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Nuclear Reactors for
Ram-Jet Propulsion, C-90
M-3679 (27th Ed.)

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Lawrence Radiation Laboratory
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TORY II-C INSTRUMENTATION -
PART 6 OF THE TORY II-C PROGRAM

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January 1, 1963

MASTER

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FOREWORD

This is Part 6, "Tory II-C Instrumentation," of the 10-part report UCRL-7036. A list of all 10 parts, including titles and major subheadings, appears on the following page.

LIST OF PARTS ISSUED UNDER UCRL-7036
THE TORY II-C PROGRAM:

- Part 1 Introduction and General Description
- Part 2 Structure of Reactor
(Description of Mechanical System, Fuel Loading, Structural Analysis)
- Part 3 Technology of Ceramic Components
(Fabrication Procedures, Characteristics of Ceramic Elements)
- Part 4 Design Aspects (Presented in three separate sections)
(Section A: Neutronic - Design criteria, Fuel map, Control system; Section B: Radiation Effects - Nuclear heating, External radiation levels, Activation of components; Section C: Heat Transfer and Fluid Flow - Design criteria, Pressure profiles, Component temperatures, Performance.)
- Part 5 Control System
(System Requirements, Mechanical Description, System Analysis)
- Part 6 Instrumentation
(Nuclear, Nonnuclear)
- Part 7 Test Vehicle
(Description, Safety Features)
- Part 8 Test Facility
(Site Description, Safety Features)
- Part 9 Operations
(Staff Organization, Test Program, Emergency Plan)
- Part 10 Hazards of Operation
(Normal Operation, Credible Accidents, Incredible Accident, Site Radiation Levels)

TORY II-C INSTRUMENTATION -
PART 6 OF THE TORY II-C PROGRAM

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January 1, 1963

1.0 INTRODUCTION

The objectives of the TORY II-C test program require an exceedingly complex and flexible instrumentation system. A great number of parameters must be monitored, usually under adverse conditions, both for control of the reactor and air delivery system and for the acquisition of basic performance data. This report is a general description of the more important aspects of the data system and its capabilities.

Actually there are two independent systems to consider. One is concerned with nuclear measurements and the other with the nonnuclear parameters (primarily pressures and temperatures). To illustrate the priority of the measurements they may be grouped on a functional basis as follows:

a) Direct Control and Safety - This group is used for operational control of the reactor and air delivery systems. The important parameters are reactor power level and period, reactor core temperature, inlet air temperature, and air flow rate obtained from pressure and temperature measurements.

b) Indirect Control - These are monitored to insure that design constraints relating to component temperature, pressure, and structural integrity, are not exceeded during operation.

c) Performance and Engineering Data - This information is needed to evaluate and verify component design and answer basic questions relating to future reactor development.

d) Failure Diagnostics - These measurements are redundant if all goes well; however, they may yield valuable data in the event of an operational difficulty.

A major requirement imposed on the instrumentation is flexibility, due to the nature of the test program and the extreme range of some of the measurements. The data system must be able to support the low-power critical experiments on the reactor, the blowdown facility qualification tests, and finally integrated operation of all systems.

To permit rapid evaluation of test results, which are often essential in the planning of subsequent tests, automatic data reduction techniques have been developed. The nuclear counter channels utilize an on-line data collection system to print out counter data in digital form. The bulk of the temperature and pressure data will be recorded on magnetic tape. After a test this data will be converted to digital form for final reduction on a high-speed computer at Livermore.

2.0 NUCLEAR INSTRUMENTATION SYSTEM

The basic design criteria for this system are largely based on experience gleaned from the operation of the Tory II-A reactor. Three major areas of difficulty were encountered in the use of the first nuclear instrumentation system. These were briefly: 1) overall flexibility, 2) adequate overlap in all ranges, and 3) nonlinearity with respect to calorimetric power.

The nuclear detectors will be exposed to the leakage neutron flux from the reactor during operation. Since the reactor is unshielded a certain degree of latitude is permissible in sensor placement. This is fortunate because positions close to the reactor present too severe an environment for conventional detectors. A difficulty which arises in planning nuclear instrumentation for the reactor is the uncertainty in the neutron energy spectrum of the leakage flux which the detectors may be expected to see at any time. Thus a large margin of flexibility in the system is desirable to insure safe instrumentation coverage in all operating ranges.

The detector placement scheme for the Tory II-A experiment had the power-range detectors positioned upstream and on the axis of the reactor, thereby relying primarily on neutron leakage through the main inlet air duct. At high flow rates there was a noticeable attenuation of the flux due to the increased mass of air in the pipe. For this reason the power-range detectors are placed off to the side of the Tory II-C test vehicle.

Another design consideration was detector accessibility for maintenance or replacement, even though personnel access to the test pad after high-power operation is limited. Retractable detector systems have been designed so that the detectors may be remotely withdrawn into the concrete-shielded test bunker for service.

Five groups of nuclear instruments have been provided. Three of these groups comprise the standard operating or control instrumentation. These are: a fission-chamber counter system for startup, a low-level logarithmic current system, and a high-level logarithmic current system. Two other systems are available, mainly for information and backup control purposes. These consist of a very low-level BF_3 counter system and a reference linear current-measuring system.

Each group can cover from five to nine decades of reactor power. Through the use of the remotely-controlled drive mechanism the positions of the detector groups can be varied, thus extending their ranges an additional two to four decades. The large range of each detector system allows for errors in the calculation of flux at given locations and for sensitivity variations with neutron energy spectra.

2.1 Detector Groups

2.1.1 "B" Detector Group

This group consists of a pair of BF_3 chambers mounted on a trolley running parallel to the axis of the reactor, ten feet above ground level and about eight feet from the core centerline. The BF_3 's will serve as the primary instrumentation during the very low-power critical experiments where high sensitivity is required. They may also be used to supplement the startup fission chambers in the event that these detectors are not sensitive enough to be on scale at startup and shutdown.

The detectors planned for the "B" group are G20-12 with a rated sensitivity of 20 counts/sec.nv. Should this prove not sensitive enough, other BF_3 chambers with a sensitivity of 200 counts/sec.nv can be used. Attenuation can be varied 2-1/2 decades by sensor relocation along the trolley. The basic block diagram of the system is shown in Fig. 1. The nonradiation-tolerant preamplifier is attached directly to the detector. Preamplifier gain is about 20 with the output pulse clipped to a width of 0.6 μsec . The output from

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Fig. 1. Block diagram of the BF₃ detector system.

the preamplifier is fed to a line-driving amplifier in the test bunker which sends a pulse out through 10,000 feet of cable to the control point. The pulse is stretched timewise by about 0.5 μ sec and is reduced in amplitude to about 1/5 by the cable.

At the control point the pulse is amplitude discriminated and counted and is then fed to a six-decade log count-rate circuit. The upper limit of the count rate is approximately 10^5 counts/sec (average). The log count rate and its period are displayed for the reactor operator. The range covered by the "B" series is shown in Fig. 2 relative to the rest of the instruments.

2.1.2 "S" Detector Group

The startup series uses two sets of fission-chamber clusters on individual drive mechanisms. They are under the test car between the rails, parallel to and eight feet from the core centerline. These channels have three detectors for each channel and have a common radiation-tolerant preamplifier. The detector sensitivities are 1, 0.1 and 0.01 counts/sec·nv, each channel being selected by the appropriate reed relay. The output from the preamplifier is fed to a line-driving amplifier. This is the same type of amplifier used for the BF_3 systems; the amplifier has two options, one for the output of BF_3 system and the other for the fission chamber system. The BF_3 section has a gain of 20 to 40 noninverting, and the fission chamber section has a gain of 100 to 200, inverting and clipping the output to a width of 0.5 μ sec. From the line drive amplifier the electronic circuitry is identical with the BF_3 system. The block diagram is shown in Fig. 3, the reactor power range covered is shown in Fig. 2.

The counter channels have a semiautomatic data collection system for operator assist. The system consists of a digital timer (synchronized to the master time-code generator), a data scanner, and a printer. The digital timer is used to preset the amount of time a count is to be taken. The timer gates the scalers on and off for the preset time after the timing sequence is initiated. At the end of the count time the scanner is started and takes the data stored in the scalers and routes it to the printer. Each scaler is interrogated in sequence and the stored data printed out. The printout contains the channel identification, time of day, count time, and the stored count.

Fig. 2. Estimated detector-reactor power map for Tory II-C operation.

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Fig. 3. Block diagram of the fission chamber system.

2.1.3 Low Log N Detector Group

These are three compensated ionization chambers (Type 6377, 4×10^{-14} amp/nv) connected to current amplifiers; the output of the current amplifier is a voltage proportional to the logarithm of the input current. Each channel has an individual drive mechanism. The chambers are in the same location as the "S" series detectors, i. e., under the test car. During normal operation these chambers are used for intermediate-power-range automatic control feedback. Provision has been made to connect these chambers to the micromicroammeters for use in the critical experiments. The logarithmic amplifiers have a useful current range of 10^{-10} to 10^{-4} amp and are only of limited use during the critical experiments. The micromicroammeters have a useful range of 10^{-13} to 10^{-3} amp, using range switching and a linear readout. More precise measurements are thus possible during the critical experiments. The logarithmic amplifier output is sent through signal-conditioning circuitry which provides the automatic control system with the proper level and polarity. The conditioner also takes the derivative of the log-level signal and makes available the period information contained. The level and period information are transmitted to the control point and are displayed for the operator. The block diagram for the Log N system is shown in Fig. 4, and the reactor power range covered is shown in Fig. 2.

2.1.4 High Log N Detector Group

This power range group is identical with the Low Log N group except that the detectors are mounted in pipes penetrating the instrument room wall. This is shown in Fig. 6. This group has an attenuation range of 10^4 compared to the 10^3 available to the Low Log N group. The block diagram is identical to the Low Log N system and is shown in Fig. 4. The reactor power range covered is shown in Fig. 2.

2.1.5 Micromicroammeters

Three Type 6377 compensated ionization chambers are connected to current amplifiers. The output of these amplifiers is a voltage proportional to the input current. Remote-controlled range switching is provided to cover many decades - the useful range of these instruments is from 10^{-13} to 10^{-3} amp. During normal operation the detectors are in pipes penetrating the

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Fig. 4. (Top) Logarithmic current system.

Fig. 5. (Bottom) Micromicroammeter system.

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Fig. 6. Physical layout of the detector system.

instrument room wall. Each chamber has an individual drive mechanism for remotely positioning the chamber (and adjusting the amount of leakage neutrons from the reactor that it "sees"). The pipes are positioned approximately 40 feet from the center of the reactor core. Retracting the detectors fully into the bunker should give (from best available data) a decrease of approximately 10^4 in apparent flux. During critical experiments these chambers can be disconnected from, and the chambers below the test car connected to, the micromicroammeters. This will allow current measurements at very low powers. From best currently available figures this would be around 10^{-12} amp at a reactor power of 10 mW. The range covered by these channels with their normal detectors is shown in Fig. 2. Figure 5 is a block diagram of the system. These channels are intended primarily for reference and data reduction rather than control.

A composite, simplified block diagram of the nuclear instrument system is shown in Fig. 7. The ranges covered and reactor power are based upon the currently available data for Tory II-C and extrapolation of data observed during the Tory II-A experiment.

2.2 Calibration of Systems

The count-rate channels have a calibrator which can insert uniformly spaced pulses into the preamplifier of the selected channel. The pulses are approximately the same size as the counter-tube output pulse. The result is that the test pulses are amplified and then recorded on the scalers. The count-rate equipment will indicate a count rate greater than the actual count rate of periodic pulses. This is due to the count-rate equipment's being calibrated to read average count rate for aperiodic pulses from a statistical source. Calibration curves are provided to convert the periodic input repetition rate to the meter reading. An exponentially increasing pulse train can be provided which will cause a period signal to be generated. The exponent can be preselected to present a desired period. The period-calibrate mode of operation causes the exponential to cycle, i. e., once a high count rate is reached, the count rate decreases exponentially. When the lower count rate limit is reached, the positive exponential starts over again.

It will be necessary to run voltage and discriminator plateaus prior to operation. This will be done in the standard manner using a moderated

Fig. 7. Block diagram of the Tory II-C nuclear instrumentation system.

neutron source. The semiautomatic data-collecting system should be a considerable help in this calibration.

The individual ionization chambers will not be calibrated for neutron flux. Prior experience with these detectors has indicated very uniform neutron sensitivity and high quality. The individual chambers do vary in gamma-compensating characteristics, so the compensating characteristics will be determined for each detector. Using 600 volts (from a battery supply) on the chambers gives adequate margin to operate the detectors linearly up to 7×10^{-4} - amp signal current. This assures that the chambers will still be linear and on the high-voltage plateau. This current is seven times greater than the maximum allowable for the Log N amplifiers, but is below the upper limit of the micromicroammeters. Since the reference micromicroammeters will be in the same location as the high-range-control Log N channels, operation of the reference channels above this region is not anticipated.

The current amplifiers themselves will be calibrated with a current source. A constant-current source is provided for this. Since there is no calibration adjustment for the amplifiers, calibration curves will have to be provided where there is significant deviation from standard.

The Log N amplifiers have an internal current source which can be switched in locally or remotely from the control point. This internal current source is not intended to replace current calibration, but is to be used for a quick check of amplifier operation. The micromicroammeters do not have such a test current built in. Prior to any nuclear operation (where practical) a large neutron source will be used for response checks of the various detectors. The main thing this accomplishes is to determine whether each system will see an increase in neutron flux.

2.3 Response of Systems

The resolution time for the counter systems is approximately one microsecond. This means that it will resolve a pulse pair one microsecond apart, but not necessarily for a periodic input with pulses one microsecond apart. Pulse pileup would result. The maximum continuous counting rate is on the order of 10^5 counts/sec. The metering time constant for the log count rate is approximately one second throughout its range. This is adequate

for use with the meter-relaying system connected to the scram circuit. The period circuitry has a one-second time constant also, but uses an internal electronic trip. At the very low count-rate levels, period information is not extracted, since the statistical fluctuations are too large for useful period data.

The logarithmic amplifiers at the bottom of the scale have a time constant of approximately 100 milliseconds decreasing to 1 millisecond two decades above bottom and staying at 1 millisecond to full scale. Period information for control indication and safety is not extracted by the Log N amplifier, but is performed at another location in the control equipment. The scram system sensing Log N level is a coincident two-of-three electronic trip; response time is on the order of 4 milliseconds.

The response time of the micromicroammeter is a function of the input current:

Range (amp)	Response Time (msec)
10^{-9} to 10^{-3}	less than 1
10^{-10}	less than 10
10^{-11}	less than 100
10^{-12}	less than 1000

The micromicroammeters have an internal electronic trip or, as an alternate, limit switches on the linear power level recorders may be used. The actuation of the internal electronic trip puts out a voltage level in 1 millisecond or operates a set of contacts in 15 milliseconds.

2.4 System Operation

If the calculated coverage of the detectors is found experimentally to be correct, and shutdown reactor power is at least a milliwatt, coverage of the entire range of power may be possible using the fission-chamber-cluster Log N systems. The optimum operational location of each system can be determined at low power with a simple flux-mapping traverse.

Minimum nuclear sensing coverage at any reactor power should be one channel of period information and two channels of level information. In the upper ranges of power, when the reactor is being controlled through one of the Log N systems, the scram logic is two-out-of-three coincidence, while at the lower levels the reactor will scram if any level or period limits are exceeded.

Moving the chambers with the remote drive mechanism will tend to induce electrical noise in the cabling. This is particularly true at the low-current levels for the current systems. It is probably best that any scrams associated with a particular channel be invalidated while the detector is being moved. Under no conditions will a channel be used for control or safety information while it is being relocated. The period signal associated with the Log N channels will be quite noisy when the input level is below the bottom of the scale. This occurs because the gain of the amplifier will be at a maximum with the input at a very low level, so that the output will strongly reflect the statistical fluctuations of the source. Other noise contributions will be on the same order of magnitude as the input signal level. In order to avoid spurious scrams it will be necessary to bypass the period safety circuitry in the Log N groups until they begin coming on-scale.

3.0 NONNUCLEAR INSTRUMENTATION

3.1 Air Flow Metering System

A schematic of the air delivery system is shown in Fig. 8. Depending on the range of flow rates desired for a particular run, one of three flow tubes may be selected. These are designated as FM-1A, FM-1B, and FM-2. The accuracy required of the system is that the flow rate error shall not exceed 2% in any range from 0 to 2000 lb/sec.

FM-1A and FM-2 are actually the same flowmeters which were used during the Tory II-A tests. A third venturi, designed to be interchangeable with FM-1, has been added to insure accurate measurements in the middle range of flow rates where the previous system was deficient. Also to further increase operational flexibility, each flow tube is equipped with two ranges of transducers and range switching can be accomplished at the control console during a run.

The flowmeters are equipped with copper/constantan thermocouples to measure inlet air temperature over a range of -40 to +110°F. FM-2 meters air in the 6-inch supply line and will operate in a choked condition over most of its range which extends up to 450 lb/sec. For low-flow blowdowns pressure and temperature measurements at FM-2 will supply feedback signals to the air flow control system (described in Part 5 of UCRL-7036).

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Fig. 8. Schematic diagram of the air delivery system.

FM-1A and 1B are interchangeable venturis in the main 24-inch supply line. The new flow tube will operate choked above 35 lb/sec and will permit accurate flow rate determination up to 1600 lb/sec, an important region of flow rates since many of the facility qualification tests will probably be conducted in that range. Operation at higher flow rates with FM-1B will not be possible because of the danger of overpressuring the piping upstream of the venturi section. FM-1A is a venturi-type flow tube capable of measuring steady-state flow in excess of 2000 lb/sec. The flow tube becomes choked at relatively high flow rates; therefore differential pressure measurements must be made over a good portion of midrange operation. These measurements proved to be very inaccurate during the Tory II-A tests, and the error in flow rate determination was larger than 2% for flow rates below 800 lb/sec. For flow rates in the intermediate range the air flow control loop will be closed on information from FM-1B. Because of the unreliability of FM-1A, at high flow rates the control loop will be closed on signals from measurements made downstream at the #0 rake station. The following table indicates the operating ranges for each of the flowmeters.

Range designation	Flow rate range (lb/sec)	Differential pressure range (psid)	Inlet pressure range (psia)
FM-2-A	0 - 200	choked	0 - 350
FM-2-B	0 - 450	choked	0 - 750
FM-1B-A	0 - 900	0 - 250	0 - 500
FM-1B-B	0 - 1200	0 - 350	0 - 750
FM-1A-A	0 - 1600	0 - 250	0 - 500
FM-1A-B	0 - 2000	0 - 350	0 - 750

Additional flow rate determinations will be possible through measurements at the two bunker rake stations, the grid section and the exit nozzle.

There are several incentives for all these measurements. Good flow rate information is vital for control purposes and post-run calculation of the reactor's heat transfer characteristics and calorimetric power output. By correlating independent flow rate measurements, which are transmitted and recorded by independent systems, it is hoped that flagrant systematic errors may be recognized early and eliminated.

3.2 Test Vehicle Instrumentation

Each phase of the test program* will place emphasis on a different set of measurements, and specific instrumentation requirements may even vary from run to run. This section will outline the types of measurements that will be made and the approximate number and locations of transducers.

Measurement Summary

Measurand	Number of channels
Strain	20
Displacement	18
Acceleration	11
Stagnation Pressure	42
Static Pressure	28
Transient Pressure	2
Stagnation Temperature	21
Reactor Component Temperature	182
Control Actuator Component Temperature	28

Transducer	Types	Temperature Limit (°F)
Strain gage	SR-4	1100
Displacement gage	LVDT	400
Accelerometer	Ceramic-Self Checking	120
Pressure sensor	Bonded Strain Gage	120
Thermocouples	Platinum/Platinum-10%-Rhodium	2700
	Chromel/Alumel	1800

An important group of measurements involving control element positions will not be discussed here. These are covered in Part 5 of UCRL-7036. Table I is a more comprehensive instrumentation listing. The station numbers may be referred to Fig. 9.

*See Part 9 of UCRL-7036.

Table I. Tory II-C test vehicle measurement summary.

Station numbers* (inches)	Measurements	Purpose
00 0	2 Strain gages 2 Position indicators 2 Thermocouples	Measure strain in the clamps at the disconnect section Measure horizontal and vertical displacement of the duct with respect to the ground Measure temperature of the air duct clamps at the disconnect section
85 8	<u>#2 Rake Assembly</u> 8 Total pressures 2 Static pressures 2 Total temperatures	Data from these measurements used to obtain flow rate at the grid
95	2 Static pressures	Measure static pressure (at duct wall) just upstream of grid
100	2 Strain gages	Measure strain on flange at grid station
184	3 Accelerometers	Measure tri-axial acceleration on duct flange
248	<u>#4 Rake Assembly</u> 4 Total pressures 2 Static pressures 2 Wall static pressures 2 Duct wall temperatures	Air stream measurements in the vicinity of the actuators
250	2 Accelerometers	Measure acceleration in axial and vertical directions on the shim actuator housing
278	10 Strain gages 2 Accelerometers 22 Thermocouples	6 gages measure strain on duct flanges and supporting frame, and 4 gages measure strain on bolts Measure acceleration in axial and vertical directions on the shim actuator housing Measure actuator and control rod operating temperatures
338	3 Accelerometers	Measure tri-axial acceleration on flange upstream of core vessel
348	<u>#6 Rake Assembly</u> 8 Total pressures 4 Static pressures 1 Wall static pressure	Measure pressures near the core front support structure Close-coupled, high frequency response transducer to measure transients in the air stream upstream of the reactor
367	5 Displacement gages 1 Wall static pressure	Measure relative displacement between core and duct and car, and car and ground Measure pressure in the core side support rail system
396	6 Thermocouples	Measure outer duct temperatures over side support rails and bolts
405	4 Wall static pressures 6 Thermocouples 4 Displacement gages	Measure static pressure in the rail system near hottest region of core Measure outer duct temperatures over side support rails and bolts Measure displacement between duct and core vessel
Core	182 Thermocouples	Measure temperatures in ceramic components springs, side support structure, etc
421	5 Displacement gages 1 Wall static pressure	Measure displacement between duct and core duct and car, and car and ground Measure pressure near aft end of core between the side support rails
441	1 Wall static pressure 6 Thermocouples 3 Accelerometers 6 Strain gages	Close-coupled high frequency response transducer to measure transients in the air stream downstream of the reactor Measure temperatures on the aft support ring Measure tri-axial acceleration on aft support ring Measure strain on the aft support ring
448	<u>#10 Rake Assembly</u> 10 Total pressures 12 Total temperatures	Measure temperature and pressure of air stream leaving the core
Nozzle	4 Wall temperatures 1 Thermocouple 4 Wall static pressures	Measure inner nozzle wall temperatures Measure nozzle cooling air temperature Measure static pressures at inner nozzle wall

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*Refer to Fig 9

TORY II-C INSTRUMENTATION LIST & ASSEMBLY

Fig. 9. View of the test vehicle showing rake assembly locations.

3.2.1 Air Stream Pressure and Temperature Measurements

Six rake assemblies have been provided for measurements on the air-stream downstream of the heaters. The location of the probes is shown in Fig. 9. Two of the rakes are located in the bunker. The #0' rake is located in a bypass line which is designed to vent through the top of the bunker and will allow early blowdowns to be performed without the test vehicle in place.

Temperature measurements at the #0 rake station will supply feedback signals to the automatic inlet air-temperature control system. During runs near design flow rates the air flow control system will close its loop on flow information obtained at this station.

The #2 rake is just upstream of the grid section. The grid is simply a perforated plate placed across the airstream. Each flow passage is a miniature diffuser. At fairly low flow rates the grid will choke, thus isolating the reactor section from perturbations in the air delivery system. Pressure and temperature data obtained from the #2 rake assembly should yield accurate flow rate information which can be used to calibrate the #0 rake data.

The #4 and #6 rakes are situated in the control sections just upstream of the reactor to provide information on the actuator environment and the flow patterns of the air in that region. The last rake, #10, is positioned to provide data on the pressure and temperature of the air as it leaves the reactor. The temperature measurements here are vital to the determination of reactor calorimetric power. The probes have been positioned on the rake so that the average of their outputs will be very close to the mixed mean temperature of the air.

Two close-coupled transducers will be mounted on the test car, one upstream and one downstream of the reactor, to monitor any high-frequency transients in the air stream. A number of static pressure measurements are also made at various stations along the duct. The exit nozzle will be cooled by air bled off from the tank farm; this system includes pressure and temperature instrumentation to control flow rate.

Most of the pressure transducers will be mounted in the test bunker and connected to measurement sites on the test vehicle by long supply lines. This will serve to cut down the response of the measurements; however, the primary interest here is in steady-state pressure levels. Placing the

transducers in the bunker avoids the severe temperature, vibration, and radiation environment on the test pad and allows access to the instruments at all times for calibration or maintenance. Normal calibration procedure will be end-to-end; a known pressure will be impressed on the transducer and the output transmitted to the control point to be recorded. Occasionally the spacing of runs may be too close to permit such thorough calibration prior to every run. However an automatic electrical calibration will be used in any case.

3.2.2 Core Temperature Measurements

These measurements are vital not only to operate and control the reactor, but to obtain basic information on its performance. Four issues are involved: a) selection of the proper transducer, b) installation of the transducer, c) presentation of pertinent data to the nuclear operator during a test, and d) post-run data reduction. The transducer chosen for this purpose is the platinum/platinum-10%-rhodium thermocouple. This transducer did an excellent job during the Tory II-A tests. With a few improvements in installation practice the previously obtained performance levels should be surpassed during the Tory II-C tests.

The distribution of measurement sites within the reactor was based on neutronics and heat-transfer data requirements as well as assembly and operational considerations. Some specific kinds of data desired are:

- a) Radial temperature profiles.
- b) Axial temperature profiles.
- c) Axial temperature profile along a control rod.
- d) Temperature distribution near anticipated hot spots.
- e) Temperature distribution near tie rods.
- f) Temperature profile across the side reflector.
- g) Temperature profile across the forward reflector.
- h) Temperature extremes within the reactor.
- i) Operating temperatures in the side reflector, nickel shims, springs, side support annulus and duct wall.

The heaviest concentration of thermocouples was placed in a pie-shaped segment of symmetry covering about one-sixth of the area in the highest-fueled axial plane. The total number of thermocouples in the core is 144,

and these are all of the coaxial type. Thirty-eight thermocouples have been placed in the side support structure and assembly and these are of the two-wire type.

The thermocouples will be installed as the core is assembled, using essentially the same procedure as was used in the Tory II-A program. Un-fueled tubes are incorporated in the core as thermocouple lead wire passages. From the measurement sites the lead wires will cross over to an unfueled tube column and from there go upstream, terminating within four inches of the front cell plates. At this point connection is made to 1/8-inch (2-wire) platinum/platinum-10%-rhodium extension wire covered with a stainless steel sheath. These wires penetrate the duct near the #6 rake station and enter connection boxes mounted directly to the duct. From there connection is made to longer extension wires which run along a wireway into the test bunker where the reference junctions and transmission systems are located.

3.2.3 Strain-Vibration-Displacement

These measurements are designed to yield information on the dynamic behavior of the air duct and supporting structures to insure that design limits are not exceeded. It has been pointed out that the temperature limit on the accelerometers is approximately 120°F so their usefulness will be limited to nonnuclear blowdowns. The displacement gages are intended to supply information on dimensional changes in the duct and core vessel during tests, the primary source of which will probably be thermal expansion. Of particular interest from the neutronic standpoint is the size of the "barreling effect" which the core exhibits at high temperatures.

3.3 Data Transmission and Recording Systems

A great degree of flexibility is achieved in this portion of the system through the use of patch boards at the test bunker and at the control point which permit any input transducer signal to be sent to any transmission channel and then to any recording system or visual display. Two pairs of patch boards are used, one pair for process parameters and the other for test vehicle data.

All input transducer signals will be brought to the appropriate patch board in the bunker. The process board has 1632 input/output connection points, while the vehicle instrumentation board has a capacity of 4896 points.

The transmission links are all coaxial cable to the control point. Data is transmitted either via single, continuous analog channels or via one of three multiplexed channels, each of which transmits 84 channels of data and 4 reference channels. The bulk of the pressure and temperature data from the test vehicle and a few process parameters will be multiplexed. The bandwidth of these channels is about 1.5 cps. The direct analog channels are reserved for parameters like strains, accelerations, and control system data which require a broad frequency band.

3.3.1 Magnetic Tape Recording System

A pair of 14-track magnetic tape recorders will be operated in parallel at the control point. Four channels will be reserved for multiplexed data — three of these channels originate in the test bunker and the fourth is a channel of data multiplexed at the control point. Other channels on the magnetic tape will be used to record accelerometer data, operator conversation during runs, and IRIG-B time code.

3.3.2 Pulse Duration Modulation (PDM) System

Data multiplexing will be accomplished by pulse duration modulation. In the test bunker transducer signals are diverted at the test vehicle patch board to one of three PDM solid-state multicoders. The multicoder portion of each system samples each of the parallel data inputs ten times a second, producing a train of amplitude-varying pulses. These PDM pulses are then converted to a train of duration-varying pulses of constant amplitude by the keyer or PDM encoder and transmitted to the control point via a single cable. Each system has a capacity of 88 data channels and two consecutive blank channels reserved for frame synchronization. The first four channels carry constant-input reference voltages set at zero, one-third, two-thirds, and full-scale levels. The sampling rate of each system is 900 samples per second.

A fourth multicoder is located at the control point to sample miscellaneous parameters which originate there, or have been transmitted from the bunker via a continuous analog channel. The four PDM pulse trains are recorded on magnetic tape and then sent to their respective ground stations for decommutation. The PDM signals are displayed, as they are received,

on a 17-inch bar oscilloscope. This "quick-look" display consists of a series of vertical lines on the face of the raster, with the length of each line proportional to a transducer output.

Four channels from each unit may be selected for simultaneous recording on a strip-chart recorder for quick post-run analysis. After a run the magnetic tape can be played back to produce the raster display again and to generate a different set of strip charts. Actually, because of patch board capability, the decommutated PDM data can be distributed to any other strip-chart recording system as necessary.

3.3.3 Strip-Chart Recording Systems.

These recording systems are supplied by signals transmitted by the continuous analog channels. Transducer outputs are sent to the bunker patch boards and then to appropriate signal conditioning networks for transmission down the long lines to the Control Point (CP) patch boards. The multiplexed channels bypass the patch boards and go directly to the magnetic tape recorder and their respective ground stations.

The high-level boards at the CP contain 816 points for process data and 1632 points for test vehicle parameters. From these boards the data signals may be distributed to meters for visual display, console strip-chart recorders, the tape recorder, the CP commutator for multiplexing, or the fast-response strip-chart recorders; or any combination by parallel connections.

Pressure and temperature data required for flow rate feedback is sent to a modified analog computer which computes measured flow rate. This information is sent to the air flow control system and is recorded. Eleven 8-channel fast-response strip chart recorders are provided for broad band measurements up to 150 cps. Strain gage data, valve positions, important pressures, and miscellaneous process parameters will be recorded in this manner. Figure 10 is a block diagram of the entire data system.

3.4 Master Time Code Generator System

The master timing system supplies time information to all recording systems to allow time correlation of data records. The time base is derived from an internal quartz-crystal-controlled oscillator and is regularly

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Fig. 10. Block diagram of the Tory II-C data distribution system.

compared with a signal from Radio Station WWV to minimize drift. A visual decimal display of days, hours, minutes, and seconds is provided in the control room.

The generator supplies time in three formats which are illustrated in Fig. 11a, b and c. These are, a) IRIG standard B format for recording on magnetic tape, b) IRIG standard D format for strip-chart recorders running at 20 inches per hour, and c) a special Lawrence Radiation Laboratory time code for strip-chart recorders running at 2.5 millimeters per second.

3.5 Data Reduction

Test data will be recorded in four forms: a) pen traces on a strip-chart, b) digital printouts, c) PDM pulse trains on the magnetic tape, and d) FM signals on the magnetic tape. The first two forms of data will be reduced by hand. Most strip-chart channels will not normally require more than a cursory examination. The charts relating to process parameters will require more complete reduction, and to assist this effort an optical line follower will be used to graphically transfer strip-chart traces to an X-Y plotter to produce standard-size graphs. Accelerometer data will be recorded in the form of FM signals on the magnetic tape. A spectrum analyzer will be used to reduce this data.

The PDM data will be reduced at Livermore using automatic methods. An analog-to-digital converter (designated as MADIC, minimum analog to digital information converter) has been constructed to convert pulse-width information to digital form and prepare computer quality digital tapes. A series of data reduction codes has been prepared to apply calibration information to the raw data and to produce tabulations and plots of each parameter versus time. Parameters which will be handled in this way include temperatures, pressures, valve positions and voltage levels. Output may be obtained in the following units: microseconds, millivolts, degrees F, psia, and percent open. This list may be expanded at any time.

In addition to the tabulations and plots, the reduced data will be written on an answer tape. This tape will serve as a permanent record of the run and will be used as input for a final-analysis stage of data reduction. In this stage average temperatures and pressures, flow rates, and calorimetric power levels will be computed from the test data.

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Fig. 11a. IRIG Standard B 100 pps time code format.

R = 1 HR REFERENCE MARKER
P = POSITION IDENTIFIER, 48 SEC DURATION
W = WEIGHTED CODE DIGIT, 30 SEC DURATION
C = CONTROL ELEMENT (EXAMPLE), 30 SEC DURATION
DURATION OF INDEX MARKERS = 12 SEC

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TIME AT POINT A = 21 HR + 57 MIN
ON DAY 173

Fig. 11b. IRIG Standard D 1 ppm time code format.

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R = P = 1.6 SECONDS - R = MINUTE REF., P = 10 SEC POSITION

ZERO = 0.4 SECONDS

Y = YES = 1 SECOND

TIME FRAME - 1 MINUTE

LEADING EDGE OF PULSE 2 SECONDS APART

Fig. 11c. Lawrence Radiation Laboratory marker code.

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