	14.75	1.20	15.25	1.20	14.00		
1.40	16.00	1.40	15.50	1.38	15.50	1.40	15.50	1.40	16.00		
1.60	19.00	1.60	18.25			1.60	18.25	1.60	18.00		
1.81	20.00	1.80	19.75	1.81	19.00	1.80	19.50	1.81	19.00		
2.00	21.00	2.01	20.00	2.01	20.00	2.00	20.75	2.01	20.50		
2.20	23.00	2.20	22.50	2.20	23.00	2.20	22.75	2.20	22.25		
2.41	24.00	2.40	24.00	2.40	24.75	2.39	24.25	2.40	23.25		
2.60	25.00	2.61	24.75	2.60	24.75	2.59	24.75	2.60	25.00		
2.80	26.25	2.81	26.25	2.80	26.50	2.79	25.75	2.80	27.00		
3.00	27.00	3.00	28.50	2.99	27.00	2.99	27.25				
3.20	27.50	3.20	30.00	3.20	27.50						
3.40	30.00			3.38	30.00	3.42	30.75	3.41	30.50		
3.60	31.00							3.59	31.00		

Table A4.g

Primary Time-Displacement Data From Safety Reflector Drop-time Test 7

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	2.00	0.11	1.75	0.09	2.25	0.10	2.00	0.11	2.00		
0.19	3.50	0.20	3.25	0.19	4.25	0.20	3.50	0.21	2.75		
0.40	6.00	0.41	6.00	0.40	6.00	0.40	5.75	0.42	5.75		
0.60	8.75	0.60	7.25	0.59	8.00	0.60	8.25	0.60	8.00		
0.80	9.75	0.81	9.00	0.82	9.25	0.81	9.00	0.79	9.00		
1.00	12.25	0.97	11.50	0.99	12.25	0.98	12.00	1.00	12.25		
1.21	15.00	1.18	14.25	1.20	15.00	1.19	14.00	1.20	14.75		
1.41	15.50	1.38	15.25	1.41	15.25	1.40	15.00	1.40	15.25		
1.61	18.00	1.60	18.00	1.59	18.50	1.60	18.00				
1.81	20.25	1.79	19.50	1.80	20.00	1.80	20.25	1.81	19.75		
2.01	20.50	1.98	20.50	2.00	21.00	2.00	20.50	2.01	20.25		
2.22	22.75	2.19	21.75	2.19	23.00	2.20	22.00	2.19	22.75		
2.39	24.00	2.39	22.00	2.40	24.00	2.41	24.00	2.40	24.00		
2.62	24.75	2.60	25.75	2.58	25.50	2.61	25.00	2.59	24.75		
2.79	26.50	2.80	25.75	2.81	26.25	2.78	26.00	2.79	26.00		
2.98	26.75	2.98	27.50	3.00	27.25	3.00	27.00	2.99	27.00		
								3.21	30.00		
3.41	30.25			3.40	30.25	3.42	30.00	3.39	30.25		
				3.58	31.75	3.60	31.00	3.60	30.50		
								3.81	31.25		
								4.02	32.25		
								4.20	32.75		
								4.40			

Table A4.h

Primary Time-Displacement Data From Safety Reflector Drop-time Test 8

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.25	0.10	2.00	0.10	2.25			0.10	1.75	0.11	2.50
0.20	3.00	0.19	2.75	0.20	3.00			0.19	2.50	0.20	3.00
0.39	5.75	0.40	5.75	0.40	6.75			0.41	5.25	0.41	6.00
0.61	7.50	0.61	8.25	0.60	8.25			0.60	8.00	0.60	7.75
0.80	9.75	0.80	9.00	0.79	9.50			0.81	9.00	0.81	9.50
1.01	12.00	0.99	11.75	1.00	12.75			1.00	12.00	1.00	12.25
1.21	14.00	1.21	14.25	1.20	14.00			1.18	13.75	1.19	14.25
1.40	15.50	1.39	15.25					1.40	15.25	1.41	15.75
								1.59	18.00	1.60	18.00
1.80	19.00	1.80	18.50	1.81	18.50			1.80	18.75	1.80	19.00
2.01	20.75	2.01	20.00	1.99	20.25			2.02	20.00	2.01	20.50
2.20	22.00	2.20	21.75	2.20	22.00			2.20	21.50	2.20	22.00
2.40	23.00	2.41	23.50	2.41	23.75			2.39	23.50	2.40	24.00
2.59	24.25	2.60	24.75	2.60	25.00			2.60	25.00	2.58	24.50
2.80	25.75	2.79	26.25	2.81	26.00			2.79	25.75	2.80	26.50
3.00	26.75	3.00	27.25	3.00	27.00			3.00	27.00	2.99	27.25
3.20	28.00	3.19	28.25	3.20	27.50						
		3.42	30.00	3.39	28.00						
3.59	30.00	3.59	30.25								
3.80	30.50	3.76	30.50								

Table A4.1

Primary Time-Displacement Data From Safety Reflector Drop-time Test 9

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.00	0.10	1.75	0.09	2.00	0.10	2.50	0.11	2.75		
0.20	2.50	0.21	3.00	0.19	4.00	0.20	3.00	0.21	3.00		
0.41	6.00	0.40	5.75	0.39	6.00	0.40	5.00	0.40	5.50		
0.60	8.25	0.60	8.00	0.60	8.25	0.60	8.00	0.60	8.00		
0.80	9.00	0.79	9.25	0.80	9.25	0.80	9.00	0.82	9.25		
0.98	12.00	0.98	12.00	1.01	12.00	1.00	11.75	0.99	11.25		
1.21	13.75	1.20	13.75	1.21	13.75	1.20	13.75	1.19	13.00		
1.41	15.25	1.41	15.25	1.42	15.25	1.40	15.25	1.41	15.50		
1.70	18.75			1.60	18.00	1.60	16.75	1.59	16.50		
1.80	19.00	1.80	18.75	1.78	18.75	1.80	19.00	1.80	18.25		
1.99	20.25	2.00	20.00	2.01	20.75	2.00	20.25	2.00	20.00		
2.21	21.00	2.20	21.50	2.19	22.25	2.20	21.75	2.20	22.00		
2.41	23.00	2.42	22.25	2.40	22.75	2.41	23.00	2.40	23.00		
2.60	24.75	2.59	24.25	2.58	24.00	2.60	24.50	2.60	24.00		
		2.79	25.75			2.79	25.00	2.81	25.00		
		2.98	27.25			3.01	26.75	3.00	26.50		
								3.17	27.25		

Table A4.j

Primary Time-Displacement Data From Safety Reflector Drop-time Test 10

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0 10	2.25	0.10	2 00	0.09	2.25	0.10	2.00	0.09	2.25
		0.21	3.25	0.20	2.75	0.20	2.75	0.20	2.75	0.19	2.50
		0.41	5.50	0.39	5.75	0.41	6.25	0.38	5.75	0.40	6.50
		0.59	8.00	0.59	8.00	0.61	8.00	0.60	8.00	0.61	8.25
		0.81	9.00	0.80	9.25	0.80	9.25	0.80	9.50	0.80	9.25
		1.00	12.00	1.00	12.00	1.01	12.25	0.98	12.25	1.01	13.00
		1.21	14.00	1.20	13.75	1.21	14.25	1.20	14.75	1.19	14.25
		1.41	15.75	1.42	16.00	1.39	15.75	1.38	16.00	1.40	15.25
		1.59	17.75			1.60	18.00	1.60	16.50	1.61	17.75
		1.79	18.50	1.81	18.00	1.80	19.00	1.81	19.50	1.80	19.50
		2.01	20.25	2.00	20.25	2.00	21.00	2.00	21.00		
		2.21	22.00	2.20	22.00	2.22	21.75	2.22	22.25	2.20	22.75
		2.45	23.75	2.40	23.25	2.40	23.00	2.40	23.50	2.40	23.50
				2.59	24.00	2.61	25.00	2.62	25.00	2.59	24.75
				2.80	26.25	2.79	26.00			2.80	26.00
				3.00	27.25					3.01	27.50
				3.23	28.25						

Table A4.k

Primary Time-Displacement Data From Safety Reflector Drop-time Test II

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.25	0.09	1.25	0.09	1.50	0.10	1.75				
0.20	1.50	0.20	2.75	0.20	2.25						
0.40	5.75	0.40	5.75	0.42	5.00	0.40	4.75	0.39	4.75		
0.59	8.00	0.59	8.00	0.61	7.50	0.60	7.50	0.60	7.25		
0.80	9.25	0.78	9.75	0.80	9.25	0.81	9.75	0.81	9.50		
1.00	11.25	1.00	11.75	1.01	11.25	0.98	11.25	0.99	11.00		
1.21	14.00	1.20	14.00	1.20	13.50	1.20	13.50	1.20	13.50		
1.40	14.50	1.41	15.75	1.40	15.00	1.41	15.50	1.39	15.00		
1.59	16.75			1.60	17.00						
1.79	19.25	1.79	19.00	1.78	18.50	1.80	18.75	1.81	18.50		
2.00	19.75	2.00	20.50	2.00	20.00	2.00	20.50	1.98	20.25		
2.22	22.25	2.20	22.25	2.19	21.75	2.20	22.00	2.70	21.75		
2.40	24.00	2.39	23.50	2.40	23.25	2.39	23.50	2.39	23.00		
2.59	24.25	2.60	25.25	2.60	24.50	2.61	24.75	2.62	24.75		
2.80	25.75	2.81	26.25	2.80	26.00	2.81	26.25	2.80	25.75		
		3.00	27.25	2.98	27.00	2.98	27.25	3.00	27.50		
		3.19	28.25	3.19	28.75						
		3.41	30.25								
				3.59	30.75			3.60	30.75		
								3.81	31.75		
								4.01	32.75		
								4.20	34.00		

Table A4.1

Primary Time-Displacement Data From Safety Reflector Drop-time Test 12

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	3.00	0.10	2.25	0.10	2.50	0.09	2.75	0.11	2.00		
0.20	4.00	0.20	3.00	0.20	3.75	0.19	4.00	0.20	3.00		
0.39	6.00	0.40	5.50	0.41	6.25	0.39	5.25	0.40	6.25		
0.60	8.00	0.61	8.50	0.60	8.25	0.60	8.50	0.61	8.50		
0.81	8.50	0.80	8.75	0.80	8.50	0.80	8.75	0.82	8.25		
1.00	12.25	1.00	12.00	0.99	11.75	0.99	11.75	1.02	11.25		
1.20	13.00	1.20	14.00	1.19	13.25	1.19	14.00	1.19	14.00		
1.40	14.25	1.40	15.00	1.39	15.00	1.39	14.50	1.39	14.25		
1.60	17.00	1.59	17.25			1.60	16.25				
1.80	18.25	1.80	18.50	1.80	18.75	1.80	19.50	1.80	18.25		
1.99	19.50	2.00	20.50	1.99	20.50	1.99	20.00	2.00	20.25		
2.20	22.50	2.19	22.00	2.20	22.00	2.21	21.50	2.21	22.00		
2.40	23.00	2.40	23.75	2.39	23.25	2.40	23.50	2.38	23.00		
2.60	24.00			2.60	24.75	2.60	24.00	2.59	24.25		
2.80	25.75			2.79	25.50						
3.00	26.75										
3.20	28.50										
3.40	30.00										
3.60	31.25										

Table A4 .m

Primary Time-Displacement Data From Safety Reflector Drop-time Test 13

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.50	0.09	2.50	0.11	2.50	0.11	2.00	0.10	2.25		
0.18	3.25	0.20	3.50	0.19	3.25	0.20	2.50	0.21	3.00		
0.39	6.00	0.40	6.75	0.39	5.50	0.39	6.00	0.41	6.25		
0.59	7.50	0.60	8.00	0.59	8.00	0.59	8.00	0.61	8.50		
0.78	8.00	0.81	8.75	0.79	8.50	0.79	8.00	0.81	8.75		
0.98	11.50	1.00	12.50	0.99	11.00	0.99	12.00	1.01	11.50		
1.22	14.25	1.20	14.50	1.19	14.00	1.19	14.50	1.20	13.50		
1.41	14.75	1.40	15.25	1.39	14.50	1.39	15.00	1.40	15.00		
1.58	17.00	1.61	17.00	1.60	16.00	1.59	17.50	1.61	16.50		
1.81	19.75	1.80	20.00	1.80	18.00	1.79	18.50	1.81	18.25		
2.01	20.00	2.01	20.25	1.99	19.25	1.99	19.25	2.00	19.50		
2.21	23.00	2.20	22.75	2.19	20.25	2.18	21.50	2.20	20.25		
2.41	24.25	2.40	24.00	2.39	23.00	2.39	23.25	2.40	22.50		
2.61	24.50	2.61	24.75	2.60	24.00	2.59	23.75	2.60	24.00		
		2.81	26.25	2.80	25.50	2.82	26.00	2.80	25.50		
		3.01	27.00	3.00	26.25	2.98	27.00	3.00	26.50		
		3.21	28.25	3.20	28.00	3.18	27.25	3.20	28.50		
		3.41	30.00								
				3.60	29.75	3.58	30.75	3.60	30.25		
						3.79					

Table A4 .n

Primary Time-Displacement Data From Safety Reflector Drop-time Test 14

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.25	0.10	2.00	0.09	2.00	0.10	1.75	0.11	2.00		
0.21		0.19	2.50	0.20	2.25	0.19	3.00	0.19	2.75		
0.41	6.00	0.38	6.00	0.40	6.00	0.41	7.25	0.39	7.00		
0.61	8.50	0.58	8.25	0.60	8.00	0.59	8.25	0.60	7.75		
0.81	8.50	0.79	8.75	0.81	8.50	0.82	8.75	0.80	8.00		
1.01	11.75	0.99	11.50	1.00	11.75	1.02	13.00	0.99	12.00		
1.20	13.75	1.22	14.00	1.20	13.75	1.21	14.50	1.20	13.75		
1.40	14.50	1.39	14.50	1.40	14.25	1.40	15.00	1.39	14.75		
1.60	17.75	1.62	17.25	1.60	15.25	1.58	18.25	1.60	16.75		
1.80	20.00	1.82	18.75	1.80	19.25	1.81	19.75	1.80	18.00		
2.00	20.00	1.98	20.00	2.00	20.00	2.00	20.00	2.00	19.00		
2.20	21.75	2.18	21.75	2.20	22.00	2.20	23.00	2.20	20.50		
2.40	23.75	2.41	23.00	2.40	23.00	2.40	24.00	2.40	23.00		
2.60	24.00	2.58	24.25	2.61	23.75	2.60	24.25	2.60	24.00		
2.80	26.00	2.79	25.50	2.81	25.50	2.81	26.25	2.80	25.50		
3.00	26.25	3.02	27.00	3.00	27.00	3.00	27.25				
3.20	27.50	3.19	29.25			3.20	27.75				
		3.42	31.00								
		3.59	31.25								
		3.79	32.00								
		3.99	33.25								

Table A4.0

Primary Time-Displacement Data From Safety Reflector Drop-time Test 15

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.50	0.10	1.50	0.10	1.50	0.10	1.50	0.11	1.75		
0.19	2.50	0.20	2.50	0.21	2.75	0.19	2.75	0.20	2.25		
0.39	6.25	0.39	6.75	0.41	6.00	0.41	6.25	0.40	6.00		
0.59	9.00	0.60	9.00	0.61	9.00	0.59	9.00	0.60	9.00		
0.78	9.75	0.80	9.75	0.79	9.75	0.78	9.75	0.80	9.50		
0.99	12.25	0.99	13.00	0.99	12.50	1.01	13.00	1.00	13.00		
1.21	15.25	1.20	15.75	1.19	15.25	1.19	15.50	1.20	15.50		
1.40	16.00	1.39	16.00	1.39	16.75	1.39	16.00	1.40	16.00		
1.60	19.00	1.59	18.50	1.59	18.75	1.59	18.50	1.60	18.75		
1.80	20.75	1.79	21.00	1.80	20.75	1.79	20.00	1.80	20.75		
2.00	22.00	1.99	21.00	1.99	22.00	1.99	21.50	2.01	21.75		
2.20	24.00	2.20	24.00	2.20	24.00	2.20	24.00	2.20	24.00		
2.40	27.00	2.39	26.25	2.40	25.50	2.39	26.00	2.41	25.50		
2.60	27.25	2.60	26.50	2.60	26.75	2.60	26.25	2.61	26.25		
2.80	28.00			2.80	28.00	2.80	28.00	2.79	27.25		
				3.00	28.50	3.00	29.00	3.02	28.75		
				3.20	30.75			3.19	30.00		
3.00	29.75							3.39	30.75		
3.20	30.75										

Table A4.p

Primary Time-Displacement Data From Safety Reflector Drop-time Test 16

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0.10	2.25	0.09	2.25	0.10	2.50	0.09	2.50		
0.21	3.00	0.19	3.00	0.20	3.75	0.19	2.75	0.20	2.75		
0.40	6.00	0.40	6.00	0.40	6.00	0.38	6.00	0.40	6.75		
0.61	8.00	0.61	8.00	0.60	8.00	0.62	8.50	0.60	8.25		
0.80	10.25	0.81	10.00	0.80	10.50	0.81	10.25	0.80	10.00		
1.00	13.25	1.00	12.50	0.99	13.25	1.01	13.25	1.00	13.75		
1.20	15.00	1.20	15.00	1.19	15.50	1.20	15.50	1.20	15.75		
		1.40	16.25	1.41	17.00	1.40	17.50	1.40	17.50		
1.60	19.25	1.60	19.00	1.61	19.25	1.60	19.50	1.60	19.50		
1.80	21.00	1.80	21.00	1.81	21.25	1.80	21.25	1.80	21.50		
2.00	21.50	1.99	22.00	2.00	22.75	1.99	22.75	2.00	22.50		
2.20	24.25	2.21	24.00	2.20	24.25	2.19	24.50	2.20	24.50		
2.40	25.75	2.41	25.75	2.40	26.00	2.42	26.25	2.40	26.00		
2.60	27.00	2.62	27.00	2.60	27.25	2.62	27.25	2.60	28.25		
2.80	28.00	2.81	28.50								
3.00	30.00	3.00	29.50					3.00	30.00		

Table A4.q

Primary Time-Displacement Data From Safety Reflector Drop-time Test 17

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.25	0.11	2.00	0.12	2.25	0.10	2.50	0.09	2.00		
0.18	3.00	0.19	2.50	0.20	3.25	0.21	3.50	0.20	3.00		
0.41	7.00	0.42	6.50	0.40	6.25	0.40	6.75	0.40	6.50		
0.58	8.25	0.59	8.25	0.60	8.25	0.61	8.50	0.60	8.50		
0.82	10.50	0.79	10.00	0.80	10.00	0.81	10.75	0.80	10.00		
1.01	13.50	1.01	13.75	1.00	13.25	1.00	13.50	0.99	13.25		
		1.21	16.00	1.20	15.50	1.20	16.00	1.19	15.50		
1.40	17.50	1.40	17.25	1.40	18.00	1.40	18.00	1.38	18.00		
1.61	19.50	1.61	20.00	1.61	19.50	1.60	20.00	1.59	19.00		
1.80	21.50	1.81	22.00	1.81	20.50	1.80	21.50	1.82	21.50		
2.00	22.50	2.00	23.75	2.00	22.00	1.99	22.75	2.01	22.25		
2.20	24.50	2.20	24.50	2.21	24.50	2.19	24.50	2.21	24.75		
2.40	26.00	2.40	26.25	2.40	25.75	2.39	26.00	2.40	26.00		
2.60	27.00	2.60	27.25	2.61	26.75	2.60	27.00	2.60	27.00		
2.80	28.75	2.80	29.00	2.81	28.25	2.79	28.25	2.81	28.25		
		3.00	29.50					3.00	29.50		
		3.20	30.50	3.21	30.25	3.21	30.25	3.20	30.25		
				3.38	31.25	3.39	30.75	3.40	31.00		
				3.59	32.00	3.59	31.75	3.60	31.75		
						3.79	33.50	3.80	33.00		
						3.99	34.00	4.00	34.00		
						4.19	34.50	4.20	34.25		
								4.39	35.00		

Table A4 .r

Primary Time-Displacement Data From Safety Reflector Drop-time Test 18

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	2.25	0.11	2.50	0.11	2.75	0.10	2.25	0.09	2.00		
0.19	3.25	0.20	3.50	0.22	3.50	0.21	3.25	0.20	3.00		
0.42	7.25	0.39	6.50	0.42	7.00	0.41	7.25	0.40	6.00		
0.62	9.00	0.59	8.50	0.59	8.50	0.61	9.00	0.60	8.25		
0.81	11.00	0.79	10.50	0.81	10.75	0.81	11.00	0.79	10.00		
1.01	14.00	0.99	13.50	1.01	14.00	1.00	14.50	0.99	11.00		
1.20	16.00	1.21	15.75	1.20	16.00	1.20	16.25	1.21	16.00		
1.40	17.75	1.41	17.00	1.40	18.00	1.40	17.75	1.41	17.75		
1.60	19.75	1.61	20.00	1.60	20.25	1.60	20.00	1.61	19.25		
1.80	21.25	1.81	21.25	1.80	21.50	1.80	21.50	1.81	21.25		
1.99	22.50	2.01	22.25	1.99	22.50	2.00	22.50	2.00	22.50		
2.19	24.75	2.20	24.75	2.19	24.00	2.19	24.50	2.20	24.25		
2.39	25.75	2.40	26.00	2.39	26.00	2.40	25.75	2.40	25.00		
2.58	26.75	2.60	27.00	2.59	26.50	2.60	27.00	2.60	27.00		
2.82	28.50	2.80	28.00	3.79	28.25	2.79	28.25	2.80	28.00		
3.01	29.25					2.99	29.25				
3.21	30.25	3.20	30.00	3.21	30.00	3.21	30.00	3.19	30.00		
3.41	30.75	3.40	31.00	3.41	30.75	3.42	30.75	3.39	30.75		
3.61	32.00	3.60	31.25	3.61	31.75			3.59	31.00		
3.81	32.25	3.80	32.75	3.81	33.00			3.79	32.25		
4.01	34.25	4.00	34.25	4.01	34.25			3.98	34.00		
4.21	34.75	4.20	34.75					3.22	34.25		

Table A4 .s

Primary Time-Displacement Data From Safety Reflector Drop-time Test 19

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	1.75	1.11	1.75	0.10	1.50	0.10	1.75	0.10	1.75		
0.20	2.50	0.20	2.25	0.21	2.75	0.21	2.50	0.21	2.50		
0.40	5.75	0.40	5.00	0.41	5.25	0.41	5.75	0.41	5.75		
0.60	8.00	0.60	8.00	0.61	8.00	0.58	7.50	0.61	8.25		
0.80	9.00	0.80	8.25	0.81	9.25	0.81	9.25	0.81	9.25		
1.00	12.00	1.00	11.75	1.01	12.00	1.01	11.75	1.00	12.00		
1.19	15.00	1.19	14.75	1.20	14.50	1.20	14.50	1.20	14.50		
1.39	14.75	1.39	15.00	1.40	15.00	1.40	14.75	1.40	15.00		
		1.60	17.50			1.60	17.25				
1.80	20.00	1.79	19.50	1.80	19.00	1.80	18.50	1.80	19.50		
		1.99	19.75	2.00	19.25	2.00	19.50	2.00	20.00		
2.19	22.50	2.19	22.00	2.19	22.25	2.20	22.00	2.20	22.50		
2.38	23.25	2.39	23.75	2.41	23.50	2.40	23.75	2.40	23.75		
2.59	25.00	2.59	25.75	2.60	25.50	2.60	25.00	2.60	25.50		
2.79	27.00	2.79	27.00	2.79	27.00	2.80	26.50	2.80	27.75		
2.99	27.25	2.99	27.25	2.99	28.25	3.00	26.75	3.00	29.50		
3.19	29.50			3.19	28.75	3.20	28.50	3.20	30.00		
3.39	30.75	3.39	30.50	3.39	31.00	3.40	30.00	3.40	31.00		
3.60	32.75	3.59	32.75	3.59	32.50	3.60	31.75	3.60	32.50		
		3.79	32.75	3.79	32.75	3.80	32.25	3.80	33.00		
						4.00	33.25	4.00	34.25		
						4.21	35.25				

Table A4.t

Primary Time-Displacement Data From Safety Reflector Drop-time Test 20

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.00	0.10	1.00	0.10	1.00	0.10	1.50	0.10	1.00		
0.21	4.00	0.19	4.00	0.20	3.50	0.20	5.75	0.20	4.75		
0.30	7.50	0.31	8.50	0.30	9.00	0.30	10.25	0.30	9.00		
0.39	12.25	0.41	14.50	0.40	14.25	0.40	15.00	0.40	14.75		
0.50	19.50	0.50	20.00	0.50	20.25	0.50	20.75	0.50	21.00		
0.59	22.75	0.60	23.00	0.60	24.00	0.59	24.25	0.60	23.75		
0.70	26.75	0.70	27.00	0.71	28.00	0.69	27.75	0.71	27.00		
0.80	29.00	0.80	29.50	0.81	31.75	0.80	31.00	0.81	30.25		
0.90	32.25	0.90	33.25	0.91	34.00	0.90	33.25	0.87	32.50		

Table A4.u

Primary Time-Displacement Data From Safety Reflector Drop-time Test 21

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.75	0.10	2.00	0.10	1.00	0.09	1.50	0.10	1.00		
0.20	6.00	0.20	6.50	0.20	3.00	0.19	4.75	0.20	3.50		
0.30	11.00	0.31	12.00	0.30	8.00	0.29	8.25	0.30	8.00		
0.40	17.25	0.39	16.25	0.40	13.00	0.39	15.00	0.40	14.25		
0.50	22.00	0.49	21.50	0.50	19.25	0.50	21.25	0.50	20.25		
0.60	26.00	0.60	26.00	0.61	24.25	0.60	24.50	0.60	24.25		
0.71	29.75	0.70	27.75	0.71	27.75	0.70	27.50	0.71	27.75		
0.80	32.00	0.80	32.50	0.81	30.25	0.80	31.00	0.80	30.75		
		0.89	35.00	0.89	34.00			0.91	34.00		

Table A4.V

Primary Time-Displacement Data From Safety Reflector Drop-time Test 22

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	1.00	0.10	1.00	0.10	1.75	0.09	1.50	0.10	1.25		
0.20	5.00	0.20	4.00	0.20	6.00	0.20	5.50	0.20	5.00		
0.30	8.00	0.30	8.50	0.30	10.25	0.31	11.00	0.30	10.25		
0.40	14.75	0.41	14.50	0.40	16.75	0.39	16.0	0.40	16.25		
0.50	21.00	0.49	19.75	0.50	21.50	0.50	22.00	0.50	22.00		
0.60	25.00	0.59	24.00	0.59	25.00	0.60	25.50	0.59	25.00		
0.70	28.50	0.70	27.25	0.69	28.00	0.70	29.50	0.71	29.00		
0.81	30.50	0.80	30.25			0.80	32.00	0.80	31.50		
0.90	33.50										

Table A4 .w

Primary Time-Displacement Data From Safety Reflector Drop-time Test 23

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.25	0.11	1.00	0.10	1.00	0.10	1.00	0.10	1.25		
0.19	4.25	0.21	3.75	0.20	3.50	0.21	3.75	0.20	4.50		
0.29	8.75	0.31	8.00	0.30	7.00	0.31	7.25	0.30	8.75		
0.40	15.00	0.39	12.25	0.40	13.00	0.41	13.00	0.40	15.00		
0.50	21.25	0.50	18.50	0.50	19.00	0.49	18.00	0.50	20.25		
0.60	24.00	0.60	23.00	0.60	22.50	0.60	22.00	0.59	23.00		
0.70	27.00	0.70	26.25	0.71	25.00	0.70	25.00	0.71	26.25		
0.80	30.00	0.80	29.00	0.79	28.00	0.80	27.75	0.81	29.00		
0.90	33.50			0.91	30.50	0.90	30.25	0.91	32.75		
				1.00	33.75						

Table A4. x

Primary Time-Displacement Data From Safety Reflector Drop-time Test 24 & 35

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.25	0.11	1.25	0.10	1.00	0.10	1.00	0.10	1.00		
0.20	4.25	0.20	4.75	0.20	4.25	0.20	4.50	0.20	4.00		
0.30	9.00	0.30	8.00	0.30	7.75	0.30	8.00	0.31	8.50		
0.41	15.50	0.40	13.50	0.40	14.50	0.40	14.25	0.40	13.25		
0.51	21.25	0.50	19.75	0.50	19.50	0.50	19.25	0.50	19.25		
0.59	24.75	0.60	24.50	0.60	23.75	0.59	22.00	0.60	22.50		
0.71	28.00	0.70	27.00	0.70	27.50	0.70	27.00	0.71	26.50		
0.81	31.25	0.80	30.00	0.80	31.50	0.79	29.00	0.80	29.50		
0.90	33.25	0.90	33.00	0.89	34.00						
Test 35											
0.90	34.00	0.90	33.50	0.91	35.00	0.90	33.75	0.90	35.00		
1.00	37.25	1.01	38.00	0.99	38.00	1.01	38.50	0.99	37.75		
1.09	40.25	1.09	39.50	1.09	42.00	1.09	42.00	1.10	41.75		
1.19	43.25	1.19	42.25	1.19	44.00	1.19	44.50	1.21	44.00		
1.31	44.75	1.30	44.00	1.29	45.00	1.31	44.50	1.29	45.25		
1.41	45.25	1.40	45.25	1.39	45.50	1.40	45.00	1.40	45.75		
1.51	46.25										

Table A4 . y

Primary Time-Displacement Data From Safety Reflector Drop-time Test 25-36

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00	0.10	1.00	0.10	1.00	0.10	1.00	0.10	1.50		
0.20	4.25	0.20	4.00	0.20	4.75	0.20	3.75	0.20	5.50		
0.30	8.75	0.30	8.50	0.30	8.75	0.30	9.25	0.30	10.00		
0.40	14.50	0.40	13.75	0.40	14.00	0.40	14.75	0.40	16.00		
0.50	20.00	0.50	19.50	0.51	19.50	0.50	20.25	0.50	20.25		
0.60	23.00	0.60	23.00	0.60	22.75	0.60	22.50	0.60	24.00		
0.70	25.00	0.70	25.25	0.70	26.25	0.70	26.50	0.70	28.25		
0.80	29.75	0.80	29.25	0.80	30.25	0.80	30.25				
					Test 36						
								0.80	31.00		
0.90	36.00	0.90	32.00	0.90	33.50	0.90	34.00	0.90	34.00		
1.00	38.75	1.00	37.00	0.99	36.50	1.00	37.00	1.00	37.25		
1.10	42.50	1.10	40.50	1.10	40.25	1.11	40.50	1.10	40.75		
1.19	44.00	1.20	43.00	1.20	42.00	1.20	42.25	1.20	43.00		
1.30	45.00	1.30	45.00	1.30	44.00	1.30	44.75	1.30	44.50		
1.40	45.75	1.40	45.50	1.39	45.00	1.41	45.25	1.39	45.50		

Table A4 .z

Primary Time-Displacement Data From Safety Reflector Drop-time Test 26 & 37

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.15	3.00	0.10	1.25	0.10	1.25	0.10	1.50	0.10	1.00		
0.26	8.00	0.20	4.00	0.20	4.00	0.20	4.75	0.21	4.00		
0.36	13.00	0.30	8.75	0.30	8.75	0.30	9.50	0.30	8.75		
0.46	18 50	0.40	13.50	0.40	14.00	0.40	14.75	0.40	13.75		
0.50	20.00	0.49	18.50	0.50	19.75	0.50	20.50	0.50	19.00		
0.60	24.00	0.60	23.75	0.59	23.25	0.60	23.50	0.60	23.50		
0.70	27.50	0.70	25.50	0.70	28.00	0.70	27.50	0.70	27.00		
0.80	30.25	0.80	30.00	0.80	30.25	0.80	29.25	0.80	29.25		
0.90	34.00	0.90	32.00	0.90	32.50	0.90	33.50	0.90	33.00		
					Test 37						
1.00	37.50	1.00	37.00	1.00	38.50	0.99	36.00	1.00	37.75		
1.11	40.50	1.10	40.25	1.10	41.00	1.10	39.25	1.09	40.75		
1.20	42.50	1.21	43.25	1.20	43.00	1.20	42.00	1.20	43.25		
1.30	43.00	1.30	44.00	1.31	43.75	1.31	44.00	1.30	44.50		
1.40	44.00	1.40	45.00	1.40	44.25	1.39	44.00	1.41	44.75		

Table A4 .aa

Primary Time-Displacement Data From Safety Reflector Drop-time Test 27

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00	0.10	1.00	0.10	1.00	0.10	1.00	0.10	1.25		
0.20	3.50	0.21	3.75	0.20	3.50	0.20	3.50	0.21	4.00		
0.30	6.50	0.29	6.75	0.30	7.50	0.30	7.00	0.30	8.25		
0.40	12.00	0.39	12.00	0.41	12.75	0.40	12.50	0.40	15.25		
0.49	18.25	0.50	18.25	0.50	18.25	0.50	19.00	0.50	19.25		
0.61	24.00	0.60	24.00	0.59	24.00	0.59	24.00	0.60	25.00		
0.70	25.50	0.70	26.25	0.70	26.50	0.71	26.50	0.70	27.00		
0.80	27.75	0.80	28.00	0.80	28.25	0.79	28.25	0.80	29.50		
0.90	30.75	0.90	32.00	0.90	31.50	0.90	31.75	0.90	32.50		

Table A4 .bb

Primary Time-Displacement Data From Safety Reflector Drop-time Test 28

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.25	0.09	1.00	0.11	0.75	0.10	1.00	0.11	1.00		
0.21	4.50	0.20	3.00	0.21	3.00	0.20	3.25	0.20	3.00		
0.31	8.25	0.30	6.00	0.31	6.25	0.30	6.75	0.31	6.50		
0.39	13.50	0.40	12.00	0.39	11.00	0.39	11.75	0.40	12.00		
0.50	19.50	0.50	18.25	0.50	15.50	0.50	17.25	0.49	14.75		
0.60	23.00	0.60	22.25	0.60	22.00	0.60	22.00	0.60	22.00		
0.70	26.00	0.70	25.25	0.70	25.00	0.70	24.50	0.70	25.00		
0.80	28.25	0.80	27.75	0.80	27.00	0.80	27.75	0.80	27.00		
		0.90	30.00	0.90	29.00	0.90	30.00	0.90	29.75		
		0.99	32.75	0.99	32.25			1.00	33.25		

Table A4 .cc

Primary Time-Displacement Data From Safety Reflector Drop-time Test 29

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00	0.11	1.75	0.10	2.00			0.10	1.00		
0.20	4.00	0.20	6.25	0.20	5.50			0.20	4.00		
0.30	10.00	0.30	11.25	0.30	12.00			0.29	9.50		
0.40	15.00	0.40	16.50	0.40	16.75			0.40	14.00		
0.50	20.25	0.50	22.00	0.50	22.25			0.50	21.50		
0.60	25.50	0.60	26.25	0.60	24.75			0.60	22.25		
0.70	28.00	0.71	29.25	0.71	29.00			0.71	26.00		
0.80	32.00	0.80	32.00	0.80	32.00			0.80	29.25		
0.90	33.50							0.90	33.00		

Table A4 .dd

Primary Time-Displacement Data From Safety Reflector Drop-time Test 30

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.25	0.10	0.75	0.10	1.00	0.10	1.25	0.10	1.00		
0.20	4.25	0.20	4.00	0.20	4.00	0.20	4.00	0.20	5.00		
0.31	9.50	0.30	9.00	0.29	8.50	0.30	10.00	0.30	9.25		
0.40	13.00	0.40	13.50	0.40	13.00	0.40	15.25	0.41	13.50		
0.50	16.50	0.50	17.00	0.50	17.50	0.50	20.00	0.50	18.00		
0.60	21.00	0.60	20.75			0.60	23.75	0.60	23.50		
0.70	24.00	0.70	26.00			0.70	28.00	0.70	26.50		
0.80	28.00					0.80	30.50	0.80	30.00		
0.90	32.50										

Table A4 .ee

Primary Time-Displacement Data From Safety Reflector Drop-time Test 31

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.50	0.10	1.00	0.10	2.75	0.10	2.00	0.10	1.75		
0.20	6.75	0.21	4.00	0.20	6.00	0.20	7.00	0.20	6.00		
0.30	11.75	0.30	8.00	0.30	12.00	0.30	12.00	0.30	10.00		
0.40	15.25	0.40	13.25	0.40	17.50	0.40	16.00	0.40	15.00		
0.50	21.00	0.50	18.25	0.50	21.00	0.51	22.00	0.50	20.50		
0.60	25.00	0.60	22.50	0.60	25.00	0.60	24.00	0.60	24.25		
0.70	28.25	0.70	26.50	0.70	27.50	0.70	27.75				
0.80	32.00	0.80	30.00	0.80	31.50						

Table A4 ff

Primary Time-Displacement Data From
Safety Reflector Drop-time Test 32 & 38

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00	0.10	1.50	0.10	3.00	0.10	1.00	0.10	3.00		
0.20	4.00	0.19	4.00	0.20	8.00	0.20	4.00	0.20	7.00		
0.30	8.25	0.31	10.25	0.30	12.50	0.29	7.75	0.30	11.00		
0.39	13.00	0.40	14.00	0.40	19.50	0.40	13.00	0.40	15.00		
0.50	18.00	0.50	20.50	0.50	24.00	0.50	18.25	0.50	23.00		
0.60	23.50			0.60	27.00	0.60	24.00	0.60	26.00		
0.70	26.00			0.70	29.25			0.70	29.00		
0.80	30.50			0.80	32.50			0.80	31.00		
0.90	33.00										
Test 38											
0.50	21.00	0.50	20.00	0.50	20.00	0.50	23.50	0.50	20.50		
0.60	24.50	0.60	24.50	0.60	24.50	0.60	26.50	0.60	24.50		
0.70	27.50	0.70	27.50	0.70	27.50	0.70	28.50	0.70	28.00		
0.80	30.50	0.80	30.50	0.80	30.75	0.80	33.00	0.80	30.50		
0.90	34.00	0.90	33.50	0.90	34.50	0.90	36.00	0.90	34.00		
1.00	38.00	1.00	37.00	1.00	37.50	1.00	39.00	1.00	37.75		
1.10	41.00	1.10	40.00	1.10	39.50	1.10	41.00	1.10	39.00		
1.20	42.50	1.20	42.25	1.20	42.00	1.20	42.50	1.20	41.00		
1.30	43.00	1.30	43.00	1.30	43.00	1.30	42.50	1.30	42.00		
1.40	44.00	1.40	43.50	1.40	44.00	1.40	44.50	1.40	44.00		

Table A4.gg

Primary Time-Displacement Data From Safety Reflector Drop-time Test 33 & 39

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00	0.10	1.00	0.10	3.25	0.10	2.50	0.10	2.25		
0.20	4.75	0.20	5.00	0.20	7.00	0.20	7.00	0.20	6.00		
0.30	7.00	0.30	10.00	0.30	10.25	0.30	9.75	0.30	12.00		
0.40	13.50	0.40	13.00	0.40	16.00	0.40	18.25	0.40	15.00		
0.50	18.00	0.50	17.50	0.50	22.00	0.50	20.00	0.50	21.00		
0.60	22.50	0.60	20.00	0.60	24.00	0.60	24.00	0.6	24.00		
0.70	27.75	0.70	24.00	0.70	27.75	0.70	26.50	0.70	29.00		
0.80	29.75	0.80	29.00	0.80	31.50	0.80	27.00	0.80	30.50		
0.90	33.00	0.90	32.50								
Test 39											
0.50	18.50	0.50	20.50	0.50	20.00	0.50	20.50				
0.60	23.50	0.60	24.75	0.60	23.00	0.60	23.00				
0.70	26.50	0.70	28.00	0.70	27.00	0.70	27.00				
0.80	29.50	0.80	30.75	0.80	31.00	0.80	30.75				
0.90	33.75	0.90	33.50	0.90	34.00	0.90	33.50				
1.00	37.25	1.00	37.00	1.00	37.00	1.00	37.25				
1.10	39.25	1.10	39.00	1.10	39.50	1.10	40.00				
1.20	41.25	1.20	40.75	1.20	41.75	1.20	41.00				
1.30	43.50	1.30	42.75	1.30	43.00	1.30	43.25				
1.40	44.25	1.40	43.25	1.40	44.00	1.40	44.25				

Table A4.hh

Primary Time-Displacement Data From Safety Reflector Drop-time Test 34 & 40

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.50	0.10	2.00	0.10	1.50	0.10	2.00	0.10	2.00		
0.20	6.00	0.20	7.00	0.20	5.50	0.20	6.00	0.20	6.50		
0.30	9.00	0.30	10.00	0.31	9.00	0.30	8.60	0.30	10.00		
0.40	14.00	0.40	13.00	0.40	13.00	0.40	14.00	0.40	14.00		
0.50	18.00	0.49	17.00	0.50	18.00	0.50	18.50	0.50	19.00		
0.60	21.75	0.60	22.00	0.60	22.25	0.60	22.00	0.60	24.00		
0.70	24.50	0.70	26.50	0.70	25.00	0.70	25.00	0.70	27.00		
0.80	30.50	0.80	30.00	0.80	29.00	0.80	30.00	0.80	31.00		
								0.90	33.00		
Test 40											
0.49	20.00	0.50	19.50	0.51	20.50						
0.60	25.00	0.60	24.50	0.60	24.50						
0.70	28.50	0.70	27.00	0.70	27.75						
0.80	31.50	0.80	31.00	0.79	30.50						
0.90	34.00	0.90	34.25	0.90	34.50						
1.00	37.50	0.99	36.50	1.00	37.00						
1.10	39.00	1.10	40.50	1.10	40.00						
1.19	40.50	1.20	42.25	1.21	41.50						
1.30	42.00	1.30	42.50	1.29	42.0						
1.40	43.5	1.39	43.50	1.40	43.5						

Table A4.ii

Primary Time-Displacement Data From Safety Reflector Drop-time Test 201

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.75	0.10	1.75	0.11	1.25	0.09	1.25	0.10	1.75		
0.19	2.00	0.19	3.50	0.20	2.75	0.20	2.75	0.20	2.25		
0.40	5.75	0.38	7.50	0.40	6.00	0.40	6.25	0.39	6.00		
0.59	8.75	0.59	9.75	0.60	8.25	0.60	8.75	0.60	9.00		
0.79	11.00	0.80	10.50	0.80	10.50	0.81	10.75	0.80	10.50		
1.00	13.75	1.00	13.75	1.00	13.25	1.00	13.75	1.00	13.25		
1.20	15.50	1.20	14.50	1.20	14.75	1.19	15.25	1.21	16.00		
1.40	18.00	1.40	18.00	1.40	16.50	1.39	17.75	1.41	17.50		
1.60	20.25	1.60	20.75	1.60	19.50	1.60	20.25	1.59	20.00		
1.80	22.25	1.80	21.75	1.80	21.50	1.80	21.50	1.80	20.75		
2.00	24.50	2.00	24.50	2.01	24.25	2.00	24.00	2.00	24.00		
2.21	25.25	2.18	25.00	2.19	25.00	2.21	25.50	2.20	26.00		
2.41	26.50	2.41	25.50	2.39	25.75	2.41	26.75	2.40	26.25		
2.59	28.25	2.61	28.25	2.60	28.25	2.59	28.00	2.59	28.25		
2.79	30.50	2.79	30.00	2.80	29.25	2.81	30.00	2.79	30.00		
3.00	32.00	3.00	31.00			3.00	31.00	3.00	30.50		
3.19	32.50	3.20	33.25			3.21	32.50	3.20	32.00		
3.40	33.00					3.40	33.25				
3.60	34.00										

Table A4 .ii(Continued)

Primary Time-Displacement Data From Safety Reflector Drop-time Test 201

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.01	16.00	1.00	14.00	1.00	16.00	1.00	16.00	1.10	16.00		
1.39	19.50	1.40	20.00	1.40	19.00	1.40	19.00	1.40	19.00		
1.80	24.00	1.81	24.00	1.81	24.00	1.80	25.00	1.80	25.00		
2.19	28.00	2.19	28.50	2.19	28.00	2.19	28.25	2.20	28.00		
2.60	31.50	2.60	31.00	2.60	31.00	2.60	30.5	2.60	30.00		
3.00	34.00	3.0	34.00	2.99	33.00	3.01	33.50	3.01	34.00		
3.39	36.00	3.41	36.00	3.39	35.75			4.00	39.00		
3.80	37.50	3.80	38.00	3.80	37.5			5.00	42.00		
4.00	38.00	4.00	38.50	4.00	38.00	4.00	38.00	5.50	43.00		
5.00	41.00	5.00	42.00	5.00	42.00	5.00	41.00				
6.00	43.50	5.50	43.00	6.00	43.50	6.00	43.50				
7.00	44.00										

Table A4.jj

Primary Time-Displacement Data From Safety Reflector Drop-time Test 202

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	1.25	0.09	1.50	0.09	1.25	0.08	1.00	0.09	1.75		
0.20	2.25	0.21	2.00	0.20	2.50	0.20	2.75	0.20	2.25		
0.40	5.75	0.41	6.00	0.40	4.75	0.40	5.75	0.40	7.25		
0.60	9.00	0.61	9.25	0.60	9.00	0.60	9.00	0.61	10.00		
0.81	11.00	0.79	11.00	0.80	10.50	0.81	10.50	0.79	10.75		
1.01	13.50	1.00	13.50	1.01	13.25	1.01	13.25	1.00	13.50		
1.19	15.00	1.20	15.50	1.19	14.25	1.19	14.75	1.20	17.00		
1.39	17.50	1.40	18.00	1.40	18.00	1.39	17.75	1.40	18.25		
1.60	19.75	1.60	20.00	1.60	20.25	1.60	19.75	1.61	20.25		
1.80	21.00	1.81	21.50	1.80	22.00	1.80	21.25	1.80	22.75		
2.01	23.75	2.01	24.50	2.01	24.25	2.01	24.25	2.00	24.50		
2.19	25.75	2.19	25.25	2.19	25.00	2.19	25.25	2.20	25.25		
2.40	25.75	2.39	26.00	2.39	25.75	2.39	25.50	2.40	27.25		
2.60	28.50	2.60	28.75	2.60	28.75	2.60	28.00	2.61	27.75		
2.80	29.75	2.80	30.00	2.80	29.25	2.80	29.50				
3.01	30.25	3.00	30.75	3.01	30.00	3.00	32.00				
3.16	32.00	3.13	32.75	3.22	32.00	3.19	33.25				
				3.39	32.50						

Table A4.11 (Continued)

Primary Time-Displacement Data From Safety Reflector Drop-time Test 205

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.01	15.00	1.00	15.00	0.99	15.50	1.00	15.00	1.00	12.25		
1.39	18.50	1.40	19.00	1.40	19.00	1.40	18.75	1.40	18.00		
1.81	22.75	1.80	24.00	1.79	24.50	1.79	24.50	1.80	21.25		
2.20	27.25	2.21	28.00	2.20	28.25	2.20	28.50	2.20	25.50		
2.60	29.75	2.60	31.00	2.60	30.75	2.60	30.25	2.60	28.50		
2.99	32.25			3.00	34.00	3.00	33.50	3.00	31.00		
4.00	38.00	4.00	38.25	4.00	38.50	4.00	38.50	3.97	36.50		
5.00	41.25	5.00	42.00	5.00	42.00	5.00	41.75				
5.50	43.00										
				6.00	43.75	6.00	43.75				

Table A4 . kk

Primary Time-Displacement Data From Safety Reflector Drop-time Test 203

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.09	1.25	0.09	1.25	0.09	0.75	0.09	1.25	0.09	1.50		
0.20	2.75	0.20	2.00	0.20	2.25	0.20	2.00	0.20	2.75		
0.41	6.00	0.40	5.00	0.40	6.00	0.40	6.00	0.40	6.50		
0.61	9.25	0.61	8.50	0.60	8.25	0.61	9.75	0.61	9.50		
0.79	10.25	0.81	10.50	0.78	10.25	0.79	10.75	0.79	10.75		
1.00	13.00	0.99	12.75	0.99	13.00	1.00	13.50	1.00	13.50		
1.21	14.50	1.20	14.50	1.20	14.25	1.20	15.00	1.20	15.50		
1.41	18.00	1.40	17.75	1.40	15.25	1.41	18.00	1.40	18.00		
1.59	19.25	1.60	19.50	1.60	19.25	1.59	20.25	1.61	20.25		
1.80	21.25	1.80	20.25	1.81	20.00	1.80	21.00	1.79	21.25		
2.00	24.00	1.99	24.00	1.99	24.00	2.00	24.50	2.00	24.50		
2.21	25.25	2.20	24.75	2.19	25.25	2.20	25.50	2.20	25.25		
2.39	25.50	2.40	25.00	2.40	25.25	2.41	26.50	2.40	26.50		
2.59	28.25	2.60	28.00	2.60	25.50	2.59	29.00	2.59	29.25		
2.80	29.50	2.80	29.25	2.81	30.00	2.80	30.25	2.80	30.25		
		2.99	32.00	2.99	30.25	3.00	32.00	3.00	32.00		
				3.20	32.25	3.19	34.25	3.18	33.25		

Table A4.kk (Continued)

Primary Time-Displacement Data From Safety Reflector Drop-time Test 206

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.99	14.00	1.00	14.00	1.00	14.50	1.01	15.00	1.00	15.25		
1.40	18.00	1.41	18.00	1.40	18.00	1.40	18.50	1.39	18.50		
1.80	24.00	1.80	23.50	1.80	23.00	1.79	24.00	1.81	24.00		
2.20	27.25	2.20	27.00	2.19	26.50	2.20	27.50	2.21	27.25		
2.59	29.25	2.61	30.00	2.60	28.75	2.59	29.50	2.59	30.25		
3.01	32.50	3.00	32.50	3.00	32.50	3.00	33.00	3.01	33.00		
3.49	35.75	3.51	35.50	3.50	35.50	3.51	36.00	3.48	36.00		
4.00	38.00	4.00	37.75	4.01	37.75	4.00	37.25	4.00	37.00		
4.51	39.50	4.50	39.25	4.49	39.50	4.50	39.25	4.51	39.50		
5.00	41.00	5.00	41.00	4.91	41.00			4.99	41.25		
5.51	42.25										
6.00	43.00										

Table A4.ll

Primary Time-Displacement Data From Safety Reflector Drop-time Test 301 & 304

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.25	0.10	1.25	0.10	1.00	0.10	0.75	0.10	1.00		
		0.20	4.00	0.20	2.75	0.20	3.50	0.20	3.25		
0.30	9.75	0.30	8.50	0.30	8.00	0.30	9.50	0.30	8.25		
0.40	15.50	0.40	14.25	0.40	14.50	0.40	14.50	0.40	15.00		
0.50	22.75	0.50	20.50	0.50	20.25	0.50	21.00	0.50	19.25		
0.70	28.25	0.70	27.00	0.70	26.75	0.70	26.25	0.70	26.75		
0.90	35.00	0.90	33.25	0.90	33.50	0.90	34.25	0.87	33.00		
					Test 304						
0.30	12.75	0.30	9.75	0.30	10.00	0.30	10.50	0.30			
0.40	18.60	0.40	14.50	0.40	15.75	0.40	17.00	0.40	14.00		
0.51	21.50	0.50	20.25	0.50	20.00	0.49	20.50	0.50	19.75		
0.70	30.50	0.70	27.25	0.69	28.50	0.70	28.00	0.70	27.75		
0.90	36.50	0.90	34.25	0.90	36.00	0.90	35.75	0.90	35.00		
1.10	41.50	1.10	40.50	1.10	39.50	1.10	40.50	1.10	40.25		
1.30	44.25	1.30	43.25	1.30	43.25	1.30	43.75	1.29	43.50		
1.39	44.50	1.50	45.25	1.50	44.50	1.49	45.75	1.40	44.50		
				1.70	45.25						

Table A4 .mm

Primary Time-Displacement Data From Safety Reflector Drop-time Test 302 & 305

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.75	0.10	1.50			0.10	1.00				
0.20	3.00	0.20	4.25	0.20	2.00	0.20	5.00	0.20	3.00		
0.30	8.50	0.30	10.25	0.30	7.00	0.30	10.50	0.30	9.00		
0.40	14.50	0.40	15.50	0.40	13.25	0.40	15.75	0.40	15.25		
0.50	19.75	0.50	19.50	0.50	18.75	0.50	21.00	0.50	20.00		
0.70	26.50	0.70	28.00	0.70	24.75	0.70	26.00	0.70	27.50		
0.90	33.50	0.90	34.25			0.90	35.00				
Test 305											
0.40	15.00	0.40	17.25	0.40	17.00	0.40	15.00	0.40	17.00		
0.50	19.25	0.49	22.25	0.51	21.75	0.50	20.00	0.50	22.00		
0.70	27.25	0.70	30.00	0.70	29.50	0.70	27.75	0.71	30.00		
0.90	34.50	0.90	36.50	0.90	36.00	0.90	35.00	0.90	36.50		
1.10	39.50	1.10	41.00	1.10	41.00	1.10	40.00	1.10	40.25		
1.30	43.25	1.30	44.50	1.31	44.50	1.30	43.00				
1.49	44.50			1.50	45.75	1.40	44.50				

Table A4 .nn

Primary Time-Displacement Data From Safety Reflector Drop-time Test 303 & 306

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	1.00							0.10	0.75		
0.21	5.50	0.20	3.25	0.20	2.75	0.20	3.75	0.20	4.00		
0.30	10.25	0.30	8.00	0.30	6.50	0.30	9.50	0.30	9.75		
0.40	15.50	0.40	14.75	0.40	14.00	0.40	15.25	0.40	15.50		
0.50	19.50	0.50	19.00	0.50	18.00	0.50	20.25	0.50	19.75		
0.70	27.75	0.70	26.00	0.70	27.00	0.71	27.75	0.70	26.75		
0.80	31.25	0.80	30.50	0.89	33.00	0.90	33.75	0.90	34.25		
Test 306											
0.29		0.30	11.75	0.31	12.00	0.30	12.25	0.30	15.50		
0.39	15.25	0.40	15.50	0.39	16.25	0.40	15.75	0.40	21.00		
0.49	21.00	0.50	21.50	0.50	22.25	0.50	21.75	0.50	24.75		
0.70	28.00	0.70	28.50	0.70	28.50	0.70	28.50	0.69	32.00		
0.90	35.00	0.90	35.25	0.90	36.00	0.90	36.00	0.90	38.00		
1.10	40.25	1.10	41.00	1.10	40.75	1.09	40.50	1.10	42.50		
1.30	43.75	1.30	44.50	1.30	44.50	1.29	44.25	1.30	45.50		
1.50	45.50	1.40	45.50	1.50	46.00	1.50	36.25	1.50	47.25		
1.70	46.00										

Table A4 .00

Primary Time-Displacement Data From Safety Reflector Drop-time Test 307-310

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	4.00	0.10	4.00	0.10	2.50	0.10	2.50	0.10	4.00		
0.20	8.00	0.20	6.75	0.20	6.00	0.20	6.00	0.20	7.00		
0.30	12.00	0.30	11.00	0.31	10.00	0.29	12.00	0.30	12.00		
0.40	16.00	0.40	14.50	0.41	16.00	0.40	16.00	0.40	16.00		
0.50	22.00	0.50	21.00	0.49	21.00	0.50	21.00	0.50	21.00		
0.70	29.00	0.69	25.75	0.70	28.00	0.70	27.00	0.70	30.00		
					Test 310						
		0.20	12.00								
0.30	14.00	0.30	16.00	0.30	15.00	0.30	13.00	0.30	12.00		
0.40	16.00	0.40	20.00	0.40	19.50	0.40	17.00	0.40	17.00		
0.49	22.00	0.50	26.00	0.49	24.00	0.50	23.00	0.50	22.00		
0.70	31.00	0.71	32.00	0.70	34.00	0.70	33.00	0.70	30.00		
0.90	36.00	0.90	37.00	0.90	38.00	0.90	36.00	0.90	36.00		
1.09	40.00	1.10	41.00	1.11	41.00	1.10	40.00	1.10	41.00		
		1.31	43.00	1.31	43.00	1.30	43.00	1.29	42.00		
		1.49	43.50	1.50	43.50	1.50	43.50	1.50	43.50		

Table A4.pp

Primary Time-Displacement Data From Safety Reflector Drop-time Test 308-311

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0.10	3.00	0.10	2.00	0.10	2.00	0.10	4.00		
		0.20	7.00	0.20	6.00	0.20	5.50	0.21	8.00		
		0.30	11.00	0.30	10.00	0.30	10.00	0.30	12.00		
		0.41	16.00	0.40	15.00	0.40	15.00	0.39	16.00		
		0.49	18.00	0.50	22.00	0.50	21.00	0.50	22.00		
		0.70	25.00	0.70	30.00	0.70	27.00	0.70	27.00		
		0.90	34.00	0.90	34.00	0.90	33.00	0.80	32.00		
					Test 311						
0.30	13.00	0.29	15.00	0.30	13.00						
0.41	18.00	0.40	18.00	0.40	19.00	0.40	19.00	0.40	16.00		
0.50	22.00	0.50	23.00	0.49	24.00	0.50	22.00	0.50	22.00		
0.70	30.00	0.70	33.00	0.70	31.00	0.70	30.00	0.70	32.00		
0.90	36.00	0.90	36.50	0.90	36.50	0.90	36.00	0.90	36.00		
1.10	40.00	1.10	41.00	1.09	40.00	1.10	41.00	1.10	41.00		
1.30	42.00	1.30	44.00	1.30	42.00	1.30	44.00	1.31	44.00		
1.50	44.00	1.50	45.50	1.50	44.00	1.50	44.00	1.51	46.00		

Table A4 .qq

Primary Time-Displacement Data From Safety Reflector Drop-time Test 309-312

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	3.50	0.10	3.00	0.10	2.00	0.10	3.00	0.10	4.00		
0.19	7.50	0.20	7.00	0.20	6.00	0.20	7.00	0.20	7.00		
0.29	12.00	0.30	12.00	0.30	10.00	0.30	11.00	0.30	12.00		
0.40	18.00	0.40	17.00	0.40	16.00	0.40	17.00	0.41	17.00		
0.50	23.00	0.50	23.00	0.50	21.00	0.50	22.00	0.50	22.00		
0.70	28.00	0.70	29.00	0.70	29.00	0.70	31.00	0.70	30.00		
0.80	32.00			0.90	34.00			0.80	33.00		
					Test 312						
0.40	18.00	0.40	17.00	0.40	18.00	0.40	15.00	0.40	16.00		
0.49	22.00	0.50	21.00	00.50	23.00	0.50	22.00	0.50	22.00		
0.70	30.00	0.70	30.00	0.70	31.00	0.70	30.00	0.71	30.00		
0.90	36.00	0.90	36.00	0.90	36.00	0.90	36.00	0.89	35.00		
1.09	42.00	1.09	42.00	1.10	42.00	1.10	41.00	1.10	41.00		
1.30	44.00	1.30	44.00	1.31	44.50	1.30	44.00	1.30	44.00		
1.50	45.00	1.50	46.00	1.49	46.00	1.50	46.00	1.50	46.00		

Table A4 .rr

Primary Time-Displacement Data From Safety Reflector Drop-time Test 401-404

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.00	0.10	4.50	0.10	2.75	0.10	3.50	0.10	4.00		
0.20	5.50	0.20	9.00	0.20	6.25	0.20	8.00	0.20	9.25		
0.30	10.25	0.30	15.00	0.29	10.75	0.30	13.00	0.30	14.00		
0.39	15.75	0.40	22.25	0.39	16.25	0.40	18.75	0.40	20.25		
0.50	23.75	0.50	25.25	0.50	22.25	0.50	25.50	0.50	27.00		
0.60	28.50	0.60	29.25	0.60	27.75	0.60	29.25				
0.70	31.50	0.70	33.75	0.70	31.75	0.70	33.00	0.70	35.00		
					Test 404						
0.29	13.75	0.29	13.50	0.30	13.50	0.30	15.00	0.30	13.25		
0.39	19.75	0.39	18.50	0.40	18.00	0.40	21.00	0.40	17.50		
0.51	25.75	0.50	24.00	0.50	24.25	0.50	25.75	0.50	23.75		
0.60	28.25	0.60	28.75	0.60	28.75	0.60	28.25	0.60	28.50		
0.70	32.75	0.70	32.75	0.70	32.00	0.70	33.25	0.70	31.50		
0.80	36.50	0.80	36.00	0.80	36.00	0.80	37.00	0.80	35.50		
0.90	39.00	0.90	39.50	0.90	37.50	0.90	38.50	0.90	38.25		
1.00	40.25	1.00	40.75	0.99	39.00	1.00	39.75	1.00	39.00		
1.10	40.75	1.10	41.50	1.10	40.75	1.10	41.25	1.10	41.00		
1.20	42.75	1.20	42.75	1.20	42.00	1.19	42.50	1.20	41.75		
1.30	43.75	1.30	43.00	1.30	43.75	1.29	43.25	1.30	43.50		
1.40	44.25	1.40	43.75	1.40	43.75	1.39	44.25	1.40	44.25		
1.50	45.50	1.50	45.00	1.50	45.00	1.50	45.75	1.50	44.75		
		1.60	45.50	1.60	46.00	1.60	46.50	1.60	45.75		
				1.70	46.75	1.70	46.50	1.70	46.75		

Table A4 .ss

Primary Time-Displacement Data From Safety Reflector Drop-time Test 402-405

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	3.25	0.10	4.25	0.10	2.50	0.10	3.00	0.10	2.25		
0.20	7.25	0.20	9.50	0.20	6.25	0.20	7.00	0.20	6.00		
0.30	12.25	0.29	14.00	0.30	11.75	0.30	12.00	0.30	10.50		
0.40	17.00	0.40	21.00	0.40	15.50	0.40	16.75	0.40	15.75		
0.50	24.00	0.50	26.75	0.50	23.50	0.50	24.00	0.50	22.00		
0.60	29.25	0.60	30.25	0.60	27.00	0.60	27.50	0.60	27.00		
0.70	32.00	0.70	33.75	0.70	30.75	0.70	30.75	0.70	30.00		
					Test 405						
0.30	12.00	0.30	14.25	0.30	14.75	0.30	13.00	0.30	15.75		
0.40	18.00	0.40	20.25	0.40	20.50	0.40	17.00	0.40	22.25		
0.50	23.25	0.50	26.00	0.50	26.25	0.50	24.00	0.50	27.50		
0.60	27.25	0.60	29.00	0.60	30.25	0.60	29.25	0.60	31.00		
0.70	31.25	0.70	34.00	0.70	33.50	0.70	32.00	0.70	34.75		
0.80	35.50	0.80	36.75	0.80	36.50	0.80	35.50	0.80	37.25		
0.90	38.00	0.90	39.25	0.90	39.00	0.91	38.25	0.90	39.50		
1.00	39.25	1.00	40.00	1.00	40.75	1.00	39.75	1.00	40.50		
1.09	39.75	1.10	42.25	1.10	42.00	1.10	41.50	1.10	41.50		
1.19	41.50	1.20	43.00	1.20	43.25	1.20	42.25	1.20	42.00		
1.29	43.00	1.30	44.50	1.30	44.25	1.30	44.00				
1.40	44.00	1.40	45.25	1.40	45.00	1.40	44.25				
1.50	44.75	1.50	46.75	1.50	45.75	1.50	45.50				
1.60	45.00			1.60	46.25	1.60	46.50				
1.70	46.50			1.70	46.50	1.70	47.00				

Table A4 .tt

Primary Time-Displacement Data From Safety Reflector Drop-time Test 403-406

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.25	0.10	4.75	0.10	2.75	0.10	2.00	0.10	3.00		
0.20	6.00	0.20	9.50	0.19	6.25	0.19	6.00	0.20	7.75		
0.30	10.50	0.30	14.50	0.29	11.25	0.29	10.25	0.30	12.00		
0.40	15.75	0.40	20.50	0.39	16.00	0.40	15.50	0.40	18.00		
0.50	22.75	0.50	25.00	0.49	22.00	0.49	21.75	0.50	24.00		
0.60	26.75	0.60	28.00	0.60	26.50	0.60	26.25	0.60	28.25		
0.70	30.00	0.70	33.00	0.70	30.00	0.69	30.50	0.70	30.50		
0.80	33.75			0.80	34.25						
					Test 406						
0.30	14.25	0.30	14.25	0.30	14.50	0.30	14.50	0.30	14.25		
0.40	19.75	0.40	18.00	0.40	20.00	0.40	20.50	0.40	19.25		
0.50	25.00	0.50	24.50	0.50	25.75	0.50	26.00	0.50	25.00		
0.60	30.50	0.60	30.25	0.60	30.00	0.60	30.00	0.60	30.00		
0.70	32.75	0.69	32.25	0.70	33.25	0.70	32.50	0.70	32.75		
0.80	35.50	0.80	35.25	0.80	36.50	0.80	36.00	0.80	37.00		
0.90	38.75	0.90	39.00	0.90	38.50	0.90	37.75	0.90	38.75		
1.00	38.75	1.00	40.75	1.00	39.75	1.00	38.75	1.00	40.00		
1.10	41.00	1.10	41.00	1.10	41.00	1.10	39.00	1.10	40.25		
1.20	42.75	1.20	42.00	1.20	42.25	1.20	40.75	1.20	41.00		
		1.29	43.00	1.30	43.25	1.30	42.00	1.30	42.50		
				1.40	44.50	1.40	43.00	1.40	43.25	1.40	43.25
				1.50	45.75	1.50	44.25				
				1.60	46.25						

Table A4.uu

Primary Time-Displacement Data From Safety Reflector Drop-time Test 407

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.75	0.10	2.25	0.10	3.00	0.10	3.50	0.10	2.50		
0.20	7.50	0.20	6.25	0.20	7.75	0.20	8.50	0.20	7.25		
0.30	12.25	0.30	11.00	0.30	12.75	0.30	13.50	0.30	12.50		
0.40	18.25	0.40	16.50	0.40	19.50	0.39	19.25	0.40	17.00		
0.50	24.00	0.50	23.00	0.50	24.50	0.49	25.00	0.50	23.75		
0.60	26.75	0.60	26.50	0.60	27.75	0.60	28.50	0.60	26.25		
0.71	32.50	0.70	30.00	0.70	32.75	0.70	33.25	0.70	31.75		

Test 410

No data obtained from this test

Table A4 .VV

Primary Time-Displacement Data From Safety Reflector Drop-time Test 408

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.50	0.10	2.75	0.11	3.50	0.10	5.00	0.10	3.25		
0.19	6.25	0.20	7.00	0.19	7.00	0.21	9.50	0.20	7.25		
0.29	11.50	0.30	11.75	0.31	12.00	0.31	14.25	0.30	12.00		
0.40	17.25	0.40	16.75	0.40	16.50	0.39	20.25	0.40	18.00		
0.50	23.00	0.50	24.25	0.50	24.00	0.50	25.75	0.50	25.25		
0.60	27.50	0.60	27.25	0.60	26.75	0.60	29.25	0.60	26.50		
0.70	30.75	0.70	32.00	0.70	32.50	0.70	33.50	0.70	32.25		
				0.80	34.25						

Test 411

No Data Obtained from this Test

Table A4 .ww

Primary Time-Displacement Data From Safety Reflector Drop-time Test 409

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	2.00	0.10	2.00	0.10	2.00	0.09	3.00	0.10	2.25		
0.20	6.00	0.20	6.25	0.19	5.75	0.20	7.00	0.20	6.25		
0.30	9.75	0.30	10.50	0.30	10.00	0.31	12.50	0.30	9.75		
0.40	15.75	0.40	16.50	0.40	15.50	0.39	18.00	0.39	14.75		
0.50	22.50	0.50	24.00	0.50	21.75	0.50	24.50	0.49	21.50		
0.60	26.50	0.60	26.25	0.60	26.75	0.60	29.00	0.60	25.50		
		0.70	32.00	0.70	30.00	0.70	32.25	0.70	32.25		
		0.80	34.25	0.80	34.25			0.80	34.25		

Test 412

No Data Obtained from this Test

Table A4.xx

Primary Time-Displacement Data From Safety Reflector Drop-time Test 413 thru 415

RUN-1		RUN-2		RUN-3		RUN-4		RUN-5		RUN-6	
TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)	TIME (sec)	DIST. (in)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

No data Obtained from These Tests

APPENDIX 5.0

"AVERAGED" TIME-DISPLACEMENT DATA

This appendix presents all the "averaged" time-displacement data generated from the polynomial fits to the primary time-displacement data presented in Appendix 4.0. These data are presented in a format considered most useful in analysis. Some of the data in the following tables is a hand fit to the data spread in the regions, principally near the beginning or end of a run, where the polynomial was a poor fit.

Table A5.a

"Averaged" Time-Displacement Data for Safety Reflector Drop Time Tests 1 thru 19 and 201 thru 206

Time, Seconds

Test No.	0.05	0.15	0.3	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.5	5.5	6.5
	Displacement, Inches												
1	0.89	2.19	4.11	6.59	12.33	17.35	21.60	25.10	27.94	30.24	34.07		
2	No Data Available from This Test												
3	0.62	1.94	3.87	6.34	12.02	17.02	21.34	25.03	28.11	30.62	34.07		
4	0.78	2.03	3.82	6.07	11.13	15.55	19.48	22.99	26.10	28.73			
5	1.00	2.33	4.25	6.70	12.23	17.02	21.15	24.71	27.83	30.64			
6	1.14	2.51	4.46	6.92	12.38	17.00	20.95	24.40	27.54	30.56			
7	1.10	2.46	4.39	6.80	12.16	16.77	20.83	24.45	27.64	30.33			
8	1.06	2.38	4.27	6.65	11.99	16.62	20.67	24.18	27.16	29.50			
9	1.14	2.48	4.36	6.69	11.78	16.20	20.16	23.69	26.56	28.34			
10	1.02	2.41	4.37	6.79	12.07	16.57	20.55	24.11	27.19	29.60			
11	0.69	2.00	3.88	6.24	11.57	16.22	20.34	24.03	27.35	30.31	34.95		
12	1.38	2.65	4.45	6.68	11.64	16.02	20.06	23.88	27.39	30.37			
13	1.23	2.53	4.38	6.68	11.71	16.07	20.02	23.67	26.99	29.77			
14	1.14	2.41	4.25	6.56	11.74	16.20	20.14	23.70	27.05	30.32			
15	0.73	2.29	4.47	7.12	12.84	17.74	22.17	26.17	29.26	30.92			
16	1.11	2.50	4.51	7.08	12.97	18.17	22.70	26.54	29.60	31.77			
17	1.07	2.50	4.57	7.24	13.33	18.57	22.95	26.52	29.38	31.70			
18	1.19	2.62	4.71	7.39	13.49	18.68	22.94	26.35	29.07	31.36			
19	0.74	2.12	4.06	6.48	11.79	16.39	20.56	24.47	28.11	31.38			
201-204	0.78	2.31	4.53	7.35	13.76	19.35	24.20	28.39	31.99	35.06	39.77	42.74	44.00
202-205	0.51	2.13	4.45	7.35	13.77	19.18	23.82	27.84	31.39	34.53	39.70		
203-206	0.68	2.15	4.30	7.05	13.37	18.96	23.87	28.16	31.85	34.99	39.67		

Table A5.b

"Averaged" Time-Displacement Data for Safety Reflector Drop Time Tests 20 thru 40 and 301 thru 312

Test No.	Time, Seconds: 0.05	0.15	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6
	Displacement, Inches											
20	0.45	2.30	9.16	14.50	19.54	23.87	27.38	30.29				
21	0.45	3.19	10.07	15.28	20.27	24.69	28.38	31.41	34.07			
22	0.70	3.10	9.99	15.21	20.48	24.60	28.40	31.39				
23	0.30	2.30	8.56	13.78	18.71	22.91	26.24	28.87	34.16			
24-35	0.32	2.50	7.70	13.51	18.14	22.75	27.16	31.25	38.07	42.84	45.70	
*25-36	0.40	2.67	9.43	14.32	18.94	23.12	26.91	30.43	37.16	43.11	45.50	
26-37	0.50	2.80	9.44	13.87	18.41	22.87	27.10	30.97	37.37	41.89	44.97	
27	0.40	2.30	8.02	13.36	18.54	23.03	26.59	29.24				
28	0.30	2.00	7.42	12.28	16.97	21.06	24.42	27.18				
29	0.25	3.01	10.48	15.95	20.92	25.01	28.21	30.83				
30	0.40	2.63	8.80	13.52	18.11	22.29	26.00	29.37	36.75			
31	0.66	3.74	10.70	15.63	20.19	24.16	27.67	31.08				
*32-38	0.71	3.65	10.25	15.29	20.23	24.69	28.50	31.69	37.90	41.80	43.90	
*33-39	1.00	4.10	10.15	14.70	19.24	23.46	27.19	30.44	36.90	41.40	43.64	
*34-40	1.05	3.90	9.51	13.94	18.52	22.92	26.90	30.39	36.90	41.43	43.50	
301-304	0.25	2.10	9.88	15.60	20.40	24.60	28.06	31.93	38.12	42.10	44.23	
302-305	0.70	2.80	9.74	14.58	19.50	24.22	28.54	32.33	38.08	41.68	44.36	
*303-306	0.40	2.00	10.23	16.04	20.95	24.93	28.30	31.42	37.81	43.60	45.93	
307-310	1.64	5.63	12.46	17.21	21.87	26.25	30.22	33.68	38.88	41.83	43.16	
308-311	1.41	5.33	12.04	16.70	21.26	25.57	29.49	32.94	38.27	41.68	43.85	46.16
309-312	1.47	5.35	12.06	16.76	21.38	25.77	29.80	33.37	38.98	42.62	44.94	

* These data were fitted with a 6th order polynomial

Table A5.c

"Averaged" Time-Displacement Data for Safety Reflector Drop Time Tests 401 thru 409

Test No.	Time, Seconds 0.05	0.15	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6
	Displacement, Inches											
401-404	1.36	5.98	13.72	18.95	23.96	28.54	32.54	35.89	40.20	42.40	44.25	45.80
402-405	1.40	5.70	13.38	18.65	23.73	28.40	32.51	35.97	40.40	42.60	44.50	46.10
403-406	1.24	5.47	13.14	18.50	23.65	28.33	32.36	35.62	39.85	41.90	43.90	46.30
407	1.30	4.82	12.83	18.33	23.34	27.75	31.81					
408	1.40	5.14	12.59	18.08	23.45	28.23	31.99					
409	0.93	3.96	10.93	16.47	22.13	27.34	31.56	34.19				

APPENDIX 6.0

SUITABILITY OF EDUCTOR SYSTEM FOR RAISING WATER LEVEL

The water jet eductor, used to raise the water level in the safety reflector column, has operated perfectly in all the safety reflector drop tests conducted since the reflector model was put in operation. Although a total of only 75 reflector drop tests (5 water drops, each) are reported herein, the water was raised and dropped, conservatively, a total of at least 500 times. No attempt was made to keep a record of the total number of times the water was raised in the safety reflector column.

The time required to raise the water from its equilibrium level in the drop tank until the safety reflector and the portion of the shim reflector above the weir between the safety and shim reflectors were full was 10 minutes or an air-removal rate of approximately 0.39 ft^3/min. During the safety reflector drop tests, time was conserved by closing the scram solenoid so as to prevent the water from dropping all the way to its equilibrium position in the drop tank. In this way, it was possible to raise the water in about 6 to 8 minutes.

About the middle of August it was noted that the time required to raise the water in the safety reflector had suddently increased to between 15 and 20 minutes. When the water jet eductor was removed, a piece of rubber cement (used to complete the seal joint between the plexiglas faces of the model and the main aluminum structure) was partially clogging the jet nozzle of the eductor. This rubber cement was removed and, when the eductor was replaced in the system, it was again possible to raise the water in 10 minutes. While it was removed, the water jet eductor was thoroughly inspected otherwise, and no visible signs of wear or corrosion were noted.

Therefore, although no specific data to this effect was obtained, it is felt that this operating experience has proved that a water jet eductor is entirely reliable and adequate in the service of raising the water level in the safety reflector. Since the reflector model system used did not utilize the water jet eductor for the purpose of providing circulation in the primary system, no conclusions as to its usefulness in this respect are warranted. However, extrapolating the eductor's reliability, in the service which it did perform to circulation in the primary system, it may be concluded that it would be equally reliable, and adequate, in this service.

A second water jet eductor, exactly the same size and model as the one used to raise the water in the safety reflector, was used to inject boric acid (or dye) solution into the circulating water of the primary system. The adequacy and reliability of this eductor for the service it performed were also excellent. The maximum rate at which it would transfer solution, however, was a functior of the differential pressure developed across the valve used to control the circulation rate in the primary system. Therefore, when water was being circulated in the primary system at 120 gpm, the maximum boric acid injection rate obtainable was only about 3 gpm whereas, with a circulation rate of 80 gpm, the maximum injection rate obtainable was about 5 gpm. If the circulation rate control valve were shut off entirely, boric acid could be injected into the system at about 10.5 gpm.

APPENDIX 7.0

LITERATURE SURVEYS AND INVESTIGATION OF ALTERNATE NEUTRON ABSORBERS

As part of the study of chemical poisons, alternate methods of analyzing for boric acid and alternate neutron absorbers were investigated. The majority of this work consisted of a literature search.

A7.1 Analysis of Boric Acid - Literature Survey

A brief literature search was made in an effort to find alternate methods of boric acid analysis. Two types of analytical methods were desired - methods applicable to in-line use and methods applicable to laboratory use. The first two methods reviewed below are suitable for in-line use. The others are laboratory methods.

A7.1.1 Neutron Absorption

The ability to absorb neutrons is the property of boric acid, or any other chemical which is used as a soluble poison, that is of major interest. The possible use of neutron absorption to determine boron in boric acid solutions by other workers was investigated. Work at both Westinghouse[2] and at Phillips Petroleum[18] indicate that neutron absorption may be used successfully to measure boric acid.

The instrument developed by Phillips Petroleum for use in the CPP was designed to measure the thermal neutrons produced by a nearby fast neutron source. The fast neutrons are thermalized by water and a portion of these thermal neutrons which are not absorbed by the boron are reflected back to the detector. Basically this instrument consisted of a polonium - beryllium source surrounding a boron trifluoride counting tube. For the CPP instrument, a source of approximately 50 millicuries of polonium and a Nancy Wood 30 cm boron trifluoride counter tube were used. Standard electronic equipment was used with this counter tube. This instrument, excluding the neutron source, was made in less than one month and cost less than $4,000.

Westinghouse developed an instrument for use with chemical control of the PWR. This instrument consisted of a polonium-beryllium neutron source located at the central axis of a pipe and a boron trifluoride counter located just outside the pipe. Pipe diameters of 4, 6, 8, 10, and 12 inches were investigated.

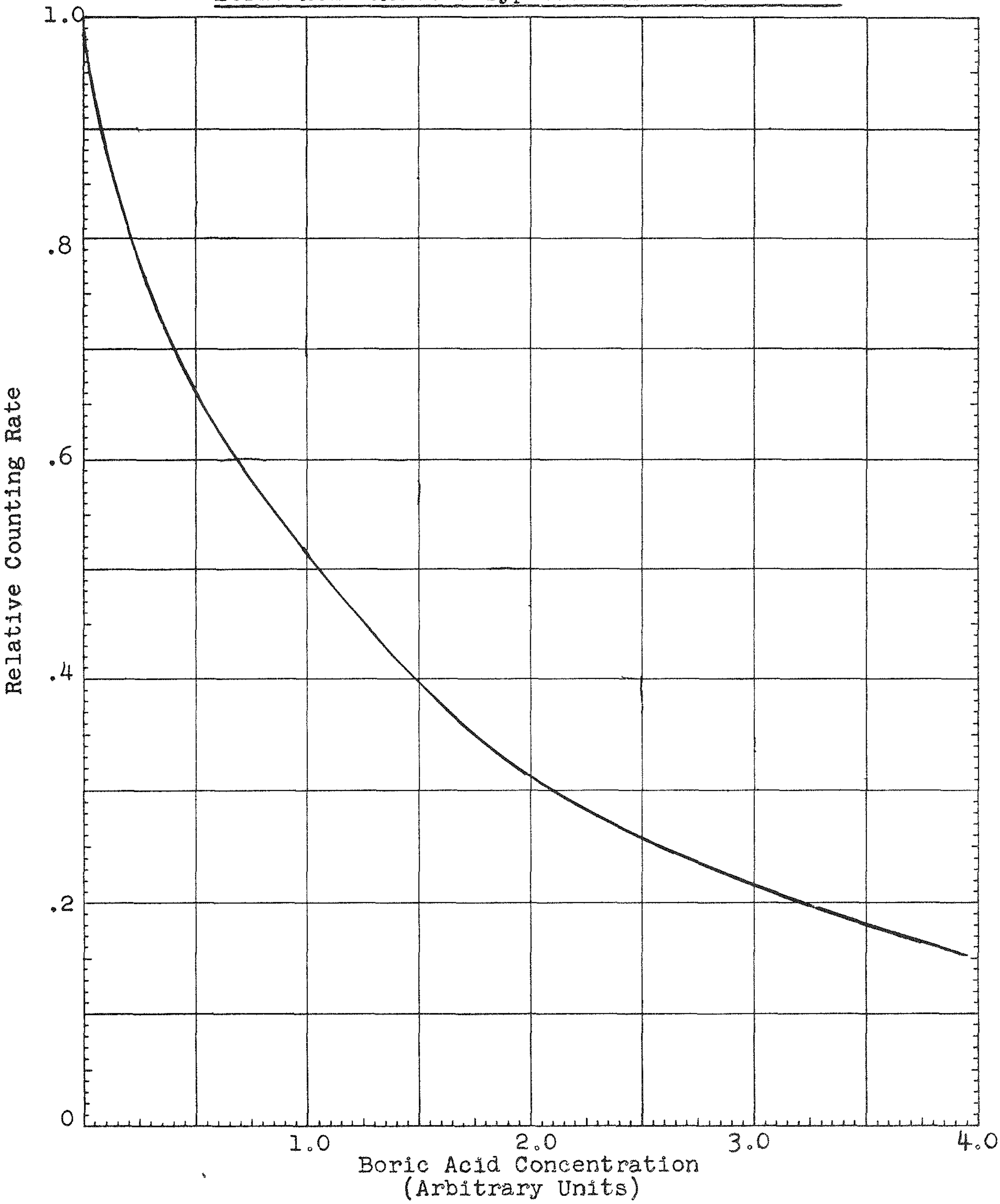
The only basic difference between the Westinghouse and the Phillips Petroleum instruments was in the location of the source relative to the counter. The difference is due to the somewhat different environments in which each was used. The Phillips instrument was designed to be placed next to or into a tank while the Westinghouse instrument was designed for use with pipes. These differences in geometries made large differences in the counting rates and source size requirements. Westinghouse estimates that a 10 to 15 curie polonium source and a number of counter tubes are required while Phillips apparently achieved satisfactory results with a source of about 50 millicuries.

The sensitivity of the neutron absorption instruments was greatest at low concentrations of boric acid. The sensitivity then decreased until a point was reached where no change occurs in the count rate with change in boric acid concentration. At this point none of the fast neutrons emitted reached the detector as they were all absorbed by the boron. A typical calibration curve is shown in Figure A7.A.

Another instrument which uses the neutron absorption principle for boron measurement is marketed by the Mine Safety Appliances Co.[19] This instrument, designed for proces monitoring of boron base fuels, uses a radium-beryllium neutron source. The neutrons are thermalized by a paraffin moderator and then passed through the monitored stream. The unabsorbed neutrons are monitored by a boron trifluoride counter, this count being converted into a boron concentration. This instrument is available on 90 to 120 day delivery and costs $12,000.

Figure A7.A

Boric Acid Monitor Typical Calibration Curve(318)



A7.1.2 pH

As boric acid is a weak acid, the possibility of measuring boric acid by pH was investigated. No references to this type of measurement for boric acid could be found in the literature. The pH of boric acid is shown in Figure A7.B. For concentrated solutions, the change of pH per unit change in concentration is quite small. For dilute solutions, the change in pH is quite large. Thus, in the absence of any other sources of hydrogen ions, pH would be suitable for measurement of boric acid concentrations below about 15 grams per liter. Above this concentration, pH would give a close estimate of the concentration.

A7.1.3 Titration

A number of references described titration methods which had been used successfully for boron or boric acid analysis. Most of these methods recommended adding ion exchange resin to remove interfering ions then add mannitol or glycerine and titrate with hydroxide to a bromothymol blue end point.[10,11]

A method of removing interfering acids[15] is to add calcium or barium carbonates in excess, filter, boil off the CO_2, then titrate with NaOH below 15°C. The titration is made potentiometrically. This report states that the titration of boric acid is impossible in the presence of $A\ell^{+3}$, Cr^{+3}, Cu^{+2}, and Fe^{+2} ions but is possible in the presence of Fe^{+3}, Ni^{+2}, Co^{+2}, Zn^{+2}, Cd^{+2}, Hg^{+2}, Mn^{+2}, and Mg^{+2}. Another report[16] presents a method of determining boric acid in the presence of interfering lead, zinc, aluminum, manganese, and iron ions. This method uses the complexon $[CH_2N(CH_2CO_2H)_2]_2$ to bind the interfering cations.

An unsuccessful method which was reported[13] involved neutralization titration with high frequency volumetric apparatus. The method was not successful as the dissociation constant for the first hydrogen was less than 10^{-9}. For the same reason, a polarographic determination[17] was unsuccessful.

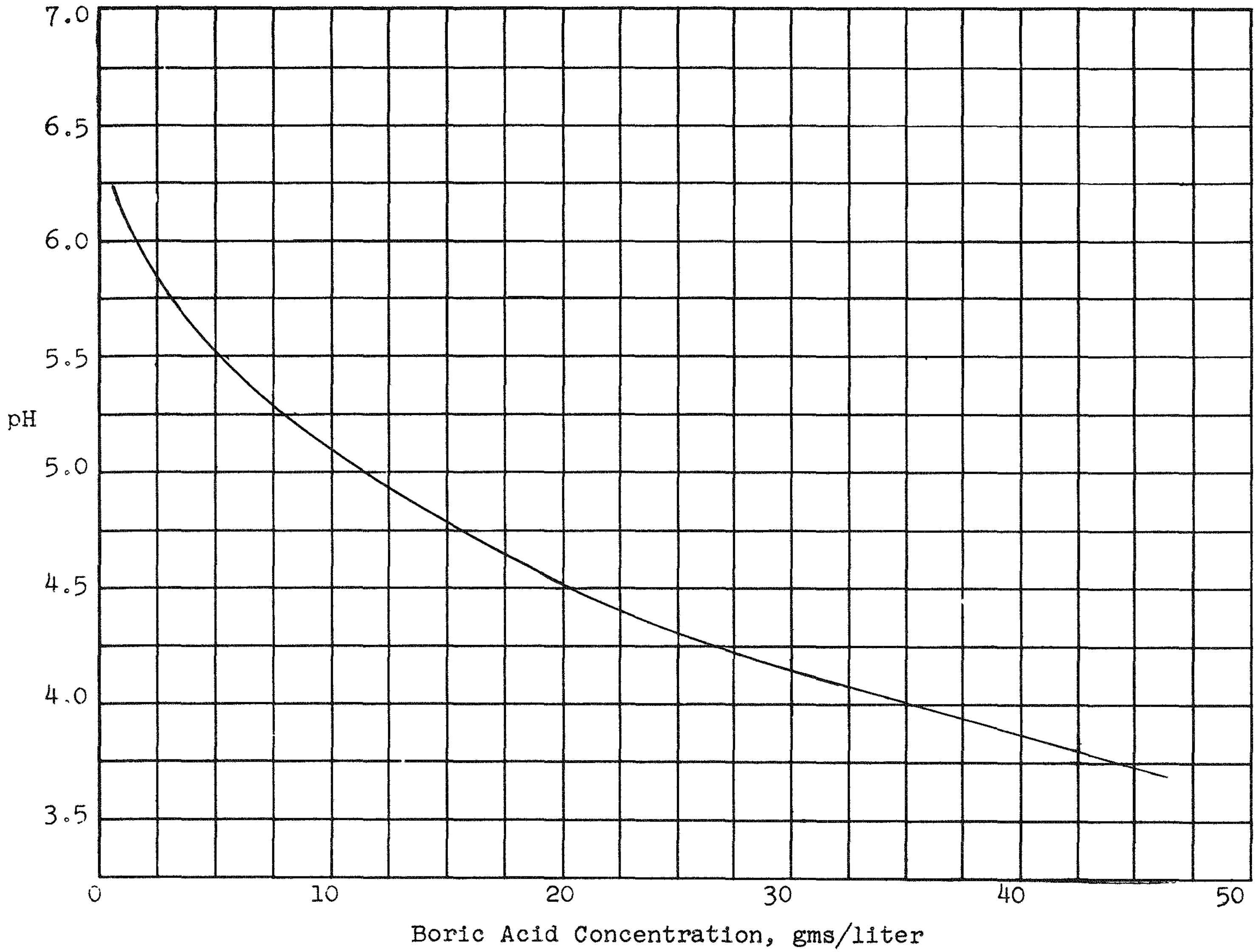


Figure A7.B

pH of Boric Acid Solutions

A7.1.4 Colorimetric

The literature search yielded a number of compounds and methods for determining boric acid by use of color changes. The most common method used was to add any one of a large number of quinones, develop the color, and measure the intensity in a photoelectric colorimeter. This method is most commonly used for analyses of agricultural and metallic samples which contain only small amounts of boron. An extensive literature survey by Ellis, et. al.[8], yielded a number of compounds which are suitable for developing a color change. Most of these compounds are listed in Table A7.a. The method recommended by Ellis, et. al., uses 1,1' - dianthrimide with a photoelectric colorimeter using a filter transmitting in the region at 620 millimicrons. A method for determining boric oxide in the 1-15 gamma range was recommended by Grill and Wohlmuth[9] which uses oxalic and turmeric acid to develop the color change. In all references, stress is placed on the use of boron free glassware.

Table A7.a

Compounds Which Give Color Changes With Boric Acid

Hydroxyanthroquinones:	1,5-
	1,2,5,8-
	1,2,4,5,6,8-
	carminic acid
1,10-phenanthroquinones:	1,2,-di
	1,2,4-tri
1-hydroxy-2,4-p-aminophenyl sulfonic acid derivative of anthraquinone	
Anthroquinone dyes whose color indexes are:	1085
	1078 (a 1,4-diamino derivative)
	1053
	1054 (basic structure 1,5-dihydroxy-4,8-diamenoanthroquinone)
1-amino-4-hydroxyanthroquinone	
1,1'-dianthrimides:	8-amino-4,4'-diamino-
	4,4'-diamino-8-nitro
trianthrimide	
pentanthrimide	
monpholquinone	

A7.1.5 Fluorametric

In their literature survey of methods for analyzing for boric acid, Ellis, et.al.[8] list a number of compounds which give changes of fluorescence in the presence of boric acid. Some of these compounds are listed in Table A7.b.

Table A7.b

Compounds Which Give Changes In Fluorencence With Boric Acid

Anthraquinone and following derivatives:

1,2-dihydroxy-
1-amino-4-hydroxy-
1-amino-
1-amino-2,4-dibromo-
1-chloro-5-amino-
1-amino-8-chloro-
1-chloro-5-nitro-
α-malein amino-
2,6-disulfo-
1-chloro-5-benzomido
N-methylamino-

Quinizarin
Leucoquinizarin
Curcumin
2-hydroxy-3-naphthoic acid

A7.2 Investigation of Alternate Neutron Absorbers

A survey of the literature was made to determine what, if any, chemicals could be used in place of boric acid as a chemical poison in aqueous shim reflector solutions.

A7.2.1 Requirements

Those chemicals which may be considered for the role of a chemical poison must fulfill certain requirements other than just a high neutron cross section. The more important of these requirements are listed below:

a) High solubility. The solubility of the chemical must be sufficiently high so that the macroscopic cross section of the solution is always sufficient to shut down the reactor. This requirement must extend over all possible temperatures which could be expected in the reactor. Also, the solubility should be high enough that only a small volume of highly concentrated solution need be added.

b) Stability. The chemical which serves as the chemical poison must be stable under all conditions encountered in the reactor. The chemical must not plate out, crystalize, or cause excessive gas production as well as be stable at high temperature and high beta, gamma, and neutron fluxes.

c) Availability of Anhydrous Form. The chemical which is to be used as a soluble poison in heavy water must be available in an anhydrous or deuterated form so as to prevent degrading the heavy water. Even chemically bonded hydrogens are to be avoided as hydrogen and deuterium undergo an exchange reaction.

d) Corrosion. The presence of the chemical poison in the reactor system must not significantly increase the rate of corrosion of reactor components nor cause any unusual crud production or deposition.

e) Removal. The chemical which is used as a chemical poison must be easily removable from the system.

f) Activity. The chemical poison must not add excessive amounts of radioactivity to the reflector system. Neither the products formed by neutron absorption nor the impurities added with the poison should be so radioactive that much more shielding and decay time is required.

g) Availability. The chemical poison should be available in sufficient quantity and quality and at a price which does not make the operating expenses excessive.

A number of chemicals were considered in view of these requirements. While none completely fulfill the requirements, a few fulfill most of them.

A7.2.2 Discussion

The three major groups of chemicals which were considered as possible alternates to boric acid were rare earth, cadmium, and boron compounds. As there are a large number of compounds which qualify as possible poisons, some means had to be devised to reduce the number considered. The first consideration of poisons was on the basis of their solubility. In Table A7.c all of the soluble compounds listed in the Chemical Rubber Handbook[20] are tabulated in order of decreasing poisoning power, i.e., the number of barns which may be dissolved in 100 mℓ of water. The cross sections used to compute their poisoning powers are listed in Table A7.d. Only those compounds whose solubility was sufficient to permit a poison effect greater than that of boric acid were considered further.

Table A7.c

Possible Soluble Poisons

Compound	Poison Effect (barns/100mℓ)	Temperature (°C)
$Cd_5(BW_{12}O_{40})_2 \cdot 10H_2O$	3070	19
$Cd(C\ell O_3)_2 \cdot 2H_2O$	2800	0
$SmC\ell_3$	2800	10
$CdC\ell_2$	2215	20
$CdSC_4 \cdot 4H_2O$	1446	0
$Gd(C_2H_3O_2)_3 \cdot 4H_2O$	1370	25
$Cd(NO_3)_2 \cdot 4H_2O$	1320	30
$Sm(BrO_3)_3 \cdot 9H_2O$	1278	25
$3CdSO_4 \cdot 8H_2O$	1129	0
$CdSO_4$	1048	0
$Cd(BrO_3)_2 \cdot H_2O$	940	17
$NaBF_4$	728	25
CdI_2	675	18
KBO_2	642	30
$Gd_2(SO_4)_3$	635	0
$CdBr_2$	596	10
$Gd_2(SO_4)_3 \cdot 8H_2O$	422	20
$K_2Cd(CN)_4$	324	20
$Sm(C_2H_3O_2)_3 \cdot 3H_2O$	306	25
$Na_2B_4O_7 \cdot 5H_2O$	223	65
$K_2B_4O_7 \cdot 8H_2O$	209	3
NH_4BF_4	177.2	16
$(NH_4)_2B_{10}O_{16} \cdot 8H_2O$	96.0	18
$(NH_4)_2B_4O_7 \cdot 4H_2O$	83.8	18
CdF_2	83.8	25
H_3BO_3	61.6	21

Table A7.d

Cross-Sections Used in Table A7.c

Boron	740
Cadmium	2,900
Chlorine	32
Gadolinium	48,000
Samarium	7,800
Wolfram	18

Boron Compounds

A number of boron chemicals were investigated as possible soluble poisons because their solubilities were greater than that of boric acid. The solubilities of five of these compounds is shown in Figure A7.C. As can be seen, the solubilities of all of these chemicals increase rapidly with temperature. In the case of boric acid, the solubility increases until the acid becomes miscibile with water in all proportions at about 340°F.[2]

The stability of boric acid and some boron chemicals has been investigated[2,22]. Both thermal and radiation stability were investigated. Boric acid was found to be stable and ammonium borate was found to be stable after the reaction $2NH_3 = N_2 + 3H_2$ reached equilibrium. The results of investigations into the effect of these borates on water decomposition was inconclusive but the effect, if any, may be small.

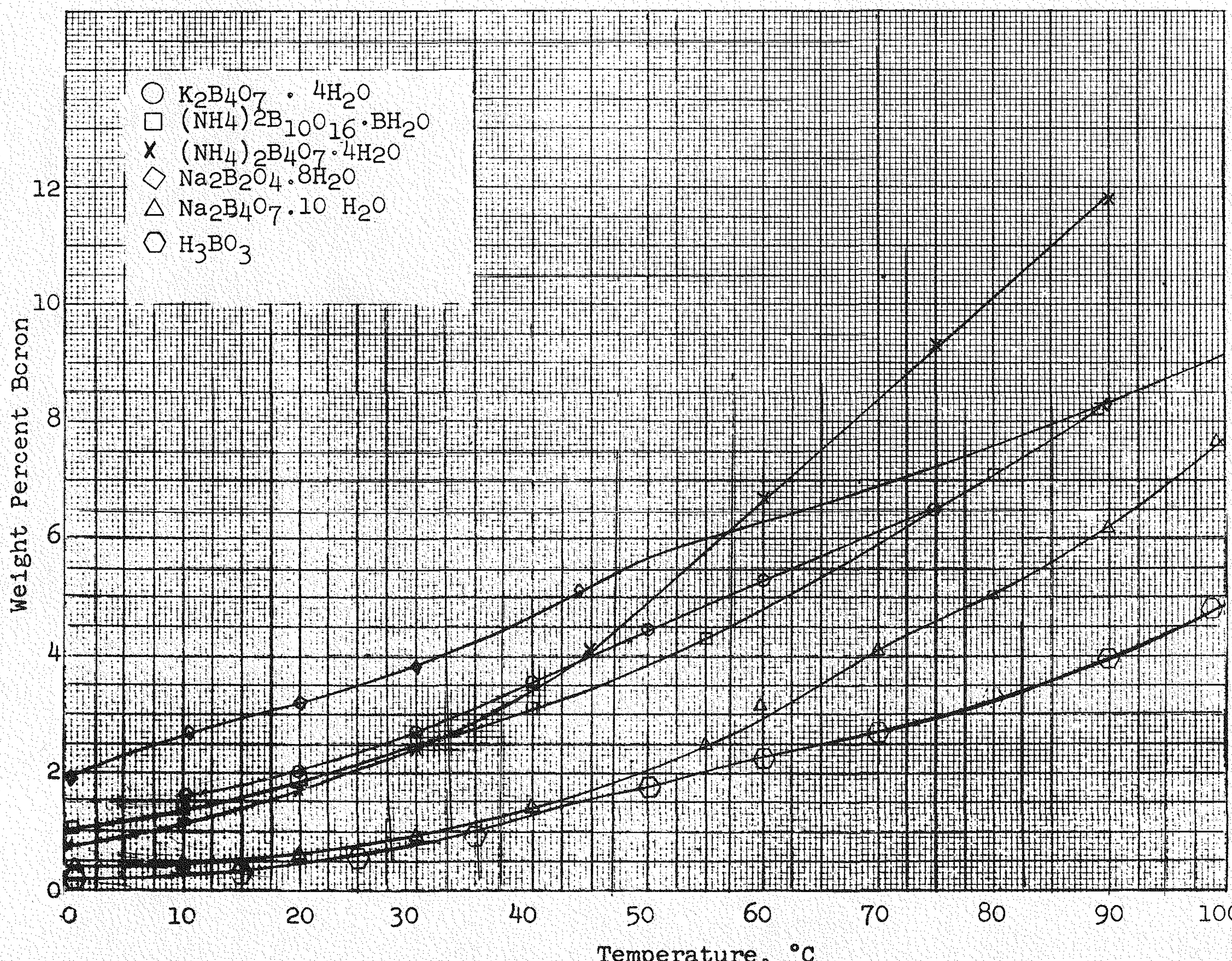
One of the disadvantages of boric acid and ammonium borates is the presence of water or hydrogen atoms. These hydrogen atoms will undergo exchange with deuterium with a resultant isotopic dilution. However, a deuterated form of boric acid may be prepared by mixing the anhydride, boric oxide, with heavy water. With the sodium and potassium borates, the water of hydration may possibly be removed by drying at high temperatures.

Cadmium Compounds

In Table A7.c it may be seen that most of the chemicals whose poison power is greater than that of boric acid are cadmium compounds. Little information was found on the investigation of these chemicals as possible poisons. The available information was brief but indicated that cadmium compounds are quite attractive with the exception of the nitrate. Cadmium nitrate decomposes with the cadmium being

Figure A7.C

Solubility of Boron Chemicals



plated out on the container walls. A few of the cadmium compounds such as the sulfate may be neglected as the solubility decreases sharply as temperature increases.

Cadmium compounds have one large disadvantage when compared with boron chemicals. This is the radioactivity of the products of neutron absorption. While boron can be used in the reflector piping system with little or no extra shielding, the products resulting from neutron absorption by cadmium require additional shielding.

Cadmium chemicals are readily available and at moderate cost. Of the compounds listed in Table A7.c, only those containing halogens present any corrosion problems.

Rare Earths

The rare earth elements are particularly attractive as neutron poisons as they all have unusually high cross sections. The use of rare earth compounds as soluble poisons has been studied by Breden and Abers.[1] From their work they concluded that the most attractive compound was samarium nitrate. Included in the investigation were rare earth oxides, chlorides, bromides, iodides, acetates, sulfates, nitrates, and chlorates. The oxides were quite insoluble; the acetates and iodides decomposed; chlorides and bromides caused the most severe corrosion of all solutions tested on both stainless steel and zirconium. Some exhibited decreasing solubility with increasing temperature, sulfates being the most pronounced. In all of the references consulted, no information could be found on the corrosion of aluminum in the presence of rare earths.

One of the drawbacks of the rare earths as soluble poisons is the price and availability. All of the compounds which are available are quite expensive (see Table A7.f), and the quantity which will be available is questionable.[7]

Table A7.e

Properties of Boron Compounds[6]

Compound	Boron Solubility at 20°C*	pH of Saturated Solution at 20°C	Cost in Less Than Car Load Lots[21] U.S.P. Grade $/ton
$Na_2B_4O_7 \cdot 10H_2O$	0.68	9.3	99.00
$K_2B_4O_7 \cdot 4H_2O$	2.8	~9	404.50**
$(NH_4)_2B_{10}O_{16} \cdot 8H_2O$	2.4	~7	295.00
$(NH_4)_2B_4O_7 \cdot 4H_2O$	2.2	8.8	417.50**
H_3BO_3	1	3.7	223.40

* Percent boron dissolved, relative to boric acid

** Technical Grade

Table A7.f

Rare Earths Costs

	Cost[7] 500 lb. Lots and Over $/lb
Samarium Oxide	40.00
Gadolinium Oxide	63.00
Samarium-Gadolinium Oxide (45%-45%)	25.00
Dysprosium Oxide	63.00
Erbium Oxide	63.00
Yttrium Oxide	65.00

A7.2.3 Conclusions

From this brief survey it may be concluded that boric acid is, at the present state of the art, the most desirable soluble poison for use in the AETR reflector. Boric acid and its anyhdride, boric oxide, are readily available and are quite inexpensive. No corrosion or stability problems are anticipated. However, with more research and development especially into the corrosion and stability of cadmium compounds, they may become more attractive than boric acid. Also, the rare earths may be attractive when more is known about their availability, cost, corrosion, and stability.

APPENDIX 8.0

BORIC ACID STUDIES

The details and all of the data from the boric acid studies are presented in this appendix. Section A8.1 presents the investigation of boric acid conductivity and Section A8.2 presents the investigation of resins and boric acid removal.

A8.1 Boric Acid Concentration and Conductivity

The following describes the detailed procedure used for measuring the conductivity of boric acid and miscellaneous solutions and presents the primary measurements.

A8.1.1 Procedure and Details

The solutions of boric acid and other chemicals whose resistivity was to be measured were made up by the following procedure. The procedure used for all solutions was the same so a typical boric acid solution is the only one described.

The desired amount of boric acid was weighed out on a triple beam balance. With moderate care, the weighings were reproducable to ± 0.05 grams. To increase the precision, all weighings were made by difference. The boric acid was placed into a 500 mℓ volumetric flask and about 400 mℓ of deionized water added. All water used was of greater than 1 megohm-cm purity and usually was of 6-8 megohm-cm purity. The boric acid was then dissolved by vigorous shaking and heating. After the boric acid was dissolved, the flask and solution were allowed to come to room temperature by standing, usually overnight. The dilution was then completed by adding more deionized water to the mark. Approximately 200 mℓ of this solution was then used to measure the solution resistivity.

A 200 mℓ tall form beaker was rinsed with three 10 to 20 mℓ portions of the solution. Then about 150 mℓ of the solution was placed into the tall form beaker and the resistivity and temperature measured. Before placing the dip-type conductivity cell into the solution, the cell was washed with deionized water and all excess water removed. After the measurement was complete, the cell was again washed with and stored in deionized water.

Initially, different concentrations of boric acid were made by successive dilutions of times two. In later work, it was desirable to cover a wider range of concentrations so dilutions of times five and times ten were used. The times two dilution was made by diluting 250 mℓ of the original solution to 500 mℓ. A 250 mℓ volumetric flask was rinsed with at least three portions of the initial solution. The flask was filled to the mark and transferred to a clean 500 mℓ volumetric flask, which in turn was filled to the mark.

The times five and times ten dilutions were made in a similar manner except that 50 mℓ portions were diluted to 250 mℓ and 500 mℓ.

A8.1.2 Primary Data

All measurements made of the resistivity of boric acid solutions and solutions which simulate corrosion products are presented in Table A8.b through A8.h. The measured resistivities have all been corrected for temperature variations to 25°C. The following relationship[23] was used:

$$R_{25} = R_t \left[1+0.025\ (t-25)\right]$$

where

R_{25} = resistivity at 25°C

R_t = measured resistivity of solution

t = solution temperature, °C

This relationship was checked by heating a boric oxide solution. The results are presented in Table A8.a. Over the temperature range of 23 to 60°C, the maximum variation was ± 1.4%. Above 60°C, the results were quite erratic probably due in part to a lack of thermal equilibrium.

Table A8.a

Effect of Temperature on Resistivity

Solution: 14.08 grams B_2O_3/liter solution

Temperature (°C)	Resistivity (ohm-cm)	Resistivity at 25°C (ohm-cm)
23	25,600	25,300
25	24,900	24,900
28	23,200	24,900
30	22,200	25,000
35	20,500	25,600
39	18,700	25,200
43	17,600	25,500
50	15,600	25,300
54	14,700	25,300
58	13,900	25,300
59	13,500	24,950
60	13,300-13,400	24,900-25,100
65	12,100	24,200
68	11,600	23,100
73	10,600	22,000
75	10,300	23,200
87	8,900	22,700
90	8,300*	21,800
84	8,400*	20,800
79	8,800*	20,700
74	9,200*	21,100

*These measurements are probably in error as the temperature was decreasing rapidly.

Table A8.b

Resistivity of Boric Acid Solutions

Run	Concentration (gm H_3BO_3/ℓ solution)	Measured Resistivity (Megohm cm)	Temperature of Solution (°C)	Resistivity at 25°C (Megorm ·cm)
A	30.0	0.0380	24	0.0370
	30.0	0.0376	24	0.0366
	15.0	0.1060	24	0.1030
	15.0	0.1059	24	0.1030
	7.50	0.2300	24	0.2240
	3.75	0.371	24	0.361
	1.88	0.540	24	0.526
	0.94	0.690	24	0.672
	0.47	0.760	24	0.740
	0.23	0.985	24	0.960
	0.12	1.018	24	0.992
	Diluent	1.380	24	1.345
B	20.0	0.069	26	0.0715
	10.0	0.166	26	0.1700
	5.00	0.294	26	0.301
	2.50	0.414	26	0.424
	1.25	0.520	26	0.532
C	20.0	0.069	27	0.0725
	10.0	0.160	27	0.1680
	5.00	0.273	27	0.287
	2.50	0.400	27	0.420
	1.25	0.530	27	0.556
D	25.0	0.0489	28	0.0525
	12.5	0.1210	28	0.1300
	6.25	0.2300	28	0.247
	3.12	0.346	28	0.372
	1.56	0.480	28	0.516
E	4.00	0.326	27	0.342
	2.00	0.470	26	0.482
	1.00	0.622	26	0.637
	0.50	0.690	26	0.707
	0.25	0.885-0.890	26	0.907-0.912
	Diluent	1.550	26	1.590

Table A8.c

Resistivity of Boric Oxide (B_2O_3) Solutions

Concentration (gms H_3BO_3/ℓ solution)*	Measured Resistivity (Megohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (Megohm-cm)
14.90	0.0220	27.5	0.0231
7.50	0.0435	27.2	0.0456
3.25	0.0828	27.0	0.0869
1.82	0.1550	27.0	0.1625
0.325	0.570	27.0	0.598
0.180	0.840	27.0	0.882
0.018	1.120	27.0	1.175
Diluent	1.140	27.0	1.196

*123.7 gms of H_3BO_3 are equivalent to 69.6 grams B_2O_3

Table A8.d

Resistivity of Al_2O_3 Solutions

Concentration (gms/ℓ solution)	Measured Resistivity (Megohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (Megohm-cm)
10* (well mixed)	0.0475	27	0.0498
10* (quiet)	0.0528	27	0.0555
Saturated	0.0520	27	0.0546

*Solution is more than saturated. The excess produces a milky mixture.

Table A8.e

Resistivity of Sodium Chloride Solutions

Concentration (gms/ℓ solution)	Measured Resistivity (ohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (ohm-cm)
10.0	54	27	56.6
2.0	244	27	256.0
1.0	470	27	494
0.2	2,260	27	2,380
0.1	4,450	27	4,670
0.02	21,900	27	23,000
0.01	42,600	27	44,700
Diluent	1,470,000	27	1,543,000

Table A.8f

Resistivity of Solutions 1 Part NaCℓ per 300 Parts H_3BO_3

Concentration gms/ℓ solution H_3BO_3	NaCℓ	Measured Resistivity (Megohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (Megohm-cm)
30.0	0.10	0.00435	27	0.00456
6.0	0.02	0.0210	27	0.02205
3.0	0.010	0.0400	27	0.0420
0.6	0.002	0.1660	27	0.1740
0.3	0.001	0.270	27	0.284
Diluent		1.120	27	1.175

Table A8.g

Resistivity of Solutions Containing 1 part NaCℓ per 1 part H_3BO_3

Concentration gms/ℓ solution H_3BO_3	NaCℓ	Measured Resistivity (ohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (ohm-cm)
10.0	10.0	54	29	59.4
5.0	5.0	101	29	111.1
2.5	2.5	194	29	213.6
0.25	0.25	1,760	29	1,936
0.025	0.025	16,800	29	18,480
0.005	0.005	77,000	29	84,700
Diluent		1,000,000+	29	1,100,000+

Table A8.h

Resistivity of Solutions Containing 1 part $A\ell_2O_3$ per 30 parts H_3BO_3

Concentration gm/ℓ solution H_3BO_3	$A\ell_2O_3$	Measured Resistivity (Megohm-cm)	Temperature of Solution (°C)	Resistivity at 25°C (Megohm-cm)
30.0	1.00	0.042	27.0	0.0441
6.0	0.20	0.270	27.0	0.284
3.0	0.10	0.443	27.5	0.465
~0.6	~0.02	0.760	27.5	0.798
0.3	0.01	0.835	27.5	0.876

A8.2 Resin Characteristics

The ability of Amberlite MB-1 monobed ion exchange resin to remove boric acid from water was investigated by use of breakthrough curves. The procedure used in making these curves is described in detail in Section A8.2.1. The data obtained and plots of the data are presented in Section A8.2.2.

A8.2.1 Procedure and Details

The resin column used in these runs was made up of weighed amounts of resin placed into a glass tube. The tube was about 2 feet long and 25 mm outside diameter. About 100-120 grams of wet resin was placed in the column. The resin weights were obtained by the difference between two large weights and thus are accurate to ±0.1 grams. The resin was added to the column in the wet but drained state in which it was received. When the column was about 3/4 full, water was passed very slowly into the column from the bottom. In this manner all of the air in the column was removed. However, the water had to be added very slowly or the monobed resin would separate into its components, the anion IRA-400 resin rising to the top. The head tank and conductivity cell were then attached to the resin column, care being exercised to remove all air from the system.

In all of the runs, a solution of 20 grams of boric acid per liter of water was used. The solution was made up by diluting 80.0 grams of boric acid with eight 500 mℓ portions of water. The boric acid and water were put into an eight liter aspirator bottle and the boric acid allowed to dissolve. Heating, violent shaking, and standing were required to completely dissolve the boric acid.

The run was started. The effluent from the conductivity cell was collected in 50 mℓ cylinders. As the cylinders became full, the resistivity was measured. In a number of cylinders, the temperature was also measured. In most of the runs, the first volume of liquid measured was a 250 mℓ portion instead of 50 mℓ portions as the resistivity usually remained uniformly high until breakthrough was approached.

A8.2.2 Primary Data

All of the data taken during the breakthrough runs is presented in Tables A8.i through A8.u. In these tables, the resistivities have been corrected for temperature variations by use of the equation presented in Section A8.1.2. The breakthrough data is plotted in Figure A8.A through A8.F.

Table A8.1

Breakthru Curve A

Resin: 131.2 grams of Wet Amberlite MB-1

Solution: 80.0 grams H_3BO_3 dissolved in 3.983 liters of deionized water. (Resistivity ≥ 3 Megohm-cm)
20.85 grams H_2BO_3/liter

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
0	-	-
30	2.56	2.62
40	3.00	3.07
50	3.25	3.33
100	6.00	6.15
130	7.70	7.88
170	7.00	7.17
185	5.20	5.33
195	5.00	5.12
200	4.58	4.69
215	4.29	4.40
230	3.96	4.06
240	4.00	4.10
250	3.60	3.69
265	3.60	3.69
275	3.45	3.54
290	3.25	3.33
300	3.00	3.07
340	2.90	2.97
350	2.75	2.82
370	2.72	2.79
400	2.65	2.72
425	2.90	2.97
450	2.78	2.85
475*	4.52	4.63
500	4.58	4.70
525	4.78	4.90
550	4.70	4.82
600	4.82	4.94
640*	6.00	6.15
650	6.50	6.67
700	6.60	6.76
750	6.60	6.76
800	6.80	6.97

* velocity increased

Table A8.i (Continued)

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
850	6.98	7.07
900	6.60	6.77
950	6.10	6.26
965	4.70	4.72
980	4.15	4.26
990	3.66	3.75
1,000	3.02	3.10
1,015	2.40	2.46
1,030	2.04	2.09
1,045	1.49	1.53
1,050	1.25	1.28
1,085	0.78	0.80
1,100	0.79	0.81
1,125	0.82	0.84
1,150	0.63	0.646
1,175	0.37	0.379
1,200	0.35	0.359
1,225	0.40	0.410
1,250	0.35	0.359
1,275	0.33	0.338
1,300	0.274	0.281
1,365	0.186	0.191
1,410	0.131	0.134
1,450	0.115	0.118
1,480	0.108	0.111
1,525	0.100	0.1025
1,550	0.097	0.0995
1,600	0.092	0.0943
1,650	0.088	0.0903
1,700	0.085	0.0872
1,750	0.083	0.0850

Table A8.j

Resin Column Shrinkage - Run A

Resin: Amberlite MB-1 Solution: 20.85 gms H_3BO_3/liter

Volume Passed Through Column (mℓ)	Percent of Breakthru (%)	Column Height (inches)	Column Shrinkage (%)
0	0	19.625	0
370	41.1	19.375	1.3
600	66.7	19.25	1.9
1,650	183.3	18.625	5.1

Table A8.k

Breakthru Curve B

Resin: 122.7 grams of wet Amberlite MB-1

Solution: 80.0 grams H_3BO_3 dissolved in 4 liters of deionized water (resistivity ≥ 3 megohm-cm)

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
250	5.60	6.15
500	6.70	7.36
750	2.70	2.97
800	1.30	1.43
850	0.680	0.750
900	0.410	0.450
950	0.290	0.320
1,000	0.205	0.225
1,050	0.168	-
1,100	0.149	-
1,150	0.130	-
1,200	0.122	0.131
1,250	0.113	0.121
1,300	0.110	0.118
1,350	-	-
1,400	0.100	0.108
1,450	0.098	0.105
1,500	0.094	0.101
1,550	0.092	0.0980
1,600	0.090	0.0966
1,650	0.088	0.0946
1,700	0.087	0.0935
1,750	0.086	0.0925
2,000	0.082	0.0882

Table A8.ℓ

Liquid Velocity in Resin Bed - Run B

Volume of Liquid Passed Through Column (mℓ)	Time (seconds)	Velocity (mℓ/sec)
0	0	
250	120	2.08
500	240	2.08
750	370	1.92
1,450	703	2.10

Table A8.m

Breakthru Curve C

Resin: 96.1 grams of wet Amberlite IRA-400 in the chloride form followed by 31.7 grams of wet Amberlite MB-1

Solution: 20.0 grams H_3BO_3/liter deionized water (water purity ≥ 3 megohm-cm)

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
~ 200	~3	-
250	1.45*	1.560
300	0.450	0.480
350	0.235	0.253
400	0.150	0.161
450	0.120	0.129
500	0.104	0.112
550	0.094	0.101
600	0.088	0.095
650	0.086	0.092
700	0.082	0.088
750	0.079	0.085
800	0.077	0.083
850	0.077	0.083
900	0.076	0.082
950	0.075	0.081

* Breakthrough occured after about 220 mℓ passed through column.

Table A8.n

Liquid Velocity in Resin Bed - Run C

Volume of Liquid Passed Through Column (mℓ)	Time (seconds)	Velocity (mℓ/sec)
0	0	
250	180	1.39
500	350	1.47
700	490	1.43
900	622	1.52

Table A8.o

Breakthru Curve D

Resin: 113.7 grams of wet Amberlite IRA-400 in the hydroxide form followed by 27.3 grams of wet Amberlite MB-1

Solution: 20.0 grams H_3BO_3/liter deionized water (water purity ≥ 3 megohm-cm)

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
0	0.30	0.33
250	0.90	0.99
300	1.30	1.43
350	-	-
400	1.90	2.09
450	2.25	2.48
500	2.50	2.75
550	2.85	3.14
600	3.10	3.41
650	3.40	3.74
700	3.60	3.96
750	3.40	3.74
800	3.55	3.90
850	3.62	3.98
900	3.20	3.52
950	2.23	2.45
1,000	1.210	1.330
1,050	0.660	0.730
1,100	0.390	0.430
1,150	0.260	0.290
1,200	0.180	0.200
1,250	0.142	0.156
1,300	0.124	0.136
1,350	0.112	0.123
1,400	0.104	0.114
1,450	0.100	0.110
1,500	0.095	0.104
1,550	0.092	0.101
1,600	0.089	0.098
1,650	0.086	0.095
1,900	0.079	0.087

Table A8.p

Liquid Velocity in Resin Bed - Run D

Volume of Liquid Passed Through Column (mℓ)	Time (seconds)	Velocity (mℓ/sec)
0	0	-
250	230	1.09
350	305	1.33
650	545	1.25
850	702	1.27
950	780	1.28
1,200	980	1.25
1,300	1,060	1.25
1,450	1,182	1.23
1,900	1,560	1.16

Table A8.q

Breakthru Curve E

Resin: 114.6 grams of wet Amberlite MB-1

Solution: 20.0 grams H_3BO_3/liter deionized water (water purity ≧ 3 megohm-cm)

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
250	3.5	3.85
500	3.8	4.18
550	3.8	4.18
600	3.1	3.41
650	2.2	2.42
700	1.4	1.54
750	0.85	0.935
800	0.53	0.583
850	0.36	0.396
900	0.26	0.286
950	0.19	0.209
1,000	0.16	0.176
1,050	0.144	0.158
1,100	0.132	0.145
1,150	0.122	0.134
1,200	0.116	0.128
1,250	0.110	0.121
1,300	0.106	0.117
1,350	0.103	0.113
1,400	0.099	0.109
1,450	0.097	0.107
1,700	0.088	0.097

Table A8.r

Liquid Velocity in Resin Bed - Run E

Volume of Liquid Passed Through Column (mℓ)	Time (seconds)	Velocity (mℓ/sec)
0	0	-
250	105	2.38
500	215	2.27

Table A8.s

Breakthru Curve F

Resin: 113.1 grams of wet Amberlite MB-1

Solution: 80.0 grams H_3BO_3 and 20.0 grams $A\ell_2O_3$ in 4 liters of deionized water water purity ≥ 4 megohm-cm

Volume Passed Through Bed (mℓ)	Measured Resistivity (megohm-cm)	Resistivity at 25°C (megohm-cm)
250	7.2	9.0
500	7.4	9.3
550	6.4	8.0
600	-	-
650	4.3	5.38
700	2.9	3.62
750	1.85	2.31
800	1.08	1.35
850	0.68	0.85
900	0.45	0.56
950	0.31	0.39
1,000	0.225	0.281
1,050	0.192	0.240
1,100	0.165	0.206
1,150	0.150	0.188
1,200	0.142	0.178
1,250	0.134	0.168
1,300	0.126	0.158
1,350	0.122	0.152
1,400	0.118	0.148
1,450	0.114	0.142
1,500	0.112	0.140
1,550	0.110	0.138
1,600	0.108	0.135
1,850	0.100	0.125

Table A8.t

Liquid Velocity in Resin Bed - Run F

Volume of Liquid Passed Through Column (mℓ)	Time (seconds)	Velocity (mℓ/sec)
250	95	2.63
500	195	2.50
1,850	735	2.50

Table A8.u

Resin Column Shrinkage

Run	Resin	Solution Material	Solution Concentration (gms/ℓ)	Column Height at Start (inches)	Column Height at End (inches)	Column Height Reduction (%)
A	MB-1	H_3BO_3	20.85	19.625	18.625	5.1
B	MB-1	H_3BO_3	20.0	19.25	18.125	5.8
C	MB-1	H_3BO_3	20.0	5.0625	4	21.0
	IRA-400*			14.5625	15	-2.6
D	MB-1	H_3BO_3	20.0	4.125	4	3.1
	IRA-400**			17.125	16.6875	2.7
E	MB-1	H_3BO_3	20.0	17.75	16.50	7.3
F	MB-1	H_3BO_3	20.0	17.125	15.625	8.8
		$A\ell_2O_3$	5.0			

* Resin was in $C\ell^-$ Form

** Resin was in OH^- Form

Figure A8.A

Breakthru Curve - Run A

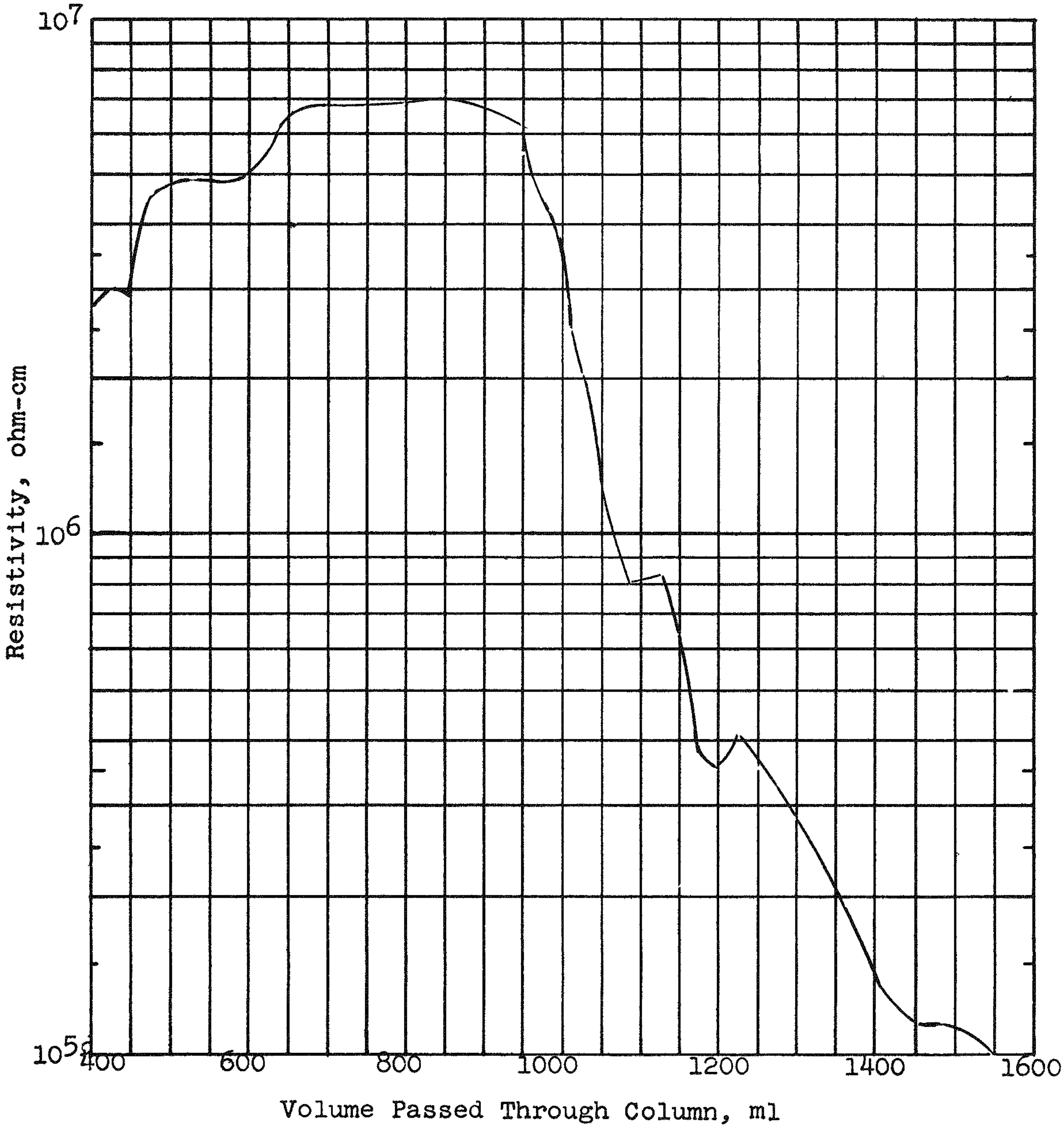


Figure A8.B

Breakthru Curve - Run B

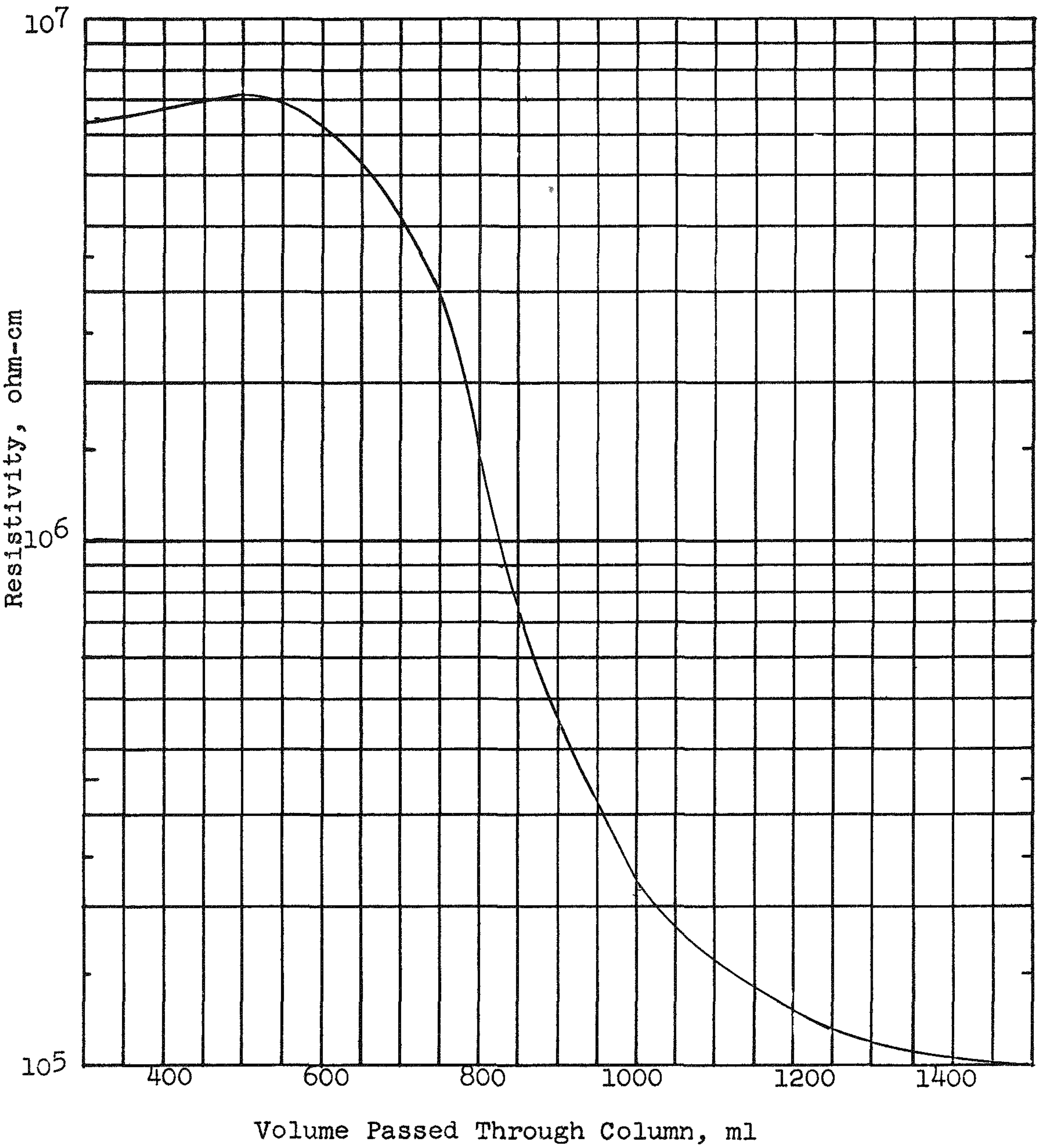


Figure A8.C

Breakthru Curve - Run C

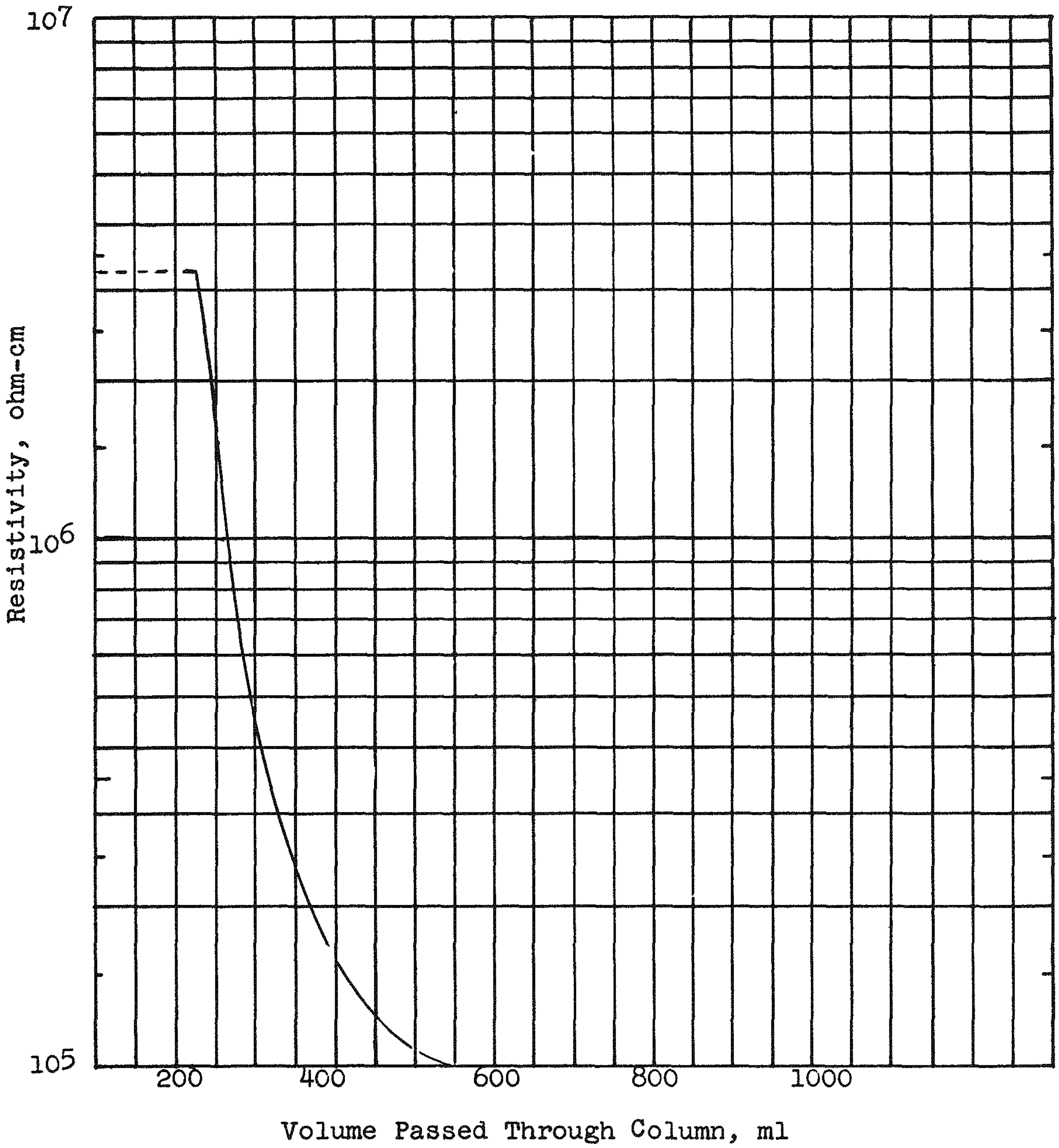


Figure A8.D

Breakthru Curve - Run D

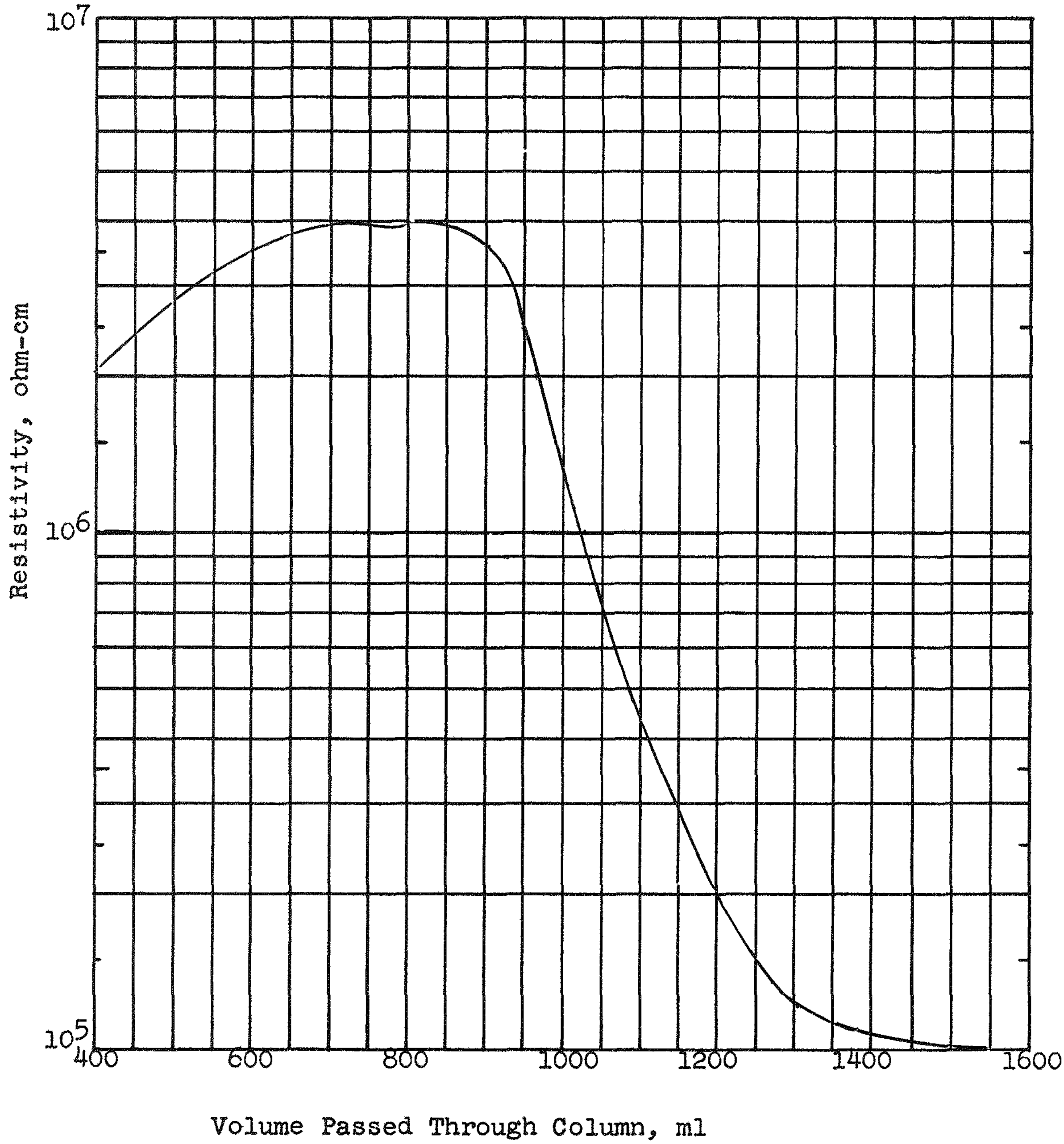


Figure A8.E

Breakthru Curve - Run E

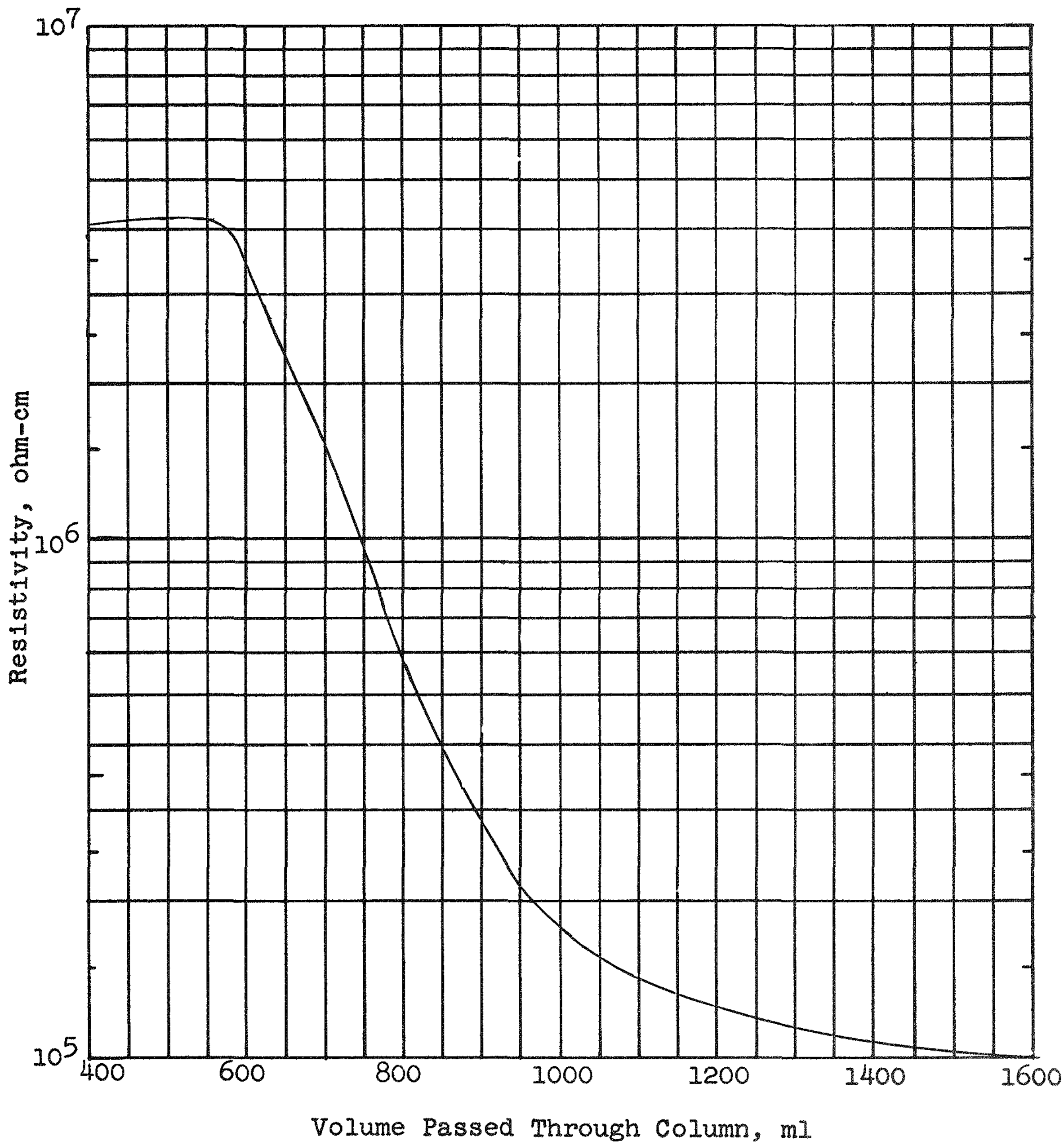
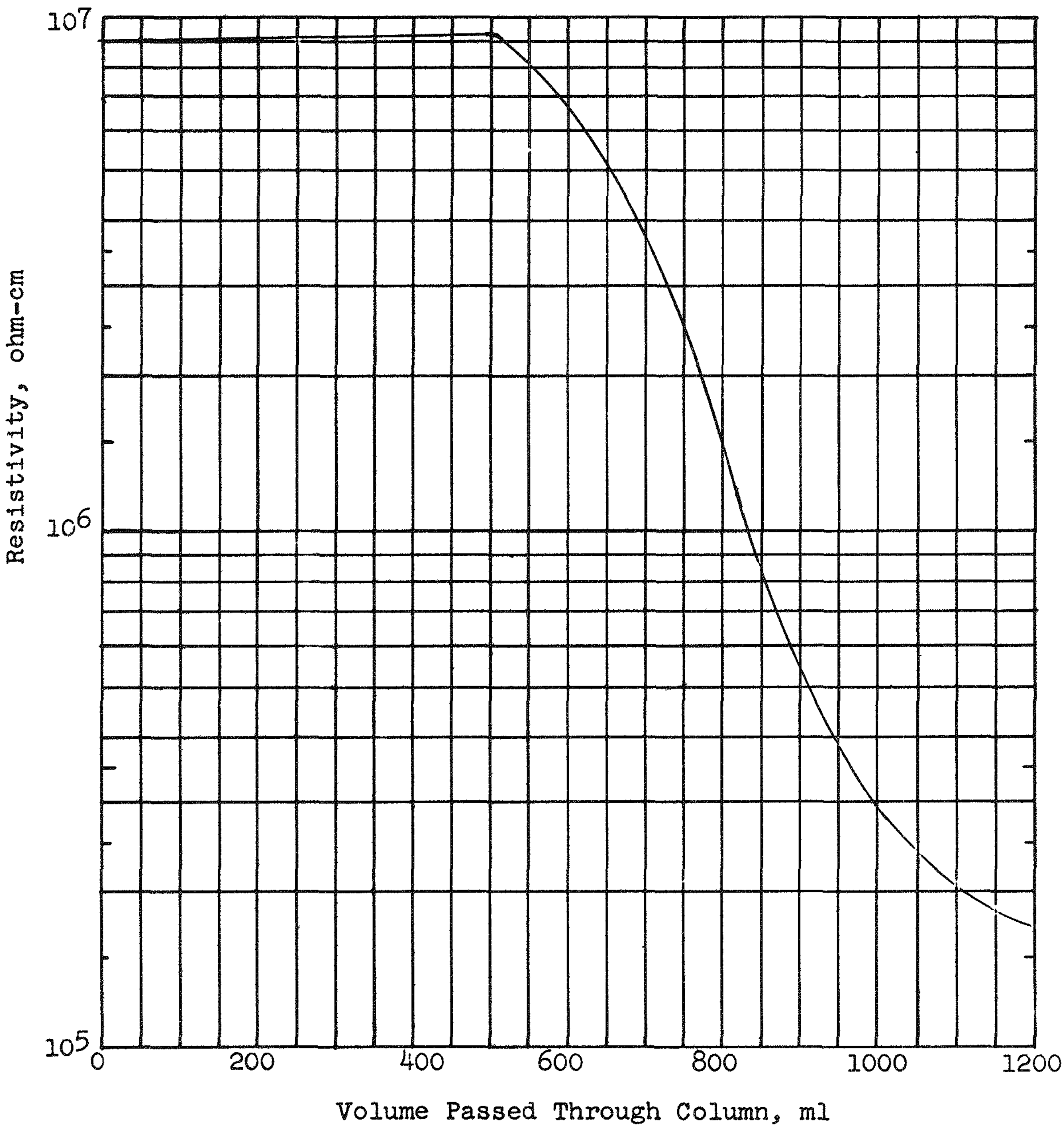


Figure A8.F

Breakthru Curve - Run F



APPENDIX 9.0

DYNAMIC OPERATION OF SHIM REFLECTOR WITH BORIC ACID INJECTION

This appendix contains the primary data obtained during the two runs of the shim reflector model. The operating conditions are summarized in Tables A9.a and A9.e. The operating logs are presented in Tables A9.b and A9.f. The remaining tables present the results of chemical analyses.

The chemical analyses of samples taken during the two runs were performed by Internuclear Company and St.Louis Testing Laboratory. Both titrated the samples with sodium hydroxide to the phenophthalien end point. St.Louis Testing Laboratory used mannitol to enhance the end point. Internuclear used glycerine to enhance the end point of samples from Run 2 and did not use an enhancing agent in the samples from Run 1.

Table A9.a

Summary of Run 1 Conditions

Run Began: 1430 hours on 9/15/59

Run Ended: 1100 hours on 9/16/59

Boric Acid Head Tank:

Concentration: 9 pounds of boric acid in approximately 30 gallons of demineralized water

Resistivity: Before adding boric acid = greater than one megohm-cm

After adding boric acid = 37,000 ohm-cm at 31.5°C.

Ion Exchange Resin: Approximately 1/2 cubic foot of Amberlite MB-2 resin and 1/6 cubic foot of Resex 130 in an Elgin 120 demineralizer.

Table A9.b

Run 1 Log

Date	Time	Water Conditions at Point A: Flow Rate Gpm	Resistivity Megohm-cm	Temperature °F	Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm cm	Temperature °C	Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
9/15/59	0915	90	0.014	86	0.0158	-	-	-	0
	0925	90	0.016	-	-	-	-	-	0
	0940	90	0.022	88	0.0253	-	-	-	0
	0950	90	0.026	88	0.0299	-	-	-	0
	0950+	90	0.017	88	0.0196	-	-	-	0
	1000	90	0.0185	88	0.0213	-	-	-	0
	1035	90	0.037	90	0.044	-	-	-	0
	1105	90	0.061	93	0.075	-	-	-	0
	1135	90	0.108	95	0.135	-	-	-	0
	1230	90	-	-	-	-	-	-	0
	1235	90	0.31	99	0.403	-	-	-	0
	1310	90	0.52	100	0.69	-	-	-	0
	1335	90	0.74	101	0.985	-	-	-	0
	1410	90	1.02	103	1.49	-	-	-	0
	1415	90	-	-	-	-	-	-	0
	1430	90	1.14	103	1.55	-	-	-	0
	1440	90	1.12	104	1.54	-	-	-	0
	1445	94	1.16	104	1.60	-	-	-	4
	1446	94	0.260	-	-	-	-	-	4
	1450	94	0.193	-	-	0.310	39	0.418	4
	1453	90	0.172	102	0.230	-	-	-	0
	1500	90	0.185	102	0.249	0.210	38.5	0.281	0
	1515	90	0.180	102	0.243	-	-	-	0
	1530	90	0.168	104	0.231	0.190	40	0.261	0
	1535	90	0.170	-	-	-	-	-	0
	1545	90	0.190	104	0.261	-	-	-	0
	1600	90	0.212	104	0.292	0.245	40.5	0.340	0
	1615	90	0.220	104	0.302	0.240	39	0.324	0
	1630	90	0.228	104	0.314	0.237	40.5	0.329	0
	1645	90	0.230	105	0.320	0.250	40.5	0.347	0

Table A9.b(Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Note 1.
9/15/59	0915	2.6	1.6	30	1.8	Pumps on 10 minutes
	0925	2.6	-	-	-	
	0940	2.6	3.3	31	3.8	
	0950	2.6	-	-	-	
	0950+	0	-	-	-	Tap water added to system Demineralized water to head tank
	1000	2.6	1.5	31	1.72	Tap water off Demineralizer on
	1035	2.6	2.7	32.5	3.5	
	1105	2.6	3.55	34	4.35	
	1135	2.6	-	-	-	
	1230	2.6	3.5	36.5	4.5	
	1235	2.6	3.5	36.5	4.5	
	1310	2.6	-	-	-	
	1335	2.6	-	-	-	
	1410	2.6	-	-	-	
	1415	2.6	~3	39	~4	
	1430	2.6	~3	-	-	Sample 100-CIR
	1440	2.6	3.3	36	4.21	Resin Replaced
	1445	0	-	-	-	
	1446	0	-	-	-	
	1450	0	-	-	-	
	1453	0	-	-	-	
	1500	0	-	-	-	Sample 101-CIR
	1515	0	-	-	-	
	1530	0	-	-	-	
	1535	2.6	2.5	38	3.3	
	1545	2.6	-	-	-	
	1600	2.6	-	-	-	Sample 102 taken from head tank
	1615	2.6	-	-	-	
	1630	2.6	-	-	-	
	1645	2.6	-	-	-	

Table A9.b(Continued)

Date	Time	Water Conditions at Point A: Flow Rate Gpm	Water Conditions at Point A: Resistivity Megohm-cm	Water Conditions at Point A: Temperature °F	Water Conditions at Point A: Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Water Conditions at Point B: Temperature °C	Water Conditions at Point B: Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
9/15/59	1700	90	0.235	105	0.327	0.250	41	0.350	0
	1715	90	0.238	106	0.334	0.183	41	0.256	0
	1730	90	0.239	106	0.335	0.260	41.5	0.367	0
	1745	90	0.240	106.5	0.338	0.262	41.5	0.370	0
	1800	90	0.240	107	0.340	0.270	41.75	0.383	0
	1815	90	0.242	107	0.343	0.264	42	0.376	0
	1830	90	0.242	107	0.343	0.162	42.5		0
	1845	90	0.242	107.5	0.344	0.148	42		0
	1900	90	0.247	108	0.353	0.083	42.5	--See Note 2---	0
	1915	90	0.242	108.5	0.349	0.122	42		0
	1935	90	0.242	109	0.350	0.099	43		0
	1945	90	0.242	109.5	0.351	0.092	43		0
	2000	90	0.241	109.5	0.349	0.099	43		0
	2015	90	0.241	109.5	0.349	0.100	44		0
	2030	90	0.241	109.5	0.349	0.102	44		0
	2045	90	0.241	109.5	0.349	0.150	44		0
	2100	90	0.241	110	0.351	0.108	44		0
	2115	90	0.241	112	0.358	0.261	45	0.391	0
	2130	90	0.240	112	0.357	0.255	45	0.383	0
	2145	90	0.240	112	0.357	0.250	45	0.375	0
	2200	90	0.240	112	0.357	0.254	45	0.381	0
	2215	90	0.241	112	0.358	0.250	45	0.375	0
	2230	90	0.241	112	0.358	0.251	45	0.376	0
	2245	90	0.241	112	0.358	0.251	45	0.376	0
	2300	90	0.240	112	0.357	0.250	45	0.375	0
	2315	90	0.240	112	0.357	0.250	45	0.375	0
	2330	90	0.240	112	0.357	0.252	45	0.378	0
	2345	90	0.240	112	0.357	0.251	45	0.376	0
9/16/59	2400	90	0.241	112	0.358	0.255	45	0.383	0
	0015	90.5	0.241	112.5	0.360	0.248	45.5	0.376	0
	0030	90.5	0.238	112	0.354	0.250	45.5	0.378	0
	0045	90.5	0.240	112	0.357	0.250	45	0.375	0
	0100	90.5	0.240	112	0.357	0.252	45	0.378	0

Table A9.b(Continued)

Date	Time	Demineralizer Outlet: Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Note 1.
9/15/59	1700	2.6	-	-	-	Sample 103-CIR
	1715	2.6	-	-	-	
	1730	2.6	-	-	-	
	1745	2.6	2.8	41	3.92	Sample 104- DIO
	1800	2.6	-	-	-	
	1815	2.6	-	-	-	
	1830	2.6	-	-	-	
	1845	2.6	-	-	-	
	1900	2.6	-	-	-	Sample 105-CIR
	1915	2.6	-	-	-	
	1935	2.6	1.3	43	1.89	Sample 106-DIO
	1945	2.6	-	-	-	
	2000	2.6	-	-	-	
	2015	2.6	-	-	-	
	2030	2.6	-	-	-	
	2045	2.6	-	-	-	
	2100	2.6	-	-	-	Sample 107-CIR
	2115	2.6	0.265	45	0.398	
	2130	2.6	-	-	-	
	2145	2.6	0.260	45	0.390	Sample 108 DIO
	2200	2.6	-	-	-	
	2215	2.6	0.259	45	0.389	Sample 109 DIO
	2230	2.6	-	-	-	
	2245	2.6	0.262	45	0.393	Sample 110 DIO
	2300	2.6	-	-	-	Sample 111 CIR
	2315	2.6	0.259	45	0.389	Sample 112 DIO
	2330	2.6	-	-	-	
	2345	2.6	0.260	45	0.390	Sample 113 DIO
9/16/59	2400	2.6	-	-	-	
	0015	2.6	0.255	45	0.382	Sample 114 DIO
	0030	2.6	-	-	-	
	0045	2.6	0.252	45	0.378	Sample 115 DIO
	0100	2.6	-	-	-	Sample 116 CIR

Table A9 b (Continued)

Date	Time	Water Conditions at Point A: Flow Rate Gpm	Resistivity Megohm-cm	Temperature °F	Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
9/16/59	0115	90.5	0.241	112	0.358	0.252	44	0.372	0
	0134	90.5	0.241	112	0.358	0.250	45	0.375	0
	0145	90.5	0.241	112	0.358	0.251	44.5	0.374	0
	0200	90.5	0.242	111	0.356	0.250	45	0.375	0
	0215	90.5	0.243	111	0.358	0.255	45	0.383	0
	0230	90	0.245	111	0.361	0.252	44	0.372	0
	0245	90.5	0.246	110	0.358	0.257	44	0.379	0
	0300	90.5	0.247	110	0.360	0.256	44	0.378	0
	0315	90.5	0.249	110	0.363	0.258	44	0.380	0
	0330	90.5	0.249	109	0.360	0.259	44.5	0.385	0
	0345	90.5	0.250	109	0.361	0.260	44	0.384	0
	0400	90.5	0.250	109	0.361	0.261	44	0.385	0
	0415	90.5	0.251	109	0.363	0.261	44	0.385	0
	0430	90.5	0.251	109	0.363	0.262	44	0.386	0
	0445	90.5	0.252	109	0.364	0.262	44	0.386	0
	0500	90.5	0.252	109	0.364	0.263	44	0.388	0
	0515	90.5	0.255	108	0.364	0.262	44	0.386	0
	0530	90.5	0.256	108	0.366	0.262	43	0.374	0
	0545	90.5	0.258	108	0.369	0.262	43	0.374	0
	0600	90.5	0.258	108	0.369	0.268	43	0.382	0
	0615	90.5	0.259	108	0.370	0.269	43	0.384	0
	0630	90.5	0.258	108	0.369	0.261	43.5	0.382	0
	0645	90.5	0.260	107	0.368	0.270	43	0.385	0
	0700	90.5	0.260	107	0.368	0.270	43	0.385	0
	0715	90.5	0.261	107	0.370	0.271	42	0.386	0
	0730	90.5	0.261	107	0.370	0.272	42.5	0.391	0
	0745	90.5	0.262	107	0.372	0.271	42	0.386	0
	0800	90.5	0.262	107	0.372	0.271	42	0.386	0
	0815	90.5	0.263	107	0.373	0.271	42	0.386	0
	0830	90.5	0.262	107	0.372	-	-	-	0

Table A9.b(Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Note 1
9/16/59	0115	2.6	0.253	44	0.374	Sample 117 DIO
	0134	2.6	-	-	-	
	0145	2.6	0.251	44	0.370	Sample 118 DIO
	0200	2.6	-	-	-	
	0215	2.0	0.255	44	0.376	Sample 119 DIO
	0230	2.6	-	-	-	
	0245	2.6	0.250	43	0.362	Sample 120 DIO
	0300	2.6	-	-	-	Sample 121 CIR
	0315	2.6	0.248	43	0.359	Sample 122 DIO
	0330	2.6	-	-	-	
	0345	2.6	0.248	43.5	0.363	Sample 123 DIO
	0400	2.6	-	-	-	
	0415	2.6	0.241	43	0.349	Sample 124 DIO
	0430	2.6	-	-	-	
	0445	2.6	0.251	43	0.364	Sample 125 DIO
	0500	2.6	0.258	42.5	0.371	Sample 126 CIR
	0515	2.6	0.258	42.5	0.371	Sample 127 DIO
	0530	2.6	-	-	-	
	0545	2.6	0.256	43	0.365	Sample 128 DIO
	0600	2.6	-	-	-	
	0615	2.6	0.258	42.5	0.371	Sample 129 DIO
	0630	2.6	-	-	-	
	0645	2.6	0.251	42	0.358	Sample 130 DIO
	0700	2.6	-	-	-	Sample 131 CIR
	0715	2.6	0.233	41.5	0.329	Sample 132 DIO
	0730	2.6	-	-	-	
	0745	2.6	0.259	41.5	0.366	Sample 133 DIO
	0800	2.6	-	-	-	
	0815	2.6	0.261	41	0.366	Sample 134 DIO
	0830	0	-	-	-	Demineralizer shut off. Valve redoped as was leaking badly. Resin replaced.

Table A9.b(Continued)

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °F	Resistivity at 25°C Megohm-cm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
		Water Conditions a Point A				Water Conditions at Point B			
9/16/59	0850	-	0.262	-	-	-	-	-	0
	0900	-	0.291	107	0.413	-	-	-	0
	0955	-	0.325	106	0.457	-	-	-	0
	1030	90.5	0.330	107	0.468	0.330	43	0.470	0
	1100	90.5	0.330	107	0.468	0.330	43	0.470	0

Notes: 1) CIR denotes sample taken from sample point B

DIO denotes sample taken from demineralizer outlet

2) Resistivity measurements in error due to contanimation of electrodes

Table A9.b(Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks
9/16/59	0850	2.6	~3	31	~3.5	Demineralizer now on stream
	0900	2.6	0.77	41	1.08	
	0955	2.6	-	-	-	
	1030	2.6	0.334	42	0.475	
	1100	2.6	0.310	42	0.441	Shutdown

Table A9.c

Analysis of Samples from Run 1

Work Performed by St.Louis Testing Laboratory*

Sample Number	Boric Acid Concentration grams/liter
100	None
101	5.79
102	30.80
103	3.91
104	3.91
105	3.91
106	3.91
107	3.91
119	3.91
134	3.91

* C.D.Trowbridge, Report No. T-36452. September 18, 1959

Table A9.d

Analysis of Samples from Run 1

Work Performed by Internuclear Company
50 m Aliquot of Sample Used

Sample Number	Sodium Hydroxide Normality(eq/l)	Sodium Hydroxide Volume(mℓ)	Boric Acid Concentration grams/liter
109	0.1	4.50	0.56
110	0.1	4.80	0.59
111	0.1	2.21	0.27
112	0.01	26.66	0.204
113	0.01	14.39	0.178
114	0.01	16.08	0.199
115	0.01	15.50	0.192
116	0.1	3.06	0.38
117	0.1	2.47	0.31
118	0.1	2.40	0.30
120	0.1	2.26	0.28
121	0.1	2.89	0.36
122	0.1	2.79	0.36
123	0.1	1.98	0.25
124	0.1	1.99	0.25
125	0.01	24.24	0.300
126	0.01	21.79	0.269
127	0.01	21.10	0.261
128	0.01	19.45	0.241
129	0.01	18.97	0.235
130	0.01	19.75	0.244
131	0.01	19.67	0.243
132	0.01	18.92	0.234
133	0.01	18.38	0.227

Table A9.e

Summary of Run 2 Conditions

Run Began: 1155 hours on 9/30/59

Run Ended: 1015 hours on 10/1/59

Boric Acid Head Tank:

Concentration:	4 pounds of boric acid in approximately 30 gallons of demineralized water.
Resistivity:	Before adding boric acid = greater than one megohm-cm.
	After adding boric acid = 0.146 megohm-cm at 27°C.

Ion Exchange Resin: Approximately 1/2 cubic foot of Amberlite MB-2 resin and 1/6 cubic foot of Resex 130 in an Elgin 120 demineralizer.

Table A9.f

Run 2 Log

Date	Time	Water Conditions at Point A: Flow Rate Gpm	Resistivity Megohm-cm	Temperature °F	Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
9/30/59	1155	99	0.0120	80	0.0125	-	-	-	0
	1220	99.5	0.0189	82	0.0202	-	-	-	0
	1245	-	0.0295	85	0.0328	-	-	-	0
	1306	-	-	-	-	0.044	31.	0.051	0
	1320	99.5	0.055	86	0.0619	-	-	-	0
	1340	99.5	0.083	89	0.097	-	-	-	
	1400	99.5	-	-	-	0.155	32	0.182	0
	1420	99	0.081	90	0.096	-	-	-	0
	1440	100	0.249	92	0.301	-	-	-	0
	1500	-	-	-	-	0.400	34.1	0.491	0
	1520	100	0.545	94	0.673	-	-	-	0
	1540	100	0.617	94.5	0.767	-	-	-	0
	1600	-	-	-	-	0.730	35.9	0.929	0
	1620	99	1.10	96.5	1.397	-	-	-	0
	1640	99	1.30	97	1.661	-	-	-	0
	1700	-	-	98	-	0.740	38	0.980	0
	1720	99	1.70	99	2.223	-	-	-	0
	1740	99-100	1.90	101	2.532	-	-	-	0
	1800	98-100	2.00	101	2.665	1.5	39.3	2.036	0
	1820	99-100	2.10	102	2.829	-	-	-	0
	1840	99-100	2.10	103	2.856	-	-	-	0
	1900	99-100	2.10	103	2.856	1.70	40	2.338	0
	1920	100	1.90	103	2.584	-	-	-	0
	1925	-	1.83	103	2.489	1.44	40.5	1.998	0
	1930	-	1.81	-	-	-	-	-	-
	1935	-	1.76	104	2.420	-	-	-	-
	1940	99-101	1.72	104	2.365	-	-	-	-
	1942	-	1.70	-	-	-	-	-	2
	1942.5	-	0.740	-	-	-	-	-	2
	1943	-	0.670	-	-	-	-	-	2
	1943.5	-	0.620	-	-	-	-	-	2
	1944	-	0.562	103	0.765	-	-	-	2
	1945	~101.5	0.505	-	-	-	-	-	2
	1946	-	0.461	-	-	-	-	-	2
	1947	101.5	0.437	102	0.589	-	-	-	2

Table A9.f (Continued)

Date	Time	Flow Rate Gpm	Demineralizer Outlet Resistivity Megohm-cm	Demineralizer Outlet Temperature °C	Demineralizer Outlet Resistivity at 25°C Megohm-cm	Remarks See Notes
9/30/59	1155	2.7	1.50	27	1.58	
	1220	2.7	-	-	-	
	1245	2.7	-	-	-	
	1306	2.7	3.15	30	3.54	
	1320	2.7	-	-	-	
	1340	2.7	-	-	-	
	1400	2.7	2.80	31	3.22	
	1420	2.7	-	-	-	
	1440	2.7	-	-	-	
	1500	2.7	2.49	34	3.05	
	1520	2.7	-	-	-	
	1540	2.7	-	-	-	
	1600	2.7	2.00	35	2.50	
	1620	2.7	-	-	-	
	1640	2.7	-	-	-	
	1700	2.7	1.91	38	2.531	
	1720	2.7	-	-	-	
	1740	2.7	-	-	-	
	1800	2.7	2.55	39	3.443	Sample 200 from H_3BO_3 Head Tank
	1820	2.7	-	-	-	
	1840	2.7	-	-	-	
	1900	2.7	2.40	40.5	3.330	Demineralizer Off
	1920	0	-	-	-	Resin Replaced
	1925	0	-	-	-	Sample 201 CIR
	1930	-	-	-	-	
	1935	-	-	-	-	
	1940	-	-	-	-	
	1942	0	-	-	-	Boric Acid Injection Std.
	1942.5	0	-	-	-	
	1943	0	-	-	-	
	1943.5	0	-	-	-	
	1944	0	-	-	-	
	1945	0	-	-	-	
	1946	0	-	-	-	
	1947	0	-	-	-	

Table A9.f (Continued)

Date	Time	Water Conditions at Point A: Flow Rate Gpm	Water Conditions at Point A: Resistivity Megohm-cm	Water Conditions at Point A: Temperature °F	Water Conditions at Point A: Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Water Conditions at Point B: Temperature °C	Water Conditions at Point B: Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
9/30/59	1948	-	0.419	102	0.564	-	-	-	2
	1949	-	0.402	-	-	0.445	40	0.612	2
	1950	-	0.390	-	-	-	-	-	2
	1951	101.5	0.380	101	0.506	-	-	-	2
	1952	-	0.375	-	-	-	-	-	2
	1953	99-100	0.386	101	0.514	-	-	-	0
	1954	-	0.382	-	-	0.390	39.5	0.531	0
	1955	99-100	0.383	101	0.510	-	-	-	0
	2000	100	0.384	101	0.511	-	-	-	0
	2005	-	-	-	-	0.415	39	0.560	0
	2015	-	0.450	101	0.599	-	-	-	0
	2020	99-100	0.460	101	0.613	-	-	-	0
	2040	99.5	0.560	102	0.754	-	-	-	0
	2100	99.5	0.606	103	0.825	0.580	40	0.798	0
	2120	99-100	0.610	104	0.839	0.580	41	0.812	0
	2140	-	0.610	-	-	0.580	41	0.812	0
	2205	99.5	0.612	105	0.850	0.600	41	0.840	0
	2215	-	-	-	-	-	-	-	-
	2220	98-101	0.610	105	0.847	-	-	-	-
	2230	-	0.610	105	0.847	-	-	-	-
	2235	-	0.620	105	0.861	-	-	-	0
	2245	-	0.680	105	0.945	-	-	-	0
	2255	-	0.740	105	1.03	-	-	-	0
	2300	99.5	0.760	105	1.06	0.720	41.5	1.02	0
	2310	-	0.825	105	1.146	-	-	-	0
	2320	98-101	0.890	105	1.236	0.870	41.5	1.23	0
	2340	99-100	1.04	105	1.44	-	-	-	0
	2354	99-100	1.17	105	1.62	-	-	-	0
10/1/59	0000	98-101	1.19	105	1.65	0.88	41.5	1.24	0
	0015	99-101	1.28	105	1.78	-	-	-	0
	0020	99-101	1.29	105	1.79	-	-	-	0
	0030	99-101	1.34	105	1.86	-	-	-	0

Table A9.f (Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Notes
9/30/59	1948	0	-	-	-	
	1949	0	-	-	-	
	1950	0	-	-	-	
	1951	0	-	-	-	
	1952	0	-	-	-	Injection stopped just after reading
	1953	0	-	-	-	
	1954	0	-	-	-	
	1955	0	-	-	-	
	2000	2.6	-	-	-	
	2005	2.6	3.70	39	5.00	Sample 202 CIR
	2015	2.6	-	-	-	Sample 203 DIO[2]
	2020	2.6	-	-	-	
	2040	2.6	1.25	40	1.72	
	2100	2.6	0.600	40	0.825	Sample 204 CIR Sample 205 DIO[3]
	2120	2.6	0.610	40	0.839	
	2140	2.6	0.592	40	0.814	
	2205	2.6	0.600	40	0.825	Sample 206 CIR Sample 207 DIO
	2215	0	-	-	-	Resin Replacement Started
	2220	0	-	-	-	
	2230	2.6	-	-	-	Resin Replacement Complete
	2235	2.6	2.85	40.5	3.96	Sample 208 DIO
	2245	2.6	-	-	-	
	2255	2.6	-	-	-	
	2300	2.6	2.46	40.5	3.41	Sample 209 CIR
	2310	2.6	-	-	-	
	2320	2.6	2.97	41	4.16	Sample 210 CIR
	2340	2.6	-	-	-	
	2354	2.6	-	-	-	
10/1/59	0000	2.6	1.12	40.5	1.55	Sample 211 CIR
	0015	2.6	-	-	-	Sample 212 DIO
	0020	2.6	-	-	-	
	0030	2.6	-	-	-	

Table A9.f (Continued)

Date	Time	Flow Rate Gpm	Water Conditions at Point A: Resistivity Megohm-cm	Water Conditions at Point A: Temperature °F	Water Conditions at Point A: Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Water Conditions at Point B: Temperature °C	Water Conditions at Point B: Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
10/1/59	0040	99-101	1.36	105	1.89	-	-	-	0
	0050	98-101	1.38	105	1.92	-	-	-	0
	0100	98-101	1.37	105	1.90	1.15	42	1.64	0
	0110	98-101	1.36	105	1.89	-	-	-	0
	0120	99-101	1.37	105	1.90	-	-	-	0
	0130	98-100	1.36	105	1.89	-	-	-	0
	0140	98-101	1.36	105	1.89	-	-	-	0
	0150	98-101	1.35	105	1.88	-	-	-	0
	0200	98-102	1.36	105	1.89	1.12	42	1.60	0
	0210	98-102	1.35	105	1.88	-	-	-	0
	0220	98-101	1.34	105	1.86	-	-	-	0
	0230	98-101	1.33	106	1.87	-	-	-	0
	0240	98-101	1.33	106	1.87	-	-	-	0
	0250	98-101	1.33	106	1.87	-	-	-	0
	0300	98-101	1.32	106	1.85	1.11	43	1.61	0
	0310	99-101	1.32	106	1.85	-	-	-	0
	0320	98-101	1.32	106	1.85	-	-	-	0
	0330	98-101	1.32	106	1.85	-	-	-	0
	0340	98-101	1.32	106	1.85	-	-	-	0
	0350	98-101	1.37	106	1.92	-	-	-	0
	0400	98-101	1.35	106	1.89	1.06	43	1.54	0
	0410	98-101	1.34	106	1.88	-	-	-	0
	0420	98-101	1.36	106	1.91	-	-	-	0
	0430	98-101	1.35	106	1.89	-	-	-	0
	0440	98-101	1.35	106	1.89	-	-	-	0
	0450	98-101	1.35	107	1.91	-	-	-	0
	0500	98-101	1.35	107	1.91	1.02	43	1.48	0
	0510	98-101	1.35	107	1.91	-	-	-	0
	0520	98-101	1.36	107	1.93	-	-	-	0
	0530	98-101	1.34	107	1.90	-	-	-	0
	0540	98-101	1.23	107	1.74	-	-	-	0

Table A9.f (Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Notes
10/1/59	0040	2.6	-	-	-	
	0050	2.6	-	-	-	
	0100	2.6	1.40	40	1.92	Sample 213 CIR Sample 214 DIO
	0110	2.6	-	-	-	
	0120	2.6	-	-	-	
	0130	2.6	-	-	-	
	0140	2.6	-	-	-	
	0150	2.6	-	-	-	
	0200	2.6	1.27	41	1.78	Sample 215 CIR Sample 216 DIO
	0210	2.6	-	-	-	
	0220	2.6	-	-	-	
	0230	2.6	-	-	-	
	0240	2.6	-	-	-	
	0250	2.6	-	-	-	
	0300	2.6	1.23	41	1.72	Sample 217 CIR Sample 218 DIO
	0310	2.6	-	-	-	
	0320	2.6	-	-	-	
	0330	2.6	-	-	-	
	0340	2.6	-	-	-	
	0350	2.6	-	-	-	
	0400	2.6	1.28	41	1.79	Sample 219 CIR Sample 220 DIO
	0410	2.6	-	-	-	
	0420	2.6	-	-	-	
	0430	2.6	-	-	-	
	0440	2.6	-	-	-	
	0450	2.6	-	-	-	
	0500	2.6	1.20	41.5	1.69	Sample 221 CIR Sample 222 DIO
	0510	2.6	-	-	-	
	0520	2.6	-	-	-	
	0530	2.6	-	-	-	
	0540	2.6	-	-	-	

Table A9.f (Continued)

Date	Time	Flow Rate Gpm	Water Conditions at Point A: Resistivity Megohm-cm	Temperature °F	Resistivity at 25°C Megohm-cm	Water Conditions at Point B: Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Boric Acid Injection Rate
10/1/59	0550	98-101	1.25	107	1.77	-	-	-	0
	0600	98-101	1.24	107	1.76	-	-	-	0
	0610	97-101	1.24	106	1.74	-	-	-	0
	0620	98-101	1.33	107	1.88	-	-	-	0
	0630	98-101	1.35	107	1.91	-	-	-	0
	0640	98-101	1.36	107	1.93	-	-	-	0
	0650	98-101	1.34	106	1.88	-	-	-	0
	0700	98-101	1.36	107	1.93	1.09	43	1.58	0
	0710	98-101	1.34	108	1.92	-	-	-	0
	0720	98-101	1.36	107	1.93	-	-	-	0
	0730	98-101	1.34	108	1.92	-	-	-	0
	0740	98-101	-	108	-	-	-	-	0
	0750	98-101	1.29	108	1.85	-	-	-	0
	0800	98-101	1.34	108	1.92	-	-	-	0
	0810	98-101	-	108	-	-	-	-	0
	0820	98-101	1.31	107.5	1.87	-	-	-	0
	0830	98-101	1.34	107	1.90	-	-	-	0
	0840	98-101	1.34	106.5	1.89	-	-	-	0
	0850	98-101	1.37	107	1.94	-	-	-	0
	0900	98-101	1.36	107	1.93	1.17	42.5	1.68	0
	0930	98-101	1.37	107	1.94	-	-	-	0
	1000	98-101	1.37	106	1.92	-	-	-	0
	1015	99.5	1.38	107	1.95	1.22	44	1.80	0

Notes: 1. CIR denotes sample taken from sample point B
2. DIO denotes sample taken from demineralizer outlet
3. Sample taken with return flow off

Table A9.f (Continued)

Demineralizer Outlet

Date	Time	Flow Rate Gpm	Resistivity Megohm-cm	Temperature °C	Resistivity at 25°C Megohm-cm	Remarks See Notes
10/1/59	0550	2.6	-	-	-	
	0600	2.6	-	-	-	
	0610	2.6	-	-	-	
	0620	2.6	-	-	-	
	0630	2.6	-	-	-	
	0640	2.6	-	-	-	
	0650	2.6	-	-	-	
	0700	2.6	1.23	41.5	1.74	Sample 223 CIR Sample 224 DIO
	0710	2.6	-	-	-	
	0720	2.6	-	-	-	
	0730	2.6	-	-	-	
	0740	2.6	-	-	-	
	0750	2.6	-	-	-	
	0800	2.6	-	-	-	
	0810	2.6	-	-	-	
	0820	2.6	-	-	-	
	0830	2.6	-	-	-	
	0840	2.6	-	-	-	
	0850	2.6	-	-	-	
	0900	2.6	1.28	41	1.79	Sample 225 CIR Sample 226 DIO
	0930	2.6	-	-	-	
	1000	2.6	-	-	-	
	1015	2.6	1.32	42.5	1.90	Sample 227 DIO Sample 228 CIR Run Terminated

Table A9.g

Analysis of Samples from Run 2

Work Performed by St.Louis Testing Laboratory*

Sample Number	Boric Acid Concentration grams/liter
200	9.64
201	0.03
202	2.19
203	less than 0.01
204	0.985
205	1.02
206	1.02
207	1.03
208	less than 0.01
209	0.57
211	0.18
212	0.07
213	0.15
214	0.15
215	0.15
216	0.15
217	0.15
218	0.16
219	0.15
220	0.16

* C.D.Trowbridge, Report No. T-36702, October 2, 1959

Table A9.h

Analysis of Samples from Run 2

Work Performed by Internuclear Company
50 mℓ Aliquot of Sample Used

Sample Number	Sodium Hydroxide		Boric Acid Concentration (grams/liter)
	Normality(eq/l)	Volume(mℓ)	
200	0.1	29.71	3.67
201	0.01	0.40	0.005
210	0.01	21.02	0.260
221	0.01	3.21	0.040
222	0.01	2.68	0.033
223	0.01	3.17	0.039
224	0.01	1.80	0.022
225*	0.01	0.38	0.005
226	0.01	2.78	0.034
227	0.01	2.56	0.032
227*	0.01	0.48	0.006
228*	0.01	0.36	0.004

* Bromthymal blue indicator used instead of phenophthalien.

Table A9.i

Measurement of Model Volume

First Test

Model Region	Scale I lbs	Scale II lbs	Weight of Water lbs
Tare	33	34	
A	59	60	52
A+B	124	127	184
A+B+C	155	160	248
A+B+C+D	256	~ 270	~ 459
E	52	54	39
E+F	112	114	159
G	{ 155	{ 160	
	256	~270	~ 707

Table A9.j

Measurement of Model Volume

Second Test

Model Region	Scale I lbs	Scale II lbs	Weight of Water lbs
Tare	34	34	
A	60	59	51
A+B	120.5	121	173.5
A+B+C	154	156.5	242.5
Tare	34	36	
D	136	133	199
D+L*	148	144	222
D+E+L	164	161	255
D+E+F+L	224	220	374
Tare	32	35	
G_1**	258	250	441
Tare	68	72	
G_2**	207	215	282

* L = Leakage from volumes A+B+C+D

** G = G_1+G_2

Table A9.k

Model Volume

Model Region	Weight of Water in Region, lbs		Average Volume	
	Test I	Test II	ft^3	gal
A	52	51	0.825	6.18
B	132	122.5	2.04	15.2
C	64	69	1.06	7.97
D	211	199	3.29	24.6
E	39	33	0.577	4.31
F	120	119	1.92	14.3
G	~707	723	11.5	85.7
Leakage from A+B+C+D		23	0.37	2.8

Leakage = 23/441.5 = 5.2%

Table A9.k

Model Volume

Model Region	Weight of Water in Region, lbs Test I	Test II	Average Volume ft^3	gal
A	52	51	0.825	6.18
B	132	122.5	2.04	15.2
C	64	69	1.06	7.97
D	211	199	3.29	24.6
E	39	33	0.577	4.31
F	120	119	1.92	14.3
G	~707	723	11.5	85.7
Leakage from A+B+C+D		23	0.37	2.8

Leakage = 23/441.5 = 5.2%

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