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PERFORMANCE OF UNIAXIAL CREEP MACHINES IN THE NRX AND NRU REACTORS

by

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ABSTRACT

Reactor Loops Branch began operating creep experiments in 1965. At that time, Mk-IV and Mk-VI machines were in use in NRX and NRU. Since then, a number of disposable machines have been built, resulting in the Mk-X design which may be used in either reactor. Control equipment has been automated, and data retrieval computerized. The original and re-designed equipment is described, with details of its operational reliability.

Chalk River Nuclear Laboratories
Chalk River, Ontario
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AECL-3738

Performance de machines uniaxiales de fluage dans les réacteurs NRX et NRU

par

P.G. Anderson

Résumé

La Section des boucles de réacteur a commencé ses expériences de fluage en 1965. On employait alors les machines Mk-IV et Mk-VI dans les réacteurs NRX et NRU. Depuis lors, un certain nombre de machines remplaçables ont été construites. Pour finir, on a mis au point la machine Mk-X pouvant être utilisée dans les deux réacteurs. Les dispositifs de commande ont été automatisés et la récupération des données se fait par ordinateur. Les machines originales et la nouvelle machine sont décrites. Leur fiabilité opérationnelle fait l'objet d'un examen détaillé.

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INTRODUCTION

Creep is defined as the time dependent deformation or strain which continues after the application of a load that is maintained on a solid (1). It is one of the major controlling factors in Canadian power reactor design. The pressure tubes must be thin as possible, for economic reasons, yet thick enough to withstand the stresses under irradiation for the life span of the reactor. Zirconium alloys are used because of their good corrosion resistance and low neutron absorption cross section, but the creep rate of the originally proposed Zircaloy-2 was found to increase under neutron flux in the 200-350°C temperature range (2).

The creep program was set up to define the temperatures and stress ranges over which the creep rate is affected by neutron flux in different Zirconium alloys, and study its mechanism. Creep machines for measuring uniaxial creep have been operating in NRX since 1961, and in NRU since 1965.

At CRNL, the load on the specimen is applied by a pneumatic bellows, and strain measurements are made using pneumatic nozzles (NRX sec. 4). Helium is the preferred gas in reactor, because of its inertness in a neutron field, and high heat conductivity which allows a wide variety of specimen test temperatures. Originally, a once-through flow from a high pressure cyclinder was used, exhausting the gas to atmosphere. When more creep experiments were planned, recirculating systems were built, which allowed recovery of helium as well as some control of back pressure on each machine.

In November 1965, on request from Reactor Materials Branch, Reactor Loops Branch took over responsibility for operation of the two creep tests then in NRX, and the installation, operation and removal of subsequent tests. The NRX Reactor Branch accepted responsibility for routine and off-shift running of creep machines in December. During the first year, supervisors and operators were trained, an operating manual was written, and drawings brought up to date with a view to a complete NRX Branch take-over. This did not prove feasible because of the subsequent increase in number of facilities, their specialized nature, and continuing design changes in the machines and control system. In NRU, Reactor Loops Branch assumed similar responsibilities after the equipment had been built to control the standardized Mk-X and Mk-XII machines. NRU Reactor Branch operate as in NRX, and each Branch has assigned an engineer on 'special irradiations' which include creep facilities. Also, one or two NRU operators at a time have been attached to Reactor Loops Branch staff since November 1965, to learn all aspects of creep operation, carry out non-routine tests in either reactor, and assist in training regular operators.

At present in NRX, there are control units for seven creep machines, all except one in-reactor. Four of these have both manual and automatic flow control and readout. The automatic system allows manual or automatic stepping of controlled flows between the units, and regular print-outs of data by the REDACE (Reactor Data Centre - basically a Honeywell H610) computer. Because of the use of high and low flow nozzles in NRX machines, continuous measuring flow on all units is not possible with the present compressor. In NRU, there are controls for four machines, three in-reactor and one out-reactor. Only machines with low flow nozzles are used, and full flows may be maintained automatically on all units at once.

Computer scans on the creep machines include readings of temperature, stress, the ΔP to calculate strain, flux, and others necessary to insure good performance of the creep machines, instruments, and fast neutron rods.

PART I NRX

1. GENERAL

The first creep machines were tested in NRX. So far, 45 tests have been installed, for varying periods, the longest being in the reactor for about three years.

Until May 1969, measurements were made of creep rate in the low strain region, i.e. below ~5% strain. In-reactor measurements of tertiary creep had been attempted using an LVDT (linear variable differential transformer) system without success. Now two tests using pneumatic gauges are in progress in Mk-X machines (Sec. 3).

Because of the greater number of tests, frequency of test changes, and similarity of control equipment between reactors, NRX has been used for training both NRX and NRU operators. However, the NRU shifts do not all have fully trained men yet, and any operations other than routine readings or off-shift emergencies are done from NRX, using the NRU operator on loan.

In order to get better off-shift and weekend supervision of the NRX machines, a scheme to fully train all NRX operators, on a rotational basis, continued from September 1968, to June 1970.

2. CREEP SITES AND CONTROLS

When Reactor Loops Branch took over the operation of creep machines, C-7 and N-5 low flux sites were in use, and three sets of controls - comprising helium flow, heater and bellows - with temperature recorders, had been built on the "Fast Neutron" (F/N) experimental platform. Nylon and rubber tubing was used in the reactor Upper Header Room (UHR) for readout and helium recirculation.

Subsequently, L-27, C-17 and K-12 were added as low, medium and high flux positions, and all sites were fitted with copper tubing in the UHR, because of susceptibility to damage of the nylon and rubber. A fourth set of controls was built, and since all lines from the five reactor positions end at bulkhead fittings on the F/N platform, suitable cross-connections allow a machine in any position to be operated from any of the sets of controls. Auto flow control and readout cabinets were later connected to the four units at the F/N platform (Figure 1). At the end of 1968, the C-7 and N-5 positions were replaced by two of high flux, G-15 and H-20. In 1969, when measurements of tertiary creep were started, position P-24 was added, H-12 was used to replace the damaged G-15, and two further sets of controls with manual flow control and readout built. In 1970, H-12 was needed by NRX for fuelling and E-15 became available for creep tests.

For out-reactor testing or commissioning, two water cooled facilities simulating F/N rods were built, one inside the New Storage Block for active machines, and the other outside for new or inactive machines. A control panel consisting of two power supplies, recorder, manual flow control and manual readout was also built at the NSB, and connected to the helium recirculating system. Also, service lines were run so that an out-reactor test can be operated from the F/N platform.

3. TYPES OF MACHINES AND HEATERS, AND MACHINE OPERATION

Machines and Heaters

The Mk-IV reusable creep machine (4) has been used since 1965, initially inside a Mk-IV and later in a Mk-III F or Mk-V heater. The insert consists of a top bulkhead for service connections, connecting tube, and lower creep machine section comprising pneumatic nozzle, yoke assembly, and bellows assembly (Figure 2). The machine may be telescoped from the heater, enabling the specimen to be changed in the Universal Cells, and is the only design to date in which many specimens have been successfully changed. It is still particularly useful for the testing of irradiated specimens, because of the ability to install them in the Universal Cells. Because of the need to go to higher flux (more γ heating), and the high cost and fairly frequent failure of thermocouples and other components,

Auto and Manual Control and Readout, Helium Recirculation Panels

Control Panels for Four Creep Machines

Figure 1: NRX In-Reactor Control Equipment

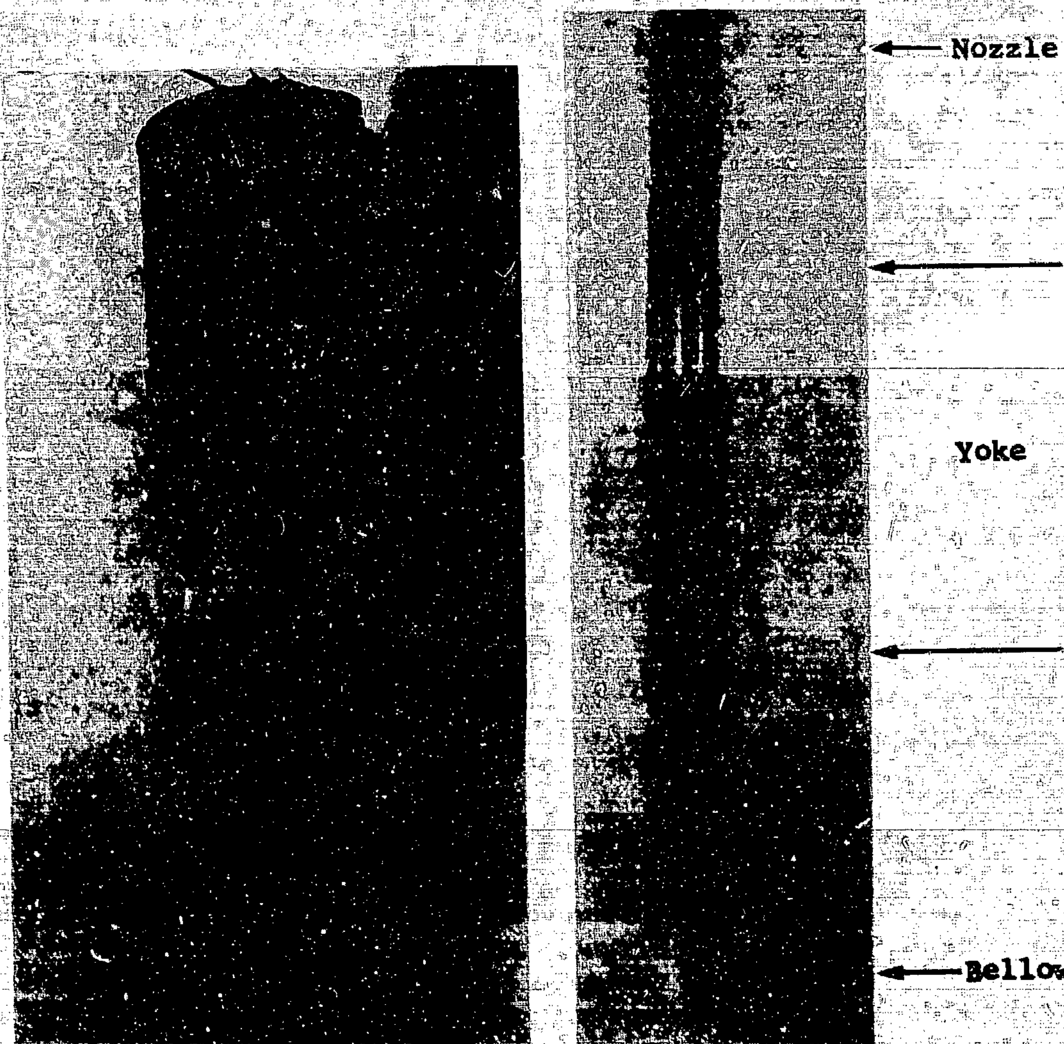

Figure 2: NRX Mk IV H Creep Machine

e.g. yoke sections that have become loose or damaged, a disposable Mk-X design was developed (3). This machine is assembled at CRNL from 'standard' components (nozzle, bellows etc.) and has a small integral three-section heater wound from thin Ceramo* type wire surrounding the specimen only, and is designated Mk IX in NRX (Figure 3). So far, only three tests have been completed in NRX with this type of machine, but experience in NRU is encouraging, and the machine is described in more detail in the NRU section 3. Because of lower γ heating and smaller space inside an NRX fast neutron (F/N) rod the cooling coil is omitted. The Mk-XII design is an Mk-X machine with a modified top section enabling irradiation in both NRX and NRU. A separate water jacket is used in NRU (NRU sec. 3).

The Mk-IV heater, used with the earlier Mk-IV H machine, was made from a single length of Nichrome wire wound on and covered by layers of sprayed 'Rokide'** insulation. Leads were tapped at intervals from the 3-4 ft heater length, producing five sections for heating gas (two), nozzle, specimen and bellows. The failure rate of these heaters was high due to shorting between the heater wire or leads, and the inner or outer sheaths. The improved Mk-V and later Mk-III F designs, which have isolated heater sections made from Ceramo type wire, have been in use successfully since 1966 (Figure 4). These two designs differ in outside diameter to allow close fits in Mk-V or Mk-III F F/N rods. Early heaters had a heat conductivity too low for operation of tests at temperatures below 300°C in high flux positions, and later models contained graphite which improved conductivity. A close tolerance to the cooled wall of the F/N rod is also necessary for successful operation at low (<300°C) test temperatures. All heaters

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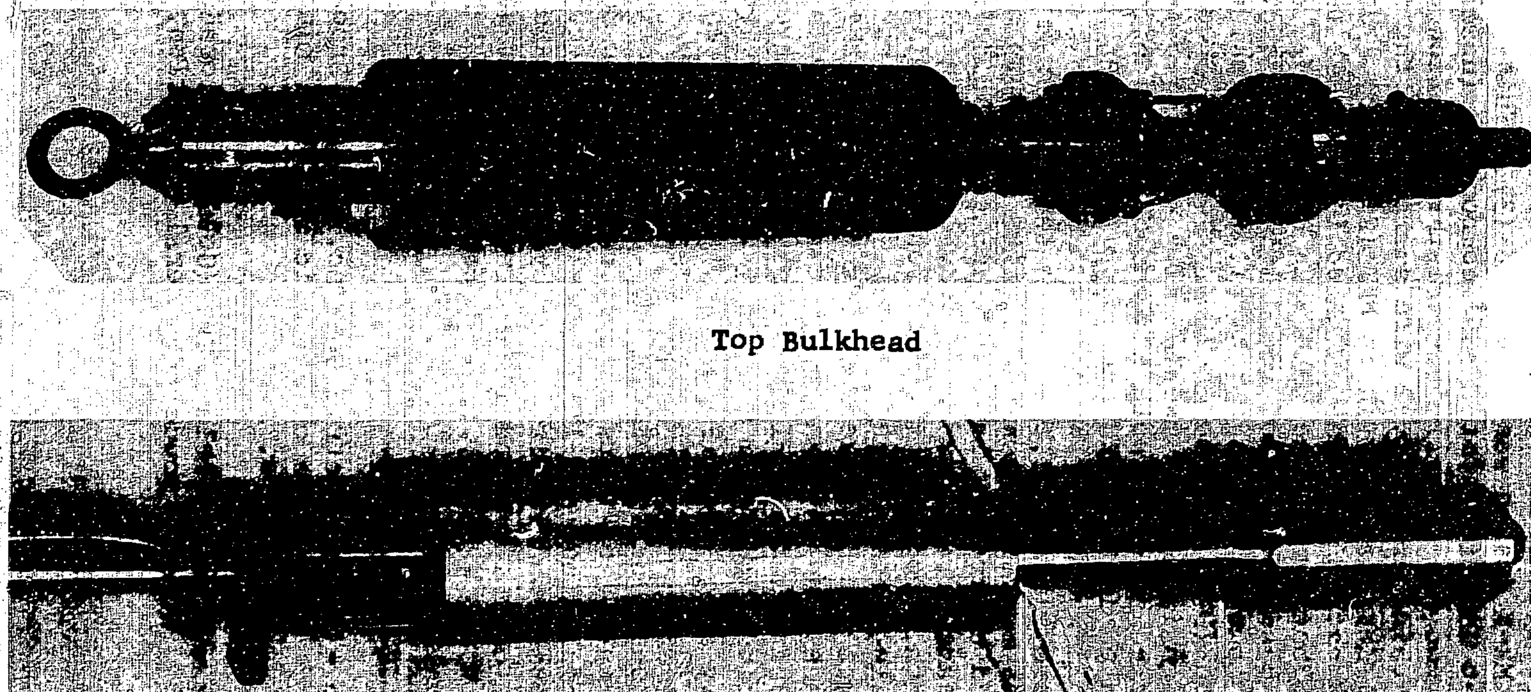
* Ceramo - Thermoelectric Co. Inc. (Saddle Brook, N.J.) trade name of metallic sheathed, mineral insulated wire.

** Rokide - Coors Porcelain Co. (Golden, Colorado) trade name of powdered mineral insulation.



Top Bulkhead

Nozzle Heater and Specimen Can Bellows

Figure 3: NRX Mk-IX Creep Machine Components

are ring gauged and have straightness specifications to avoid unduly tight fits in the F/N rods. For ease of connection in the reactor, the leads terminate in a plug at the top of each heater (Figure 4).

Mk-IV Machine Operation

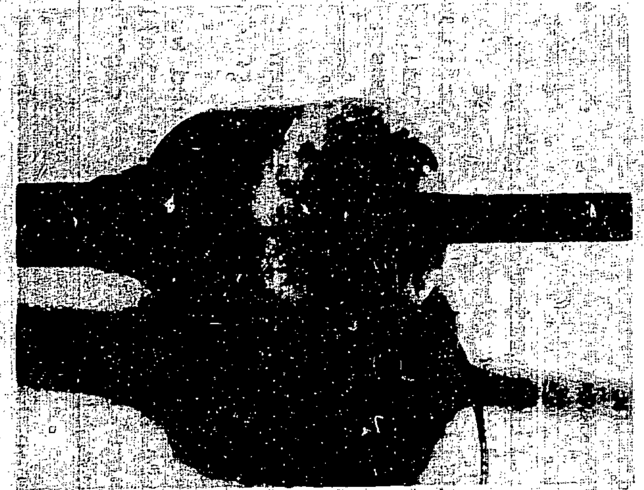
All these machines have been built under contract, and either calibrated by the manufacturer or by Reactor Materials Branch.

The specifications do not include a vacuum test of the insert, and many have leaked when first tested. Sources of leakage include the epoxy seal at the top of the insert where some thermocouples emerge, the 'O' ring seals where the replaceable thermocouples connect at the top of their guide tubes, flux monitor tubes and helium line connections at the bulkhead fittings. Most of these leaks have been fairly easily repaired after location, during the out-reactor testing. The 'O' ring seals have sometimes required epoxy sealing, and helium lines at fittings have required resoldering.

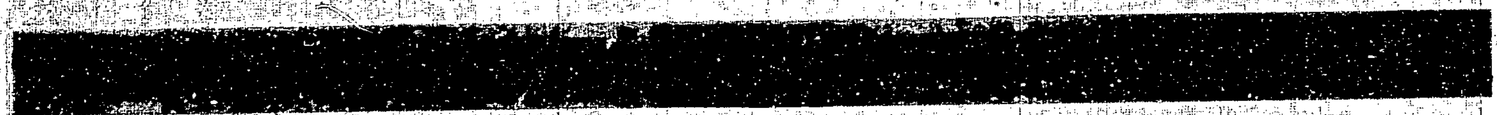
Because of close tolerances, some specimen shoulders were abraded to allow them to fit into the yoke recesses.

In-reactor, Mk-IV machines have performed well, the two main sources of trouble being leakage in the bellows systems, and pneumatic gauge instabilities or friction in the yoke-needle-nozzle assemblies.

Small leakage in the bellows or lines can be tolerated, but large leaks (say >100 lb/in^2 per hour from the supply cylinder) either reduce the stress on the specimen, cause too frequent supply cylinder changing, or upset the helium recirculation system, i.e. cause too frequent venting. If a bellows is leaking, the actual stress on the specimen can be confirmed by connecting the second bellows line (each bellows has two lines to the top of the insert) to a pressure gauge on the F/N platform. Most leaks have been in the bellows lines at joints approximately 1 ft from the bellows themselves,



Top Plug of Heater



Mk-V or III F Type Heater with Sheath Removed

Figure 4: Mk-V Heater - Outer Sheath Removed and Top Plug

and then rates of up to 100 lb/in^2 have shown no loss in specimen stress. Another source of leakage has been in the quick-disconnect fittings at the top bulkheads on the machines. This type of fitting is useful for retaining stress on the specimen when a machine is being moved. However, because a leak cannot be repaired with the reactor operating, these fittings have been replaced with Swageloks.* When leaks within a machine are intolerable, it is removed from the reactor at the first shutdown, and repairs carried out in the Universal Cells.

Instabilities in yoke assemblies, e.g. from screw loosening, are identified by abnormal strain changes or sudden shifts in the strain measurements. Moduli may be run to check the changes in gap of the needle assembly under various stresses, and if the yokes are loose, repeatability is unobtainable. If friction is present, moduli show large hysteresis and are either not reproducible, or exhibit less specimen deformation than when the test was started. Sometimes, a different stress or temperature produces more stable behaviour, but if this cannot be determined or tolerated, the machine is removed at reactor shutdown for repairs.

<u>Mk-X Machine Operation</u>

This is covered by NRU section 3.

4. STRAIN MEASUREMENTS

<u>General</u>

Strain measurements are made using a pneumatic gauge, with helium as the gas. The gauge consists of a fixed orifice and another in series whose characteristics depend on the closeness of a needle or flat baffle to it.

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* Swageloks - Crawford Fitting Co. (Cleveland, Ohio) trade name for a widely used compression fitting.

The specimen is attached to this baffle (Figure 5). Static pressure lines (P_1, P_2 and P_3) transmit pressures from each side of the fixed orifice, at P_1 and P_2, and downstream of the variable one at P_3, to sensitive differential pressure gauges. A flow to produce a constant pressure drop of 250 inH_2O (18.4 inHg) is maintained between P_1 and P_3 (P_F), and movement of the needle baffle then changes the pressure drop P_1-P_2 across the fixed orifice (P_v).
i.e. $P_1 - P_3$(constant = $(P_1 - P_2) + (P_2 - P_3)$

As the needle moves into the orifice, P_2-P_3 increases and P_1-P_2 must decrease. Hence, as the orifice size is reduced, the P_v reading decreases. Length changes in the specimen can therefore be determined by reference to the nozzle calibration curve, which relates P_v to strain.

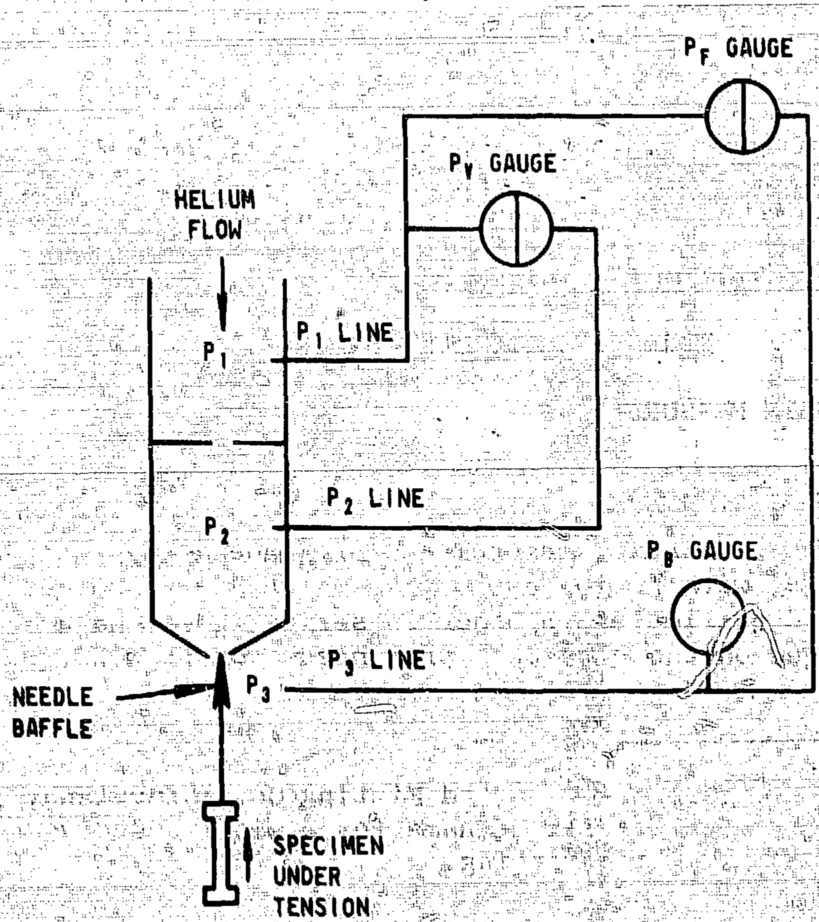


Figure 5: Pneumatic Nozzle and Manual Readout

Nozzle Calibrations

Each nozzle is calibrated before operation in a creep test. In Mk-IV machines this is done before installation of the specimen and in Mk-X machines before assembly of the machine. The nozzle is set up in a flow control and readout system, with the baffle connected to a sensitive micrometer. A plot is made of P_v (variable pressure) readings against a series of gap settings between the baffle and nozzle, at a known back pressure, P_B (Figure 6). Mk-IV machine nozzles are usually calibrated at room temperature and temperatures at which the tests may operate, because there is control of nozzle temperature. Nozzles for Mk-X machines are calibrated at room temperature and at various points up to or above the estimated maximum γ heat temperature, because their temperatures are flux dependent.

All the early machines used flat baffles, which were very sensitive over their small ranges (~0.020 in.) but showed unstable regions in the calibration curves. These instabilities are a function of orifice size and baffle machined finish and are dependent on back pressure. By varying this pressure a stable reading could usually be obtained.

Because calibr-tion curves are obtained at a particular back pressure, strain curves can only be plotted accurately knowing the P_v reading at this back pressure. Initially, all nozzles were calibrated at atmospheric pressure, but it was not feasible to operate creep machines at this pressure because of the ease with which air could leak in and contaminate the helium. Therefore high back pressures were used, and correction curves of P_B against P_v plotted at intervals during the test by varying the low pressure tank pressure, and thus P_B (Figure 7). At present, nozzles are calibrated at 34 inHg abs. but it is normally only possible to operate one machine at this back pressure since the geometry is different in different machines. Individual back pressure controls will be added, which should eliminate the need for regular correction curves. However, if unstable portions of the calibration curves are reached, large differences in P_v reading may sometimes

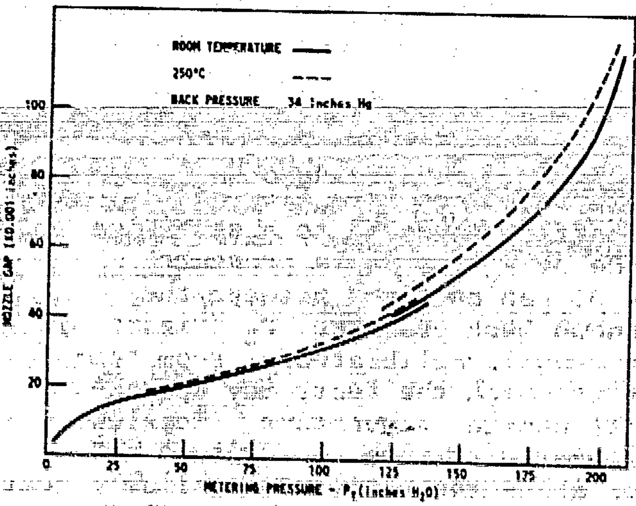


Figure 6: Typical Nozzle Calibration Curve

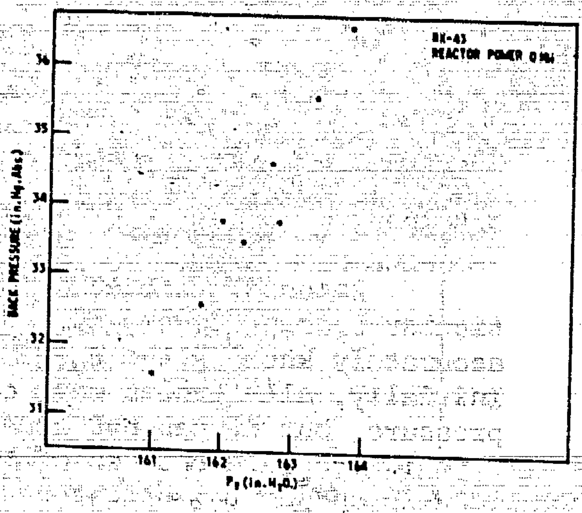


Figure 7: P_v Changes with Back Pressure

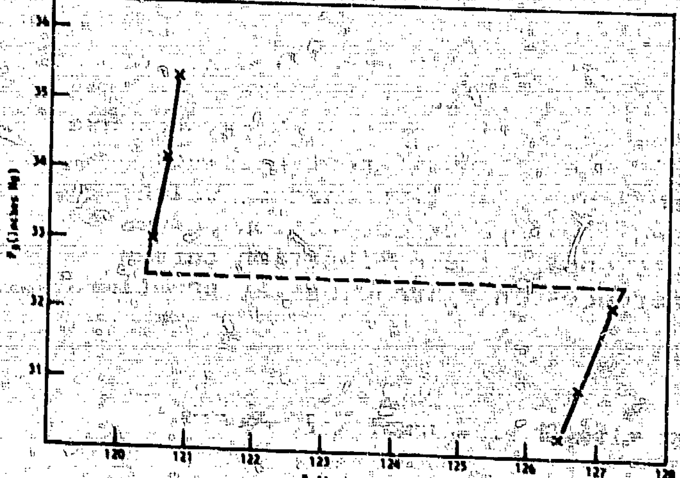


Figure 8: P_v Variation in Unstable Region of Calibration Curve

occur with small changes in back pressure (Figure 8). Back pressure correction curves are then necessary to determine a stable operating pressure.

Temperature Calibrations

In Mk-IV machines, gas, nozzle and lower yoke are kept at specimen temperature if possible, except when specimen temperatures are above 350°C, then gas and nozzle are maintained at a temperature for which calibrations are available (normally $\leq$ 300°C). Variation in any of these temperatures affects the strain measurement, and corrections can be made by plotting temperature versus P_V for various parts of the machine. For example, a nozzle temperature calibration may be obtained by varying that temperature, in 5 deg C steps, 20 deg C above and below the required temperature, and noting the P_V at each step.

In Mk-X machines, only the specimen temperature can be varied by adjustment of controllers, and temperatures of gas, nozzle etc. are dependent on γ heating. This type of machine is constructed so that these temperatures will run as low as possible (NRU machines have water cooling) and the effect due to γ heating is accounted for by measurement of the gas and nozzle temperatures and comparison with out-reactor control runs.

Manual Readout

The manual readout system uses accurately calibrated Wallace and Tiernan gauges which can be read to 0.10 inH_2O. When a strain measurement is made, the flow is adjusted to give exactly 250 inH_2O on the P_F (P_1-P_3) gauge after sufficient time has elapsed to give a steady P_V (P_1-P_2) reading. Curves have been plotted of P_V against time after the flow has been put on, and these showed variation between units in the range 2-20 minutes (Figure 9). This variation is due to slight differences in materials and construction, and times required for equilibrium temperatures of components to be reached. It was also found that a steady P_V reading was affected by make-up to the recirculating system, which disrupted the 250 inH_2O P_F. Therefore, a low leak rate on the recirculating system is desirable.

Manual P_v readings are taken once per shift on units connected in parallel to the automatic system. These serve as back-up when the auto flow control, readout, and REDACE are working, or as substitutes when any of these have failed. On the units with manual readout only, the measuring flow is left on all the time and readings are normally taken every hour.

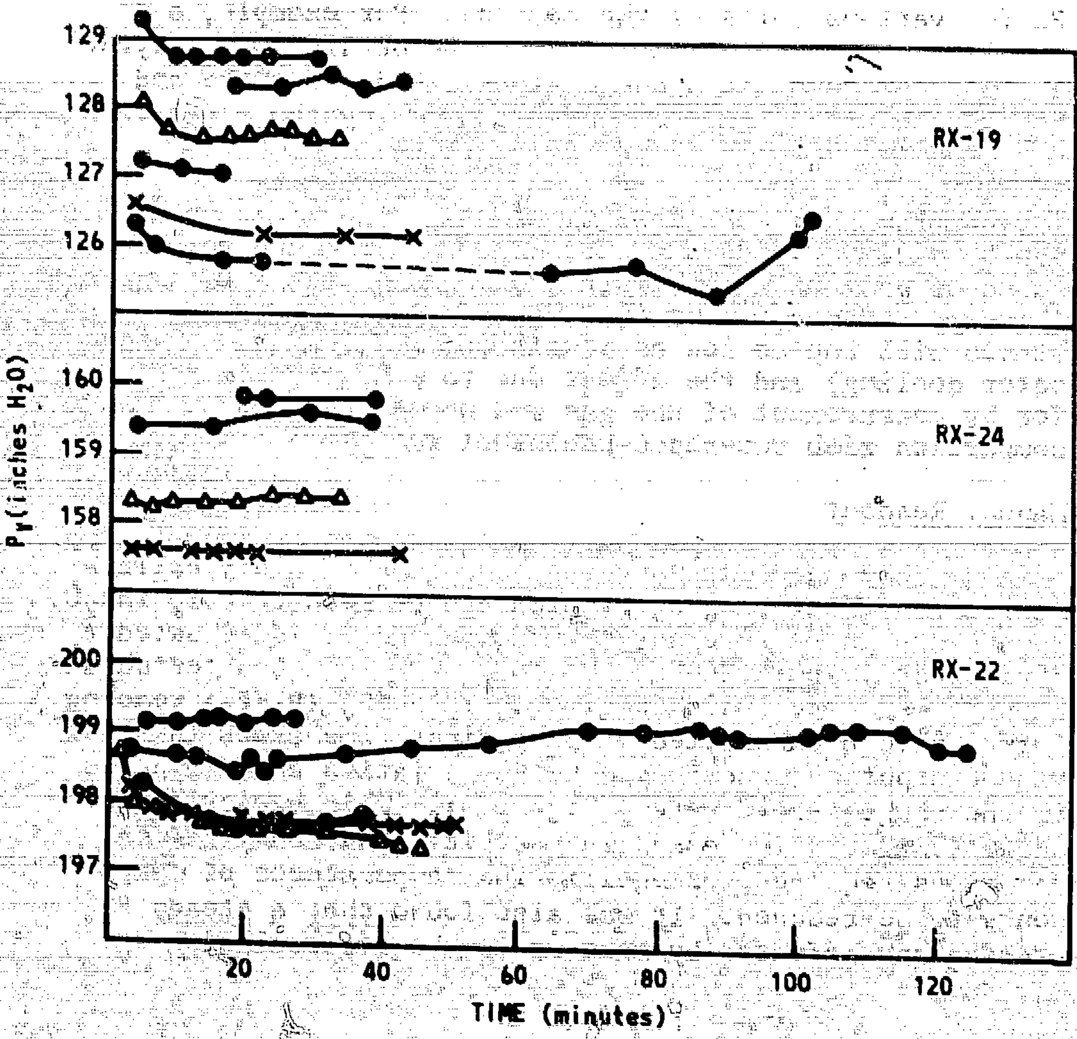


Figure 9: P_V Versus Time Plots for Different Machines

Auto Readout

A Texas Instrument Inc.* differential pressure gauge is used for automatic P_v readout (Figure 10). A variable resistor in the instrument converts the P_v reading to a millivolt signal, which is converted and printed out from REDACE in bars.

Auto readout is connected to four of the six in-reactor units, and is used in parallel with a manual readout system. Readings from both systems can be compared, since the Texas Instruments are calibrated so that equivalents between instrument readings, millivolts, bars and inches of water are known.

The auto readout system has enabled the frequency of readings to be increased, and it is the P_v's recorded on magnetic tape in REDACE that are used for the strain plots. The 'measuring flow' is programmed to switch from unit to unit so that at least one scan per hour from each unit goes to magnetic tape. The P_v Texas Instrument has been trouble-free except for two occasions when the mechanism seized.

Value of Readings

A creep rate is established from the slope of a strain (or P_v) plot against time. Since creep is a slow process, the time needed to establish a reliable creep rate may be weeks or months, dependent on test temperature, stress, type of alloy etc. with consistent strain readings. However, small changes in a number of parameters can affect the P_v readings greatly in comparison to creep, resulting

* Texas Instrument - Model 141 Fused Quartz Precision Pressure Gauge - This instrument employs an interchangeable fused quartz pressure sensitive element to measure gauge, absolute, and differential pressures. The bourdon tube deflection is measured optically and converted to a digital reading.

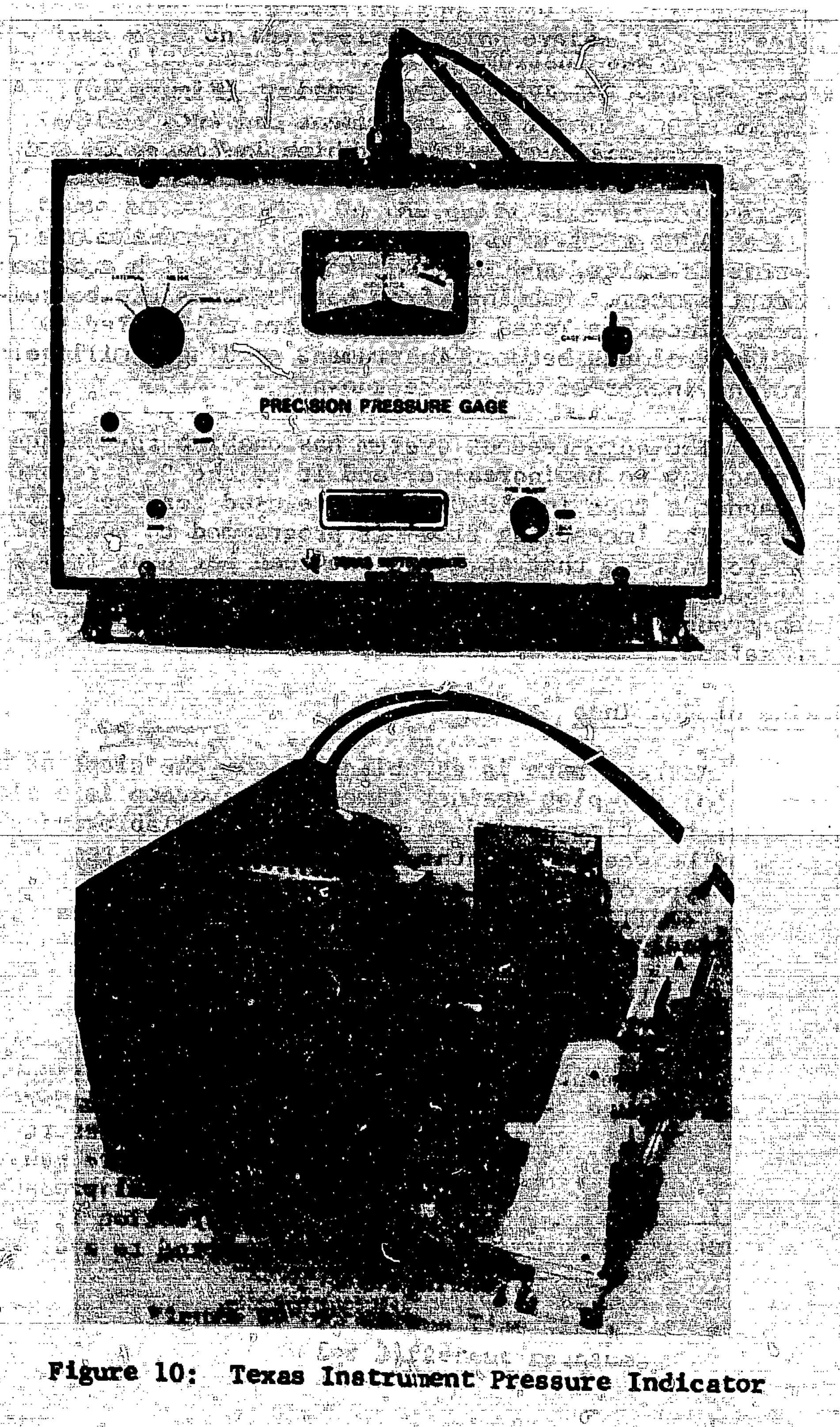


Figure 10: Texas Instrument Pressure Indicator

in widely 'scattered' readings, i.e. a temperature change of 5 deg C in the specimen may produce a P_V change equivalent to several weeks creep. Other cause of 'scatter' in the P_V readings common to the manual and automatic readouts include poor stress control, poor P_F control, changes in back pressure or reactor power, friction in the machine, and helium leakage from measuring lines. In the automatic readout, additional problems are electronic breakdowns in the instruments, poor GAIN or DAMP adjustments, and incorrect motorized valve operation in the P_1, P_2 and P_3 lines.

Temperature and stress controls have generally been within ± 1%, and P_F control within 1/4% for a specific unit. Back pressure and flux changes can be corrected from calibration curves. If friction is suspected in a machine, a stress modulus is carried out. Sometimes, a sudden change in P_V reading is caused by leakage in the P_1, P_2 and P_3 lines or malfunction of the electric valves on these lines (see section 5.1 Automatic Control). Since the manual and auto readouts are normally in parallel, poor operation of the Texas Instruments can be detected.

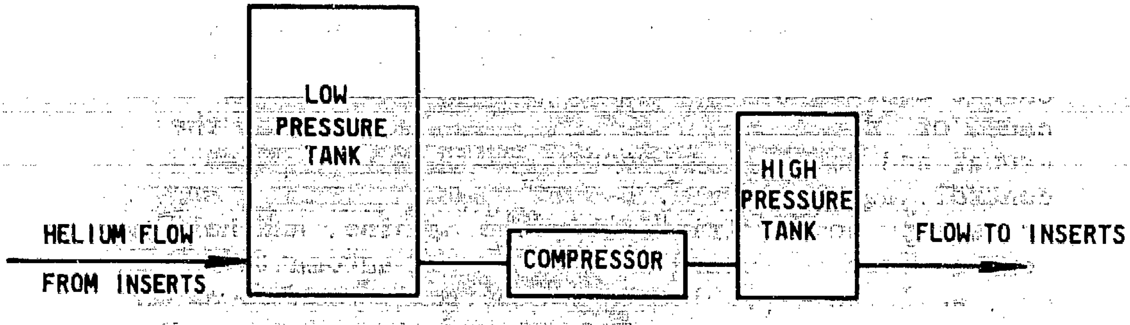
5. OPERATION OF CONTROL EQUIPMENT AND CHANGES IN DESIGN

5.1 Helium Recirculating System

General Operation

The recirculating system was built to conserve helium, by reusing the gas required for pneumatic gauge measurements. It consists basically of a low pressure storage tank, compressor, and high pressure storage tank (Figure 11). There is provision for maintaining the pressure in the low pressure tank between two limits with automatic make-up through a solenoid valve from supply cylinders, and vent through a solenoid to stack.

The original recirculating system was extended to include Units #4, #6 and #7 on the experimental platform,



Simplified Recirculating Schematic

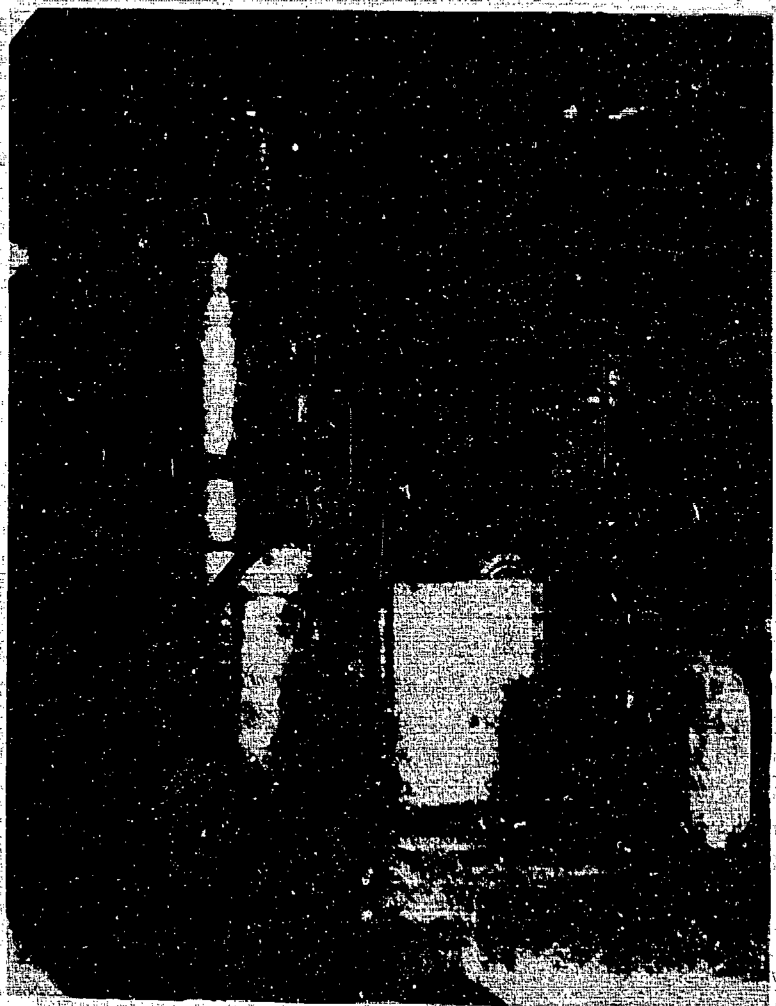


Figure 11: Helium Recirculating System

Unit #5 at the New Storage Block, and the Auto Readout panels (Figure 12).

A Budenberg pressure gauge with high and low alarms was connected in the supply line to a tee downstream of the regulators, to warn of regulator failure. An additional regulator was installed in parallel to the existing one, with isolating valves on both, to avoid interruption of helium supply on regulator failure.

Because of the requirement of sampling helium for impurities and moisture at regular intervals, a circuit was added to the low pressure tank connected to the vacuum pump so that evacuated sample bombs could be used if necessary. As a manually controlled vent is sometimes required from the helium system a Schutte and Koerting flowrator with control valve was added in the sampling line, which is connected to the exhaust stack. Recently, a dehydrafilter has been installed in the main supply line to remove traces of water in the helium. The possibility of adding both oxygen and moisture analysers in the helium system is being investigated.

The recirculating system has operated well mechanically, and the only component to give trouble was the Ashcroft low pressure tank pressure controller on the control panel. The contacts wore, causing arcing, which in turn produced make-ups and ventings of varying magnitude due to erratic solenoid operation. The pressure controller was replaced by a MonOcon gauge with associated relay box in 1968, which has been in continuous use with no maintenance since. Because of the large number of connections, the normal leak rate has been up to 300 lb/in^2 per shift (pressure drop on supply cylinder), with four machines in service. All inserts are leak tested before and after insertion into the reactor and the leaks stopped wherever possible. Particular care is taken to check the static pressure lines because leaks in those can give erroneous strain readings.

Large leaks in the system cause frequent make-ups, which affect the stability of the flow control through the

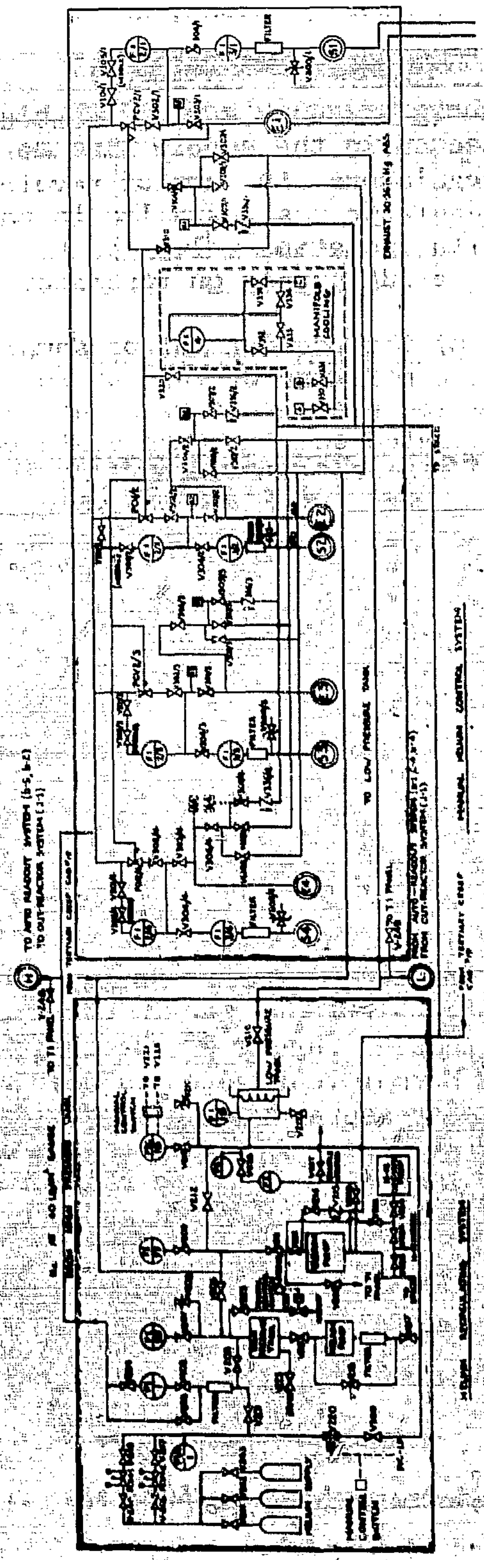


Figure 12: Helium Recirculating System Flowsheet

insert, because of changing system pressures, and hence affect the strain measurements. Sometimes, make-up rates have been reduced due to leaking bellows on the machine, i.e. leaking into the system. If these leaks are large enough to over-compensate for losses from the recirculating system, a controlled manual vent from the low pressure tank is maintained to give a make-up every 3-5 minutes.

Manual System

In this system, flows to the inserts are controlled from manually operated Moore pressure regulators on each unit. An early source of trouble was leakage in these valves, which appeared as a helium flow from the vent hole in the case, behind the diaphragm. It was repaired by applying sealing compound around the stem attached to the diaphragm. Since the manual system is now only used when repairs are being carried out on the auto control panel, or when this system is suspect, the problem has not recurred. However, when the units were valved into the auto control system there was a second large source of leakage in the same pressure regulators apparently from the body flanges. The operation of this type of regulator depends on a steady vent, which in this system is recovered to the recirculating system low pressure tank. When the manual system was shut off, the regulator common vent valve was closed because no flow was required through the regulators, and a high leak rate occurred until this valve was re-opened. i.e. a vent is required even with no flow.

Auto Control

The helium flow is controlled by a Texas Instrument* (Figure 13) containing a Moore regulator, with its quartz

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* Texas Instrument - Model 156 Precision Pressure Gauge Controller - The pressure gauge part of the instrument is essentially the same as the model 141

(cont'd)

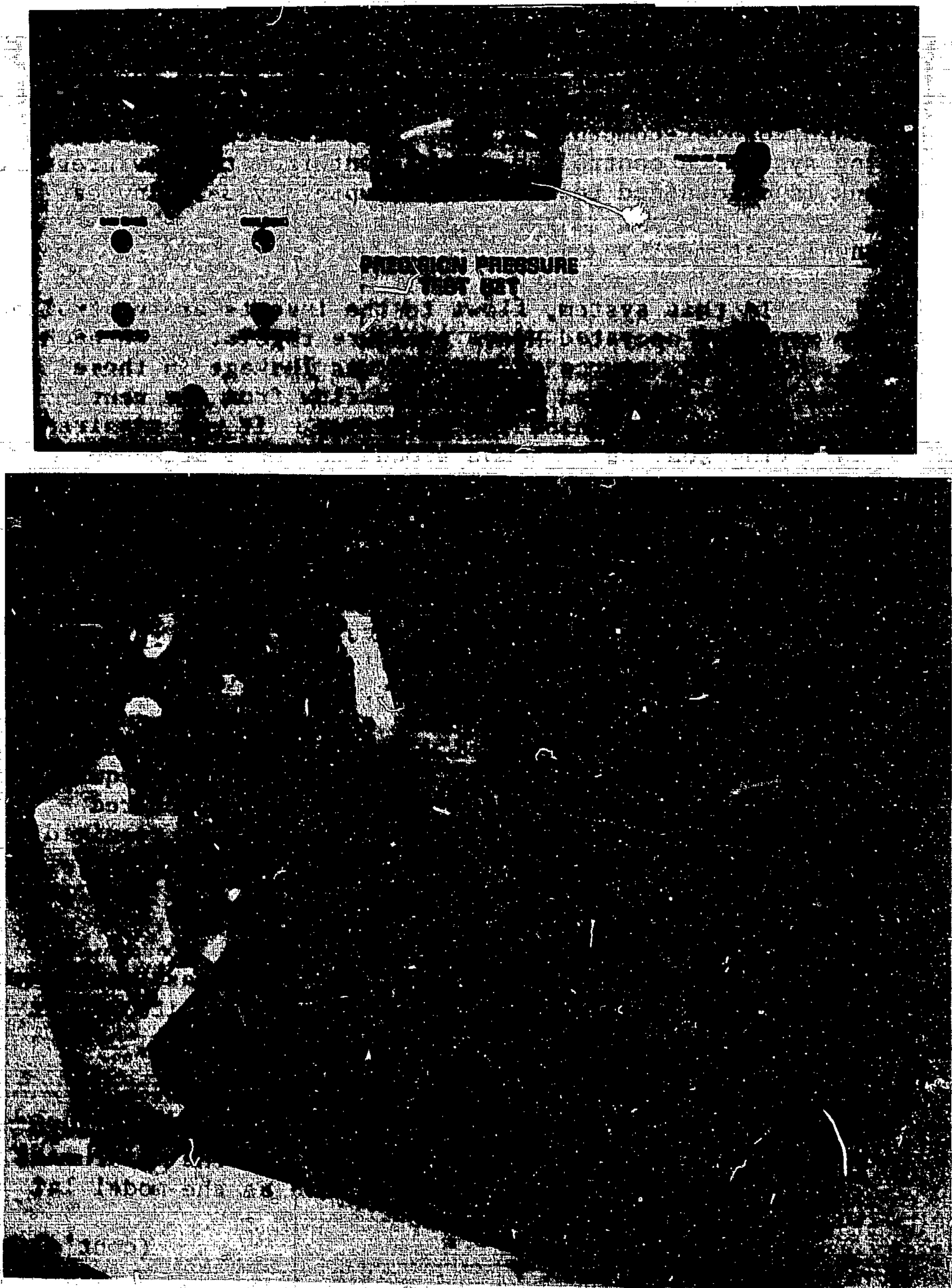

Figure 13: Texas Instrument Pressure Controller

sensing element connected between the P_1 and P_3 common lines from the inserts. After calibration against an accurate manometer, the instrument is installed in the system and the control set up with flow on a unit, by GAIN and DAMP adjustments. With this instrument switched to CONTROL and the dial setting at the calibrated figure for 250 inH_2O, the Wallace and Tiernan P_F gauge should read 250 inH_2O if the two calibrations agree. An external signal of -50 mV to +50 mV for a deviation -1/2% to +1/2% from the control point can be used for an accurate measure of control. At first, this signal was recorded on REDACE, but its disadvantage was that it did not indicate the absolute P_F (fixed pressure) reading. Later, a second Texas Instrument gauge (Sec. 4) was connected in parallel to the P_F controller and a millivolt signal from this recorded on the REDACE scans.

It was found that a control setting on the P_F controller does not give exactly the same 250 inH_2O reading for all units (maybe 0.1% out). However, when the manual readings are taken, the Wallace and Tiernan P_F reading is taken on all units and corrections can be made if necessary.

The auto flow control panel is fitted with electrically operated valves (denoted [M]–), and a stepping system either computer or manually controlled which allows a measuring flow through one insert at a time while maintaining a bleed flow of helium on the others (Figures 1 and 14). When the measuring flow is on a particular unit, electric valves on the P_1, P_2 and P_3 lines of this unit are open and all other similar valves closed. These valves move through 90° to open or close and some incorrect strain readings have been obtained because of more

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(described in Sec. 4). In the SERVO CONTROL switch position, the digital reading is preset, and the differential pressure in the capsule corresponding to this reading will automatically be obtained through a motor driven Moore regulator in the instrument.

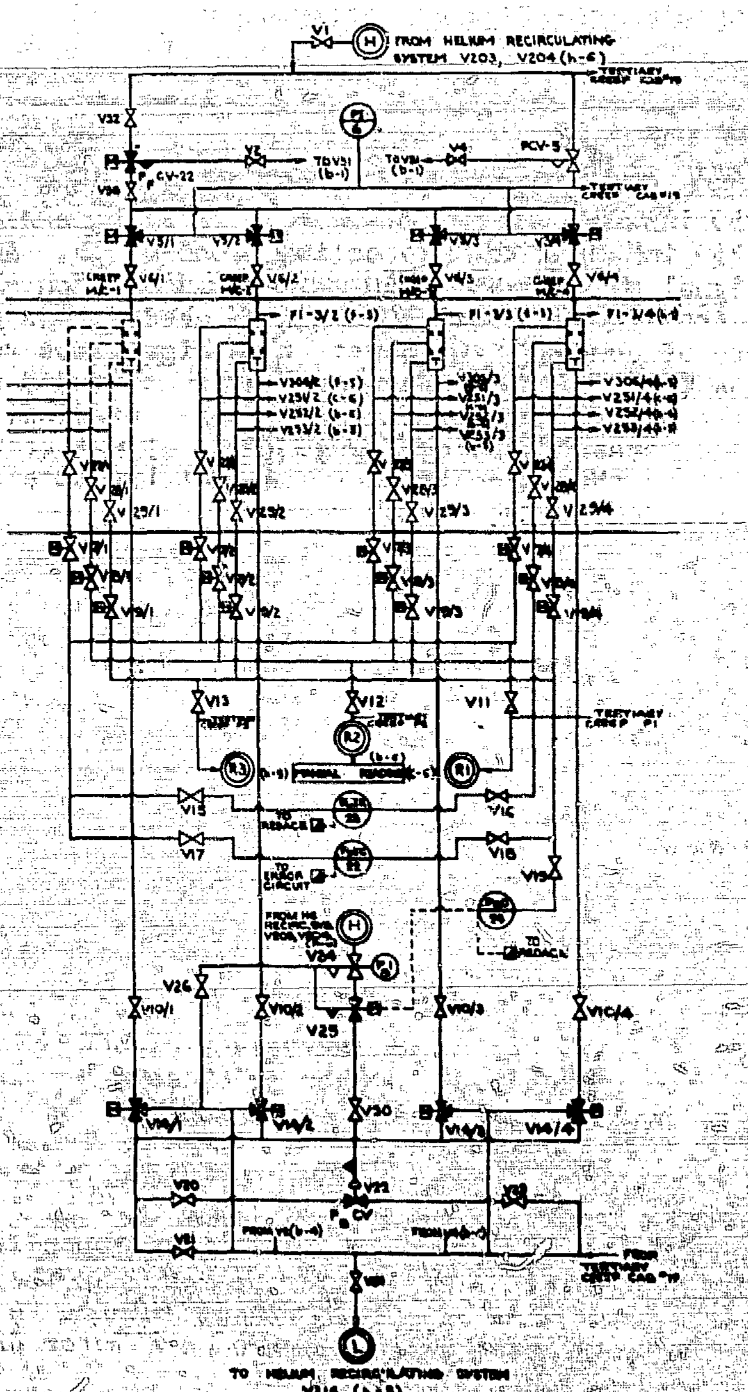


Figure 14: Automatic Flow Control Flowsheet

or less movement than is required. If a P_1 valve does not close on a particular unit when the flow is switched to another it may not be possible to obtain the 250 inH_2O differential on the second unit and a low P_v (differential between P_1 and P_2) or strain reading will result. If the P_2 valve does not close, leakage will occur from the P_2 line of the unit being read and the P_v reading will be high. If the P_3 valve does not close, leakage will occur from the P_3 line of the unit being read, and the P_B back pressure will be lower. Then the P_v reading will be lower as a result of a lower P_3 pressure, lower P_1 pressure and helium flow. Sometimes the incorrect movement of an electrically operated valve has been repaired by manually moving the stem of the valve to the correct position, after which it has operated normally. On other occasions a microswitch that controls the movement of the stem was found to be broken, and there have been cases where the position of the cam that operates the microswitch appeared to have changed. In addition to mechanical failures, another cause of valve malfunction is the switching of flows too quickly from unit to unit, without allowing sufficient time for the complete movement of the valves to take place.

The REDACE computer is programmed to switch the measuring flow from unit to unit (those that have been pre-selected) in sequence, so that the flow is on each unit at least once per hour. The switch is only made if the flow has been on one unit for a predetermined minimum time. The unit with flow on is scanned just before the flow switches, and the data is printed out.

Flow can be put on any unit manually as required, or with or without cancelling the automatic functions.

The Texas Instrument flow controller has in general been reliable, with periodic adjustments of GAIN and DAMP to improve control. Initially, the limit switch on travel of the Moore regulator stem was moved to allow more movement to obtain 250 inH_2O P_P. Two major repairs were the replacement of the solar cells after a few months operation, and later a new set of reduction gears that drive the Moore regulator were required because of stripped threads.

5.2 Vacuum System

Helium is used in the pneumatic nozzles because of its high heat conductivity and inertness. The recirculating system operates with all sections above atmospheric pressure to prevent ingress of air. Air contamination reduces the thermal conductivity of helium, and can make temperature control impossible. Oxidation of the specimen can also occur, and radioactive Ar^{41} from activation of the argon in air may cause personnel radiation problems.

The vacuum system is used to remove air from new assemblies before they are connected to the helium system, to test insert leak tightness, and to evacuate the recirculating system if air gets in accidentally.

If a pressure of 4 inHg or below is obtained on the absolute P_B gauge, and this does not increase significantly when the insert is isolated from the vacuum pump, the insert is considered satisfactory. With a poorer vacuum, the assembly is tested with helium at pressure to detect the location of leaks and repair them.

Radiation surveys are made on the recirculating system low pressure tank each shift when the reactor is operating. An increase in activity, above the normal 1-2 mR/h, indicates the presence of air, and if this increases and remains above 10 mR/h, the system is isolated, evacuated and refilled with pure helium. While this is being done, the in-reactor machines are valved into a once-through helium system from cylinders to exhaust stack.

5.3 Heater Controllers

Mk-IV heaters used controls consisting of a 220V power supply for the top two gas sections and three interconnected 115V power supplies for nozzle, specimen and bellows sections (Figure 15). Each power supply contained a silicon controlled rectifier and isolating transformer,

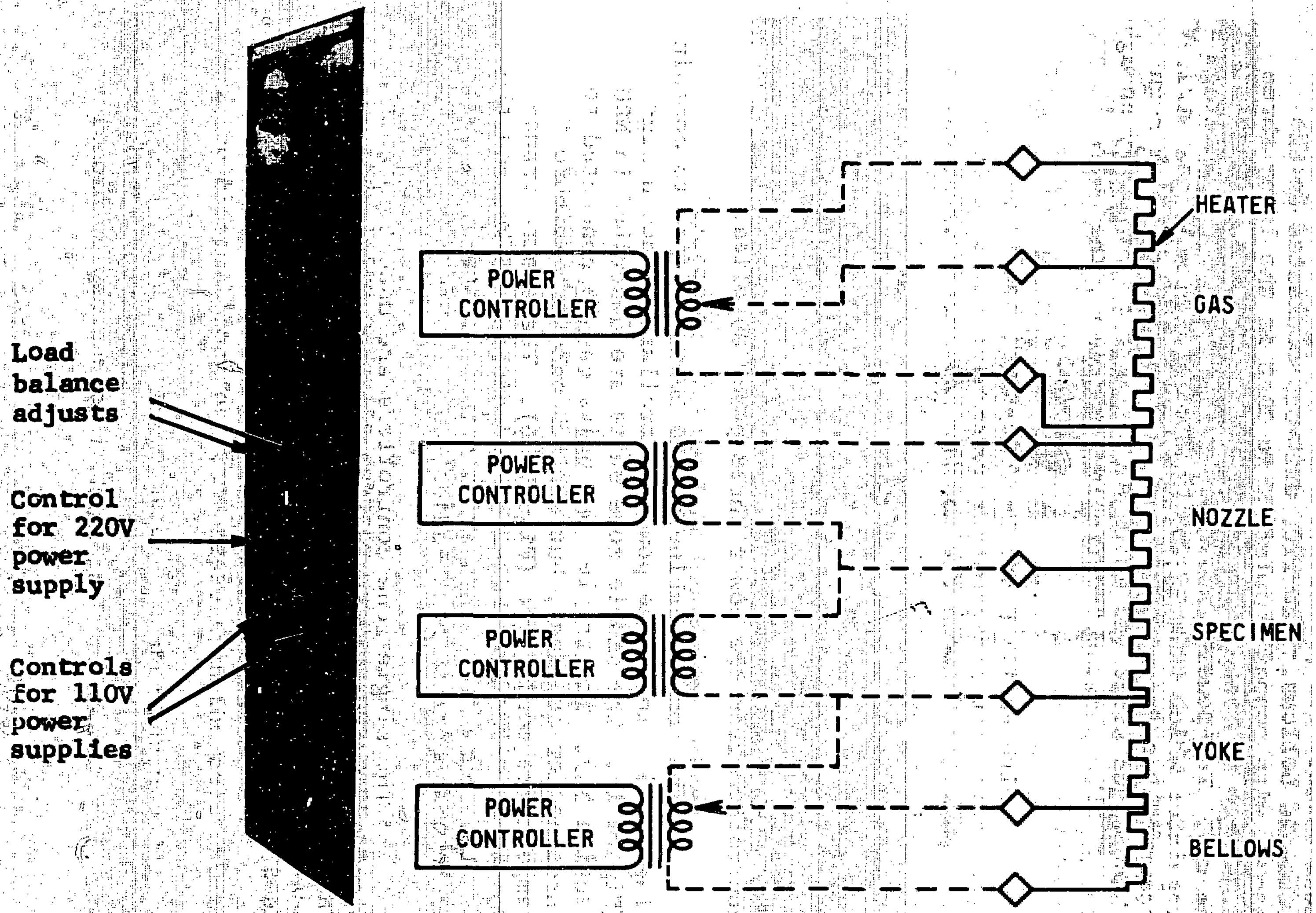


Figure 15: Mk-IV Bellows and Heater Controls and Power Schematic

and variable auto transformers had been added so that load balance was possible between the gas sections, and yoke and bellows. The 220V unit was connected to the heater with opposite polarity to that in the lower three units, to prevent an excessive voltage across the whole heater. The power controllers were fed through a voltage regulator which tripped the heater on high voltage. Trips occurred too frequently from failure in the voltage regulators, and since the voltage was found to be steady enough for good temperature controller operation, they were later removed.

With Mk-III F and Mk-V heaters, now in use, essentially the same controls were used but balance was only possible between the top two gas sections, because the other three heater sections and power controllers were isolated from each other. Sometimes it was difficult to maintain temperature in the bottom section of the heater with the reactor down, i.e. no γ heat, and a 220V transformer was installed in the lower controller. Mk-X machines, with three small integral heaters, were controlled from the lower three power supplies.

The control cabinets have been modified to contain single and triple zone power controllers of new design (Figure 1). The single zone units are described in NRU section 5.3. The triple zone units can be connected to three heater sections, but contain only one Foxboro temperature controller (Figure 16). The centre transformer is rated at 1 kW - the two ends at .5 kW, and the relative power to each section can be varied by adjustment of the appropriate power-adjust autotransformers.

The single zone controllers are used to heat the specimen and record the centre of specimen temperature. The triple zone controllers are used on the remaining heater sections to suit the particular type of machine used.

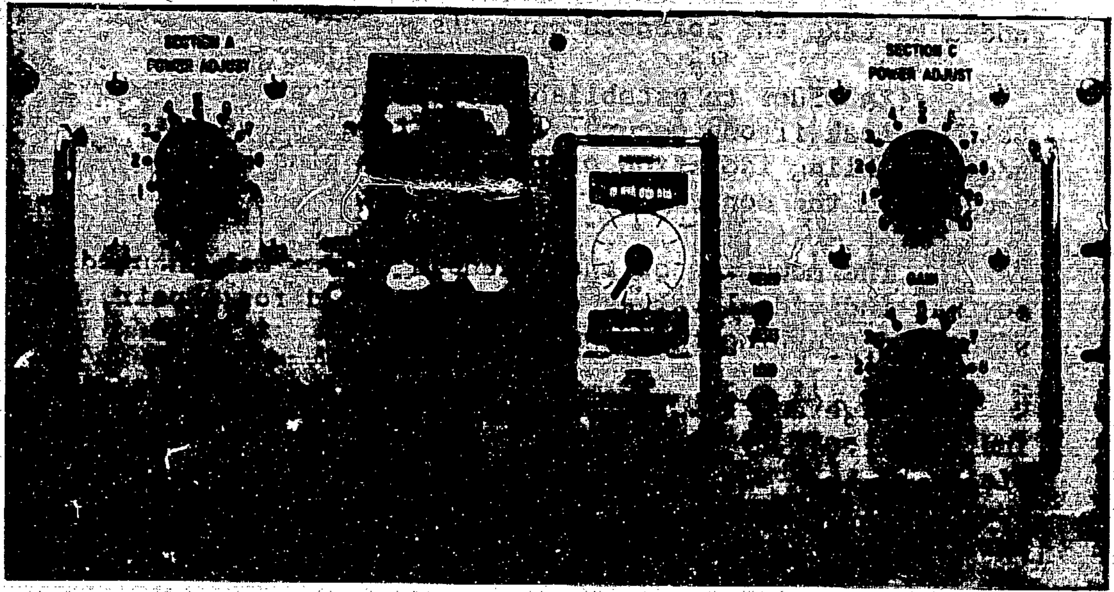


Figure 16: Triple Zone Heater Controller

5.4 Bellows Controllers

The controllers in use are those originally designed by Hawker Siddeley Engineering, with CRNL modifications. Each controller consists of a precision Heise gauge modified to include a control arm fitted with photodiodes to sense changes in indicated pressure. The associated circuits operate make-up and vent solenoid valves to maintain the pressure to within ± 0.25% of full scale (FSD). If the control fails, alarms annunciate when the pressure reaches ± .4% of full scale from the control point. If the power to the controller fails, a solenoid valve closes, 'locking' the pressure in the bellows.

Originally, the control was unreliable for two reasons. Poor seating material in the make-up and vent solenoid valves caused leakage past the seats, and contact burnout in the relays operating them produced uncertain operation. All solenoid valves have been fitted with teflon seats, which have been very reliable, and additional heavier relays, actuated by the original relays, have been added to take the solenoid currents.

In order to establish the size of an insert bellows leak if one occurs, an additional valve was added enabling isolation of the bellows plus Heise gauge from the controller.

The mounting of the solenoid valves was changed so that individual valves could be removed for repair, without disturbing the other two.

High and low bellows pressure alarms were originally indicated only by 'Bellows Abnormal Pressure' on the annunciator. With a number of creep units operating, it was sometimes difficult to ascertain which machine had alarmed, particularly if the condition cleared. Consequently, high and low indicating reset lights were added to each bellows controller.

Capacitors on the printed circuit board were replaced with ones of higher voltage rating, because of burnouts in the originals.

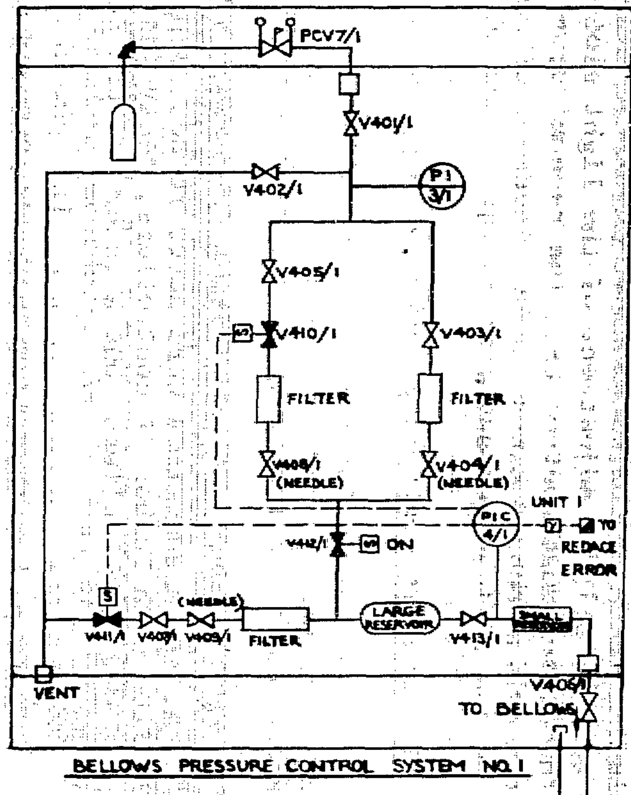
Electrical transducers have been added so that stress can be printed out in the REDACE scans. Specimens in Mk-X machines are stressed from 'inside-pressurized' bellows, with system (low) pressure on the outside. The actual stress is therefore due to the difference between these two pressures and a differential transducer is used.

The present bellows controller with the foregoing modifications and minor tubing changes is shown in Figure 17, and the specified 0.25% FSD accuracy can be maintained.

The one shown is for control of Mk-IX machines with larger bellows, where only 500 lb/in^2 is required for ~60,000 lb load on specimens. This low range gauge is replaced by one of 2000 lb/in^2 which is necessary for the equivalent loads

Front View

Back View



Flow Sheet

Figure 17: 'Hawker Siddeley' Bellows Controller and Flowsheet

on specimens in Mk-IV machines with smaller bellows.

Maintenance required on the modified units now includes the occasional renewal of photodiodes or lights and control relays, adjustment of the light slot width on the Heise gauge control arm, the renewal of filters in the helium supply lines, and replacement of manual valves due to leakage past the seats.

5.5 Temperature Control, Measurement and Record

Temperature Control until recently on Units 1, 2 and 3 has been by DeVar* controllers - five for Mk-IV machines and three for Mk-IX. Failure rate on these controllers, quite high at times, has normally been due to breakdowns in the power supply or amplifier modules, although causes sometimes were never found. Experience is limited with Foxboro** controllers, newly installed in some power controllers, but a lower failure rate is indicated.

Unit #4 was installed in March 1966 and originally used four Digiset*** controllers. These gave poor control until the 'burnout' feature, which required lower impedence thermocouples was removed. Even then GAIN adjustments were necessary to ensure control at constant temperature with the reactor up or down. In addition, when REDACE was put in service and thermocouples were connected to the computer and controllers in parallel, back millivolt

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* DeVar - an indicating controller, manual or automatic, with proportional band, reset and rate adjustments.

** Foxboro - an indicating controller, manual or automatic, with proportional band, reset and rate adjustments.

*** Digiset - a null balance indicating controller, automatic, with proportional band, and reset adjustments.

signals were produced from the controllers which gave incorrect temperature print-outs. For this reason, the specimen and bellows section power controllers were replaced with ones containing DeVar instruments.

Since creep tests have been required at temperatures from 140°C up, and the DeVar controllers only have a 300 deg C range, some ranges have been changed from the original 200-500°C to 125-425°C or 150-450°C. Each change was obtained by a zero shift and calibration check.

Thermocouples used on controllers are generally not used to record on point recorders as well, because of the effect on control when the instrument is balancing. All thermocouples are of Ceramo type, and 'double' ones (two couples in same sheath) preferable.

Originally, all temperatures were measured on 24-point Bristol recorders. As the American Society of Testing and Materials requires potentiometric checks of specimen temperatures in creep experiments, rotary switches were installed with the various switch positions connected in parallel to points on the recorders. These enabled potentiometric checks to be made on all important temperatures on each creep machine, i.e. gas, nozzle, specimen and machine. However, temperature readings through the switches were not consistently in agreement or disagreement with those on the recorders, and the discrepancies were thought to be due to the variety of metals used in the switch contacts and connections.

Later, single pen Leeds and Northrup (L and N) Speedomax recorders were added in parallel to the Bristol recorders, to enable continuous records of specimen temperatures to be made. The paralleling was done at first to observe the performance of the L and N recorders, and still keep the protective trip system of the Bristol recorders. The Speedomax recorders operated satisfactorily, and the trip and alarm system was modified as described in section 5.6. The specimen thermocouples were then connected directly to the single pen recorders. So that potentiometer readings could still be taken on the specimen thermoccuples, jacks were added which short cut the recorder alarms when the potentiometer is plugged in. The 24-pt. Bristol recorder speed was reduced to 110 s per cycle from 24 s per cycle to reduce wear and maintenace, and because the rapid print-outs for specimen temperature in particular were no longer required.

When the REDACE computer became available for temperature recording, efforts were made to ensure that this record was the most reliable. Four new six-pair thermocouple leads were run from the reactor Upper Header Room through a reference junction to the computer, eliminating any inaccuracies that occur from connections through terminal junctions, (the existing thermocouple leads had one or more connections before reaching the recorders). These new leads are also used to control and record elsewhere the important temperatures on each creep machine, through parallel connections to controllers and the L and N recorders from the reference junction terminals. REDACE does not interfere with controllers in parallel. Potentiometric readings can be made at a patch panel, also connected to the reference junction terminals, and the rotary switches previously used have been removed. Problems occur with the REDACE temperature record when the computer is out of order, or the reference junction fails. The latter occurred once and REDACE was programmed to use the temperature of an aluminum block to which the terminals were connected, as reference. However, inaccuracies can occur if there is any temperature differential between parts of the block. The reference junction temperature is printed out in all full REDACE scans, and an unusual reading indicates errors in all other printed temperatures. The system of tagging print-outs that are outside prescribed limits is described in the section 7.

5.6 Trip and Alarm System

There has never been a need for reactor trips on NRX creep machines, because they are contained in the aluminum inner tubes of fast neutron rods and the γ heating is relatively low (approx. 0.3 W/gm).

Therefore all the trips and alarms are designed for protection of the test specimens in the creep machines. Heater trips can occur on high temperature or current only, and alarms on temperature, pressure, open thermocouple, helium system abnormal, auto readout abnormal and out-reactor test abnormal.

Temperature

Before the Leeds and Northrup Speedomax specimen temperature recorders were installed, all trips and alarms were initiated from nine cams on each of the 24-pt. Bristol recorders. Thermocouples from two units were connected to each recorder.

Specimen thermocouples on each unit were connected to two cams, one of which tripped all heaters on high temperature, and the other alarmed on low temperature. Originally, a time delay of 53 seconds (3 print-outs) was allowed before the high temperature trip occurred, but because the temperature increase was so rapid with certain failures, it was removed. Machine and other important thermocouples were connected to cams which alarmed on high or low temperature. A common cam on each recorder gave overall protection to both units. This was set above all normal temperatures, and tripped the respective unit if any of its temperatures exceeded the limit. In order for any of these trips and alarms to operate on a particular unit, an alarm power switch for that unit had to be turned on.

When the Speedomax recorders were added to record specimen temperatures, high temperature trips and alarms were put into service from them. These annunciate on two common points, and inspection of the recorder charts is necessary to identify the abnormal machine. Operation of trips and alarms from the two 24-pt. Bristol recorders had never been satisfactory, because of the large number of false signals causing unnecessary trips.

Part of the trouble was due to drag of the microswitch arms on cams with the same settings. To improve this, settings were offset a few degrees but the alarm switches had to be turned off for a large proportion of time to prevent false trips due to microswitch sticking, dirty contacts or unknown causes. The thermocouple alarm unit has been modified so that one cam only is used on each unit as a high temperature trip for any pre-selected points, and the alarm power switch has been eliminated. Inspection of the recorder charts indicates which point has tripped the unit.

The trips and alarms on the Speedomax recorders will be replaced by those on the single pen Bristol recorders mounted in the single zone power controllers. These recorders have an additional microswitch for a low temperature alarm. A high or low temperature alarm on a unit is indicated by a flashing light below the respective recorder.

Heater Current

The alarming ammeters which are installed in the power controllers serve to trip the whole creep machine heater in the event of high current in any of the heater sections. The ammeter trip settings are normally set 1 ampere above the current required to maintain temperature with the reactor down.

Bellows Pressure

If the bellows pressure varies 7 lb/in^2 above or below the control pressure, a high or low alarm light shows on the bellows controller concerned, and the 'bellows pressure abnormal' annunciates.

Open Thermocouple

This alarm can be brought in from any temperature point on the 24-point Bristol recorders. When a thermocouple becomes open circuit, the 'upscale burn-out' feature on these recorders drive the print mechanism to full scale, and when the point prints in this position, 'open thermocouple' annunciates. The heater trip is nullified when the recorder prints full scale. However, if a thermocouple gradually becomes open, and the recorder prints before reaching full scale, the heaters will trip.

Helium System Abnormal

There are three conditions that annunciate this alarm; high or low helium supply pressure, actuated from two contacts on the pressure gauge in the supply line, and POWER OFF the automatic pressure control for the recirculating system low pressure tank.

Out-Reactor Test Abnormal

Sometimes out-reactor tests are operated continuously for days or weeks at a time. High temperature and high current trips, and high and low bellows pressure alarms from the controls at the New Storage Block are all connected to the 'out-reactor test abnormal' point on the annunciator.

Auto Readout Abnormal

This annunciates if REDACE has failed to scan the creep machines over a period of 100 minutes, or if the INSTRUMENTS ISOLATED switch (giving power to the Texas Instruments) is turned off.

6. FLUX MEASUREMENTS

Creep rate is dependent on neutron flux, and strain readings vary with different flux intensities because of differential expansion between the machine components (Figure 18). To compensate for the apparent change in strain due to differential expansion, and correlate in-reactor creep rates with flux intensity, a flux measurement is necessary. A direct measurement may be made using a flux monitor in the insert, or an

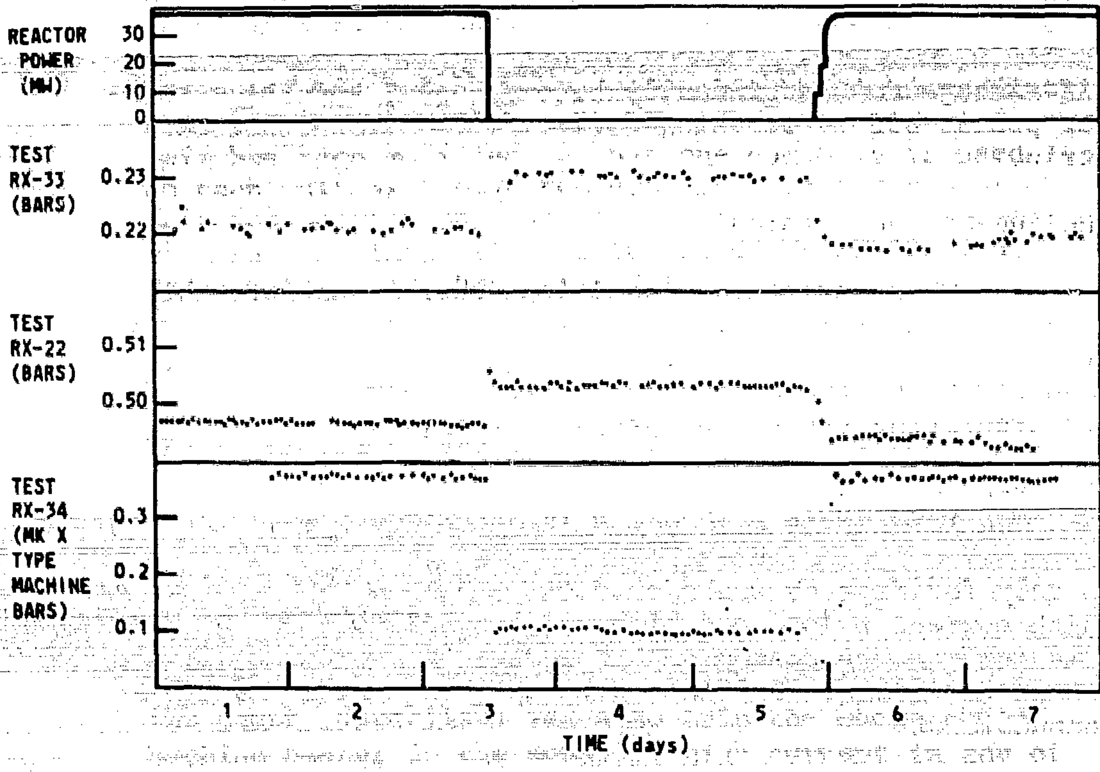

Figure 18: P_V Variation with Neutron Flux

indirect one by measurement of the heat output from the F/N rod containing the test.

Each insert is fitted with a calibrated Hilborn flux monitor (5), with a resistance (normally 10 k ohms) across its leads to convert the microamp signal to millivolts. This signal is recorded on the 24-pt. Bristol temperature recorder and REDACE. These signals are calibrated by comparing them to reactor megawatt outputs. The calibrations vary with different reactor loadings, but at steady power, either recorder or REDACE readings give indication of the relative flux at a glance. Hilborn flux monitors have operated inconsistently due to shorts in connections, damage to lead wires which are often repairable on reactor shutdowns, or breakdowns in the monitors themselves.

The heat output from a fast neutron rod relates directly to the neutron flux at a particular reactor position. As a back-up for flux monitors, or when they have failed, these rod powers can be calculated from the temperatures and outlet water pressure readings.

7. DATA RETRIEVAL AND PROCESSING

General

Since strain measurements are affected by changes in temperature, stress, flux and back pressure, a record of these parameters is necessary to plot meaningful creep curves. It is also necessary to keep the P_F (fixed pressure differential across the machine) constant or know the variation from a fixed setting.

Creep curves were plotted from manual readings (Wallace and Tiernan gauges) until auto-readout was installed, after which REDACE print-outs were used. The G-20/3100 computer system is now programmed to plot P_V (variable pressure) readings and six other parameters which may affect them. Programmes are being developed to convert P_V readings to strain with the necessary corrections, which would incorporate a rejection system to eliminate readings occurring when conditions are obviously abnormal.

Manual Readout Data

Until Reactor Loops Branch started operating creep machines, readings for strain calculations - P_V and P_B (back pressure), temperature etc., were taken as required by the researcher - normally once a day when the tests had stabilized. Subsequently, when NRX operators were trained, these readings were recorded every shift and are still continuing. In addition, rod power outputs are required, and the information to calculate these is recorded once a day.

After the auto readout system was added, the manual readout was left in parallel, and the following additional readings were taken manually - $P_F C$ Texas Instrument control setting and P_F Texas Instrument in parallel, P_V Texas Instrument, back pressure transmitter reading, and manual P_F (Wallace and Tiernan gauge) reading.

Auto Readout Data

The REDACE computer automatically scans reactor parameters and experiments every minute, recording on magnetic tape those that are programmed. Scans containing creep data are denoted 'D' scans, and the frequency at which they are regularly sent to magnetic tape depends on the 'stepping' program, i.e. the frequency the helium flow is switched from unit to unit. A scan on a unit is made just before the flow is stepped to another unit, and this is programmed so that at least one scan per hour is obtained from each unit. Additional scans may appear on tape due to special demands on creep or any other experiment contained in the 'D' scan. In addition, the regular scans are printed out on teletype. Each creep scan includes NRX/NRU and creep data (Figure 19 a) denoted as follows:

NRU	JR	- NRU reactor power
	NCR	- Number of control rod
	ZCR	- Control rod height (cm)
NRX	JRX	- NRX reactor power
	LH	- D_2O level
	TRX	- Reference junction temperature
Creep Machine	1RN	- Flux monitor
	1TA-TF (↑ Unit number ↓)	- Six temperatures usualy (a) gas, nozzle, specimen (3) yoke (Mk-IV machines) (b) nozzle, upper shoulder, specimen (3), lower shoulder (Mk-IX machines)
	1PD4	- bellows pressure difference
	1PDF	- P_F fixed pressure difference
	1PDV	- P_V variable pressure difference
	1PBK	- P_B back pressure (absolute)

So that abnormal conditions can be recognized easily a tagging system is used with letters (SAC U BIG F) after the reading, having the following meanings:

S - the first reading outside the alarm settings
A - subsequent readings outside the alarm settings
C - the first good reading after abnormal

U - the first abnormal reading after I or B

B - the first reading after false printout - the last good reading is printed
I - indicates false printout - last good reading is printed
G - the first good reading after I or B

F - denotes incorrect point and is not dependent on any settings - the next letter indicates the group which is to correct the problem, i.e. 2PD4 (Figure 19 a) is flagged F<u>L</u> for Reactor <u>L</u>oops Branch Creep group attention.

<u>Data Processing</u>

Data from the REDACE magnetic tapes are copied to short (less than 5,000 blocks) G-20 temporary tapes each day, and as these become filled, to longer (up to 16,000 blocks) permanent tapes in duplicate. NRX data and 'D' scan information containing both NRX and NRU creep data are stored on one set of permanent tapes - NRU data on another set.

To allow fast scrutiny of creep data, the 'D' scan material is retrieved each week day from the temporary tape as printed data. The following seven parameters are plotted from this at the same time:

reactor power, flux monitor, P_F, temperature of nozzle, temperature of centre of specimen, P_B and P_y. Information up to 1600 h one day is normally obtained by 0900 h the following day - the weekend data by 0900 h Tuesday.

```
  X70
0700   DLS  61200                              70 JULY 22 0700
OSW   $64000001   OIW   $67572470   OPR   $45400014
JQ     20327.6   JQX      82197.2   KNOW    25216
NRU/X REACTOR DATA
E1    39.71      E2     .0061      JR     100.5     NCR        17    ZCR   119.8
TRUB-15.85       JN    35.48       LH     289.8      JRX    33.79    EMI   16.58
TRX  100.55      TD1    35.5       TD2     35.0

CREEP TEST RX-40
2RN    .171FU   2TA   306.4      2TB   319.9      2TC   296.8FL   2TD   297.5
2TE   297.4     2TF   299.0      2PD4    -.2FL
2PDF-46.06      2PDV .3619       2PBK 1.137
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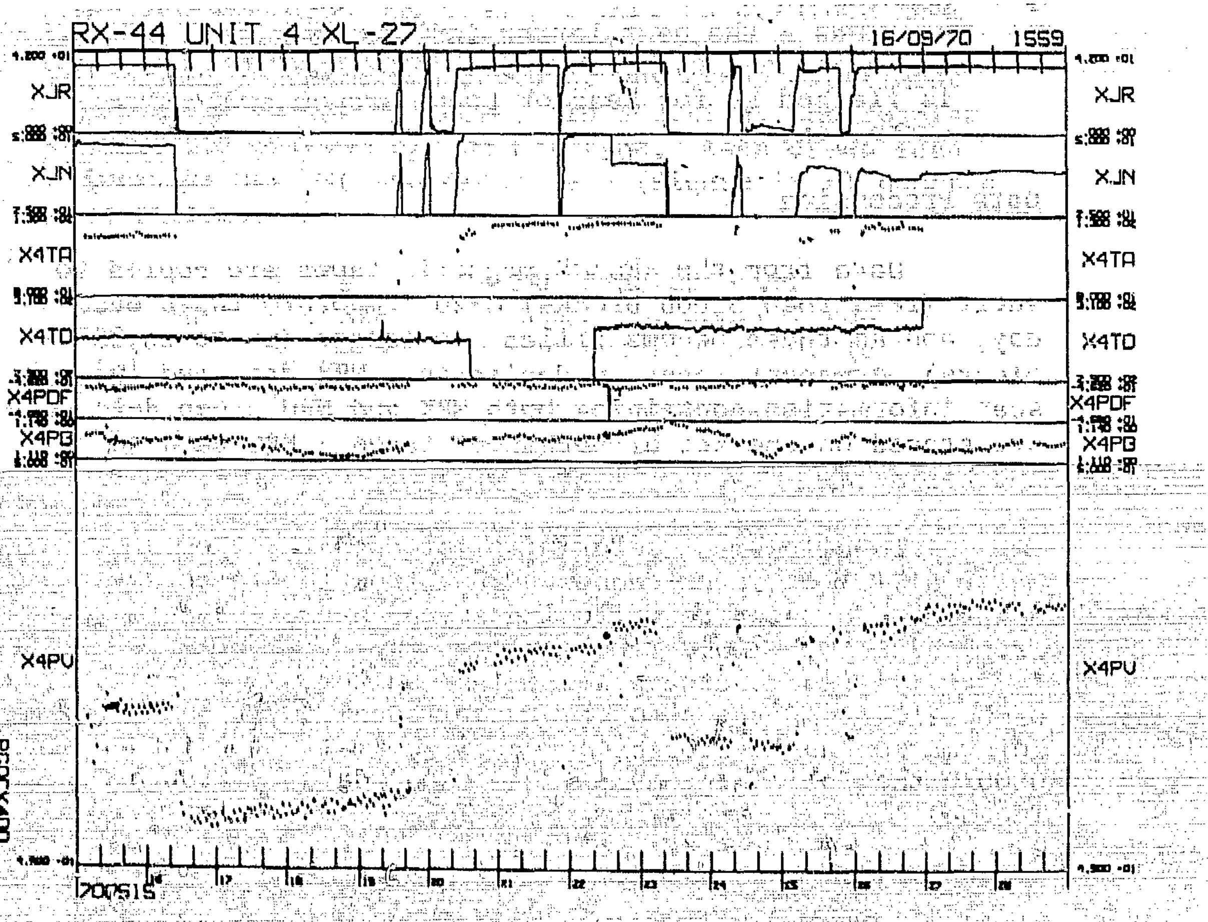
(a)



(b)

Figure 19: REDACE - Full NRX Creep Scan and Data Plot

From the data obtained this way, the progress of the tests can be assessed and the necessary adjustments made. Permanent plots for longer periods of time are obtained from the permanent tapes (Figure 19 b).

PART II NRU

1. GENERAL

Two sets of controls, similar to those used for the NRX Mk-IV machines, connected into a Helium recirculating system, were built originally to operate Mk-VI machines (4). Gamma heating was high, specimen and thermocouple changing in these machines proved difficult and prohibitively costly, and their use was discontinued in March 1967. Five tests were attempted.

Re-design and building of three sets of controls for Mk-X machines was completed in July 1968, and it is this equipment and its performance that is described. To the present, 22 tests in Mk-X type machines have been installed in the reactor.

2. CREEP SITES AND CONTROLS

In-Reactor

The only reactor position used for Mk-VI machines was G-20. Service lines to this position were run along the South access path in the reactor Upper Service Space, which also contained hot loop and facility piping. Because of the danger of damaging the rubber and polyflo helium lines, the inconvenience of connecting creep machines in this position, and a general decision to keep hot piping away from the North access path, the creep position was changed to G-12. A second was added in J-12, which subsequently became unsuitable from reactor loading considerations. By August 1967, the creep program required three sites and G-8, G-10 and G-12 were chosen, all on the East side of the North access path. When piping these positions, copper tubing replaced the original rubber and plastic.

Three sets of controls on the 'Fast Neutron'(F/N) platform denoted Facilities 6, 7 and 9, are normally used in conjunction with G-12, G-10 and G-8 respectively, but can be interchanged if necessary (Fig. 20).

NRX Machine Calibration Facility and NRU Out-Reactor Test Site

An additional set of controls was built on the main reactor floor to calibrate irradiated NRX machines, (to save time in Bldg. 234, Universal Cells) and commission new NRU ones. The NRX machines were to be contained in the creep flask which rested horizontally on a wheeled dolly. This ran on tracks, and could be used in conjunction with a small operating cell into which the specimen assembly could be telescoped. Unfortunately, the cell proved too small for specimen changes and the tracks and dolly have been dismantled. Calibrations on irradiated machines are now carried out in Bldg. 234 as their schedule permits. New machines were commissioned in a horizontal can, similar to the inside tube of a fast neutron rod, supported on trestles on the main reactor floor. Because it is desirable to test new machines vertically, a site has been chosen within the F/N platform for this purpose, and the controls have been relocated close to this position, on the F/N platform.

3. TYPES OF MACHINES AND MACHINE OPERATION

Mk-VI, IX, X and XII Machines

The Mk-VI machine was contained in a separate heater, which in turn fitted into a water cooling jacket. The assembly is shown in Figure 21 and it is described in (4).

Two Mk-IX inserts were irradiated in 1967, which led to the development of the Mk-X design (3).

The Mk-X disposable machine, now in use, consists of a shielding plug, nozzle-specimen-bellows assembly, three-section Ceramo type heater surrounding the specimen, thermocouples and aluminum cooling coil to allow operation in the 200-600°C temperature range (Figure 22 a and 22 b).

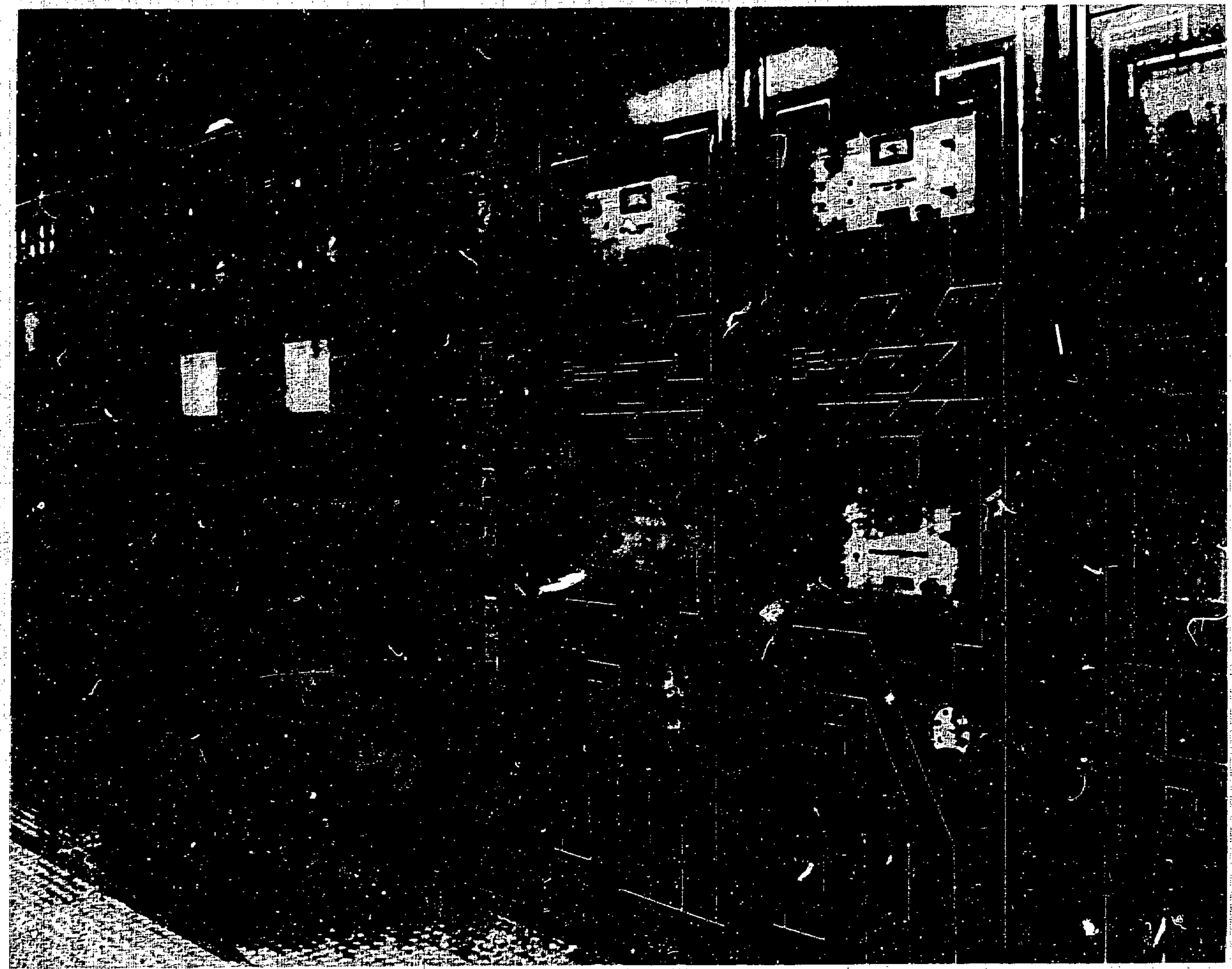


Figure 20: NRU Control Equipment for In-Reactor Facilities

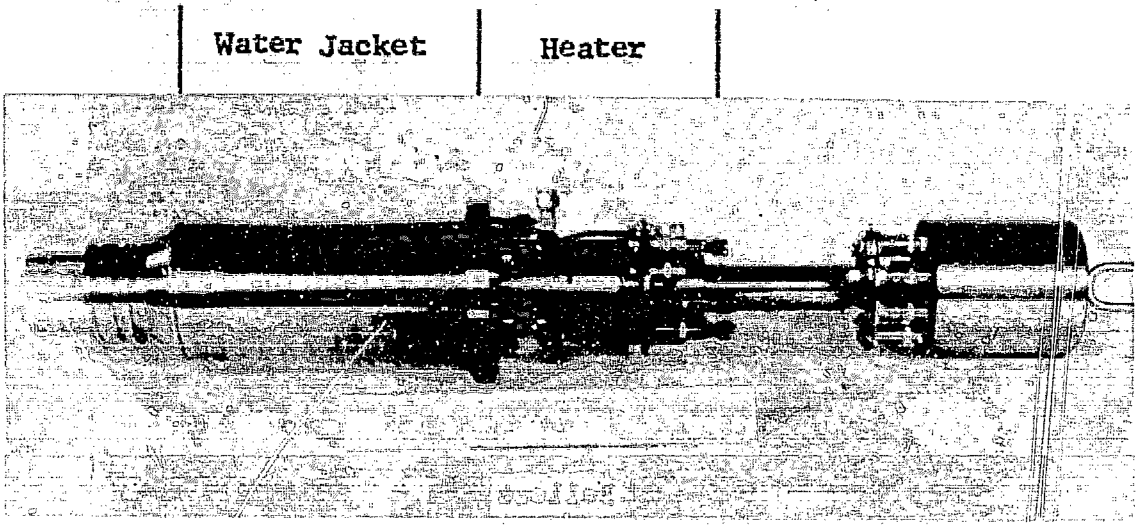


Figure 21: Mk-VI Creep Machine Assembly

The shielding plug, with terminal block at the top and the unirradiated top parts of the helium and water cooling lines, is reusable. The rest, except the specimen itself, is disposed of after the test. The nozzle is of low flow type with needle baffle and range 0.010-0.300 in. Aluminum alloy spacers surround the specimen for heat conduction. Both single and double bellows have been used, pressurized on the inside. They are about 1 in. diameter and enclosed in guide sleeves, which may be fitted with fins to conduct away γ heat. Since the heaters contain relatively large mass, γ heating is high, and for tests in the 200-300°C temperature range an efficient means of conducting heat away to the cooling water is required. A number of designs utilizing fins have been tried, the most successful being one in which the heater wires are moulded into a block of aluminum alloy with integral fins. The six heater leads

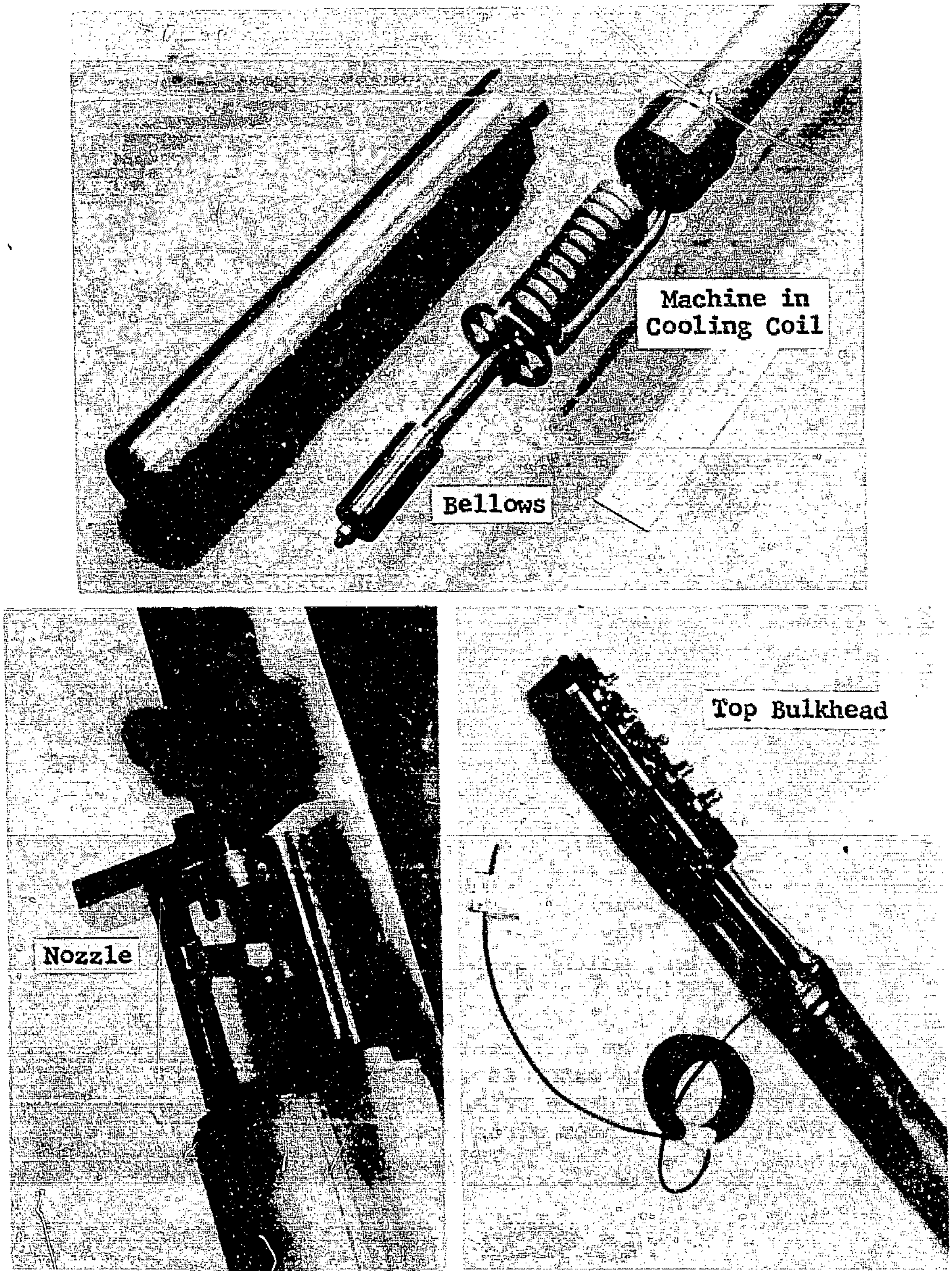


Figure 22 (a): NRU Mk-X Machine

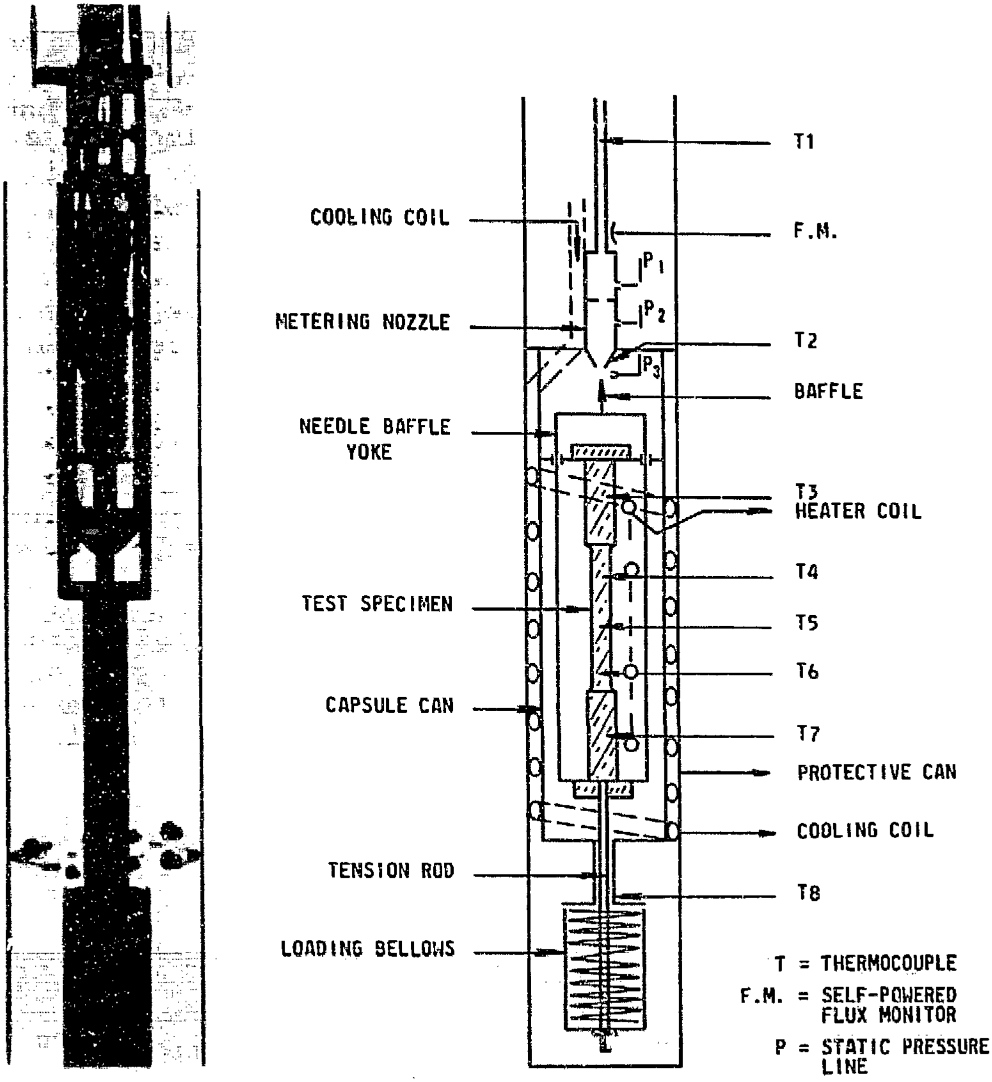


Figure 22 (b): NRU Mk-X Machine Radiograph and Schematic are terminated at an Aircraft-Marine Products plug mounted vertically at the top of the rod for easy connection in the reactor. Thermocouples are of Ceramo type, three double couples being used on the gauge length of the specimen - single couples on the rest of the machine. These also terminate in a similar vertical plug at the top of the insert. The aluminum cooling water coil is made to fit as closely as possible to the nozzle and sleeve enclosing the heater.

To test materials successively in widely different flux ranges, the Mk-XII arrangement has been developed, which allows irradiations of the same specimen in both NRX and NRU. This design consists of an Mk-X machine, which fits either directly in a fast neutron (F/N) rod for NRX, or in a shield plug with water cooling jacket in the F/N rod for NRU.

Mk-X Machine Operation

Although all Mk-X machines have been built from similar components, they have differed in the types of heater fin arrangements, bellows, and general tolerances between specimen holders and retaining sleeves, cooling coils and machine parts etc.

No tests have been installed in the reactor unless pressure cyclings on the bellows have shown the machines to be friction-free with the heaters on and off. The minor differences in individual machines described above, lead to different temperature distribution from γ heating, and a profile has always been obtained on reactor start-up. Sometimes the γ heating has been greater than expected, forcing test operation at a higher temperature than originally intended.

The most frequent causes of suspect creep results and test interruption have been excessive friction in the machines, or restriction or blockage in the pressure sensing P_1 and P_2 lines or chamber between the two nozzle orifices. Friction occurs from the partial seizing of moving parts due to differential expansion from γ heat, movement of a bellows in its containing can, i.e. buckling on expansion, or other unknown causes. In some tests, pressure cycling has been used successfully to reduce friction, in others, a change in operating temperature has improved the performance of the machine. Restrictions in the P_1 or P_2 lines cause sluggishness in reaching equilibrium but the P_v readings should be correct eventually. Blockages of course, produce erroneous readings. If the P_1 line is blocked, the 18.4 inHg across $P_1 - P_3$ cannot be obtained - if the P_2 line is blocked, the P_v (P_1-P_2) is usually abnormally high. A restriction in the fixed orifice, i.e. piece of dirt wedged in, will also give abnormally high P_v readings. All these conditions have occurred in Mk-X machines, and have usually been identified by observing the effect of blowing helium through the lines from the control panel, with an exhaust through the supply line to stack. In many cases, blockages or restrictions have been cleared by pressurizing the P_1 or P_2 lines a number of times, until the P_v is constant when the insert is returned to normal measuring flow conditions. A number of blockages were believed to be due to dust or soldering flux present when the nozzles were purchased (the remainder of the batch were returned for disassembly and cleaning) - other blockages may have occurred from poor construction methods or in the subsequent testing. The small inner sleeves used to join the pressure sensing lines during building have been replaced by outside sleeves. Greater care has been taken to ensure that helium lines in the out-reactor test site etc. are dirt free before a new machine is connected, and fine sintered filters have been added in all supply lines at the inserts.

One test was removed because of a high bellows leak rate. Since these bellows have only one pressurizing line, the actual load on a specimen stressed by a leaking bellows cannot be ascertained. In the past, some bellows were brazed on assembly in the machine, a practice discontinued since the integrity of this type of joint became suspect under irradiation. An all-welded construction is now used in bellows assemblies.

4. STRAIN MEASUREMENTS

General

Nozzle and temperature calibrations and operation of a pneumatic gauge, are described in NRX sec. 4. Back pressure control on each facility enables each test to be operated at the same back pressure as the nozzle calibration, normally 34 inHg abs. Changes in back pressure and correction curves are thus only necessary to improve readings in an unstable region of the nozzle calibration curve.

Auto Readout

A Texas Instrument differential pressure gauge (described in NRX sec. 4) is used on each unit for automatic P_V (variable pressure) readout. The millivolt signals are converted to bars in REDACE and recorded on magnetic tape every half hour for all in-reactor units. The digital indicator reading on the instrument is recorded manually twice per shift and any abnormal changes noted. If the P_V readout is suspect, the instrument can be checked by valving it in parallel with the controller, or connecting a portable Wallace and Tiernan digital gauge into tees on the P_1 and P_2 lines at the back of the cabinet.

The instruments have operated reliably, with occasional GAIN adjustments, and one case of the mechanism seizing.

Value of Readings

In general the comments made in NRX sec. 4 apply to strain measurements in NRU. There is an advantage here because there is no switching of flows between units, with associated motorized valves, and a disadvantage in the absence of manual readout. The P_V readings to REDACE are only good if the P_F (fixed pressure) constant differential is 18.4 inHg and the signal from the P_FC controller to REDACE only indicates the measure of control, not the P_F value (see 5.1 Automatic Control). Other causes of scatter or inaccuracy may be poor setting up of the P_V instrument, or upsets in the recirculating system i.e. make-ups which temporarily unbalance the P_F control.

5. OPERATION OF CONTROL EQUIPMENT AND CHANGES IN DESIGN

5.1 Helium Recirculating System

General Operation

The helium compressor, associated equipment and controls are identical to those used in NRX, and are described in NRX sec. 5.1.

Instead of flow switching between units as in NRX, the NRU system has three sets of Texas Instruments (controller and P_V readout) for automatic flow control on in-reactor machines, and a fourth set for commissioning out-reactor tests. Because the machines in NRU use low flow nozzles, a measuring flow can be maintained on all machines at once.

The NRU reactor has a helium purification and compression system to which the creep recirculation circuit is connected. The "Pure Bank" is connected to permanently placed helium cylinders for bellows and recirculation supplies, and all vent lines are connected to the low pressure recovery gas holder for purification. Because the CRNL type of bellows controller uses a Moore regulator which depends on a bleed flow for its operation, helium recovery is necessary and most of the gas returning to the purification system is from this source.

The recirculation system was built with a larger proportion of welded joints than that in NRX and consequently has a generally lower leak rate - normally < 50 lb/in^2 per shift. The Mon O Con pressure controller relay contacts were found to be very sensitive to slight pressure changes. A time delay has been added which keeps the make-up relay contacts closed for 3 seconds to prevent excessive operation of the make-up solenoid valve.

Automatic Flow and Back Pressure Controls

Each creep machine has its own automatic Texas Instrument flow controller (described in NRX sec. 5.1), and back pressure control.

The Texas Instruments are calibrated against an accurate manometer and set on SERVO CONTROL to give a P_F reading of 18.4 inHg across the nozzle. Apart from a rough visual assessment, an external millivolt signal gives an accurate measure of control. This signal varies from -50 mV to +50 mV for a deviation of -1/2% to +1/2% from the control point, and is recorded on REDACE. At the control panel, the signal can be read on a digital voltmeter permanently installed in one of the cabincts. Since there are no manual differential gauges in parallel, as in NRX, good control on a flow controller does not necessarily mean that the control is at 18.4 inHg gauge. If the control point is suspect, the Texas Instrument can be switched to SERVO GAUGE when it will indicate its control differential pressure. In addition, tees with valves have been installed on all P_1, P_2 and P_3 lines in the control cabinets so that an indicating differential pressure gauge can be installed in parallel. To aid in trouble shooting, pressure gauges were added at the inlets and outlets of the Moore regulators in the controllers. In setting up the instruments initially, Moore regulator limit switch adjustments were necessary on most instruments to allow sufficient flow for the 18.4 inHg (gauge) P_F, and GAIN and DAMP adjustments are required from time to time to improve control. One quartz bourdon tube was returned to the supplier because of calibration difficulties, which appeared to be inherent from the time of purchase. Another two required quartz tube replacement, after high pressure had been allowed accidentally on their low present sides.

Back pressure control is obtained by adjusting the flow through a Moore regulator into the exhaust helium line from the insert. One Wallace and Tiernan absolute pressure gauge is used to measure the back pressure accurately, by valving the appropriate unit into it. The back pressure is also indicated on a gauge connected to a transmitter for the REDACE signal on each unit. The lower limit to which the back pressure can be set is determined by the low pressure tank pressure, because the control system can only add to this pressure.

5.2 Vacuum System

The vacuum system in NRU is similar to that described in NRX Section 5.2.

5.3 Heater Controllers

The Mk-X power controllers were designed at CRNL and are built to include a DeVar temperature controller and a single pen Bristol recorder. Also in each circuit is a silicon controlled rectifier, isolating transformer, ammeter and ammeter control module. Units are interchangeable and each controls power to one heater section (Fig. 23).

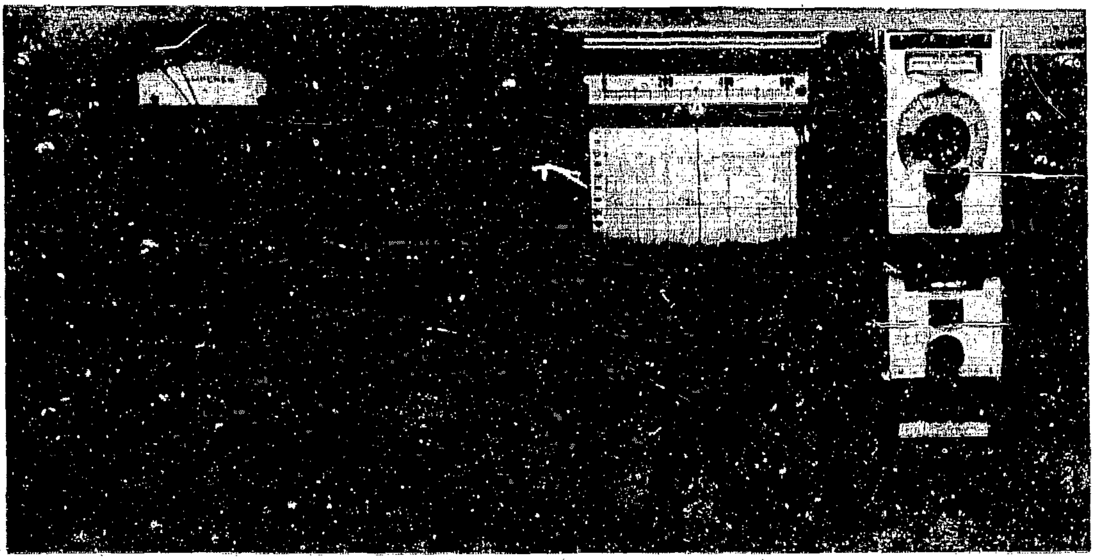


Figure 23: NRU Heater Controller

The ammeter has trip contacts and a reset button that flashes on heater trip, allowing identification of the tripped unit.

Bristol recorder high and low alarms are displayed on lights below the recorder and a heater trip is indicated on the annunciator panel. The trip and alarms may be jumpered with the plug, also below the recorder.

Because some heater sections have been made from relatively low resistance wire, and only have a total resistance of about 3 ohms, auto transformers have been added so that voltage can be controlled at low level to give power output with controller demand.

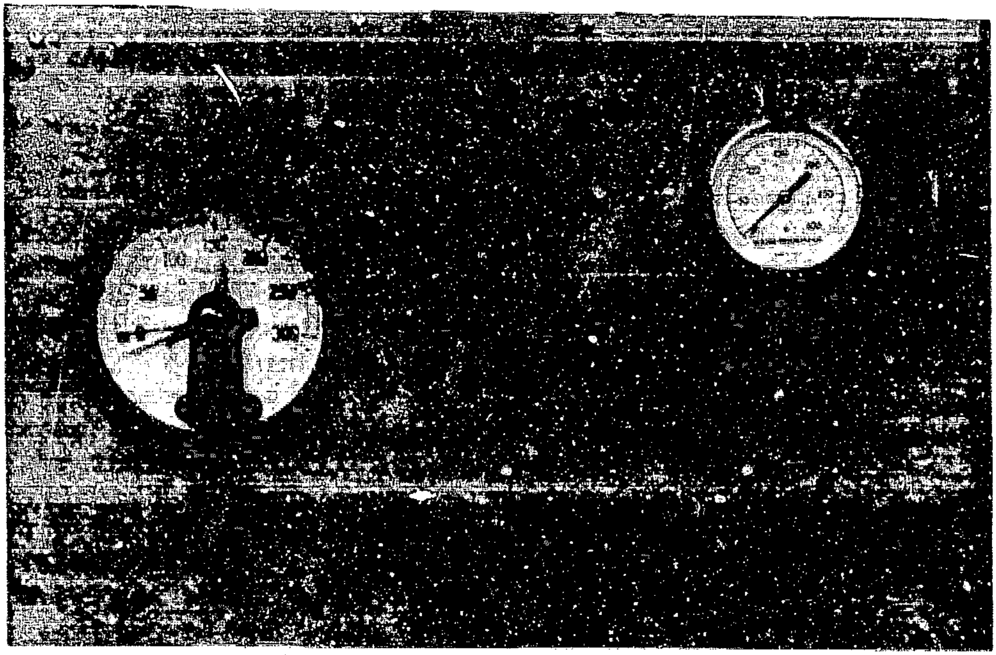
BIAS and GAIN controls associated with the silicon controlled rectifier are mounted on the front of the panel, and fitted with locking screws. A controller is set up by adjusting these screws and the auto transformer, so that the maximum power available is about 1A above that required for the test, with the reactor not operating.

5.4 Bellows Controllers

Hawker Siddeley controllers (See NRX sec. 5.4) were used on Mk-VI machines, which had bellows of similar cross-section to those on the Mk-IV NRX machines ($\sim$ 0.6 in outside diameter). The 2000 lb/in^2 pressure range is unnecessary for the larger Mk-X bellows, and a new type of controller, designed at CRNL is used in NRU (Figure 24).

A Moore regulator supplies and controls pressure, and a Budenberg differential gauge with high and low contacts is used for pressure indication. If the high pressure contact closes, the supply solenoid closes, the vent solenoid opens, and an alarm annunciates. If a low pressure exists, an alarm annunciates and the reason is investigated.

Moore regulators require a constant vent for operation, the flowrate being proportional to the differential between



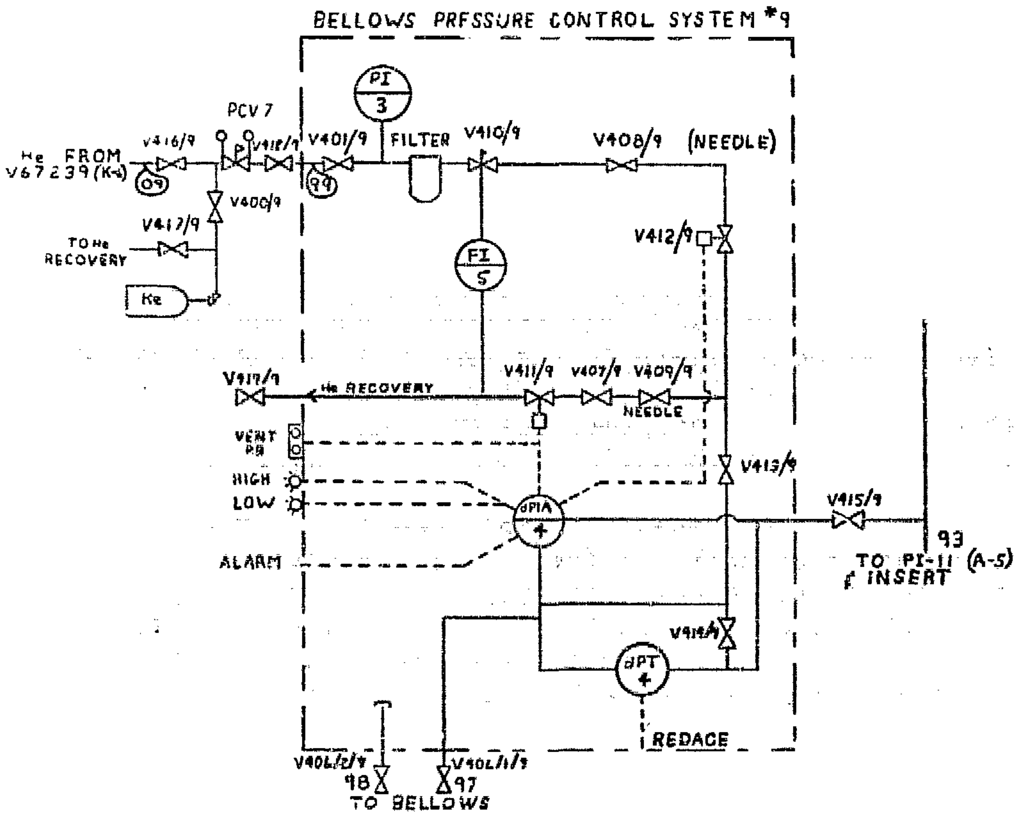


Figure 24: CRNL Bellows Controller and Flowsheet

the supply pressure from the cylinder and the regulator pressure setting. This differential is kept to a minimum, to prevent recovery of an unnecessarily large volume of helium.

The Budenberg gauge enables an indication of the actual stress on the specimen to be obtained. The high pressure side of this gauge is connected to the line pressurizing the inside of the bellows and the low pressure side is connected to the P_3 line in the machine, which transmits the pressure outside the bellows. A differential transducer in parallel to the gauge transmits a millivolt signal to REDACE, and this is used as the accurate stress measurement. The Budenberg gauge has large subdivisions and cannot be read accurately, so a laboratory test gauge is used to calibrate pressure against the signal to REDACE. The signal from the bellows transducer can be checked at the control panels by connecting to a digital voltmeter, mounted in the panels.

These controllers have operated with little maintenance, and few alarms, but changes of Moore regulators have been required because of increasing vent rates with minimum differential settings previously mentioned, or ruptured diaphragms. Schutte and Koerting flowrators have been installed on the panels so that the variations in vent rates can easily be observed.

5.5 Temperature Control, Measurement and Record

The two Mk-VI machines were each controlled by five DeVar controllers in the same way as the Mk-IV NRX machines. In addition to a 24-point Bristol recorder, three single pen instruments were used on each facility for reactor trip channels.

In the present control panels, for Mk-X machines, three power controllers (sec. 5.3) are used in conjunction with the three heater sections surrounding the specimen, and each temperature controller is connected to half of a double thermocouple on the specimen gauge length. Two recorders are used on each unit for continuous indication of specimen centre and bellows temperatures, other thermocouples from all machines are connected to the 24-pt recorder, using seven points per machine.

Operation of the original single pen recorders has not been satisfactory. The gain adjustments are unreliable, and on numerous occasions an instrument apparently set up correctly, lost the response to temperature due to loss of gain. The chart drives have also been a source of trouble, with frequent stops occurring because of gears slipping. The fibre gears used in the pen drives have stripped on occasions if the indicator has been allowed to drive upscale after disconnecting the thermocouple. Recorders are now switched off before the thermocouple is disconnected and on again only after it has been connected.

New single pen instruments replaced the original specimen temperature recorders, the old ones being retained to record bellows temperatures only. No problems have occurred so far with the new recorders.

The arrangement of thermocouples in the terminal cabinet was changed during panel revisions. Three sets of 14-pair thermocouples from the reactor terminate on one side of a terminal strip. From the same side, to avoid errors in the millivolt signals, six leads from each unit run directly to the reference junction for REDACE. The remainder are cross-connected to a second terminal strip, which contains connections to controllers and recorders. Inter-connections are always made between the two terminal strips, leaving the thermocouples from machines, controllers and recorders permanently attached (Figure 25). Potentiometric readings may be taken by plugging into a patch panel associated with the reference junction.

Test temperatures are set up using REDACE printouts, as these are considered to be the most accurate. The millivolt output from any thermocouple connected to REDACE may be checked on the digital voltmeter at the panel.

The standard plug-in thermocouple connector at the insert terminal causes some temperature measurement

Figure 25: NRU Thermocouple Terminal Arrangement

problems. Due to its small size, necessitated by space considerations, the connecting pins are small and fragile. If a pin becomes bent, connection of the plug may cause the faulty pin to miss its mating socket, and an open circuit occurs. The locking screw assembly between the two parts of the plug has sometimes been inadequate to hold the plug together, due to the strain exerted by the thermocouple cable in its normal flexed position.

5.6 Trip and Alarm System

Reactor Trips

Because of the high cost of Mk-VI machines, and the possibility of melting from γ heating, reactor trips were considered necessary when these machines were in use. Three single pen Bristol instruments were used for this purpose on each machine. Gas and two specimen temperatures were recorded, the reactor trip occurring when any two of these three temperatures rose to the trip contacts. Heater trip contacts were set lower than reactor trips to prevent these if possible, i.e. if the heaters were contributing to the excessive heat.

With the Mk-X design, reactor trips were no longer needed, and were removed. Experience had shown that γ heating was normally not too high, and in addition these machines are considerably cheaper.

Temperature

On Mk-VI machines, all thermocouples except the six on controllers and single pen instruments, were connected to the 24-point Bristol recorder. This was fitted with nine contacts, similar to the original NRX system, for specimen high trips and low alarms, machine high and low alarms, and an overall high temperature trip. The single pen recorders each had heater and reactor trip contacts.

For operating Mk-X machines, additional contacts were added to the single pen units, so that there were high temperature heater trips and high and low temperature alarms. The new single pen recorders also have triple alarms. Heater trips and alarms from all units annunciate on two common points and the condition and unit can be ascertained from individual indications on the control panels. On the 24-point instrument, the trips and alarms were removed and the overall high temperature trip was replaced with three high temperature trips that could be individually set for each unit.

Heater Current

The alarming ammeters, one in each power controller, are normally set 1 ampere above the maximum current required, and trip all three heater sections with any high current. A flashing light indicates which controller caused the trip.

Cooling Water

Budenberg gauges with double contacts were installed in the cooling water circuits of each unit, and any high or low flow actuates the alarm to individual flashing lights to indicate the unit and cause.

Other Alarms

All other alarms are similar to those in NRX and are described or refered to in NRX section 5.6:

Bellows Pressure
Open Thermocouple
Helium System Abnormal
Out-Reactor Test Abnormal
Auto Readout Abnormal

5.7 Cooling Water System

The cooling coils on the present machines are supplied with 65 lb/in^2 water from the Bismuth rod cooling circuit (NRU). Controls for each facility contain a DP cell and Budenberg gauge for flow measurement in the range 0.4-2.5 gal (UK)/min and a bypass. A flow in the range 0-0.2 gal (UK)/min can be measured on one unit at a time by directing the flow through a common flowrater.

Maximum flow from the above supply is approximately 1.5 gal (UK)/min per unit for each of the three units. The temperature of some machines has been lowered up to 20 deg C by increasing the cooling flows by use of two booster pumps capable of increasing the supply pressure to 140 lb/in^2 and flows to about 2.5 gal (UK)/min.

6. FLUX MEASUREMENTS

As in NRX, Hilborn flux monitors are installed in all inserts, and additional flux measurements are made from calculation of F/N rod powers. Monitor outputs are recorded on REDACE and the 24-pt recorder. Rod flow and temperature readings are taken manually once per day.

Fuel loading changes can be made frequently in NRU because no reactor shut-down is needed to change rods. Since strain measurements are very dependent on flux, it is desirable to have working monitors or available rod power on all units. However, because the three creep positions are adjacent, relative flux changes can be approximated for all machines from a single operating monitor, or continuous record of power output from one F/N rod.

Reliability of monitors, discussed in the NRX section 6 applies also to NRU.

7. DATA RETRIEVAL AND PROCESSING

General

Data required for plotting creep curves as in NRX, consists of temperature, stress, flux and back pressure. Computer plots from NRU creep tests differ from those in NRX in their exclusion of an absolute P_F signal, and inclusion of signals of deviation from P_F (relative to correct or incorrect control point) and stress.

Manual Readout Data

Wallace and Tiernan high accuracy gauges were used for manual readout of strain from Mk-VI machine tests, and were removed from the system when the present control panels were built.

Now, readings are taken manually every four hours on each operating unit. These include elapsed time of test, reactor power, bellows pressure, specimen temperatures and the indicator reading of the P_v Texas Instrument. Once a day measurements are recorded to calculate powers from the F/N rods in which the tests are operating.

Auto Readout Data

The REDACE computer automatically scans every minute, and scans of creep units, which include reactor data, are recorded on magnetic tape every half hour. Additional scans go to tape if requested for any experiment contained in 'D' scan. Each creep scan includes NRU and creep data (Figure 26 a) denoted as follows:

NRU	JR	- NRU reactor power
	NCR	- Number of control rod
	ZCR	- Control rod height (cm)
NRX	JRX	- NRX reactor power
	LH	- D_2O level
	TRX	- Reference junction temperature
Creep Machine	6RN	- Flux monitor
	6TA-TF	- Six temperatures usually
	↑ Unit number ↓	(a) gas, nozzle, specimen (3) yoke (Mk-VI machines) (b) nozzle, upper shoulder, specimen (3) lower shoulder (Mk-X machines)
	6PD4	- bellows pressure difference
	6PDF	- P_F fixed pressure difference
	6PDV	- P_V variable pressure difference
	6PBK	- P_B back pressure (absolute)

So that abnormal conditions can be recognized easily a tagging system is used with letters (SAC U BIG F) after the reading, having the following meanings:

S - the first reading outside the alarm settings
A - subsequent readings outside the alarm setting i.e. 9TB (Figure 26 a) is in an Alarm state
C - the first good reading after abnormal.

U - the first abnormal reading after I

B - the first reading after false printout - the last good reading is printed
I - indicates false printout - last good reading is printed
G - the first good reading after I

F - denotes incorrect point and is not dependent on any settings - the next letter indicates the group which is to correct the problem. i.e. 9PD4 (Figure 26 a) is flagged FL for Reactor Loops Branch creep group attention.

Data Processing

Data from the REDACE magnetic tapes is retrieved each week day as printed data from which the following parameters are plotted at the same time:

reactor power, flux monitor, nozzle temperature, centre of specimen temperature, stress, P_B and P_v. The performance of the tests is evaluated from the daily plots, and permanent plots for longer periods of time are obtained from the same permanent tapes as NRX creep tests (Figure 26 b).

```
   U81
0600  DAO  06996                          70 AUG.  1 0600
OSW  $60034001  OIW  $67572470  OPR  $45400014
JQ      20745.0  JQX     84985.8  KNOW    21630
NRU DOWN
 NRX DOWN

GROUP SUMMARY
NRU/X REACTOR DATA
E1    39.68      E2   -.0061     JR          .1     NCR         4      ZCR   346.0
TRUB 27.97       JN     3.58     LH      132.3     JRX      -.07      EMI    7.13
TRX 100.58       TD1     -.6     TD2      -1.1

UNIAXIAL CREEP TEST RU-22
9TA    46.7      9TB    26.0 A   9TC    299.2      9TD   299.9       9TE   299.5
9TF   289.6      9RN     .41     9PDV  .2676       9PDF-18.54        9PD4 17.51FL
9PBK 1.182
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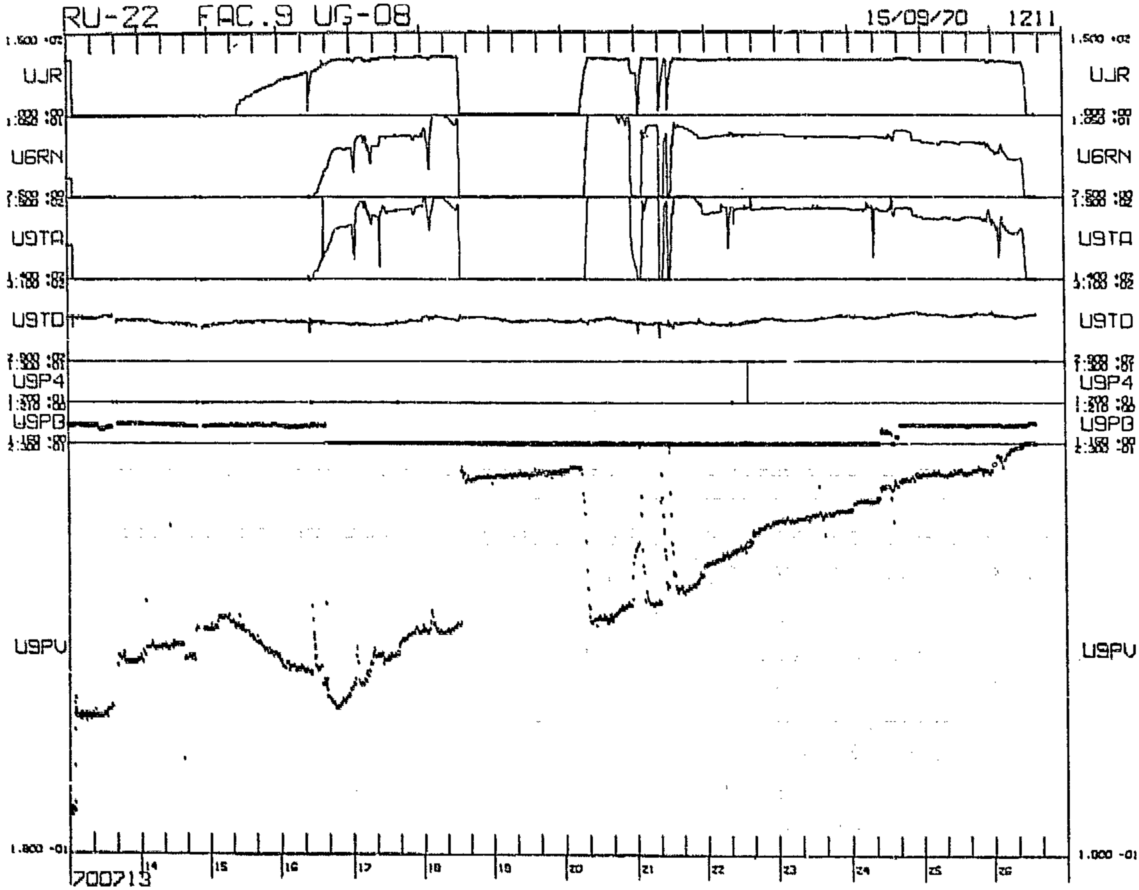
(a)



(b)

Figure 26: REDACE - Full NRU Creep Scan and Data Plot

CONCLUSIONS

The best creep results to date have been obtained from NRX Mk-IV H machines, which have had as many as five specimen changes before disposal. The early Mk-IV machines had problems with friction in the moving parts, loss of key thermocouples which were not duplicated, and leaks in the brazed joints on bellows. Design changes eliminated most of the friction, double thermocouples replaced some single ones, and welds are being used at the bellows. Improvements that could still be made to the Mk-IV H design include the use of double thermocouples for all specimen temperature measurements, details of the thermocouple location with respect to specimen, yoke members, heaters etc., and a welded construction for all bellows lines subject to irradiation.

Successive Mk-X machines were improved and tested in NRU, and useful results are being obtained from the present design in both reactors. Until recently, all machines were prototypes in the sense that slight modifications occurred in each, and their performances differed. Varying tolerances, different fin materials and design, and cooling coil fits, gave rise to different γ heating and subsequent differential expansion. Thorough documentation of all details in construction is necessary for the interpretation of the behaviour of individual machines. A number of tests have been ruined because of blockages in the P_1 and P_2 lines, discussed more fully in NRU section 3. Rigid specifications and inspection of purchased parts, and care not to introduce foreign material during construction or testing are necessary for good performance from a machine. It is also important that the connections between the various yoke components are inflexible and designed in such a way that they do not become loose during the course of a test. Because the connectors for heaters and thermocouples at the top of an insert are quite fragile it is advantageous to inspect these for damage before plugging together. A more rugged type should be used when available.

Design changes in the equipment have considerably reduced the frequency of test failure from mechanical breakdowns. A system instituted in 1968 to ensure that work by service personnel is only carried out after a countersignature by someone concerned with creep experiments, rather than a shift supervisor's signature only, has also improved test performance.

Scrutiny of creep tests has been simplified with automatic flow control and readout of strain, temperatures and other necessary parameters on the REDACE computer. Plots from the computer have proved the best means of assessing the progress of tests. Programs being developed to plot actual creep measurements, with necessary corrections for parameter variations and a rejection system for ineligible points, should enable adjustments on tests to be made sooner and more effectively. Faster access to the data would be an additional advantage.

ACKNOWLEDGEMENTS

The Creep program is organized by Dr. V. Fidleris, and the machines are built by Mr. I.R. Emmerton with assistance from Mr. H.H. Spriggs. Mr. R.D. Delaney was responsible for the design changes in control equipment, and Mr. A.J. Pitcher for the drafting.

The author is indebted to Mr. L.F. Henwood, Mr. M.J. Costello, Mr. A.R. McWade and the NRX and NRU staffs for their cooperation in operating the machines, and Dr. V. Fidleris and Mr. R.D. Delaney for their helpful suggestions in the preparation of this report.

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