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Analysis and Developement of FACE Automatic Apparatus for Rapid Identification of Transuranium Isotopes

By

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B.S. (Iowa State University of Science and Technology) 1974

M.S. THESIS

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ANALYSIS AND DEVELOPMENT OF THE FACE MACHINE

AUTOMATIC APPARATUS FOR RAPID IDENTIFICATION

OF TRANSURANIUM ISOTOPES

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ANALYSIS AND DEVELOPEMENT OF THE FACE AUTOMATIC APPARATUS FOR RAPID IDENTIFICATION OF TRANSURANIUM ISOTOPES

ABSTRACT

A description of, and operating manual for the FACE Automatic Apparatus has been written along with a documentation of the FACE machine operating program, to provide a user manual for the FACE Automatic Apparatus. In addition, FACE machine performance was investigated to improve transuranium throughput. Analysis of the causes of transuranium isotope loss was undertaken both chemical and radioactive.

To lower radioactive loss, the dynamics of the most time consuming step of the FACE machine, the chromatographic column output droplet drying and flaming, in preparation of sample for alpha spectroscopy and counting, was investigated. A series of droplets were dried in an experimental apparatus demonstrating that droplets could be dried significantly faster through more intense heating, enabling the FACE machine cycle to be shortened by 30-60 seconds. Proposals incorporating these ideas were provided for FACE

machine developement.

The 66% chemical loss of product was analyzed and changes were proposed to reduce the radioisotopes product loss. An analysis of the chromatographic cloumn was also provided.

All operating steps in the FACE machine are described and analyzed to provide a complete guide, along with the proposals for machine improvement.

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I. THE FACE AUTOMATIC APPARATUS

Introduction

The FACE automatic apparatus (Fast Automatic Chemistry of Elements) is a chromatographic chemical analyzer run by a computer which is used in the investigation of man-made transuranium elements. The use of this machine and the experiment performed with it is described in Lawrence Berkeley Laboratory report UCRL-77104 (1975) "Solution Chemistry of Element 104." by Hulet, Nitschke, Ghiorso, et al. Such apparatus is required because with the increase of atomic number, progressively shorter radioactive half-lives and smaller quantities of radioisotopes are encountered. Beyond fermium (element 100), intense neutrom flux is not used for element synthesis but instead charged-particle bombardment is used. Elements 103 (lawrencium) and 104 are produced in atom quantites and have half-lives of a minute or less. For the transfermium elements, both the extremely small quantities and the short half-lives render the usual chemical analysis procedures inapplicable, and necessitate innovative methods.

The FACE machine proper collects a sample containing the transuranium nuclei, isolates these elements by chromatography in a miniature ion-exchange column, and measures their relative abundance via the analysis of their radioactive properties.

In heavy element production, ion-exchange chromatography can be used to separate and recover individual elements up to element 104 or 105. Beyond this point, the half-lives fall to a second or less, and ion-exchange becomes too slow. Chromatographic columns allow rapid separation, with the drop position indicating valence and complex strength. The strength of a metal anion complex markedly increases with valence, so that elements of different valence are most clearly separated from each other by ion exchange.

For detection purposes, a column-eluant fraction can be dried and subjected to alpha-spectroscopy. The alpha-decay energies of the radioisotopes are distinct and specific and allow the identification and measurement of a desired product atom if present. Alpha-particle detection makes it possible to measure a single-atom event.

Because of the product's short half-life, the bombardment of each target sample and the analysis of each sample are restricted to short elapse times which are roughly equal. Only a few atoms are produced in each experiment, and therefore each individual experiment in itself is insufficient to produce the required scientific information. The FACE Automatic Apparatus allows rapid sequencing and summation of enough separation and counting to provide data with a statistically significant atomic valence and complexing strength.

The Computer and the CAMAC Interface

The complete apparatus consists of three major sections: the PDP-9 computer and associated terminals; the

CAMAC computer interface; and the FACE machine. These sections are referred to as X, Y, and Z, respectively, on figures 1 and 2. Figure 1 shows the major elements of FACE, and Figure 2 shows the components in some detail. These figures show overall relationships of the component parts, and the reader may find it helpful to refer to them as he studies the rest of this chapter.

The computer for the FACE automatic apparatus, a Digital Equipment Corporation PDP-9 (1968), is a large 32K memory general-purpose minicomputer. It operates in binary mode with single address, fixed word-ength(18 bits), and parallel transfer, as desribed in Appendix D. A PDP-11 or PDP-15 could be substituted readily. Operating programs can be entered by teletype, read in from paper tape, or recalled from disk storage.

CAMAC Interface Units

The CAMAC system (Computer Automatic Measurement and Control) is internationally used and standarized. It is a switchboard system for digital information transfer, and is especially useful when several pieces of equipment must interact mutually and with a computer. There are three units: the CAMAC interface; the CAMAC crate; and the controller. The CAMAC interface system has a cycle time of 2 μseconds, and the PDP-9 has a cycle time of 1 μsecond. The CAMAC interface ("branch driver") transfers the digital output of the PDP-9 synchronously to the CAMAC crate. As the digital output of the CAMAC system is a 24-bit word, the extra 6 bits are not used.

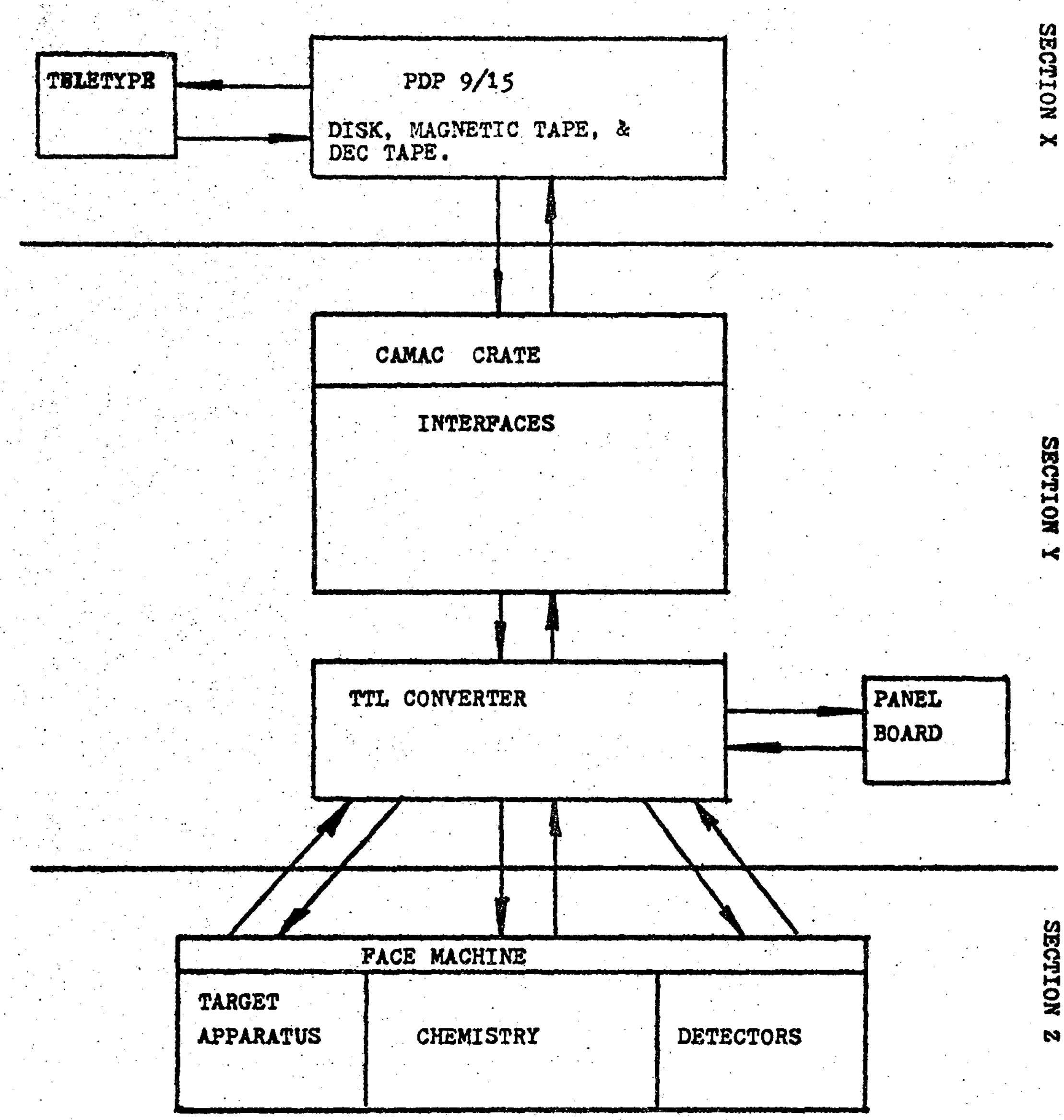


FIGURE 1 FACE AUTOMATIC APPARATUS SCHEMATIC

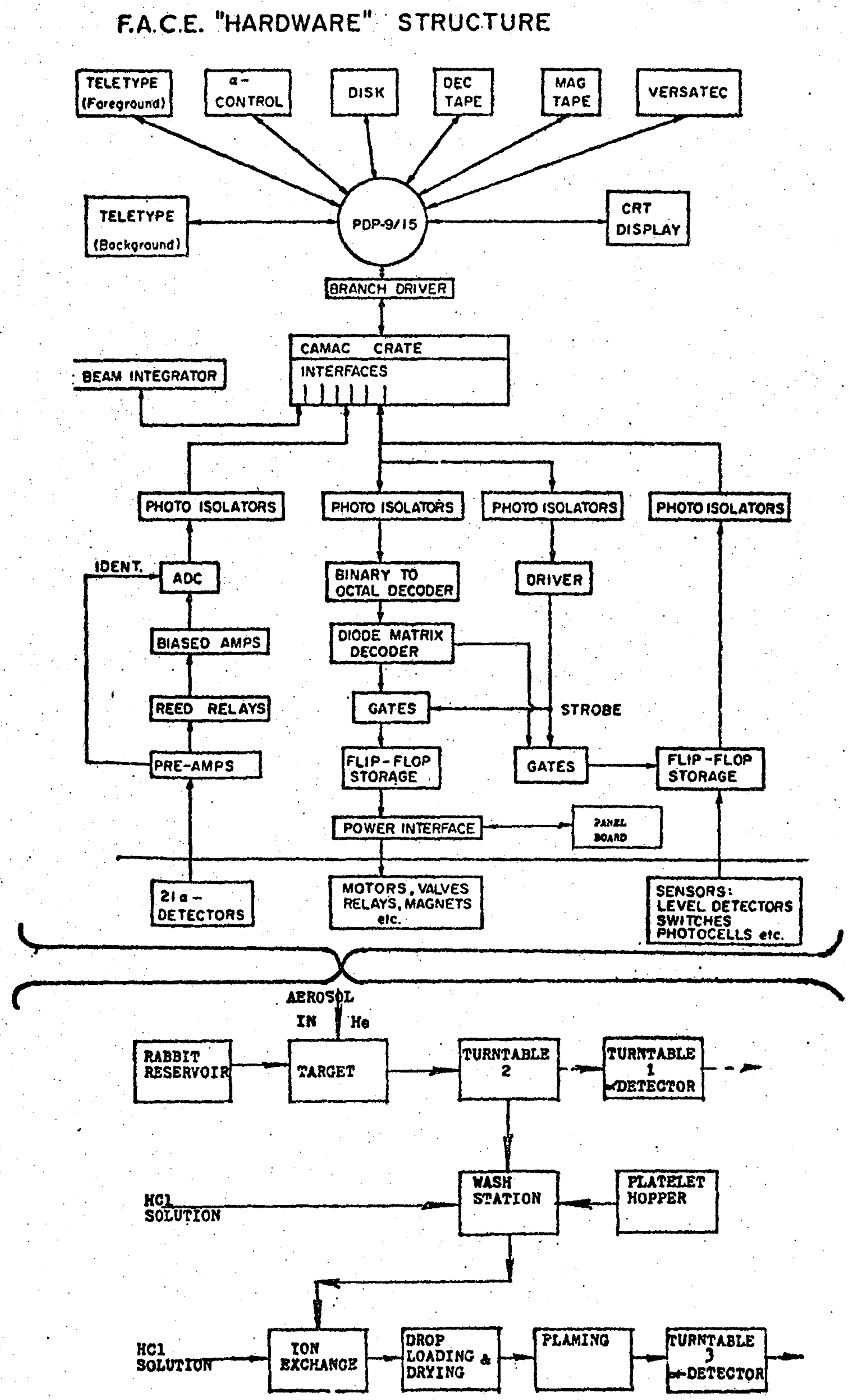
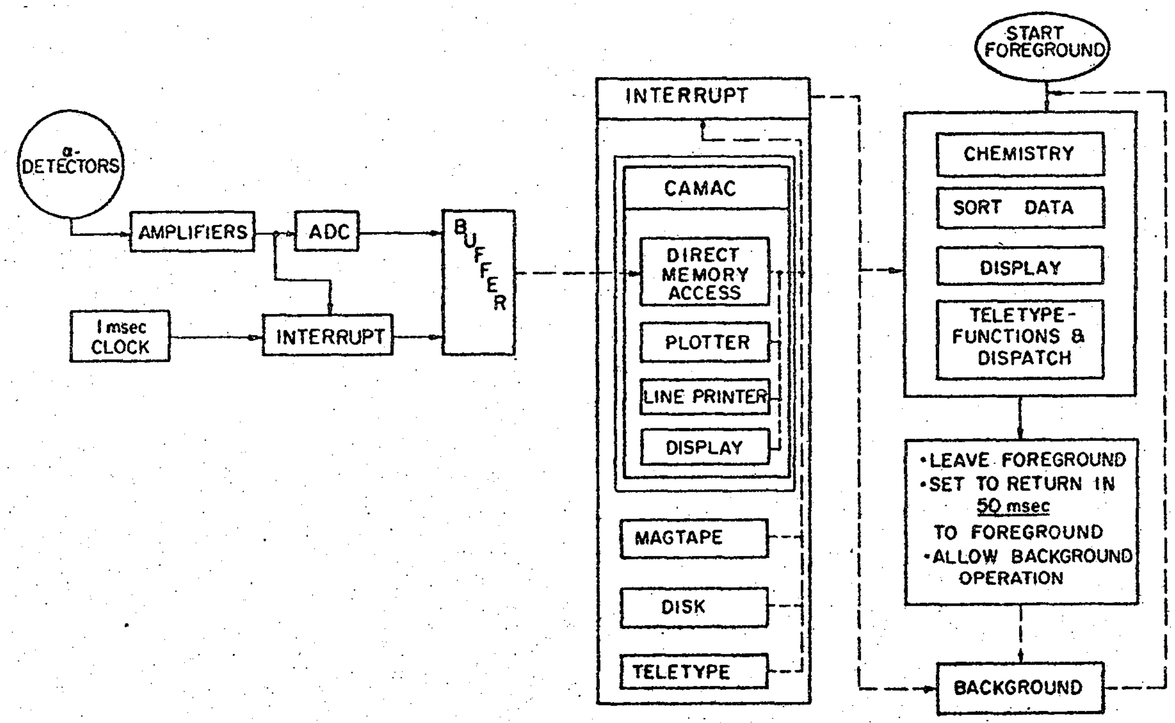


Figure 2 FACE "Hardware" Structure

FIGURE 3 PDP-9/15 ORGANIZATION FOR F.A.C.E.



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The CAMAC crate is an outlet where electronic modules can be inserted, carrying the inputs from and outputs to one or more controllers. Standard plug-ins can be read by the value of a particular bit in an 18-bit word address, indicating some particular output of a controller. The CAMAC interface transfers the digital output to the TTL logic converter. Nine bits of the 18-bit word form a three digit octal word which uniquely addresses a particular mechanical or electrical function in the FACE system. Through a flip-flop circuit, a power booster is turned on and a mechanical element of the FACE machine is operated. In a reverse of flow information, the sensor outputs of the FACE are converted to TTL logic, which is transferred through the CAMAC interface to the PDP-9 computer. Each sensor output is one bit of an 18-bit word recieved by the PDP-9. All the sensors in the FACE machine are of a binary nature; none are analog.

The TTL unit is the sector of the entire electronics which connects directly to the "real world" of the FACE machine. A computer command results in the controller's operating relays, magnets, and motors through the CAMAC interface. The TTL logic converter is completely isolated from the CAMAC crate by photoisolators which operate in the following way: The sustained output of the TTL logic converter is converted by a photo-emitting diode to a light signal which passes through an optic fiber and is received by a photodiode connected to the CAMAC crate.

The photoisolators prevent the transfer of electrical surges to the computer.

The FACE System can also be operated manually by hand switches and an octal thumb wheel address generator which directly executes mechanical or sensory functions. A switch representing each specific octal number can be used as needed to turn a mechanical element on or off or to change a sensor output.

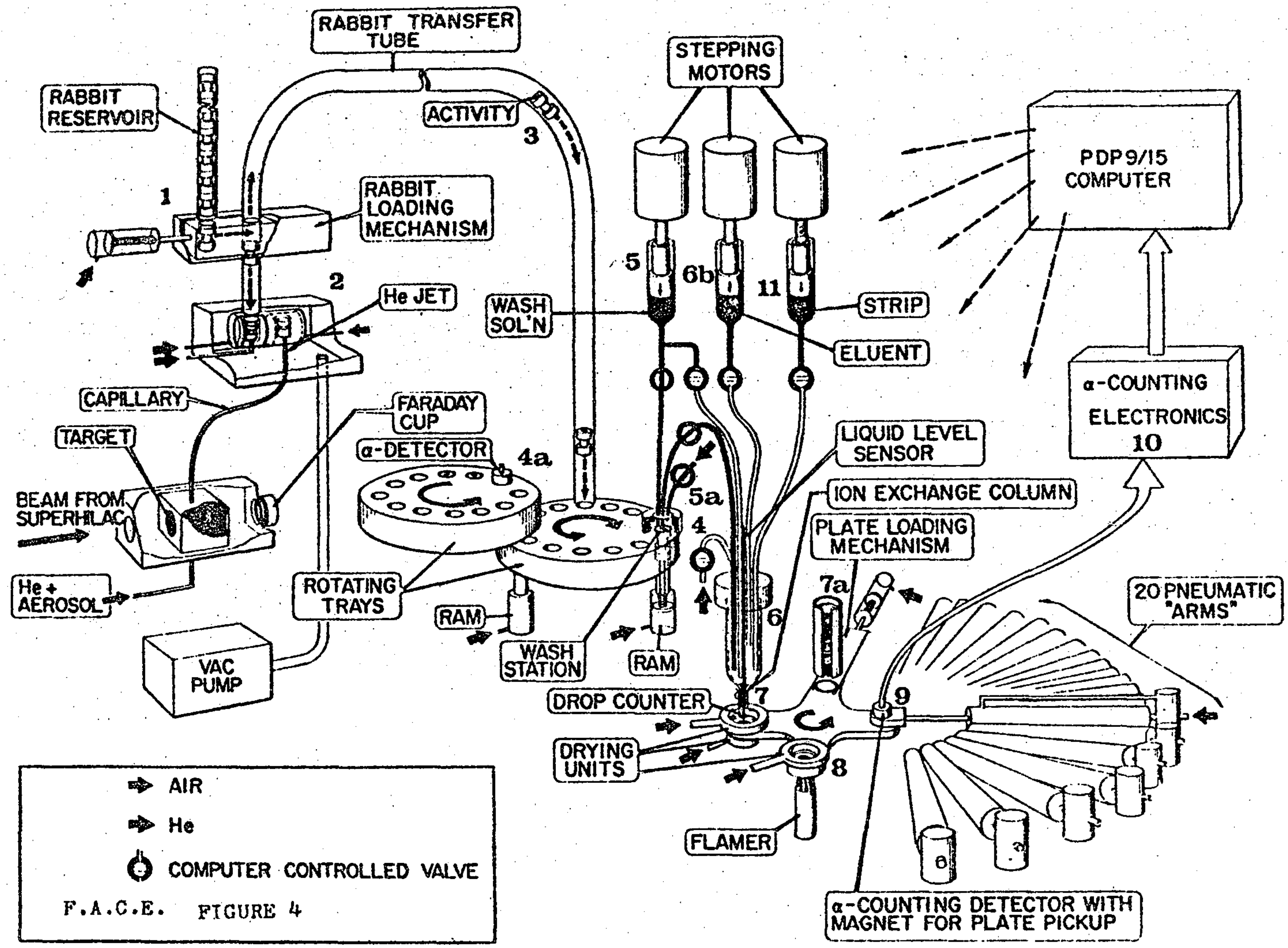
The FACE machine collects isotopes of heavy elements produced by accelerator bombardment of transuranium targets and subjects these isotopes to chemical analysis through ion-exchange chromatography. The purpose of the chemical studies is to verify that the oxidation states and complexing equilibria of the elements 103, 104. or possibly 105 corresponds to those predicted from the position in the Periodic Table.

The FACE machine consists of two units: the target apparatus and the chemistry apparatus. The target apparatus is located in a "cave", a thick concrete-wall-enclosed room which receives a high-energy heavy-ion beam from the HILAC accelerator. The chemical analysis apparatus is located in an area adjacent to the "cave".

The FACE machine is illustrated schematically in figure 4.

Element Synthesis Station

For element 104, as an example, a high-energy beam of oxygen-18 impinges on a target of curium 248, resulting in a nuclear reaction forming an isotope of element 104 with mass number 261. The beam of oxygen-18 nuclei passes through a 0.013-mm. thick beryllium foil and a helium-filled target chamber. One the beryllium foil is the target material (curium-248) which has been subliminated onto the foil. The area density of the curium is 13 $\mu g/mm^2$. The element 104 nucleus is"recoil-ejected" through the target foil in the forward direction.



F.A.C.E. FIGURE 4

The recoil nuclei are stopped in the target chamber, where the helium gas suspends a fine aerosol of sodium chloride produced continuously by passing helium over molten NaCl in a separate vessel. The recoil nuclei are collected by the NaCl aerosol particles. The recoil nuclei have an initial ionic charge of 30^+ which drops (rapidly at first, more slowly later) as the ion collides thermally with the helium atoms. The isotope has a high probability of colliding with an aerosol particle. Moreover, owing partly to residual charge of the isotope atom (ion), it has a very high sticking coefficient (100% fractional retention) once it has collided with an NaCl particle. Thus, the measured efficiency of the NaCl-aerosol capture of nuclei is essentially 100%.

Aerosol-Collection Station

The aerosol particles are removed from the discharged helium in a separate location. The aerosol from the target chamber enters an upper evacuated chamber where it impinges as a jet onto the flat closed end of a polyethylene cylinder (position 2 in Fig. 4) called a "rabbit". The rabbits are positioned and later discharged by pneumatic pistons. After an appropriate time interval (currently 2 min.), the rabbit is removed from this station carrying with it the NaCl particles.

Rabbit Loading Mechanism

The rabbit resevoir and rabbit loading mechanism store the rabbits until needed, and move them into and out of the aerosol collection station depositing area.

The rabbits are received from the FACE machine from where they were sent pneumatically. In the FACE machine, they are stored in a reservoir.

When a rabbit is needed, a piston moves the rabbit so that it will drop into a second loading piston which positions it over the helium-NaCl jet. The second piston functions as an airlock, so as to maintain a vacuum during the collection period. After collection, the piston retracts, withdrawing the rabbit from contact with the jet. Air pressure is then applied, shooting the rabbit via the rabbit transfer tube into Turntalbe 1 in the FACE machine (see Figure 4).

Tray Stations

When a rabbit is received by the FACE machine, the radioactive products it carries are used for ion-exchange chromatography and for verification of the product yield by alpha-detection. To measure the yield of recoil products collected, and transferred to the FACE machine, an alpha-counter station is installed above Turntable 1, If this counter is used, the sample undergoes no further analysis.

Each turntable is a plastic wheel with twelve holes in a circular array near the rim. These holes are of the diameter of the rabbits, and are called tray positions. Turntable 2 which rotates counter-clockwise is used to position the rabbit over the transfer ram. This ram is located four tray positions away, or 4/12ths of the turntable circumference from the arrival positions of the rabbit returning from the target apparatus. At the transfer position, a pneumatically operated ram pushes the rabbit upward into Turntable 1 where lever-tripped spring-tightened pincher hold the rabbit while the transfer ram recedes to its rest position. The rabbit is then rotated 1/6 of the circumference (or two tray positions) to bring the rabbit under the alpha-detector where the alpha-detector, under helium blanketing, counts the alpha particles emanating from the radioactive deposits on the rabbit. The salt deposit is not thick enough to significantly attenuate the alpha particles emitted.

The beam bombarding the curium target produces not only the desired element 104, but also a variety of the isotopes. The energy of an alpha particle is specific to the type of nucleus producing it, and all events are to be identified and counted separately. The production cross section for 104 is relatively low compared to those for other elements in the lead region.

By observing the decay yield of a polonium isotope, for example, which is produced thousands of times more often than element 104, the yield of the target system can be monitored to some extent. Every run of a group of rabbits is started with a yield check of the first rabbit to check that recoil nuclei are being produced, and that salt aerosol is present and has collected recoil nuclei.

After yield counting is completed, Turntable 1 is rotated to the discharge position which contains an outlet under the turntable. In the discharge position the pincher lever is tripped and the rabbit released to drop through a hole under Turntable 1. To assist the rabbit in dropping,a ram is present which will forcibly discharge the rabbit.

Wash Station

The rabbit is received from the target by Turntable 2 and transferred to the wash station by rotation of the turntable through two positions (1/6 of Turntable 2 circumference). When the rabbit is in the wash station position, a pneumatic ram propels the rabbit upwards against the wash station head, a hollowed-out Lucite half-sleeve with three metal capillaries entering it from the top.

The rabbit now completes an air-tight enclosure. The three capillaries provide respectively a vent, a feed line of wash solution (12M aqueous HCl) supplied by a syringe, with a vent branching off the feed line; an air line; and a transfer line to the chromatographic column, reaching almost to the face of the rabbit. Each capillary line is connected to a 1/16-inch Tygon tubing and is opened or closed by pneumatic pinch valves.

With the rabbit in place, 70 μl of liquid is deposited on the rabbit face to dissolve the deposited aerosol which contains the redissolved products. The resulting washing has been observed to remove 80% of the recoil nuclei.

The vent and feed line are then closed, and the connecting transfer tube to the chromatographic column is opened. The wash station enclosure is pressurized with air and the droplet is forced into the transfer line, and through it to the chromatographic column. This wash operation is repeated once.

After the rabbit is washed, Turntable 2 is rotated to a position where the rabbit drops through a hole into a catch beaker.

Chromatographic Column

The chromatographic column performs the separation of the different radioactive species dissolved off the rabbit face.

The chromatographic column, illustrated in Figure 11, is 2 cm. long and has a 2mm. inside diameter. The column packing is 0.25 F trioctylmethyl ammonium chloride diluted with ortho-xylene, supported on an inactive fluorocarbon powder. There are five Tygon lines going to the chromatographic column. They have the following functions: an air line for pressure; the transfer line from the wash station; and one line from each of three HCl solution-supply syringes, of which only two are actually used. The air line provides pressure to drive the wash solution and elutants through the column. A vent allows the release of residual pressure when solutions and elutants are being transferred into the chromatographic column vessel.

The effluent from the chromatographic column is monitored by a conductivity drop counter. A platinum wire within the column connects the solution to a voltage source. When an effluent drop is ejected, it makes contact with another platinum wire as it falls, and a pulse of current signals the computer.

Chromatographic Chemistry

A variety of metal cations dissolves from the rabbit into the 12M HCl solution. The aerosol supplies Na, and the others come from target nuclear reactions or from radioactive decay of the original product nuclei. The actinides, nobelium, fermium, and curium are present, the last of these deriving directly from the curium target.

Metal cations exhibit the following equilibrium chemistry in aqueous HCl solutions:

$$M^{+n} + (n+1)Cl^- \rightleftharpoons MCl^-_{n+1}$$

The complexing strength of metal cations increases in the following order of element groups: IA<IIA<IIIB(including actinides)<IVB.

For a 12M solution the anionic chloride complexes, especially from a metal (element 104), are strongly bound to the stationary organic phase in the column. The other metal groups complex less strongly, so that an elution sequence for different elements can be established.

After passing the wash solution liquid through the column, elution with 6M HCl is performed in which the anionic chloride complexes are less favored and hence the group IVB element is eluted. The residual wash solution (12M) is collected as a single fraction (5 free-column volumes) and is followed by two smaller elutriant fractions (6M, each 2.5 column volumes. One free-column volume is approximately 30 μl).

Each fraction from the chromatographic column is collected and dried on a platelet, as illustrated in Figure 5.

Falling onto the platelet dimple, it lands in a cupped depression and is dried by the action of a hot helium jet above the platelet and a hot air jet below. When the droplet is dried, another leaves the column and dried on the same platelet until the entire fraction is collected. The droplets evaporate, leaving the solutes, including element 104.

The 12M HCl fraction consists of approximately 8 droplets, and the two 6M fractions are four droplets each. Each droplet measures 20 μl based on the estimated free column in each fraction. From each rabbit, a total of 16 droplets is dried on three platelets.

Flaming Station

When the column fraction is collected, Turntable 3 transfers the platelet to the flamer station 90° counter-clockwise from the fraction collection station. At this point, another hot helium jet removes any residual moisture. Then the platelet is flamed from below by a gas burner, driving off any residual organics and raising the platelet to a red heat.

Alpha Detection and Counting

After the platelet is flamed, it is rotated 90° counter-clockwise to the alpha-detection station, illustrated in Figure 4. In this position, a pneumatically activated alpha-detector arm slides out and over the platelet to

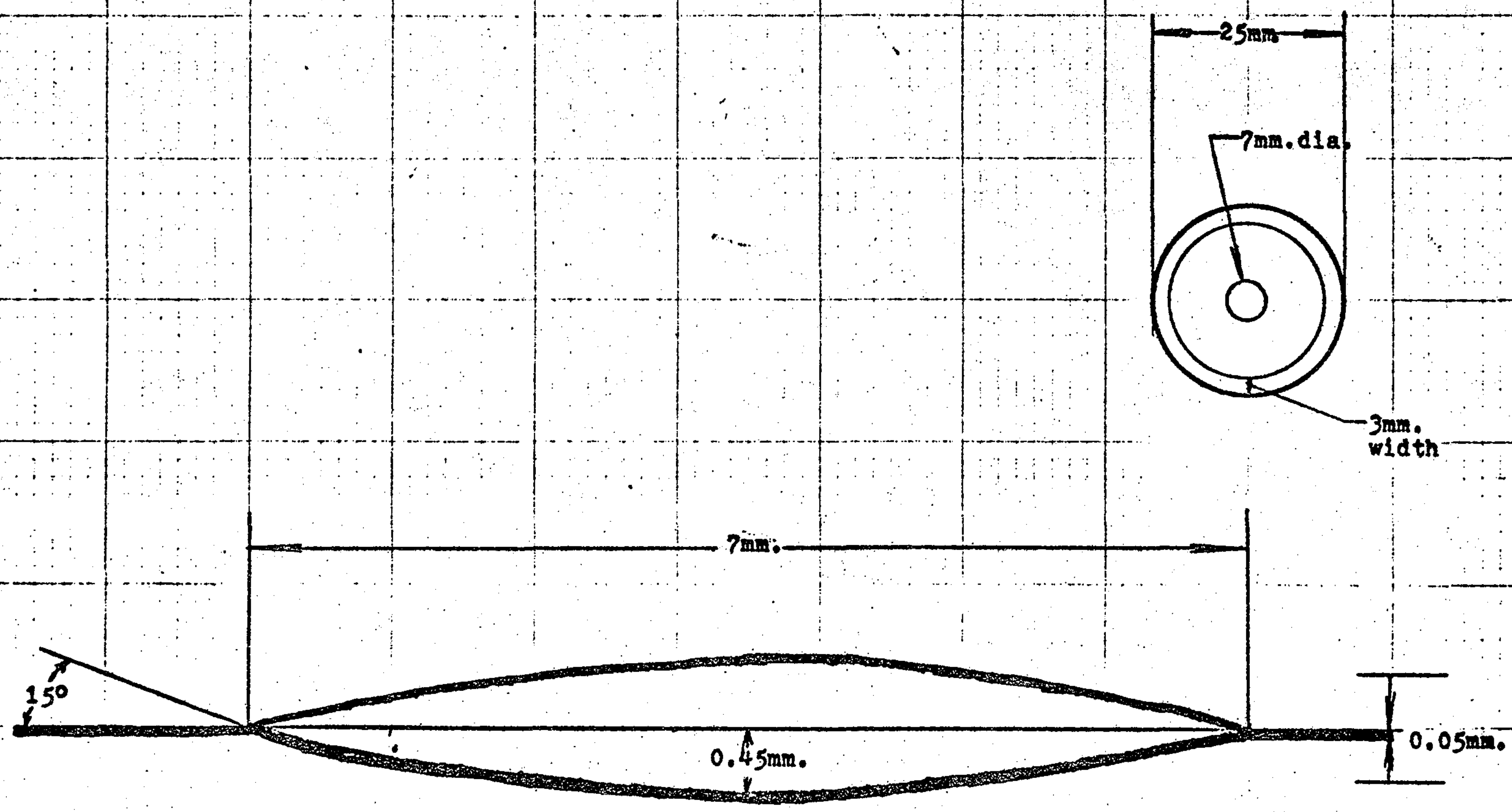


FIGURE 6 PLATELET & DROPLET DIMENSION: DIMPLE LENS VOLUME 8.7 ul; DROPLET VOLUME 19 ul; DIMPLE RADIUS 13.8 mm.

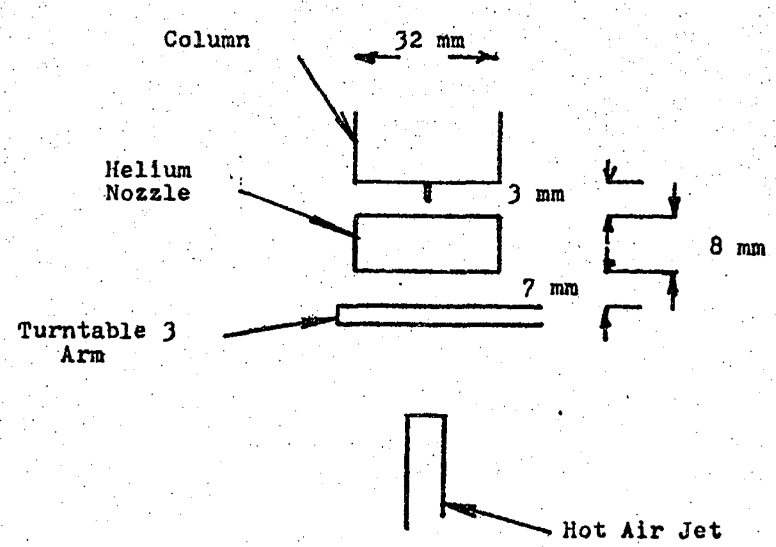


Figure 5 . Droplet Drying Station.

adhere to the detector head. The arm then returns to the conting position with the platelet.

During counting, helium is supplied to the space between the platelet and counter. Helium, with hydrogen, has the lowest rate of nuclear stopping of alpha particles because of its low density. The alpha-particle detector is of the surface barrier type with an area of $50mm^2$ and a gold coating of 40 microgram/cm^2. It is positioned directly over the platelet depression. When a radionuclide decays, a certain fraction (about 1/3) of the emitted alpha-particles strike the crystal and are detected, while the others follow trajectories into the platelet and are lost. The alpha particles are emitted with specific kinetic energies which identify the parent radionuclides. The crystal, in detecting the alpha particle, measures its energy and thus provides information about the number of counts, energies, and times of emissions from the dried column fraction. There are twenty alpha-detectors. When FACE is operating, each arm is used in rotation in numerical order to retrieve the platelets. When all the counters are in use, the next platelet is picked up by the arm which has been counting the longest, i.e., the next arm in numerical rotation. After counting, the platelet, released by turning off its electromagnet, falls through a hole beneath the counter into a catch cup. This method of counting ensures that each platelet sample will be counted as long as possible.

When 20 alpha counters are in use, the cycle time until an arm will be used again is approximately 18 minutes. Since the half-life of element 104 (isotope 261) is 65 seconds, the amount of initial isotope decaying after the platelet has been dropped is less than one part in 10^5. Nobelium 257, the alpha daughter, has a half-life of 26 seconds and is almost completely gone when the platelet is discarded.

Either of two alpha energies indicates element 102. One is from the decay of the daughter nobelium, element 102, at 8.22-8.27 Mev (any nobelium formed directly by target bombardment would be eluted in the 12M HCl wash fraction).

Efficiency of Product Recovery

The FACE machine is automatically run by the computer using the FACE program. The rabbits are irradiated and the sample processed with a cycle time of approximately 180 seconds (3 minutes).

Approximately 120 rabbits were run with the FACE machine in the last 1975 chemistry experiment with element 104*. The six events detected with the alpha counters constituted a production rate of one event per 20 rabbits.

An additonal 122 rabbits were counted with our chemistry with the Turntable 1 alpha-counter, for which 132 events from alpha decay of either element 102 (nobelium) or element 104 were observed. The low number of events detected after processing the rabbits is due to chemical loss and radioactive loss. Measurements with hafnium 181 indicated a

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*"Solution Chemistry of Element 104.", Hulet, Nitschke, Ghiorso, et al., Report UCRL-77104 (1975)

66% loss processing of a chemical nature during the process steps, by spattering, adsorption. vaporization, and/or precipitation. The removal of radionuclei from the rabbit in the wash station had an efficiency of 80%, accounting for 20% of the 66% processing loss.

The balance can be attributed to radioactive loss. Since the nobelium to element 104 production ratio of element 102 to element 104 is 1.1±.4, about half of the loss is due to radioactive decay of nobelium before it is collected, dried, and received by the alpha counters. The time between isotope production and the collection of the first eluant fraction is 105 seconds. The half-life of nobelium 257 is 26 seconds. About four half-lives will occur before it is collected for counting, resulting in a loss of 15/16 of the produced nobleium and element 104 is more thoroughly described in a later section.

II. ANALYSIS OF THE FACE PROCESS PLATELET HEATING AND DROPLET DRYING

Problems and Objectives

It is desired to increase the FACE machine output by decreasing the rabbit processing cycle time. Since droplet drying and column-fraction flaming account for most of the FACE machine cycle time, these therefore are the steps to investigate. Reduction of cycle time is important to avoid radioactive loss of the output. The product element, 104, and its daughter nobelium have half-lives of 65 seconds and 25 seconds respectively. The time lag for processing before Fraction 2 (see preceeding section on "Chromatographic Chemistry") arrives at the counter is about 150 seconds. By gaining 30 seconds in processing time, 38% more element 104 would reach the alpha counters for the same beam exposure conditions.

In processing a rabbit sample, approximately 16 droplets are dried. The reduction in time for drying each droplet is multiplied by 8, 12, or 16 to give the total time reduction for the first, second, or third column fraction respectively. Thus, even a small amount of time saved for each droplet is an important improvement. If the time required for flaming is also reduced from the present 25 seconds, perhaps even to as little as 5 seconds, the flaming station might be combined with the droplet drying station so as to enable each fraction to reach the counter approximately 30 seconds earlier than at present.

Present Methods. Droplets leaving the chromatographic column are placed on a platelet containing a small dimple, and are dried with hot helium from above and hot air from below in the apparatus illustrated in Figure 5. The platelet is made of Hastelloy sheet 0.10 mm thick with a soft-iron outer ring for magnetic lifting (shown in Figure 6), and weighs 15 grams.

The hot air is supplied through a glass tube which houses a 200-watt resistance heater with manual control. The air heater is red-hot initially (about 850°C), but visibly cools with the air flowing such that the air leaves at slightly over 100°C.

The helium is supplied through a metal ring above the platelet with an array of small holes focusing it onto the center of the platelet. The helium temperature is controlled indirectly through regulation of a thermocouple attached to the housing of the heating resistor. Helium is chosen since its thermal conductivity and diffusivity are greater than any alternate non-flammable gas. The helium temperature is initially 80-100°C and rises to approximately 200°C in about 2 minutes. The low temperatures are due to heat loss to the ring nozzle.

When a droplet leaves the chromatographic column and falls onto the platelet, the hot air and hot helium are switched on and the drop is evaporated. The time allotted for drying each droplet is constant at 7 seconds; the first drop to be dried starts at room temperature, whereas succeeding droplets contact a prewarmed platelet. In the operation of the FACE machine, 8.3 seconds are allocated per drop including the time for drop formation.

FACE Machine Experimental Results. The heating of a platelet by hot helium and air jets, separately and in combination, was investigated in the FACE machine drying station. A chromel-alumel thermocouple was fastened onto the upper side of the depression in the platelet and soldered on to provide thermal contact; the thermo-couple output was monitored by a recording voltmeter.

The thermal response of the platelet should be greater than that of a platelet with a column droplet for the following reasons. The thermocouple connection weighs a couple of grams and compared to the 15 gram weight of the platelet is not a significant change in the overall heat capacity of the platelet. The thermocouple solder droplet is smaller than the column droplet and has a lower heat capacity. Finally, although the thermocouple wires conduct heat away from the solder droplet, this is less than heat removed by evaporative effects. The importance of the thermocouple measurements is to compare the heating of the experimental apparatus to the FACE machine gas jets.

The hot-air heater was used at a constant resistor setting in the experimental runs. The results were found to reproducible and consistent, and are summarized in Table 1 and Figure 7. The droplets will concentrate to the HCl azeotrope concentration (6.1M, boiling at 110°C) on drying.

The slow heating and low final temperature of the platelet, which never reaches the azeotrope boiling point, shows that the heat flow is insufficient to evaporate the droplets. It was found that the helium contributes little toward heating the platelet in combined helium and air-heating experiments.

The thermocouple responses to hot helium at 10, 20, and 30 cubic feet per hour flows is shown in Figure 8. The results indicated a slow raise of helium temperature as the ring nozzle warms up.

These results showed the need for more extensive experiments to observe droplet evaporation and flaming and to develop methods for accomplishing these steps in minimum time without radioactive product loss. Rapid drying of droplets has two operating constraints. First, boiling is undesireable. Bubbles breaking on a liquid surface nearly always eject an aerosol which, in this case could contain an element 104 atom. Secondly the droplet must remain in the platelet dimple depression. Since the alpha-detection silicon crystal is placed immediately over the depression during counting, and decay occurring elsewhere on the platelet is not detected. To advoid laterally displacing the droplets, a practical limit is imposed on hot gas velocity. In all experiments, it was noted whether these two criteria were met.

Droplet Drying with Hot Gas Jet Above. The evaporation of a droplet cools the droplet and insulates it from the hot gas in contact with it. The droplet is insulated from the hot gas by the evaporated liquid , that provides a material

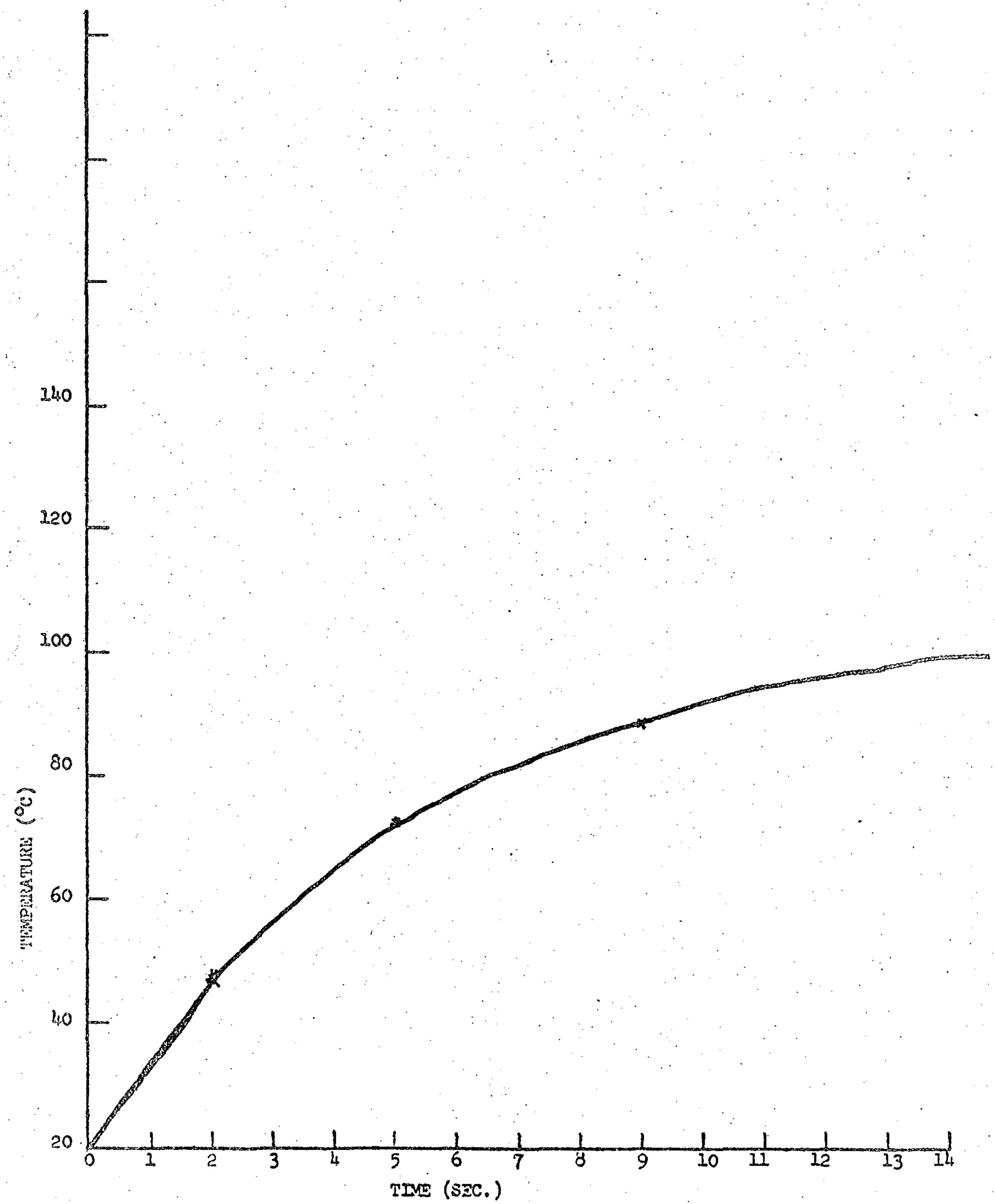


FIGURE 7 TYPICAL PLATELET HEATING RESPONSE, RESISTOR: 60% AIR FLOW: $\frac{1}{2}$ valve setting

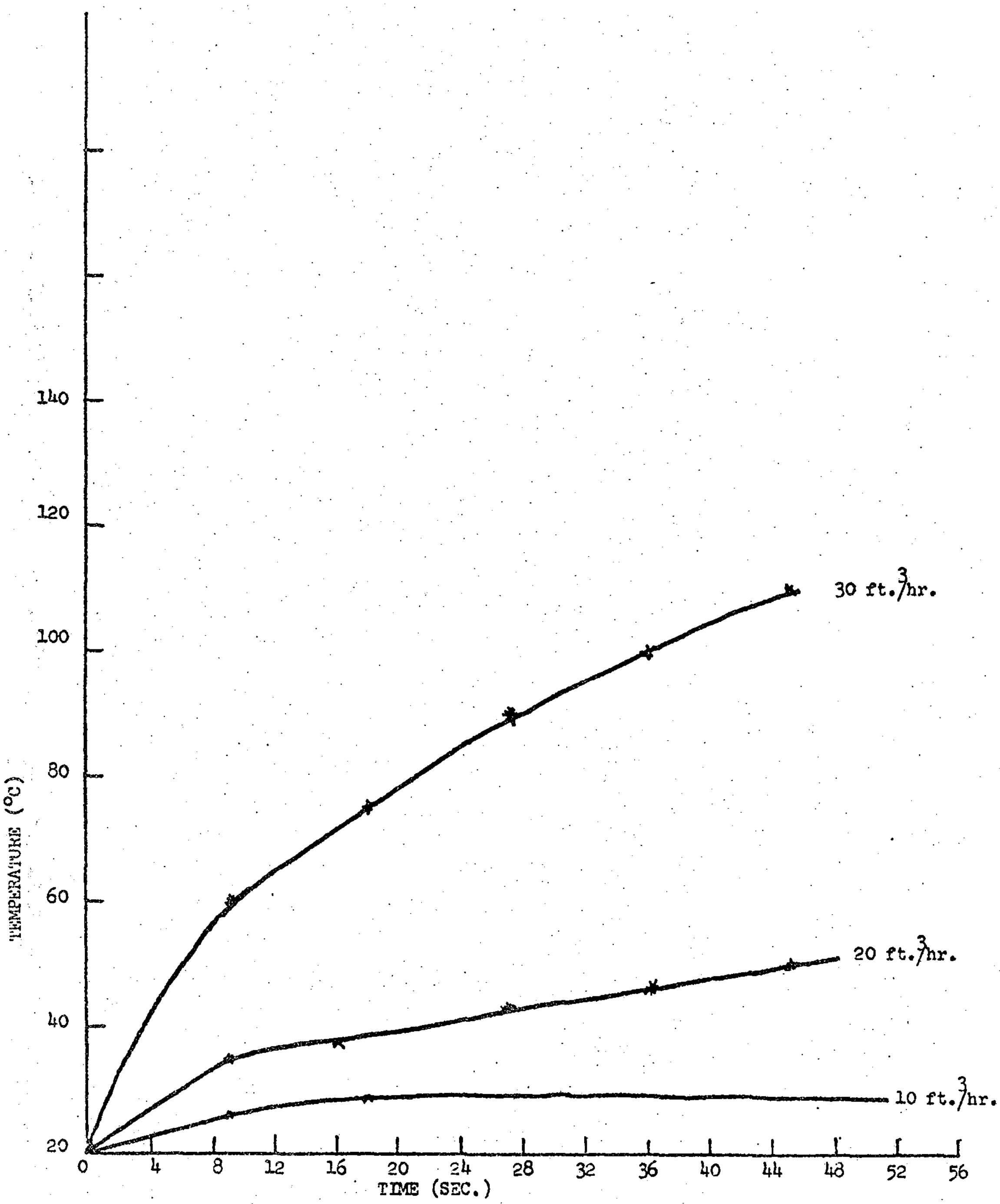


FIGURE 8 PLATELET HEATING RESPONSE TO HOT HELIUM: 600°C setting

flow away from the droplet surface against which the heat must conduct. Thus, heating supplied from hot gas impinging on the droplet is safe and self-limiting with respect to advoidance of bulk boiling.

With an increase of gas temperature immediately above the droplet, the vapor pressure (and, hence, the interface gas phase content) of the droplet fluid increases, resulting in a larger mass flow from the droplet, without much increase in the liquid temperature.

Platelet Heating From Below. Heat transfer from the platelet is a means of supplementing the heat supplied through the droplet surface. As this heating enters the droplet from below, it will tend to cause boiling, with the attendant risk of loss. To minimize this problem, it is desireable to have the heat conduct from the platelet into the edges of the droplets instead of the platelet beneath the droplet.

The vigorous forced convection currents do not reach the edge of the droplet and are circular, and parallel to the plane of the platelet. Whether the heat-transfer mechanism is conduction or convection, the resistance is proportional to droplet thickness.

The droplet is lens-shaped and rests in the platelet in a dimple depression. The platelet metal is 0.10 mm thick. The droplet has a diameter of 7 mm and a depth of 1.0 mm (see Figure 6). When heat is supplied by using hot gas from underneath the platelet, heat must conduct through the droplet at its maximum depth before reaching the droplet surface. When heat is supplied from the platelet circumference (by RF or other source), conducting toward the center, the heat conducts into the thinnest part of the droplet. The thinness of the platelet lessens the rate of horizontal heat conduction compared to vertical heat transfer into the droplet. From this, it appears that most of the heat conducting toward the center of the platelet will be transferred into the droplet within 1 mm of its outer boundary. Conduction of heat from the rim to the center of the platelet is reviewed in Appendix A. If the droplet boils along its outer edge rather than merely evaporating at its surface, it is likely that much less spatter (or aerosol formation) will occur than with central bulk boiling of the droplet.

Experimental Apparatus and Procedure

An experimental apparatus was set up to investigate the use of higher-temperature overhead gas and of RF heating, and the behavior of the drying droplets.

The Air Gun. The air gun used had a 6" long, ½" wide nozzle to avoid interfering with the RF heating and to restrict its air flow, and the air intake orifice was reduced to 1" to further restrict the air flow. The restricted air flow allowed much higher temperatures.

Radiofrequency Induction Heating. In RF induction heating, an alternating magnetic field induces eddy currents in the platelet, and its resistance to currents produced ohmic heating. The experimental apparatus had an RF frequency of 350-400 kilohertz which supplies heat only through induction, not by dielectric excitation, and thus only affects conducting objects. The RF apparatus can be controlled on a time scale of milleseconds, and is capable of heating the platelets at an initial rate of over 600°C per second. The eddy currents are located near the surface and near the outer rim of the platelet, and the interior is shielded. Under strong RF heating, the platelet rim is the first part to reach red heat.

Platelets. Two types of platelet were used. One was the circular platelet presently used by the FACE machine. The other was a slotted platelet with the rim cut inward, almost to the center dimple, along three radii 120°C apart. The tri-cut platelet was used only for RF heating and drying. The RF heat was produced at three yellow-hot points at the end of the cuts, and thus had the advantage of heat input closer to the droplets.

Platelet Heating. The heating rates of the air gun and the RF coil were measured with a chromel-alumel recording thermocouple affixed to a platelet. Comparison was made then with the results from the exiting FACE machine droplet-drying assembly.

Droplet Drying. The apparatus was then used to dry a series of 6M HCl droplets on platelets placed in the interior of the RF coil (see Figure 9). Droplets were dried with hot air alone, RF alone, and both in conjunction. The goal of the experiments was primarily to search for a min-

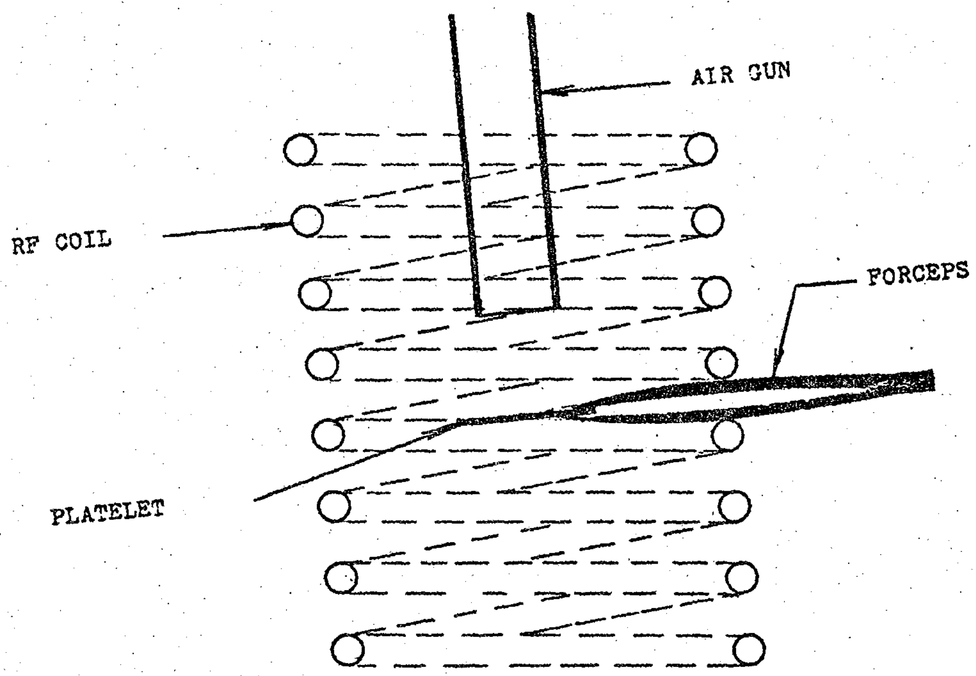


FIGURE 9 EXPERIMENTAL APPARATUS

imum droplet drying time and only secondarily to establish base line data for the droplet size of the FACE apparatus.

Two sizes of droplets were used in the experiments. First, an effort was made to put 20 μl into the platelet dimple, this being close to the FACE droplet size (a symmetrical lens of liquid resting in the dimple is about 20 μl in volume). These droplets were formed by touching the eyedropper to the platelet, they showed a considerable size variation within the range of 20 to 30 μl. Droplets falling from the eyedropper, on the other hand, were fairly constant in size and were measured to be 40 μl by counting the number needed to total 1 ml.

The droplet drying time was measured, and the droplets were viewed under a magnifying glass to observe boiling behavior.

Results

Platelet Heating. The heating response of a platelet to the modification air gun is illustrated in line 3 in Figure 10. Lines 1 and 2 in Figure 10 illustrate the heating response of the platelet to the airgun unmodified (line 1) and with a restriction to a 3/4 inch air intake orifice. All three heating responses are much stronger than the present FACE machine. In the experiments, the air gun nozzle was held approximately 1" above the droplet being dried. The air flow of the air gun was considerably greater than 30 CFH (viz., approximately 10 CHM). At no time was there any indication that this flow was likely to horizontally displace the droplets.

Droplet Drying. A series of droplets were dried for general observation, then 37 droplets were dried under specified conditions to measure droplet drying times. A difference in drying times was noted between a platelet "warm" from drying a previous droplet (150-200°C) and a room-temperature "cold" platelet. Tables 3, 4, and 5 list the results of the droplet drying. Tables 3 and 4 list results for droplets near the size of the actual FACE machine droplets of 20-30 µl, and Table 5 for 40 µl droplets.

In general, it was observed that a pre-warmed platelet reduced droplet times by approximately 10 to 20%. By applying hotter gas and RF heating, it was possible to dry 20-30 µl droplets in 5 to 6 seconds with a regular warm platelet and 4 to 5 seconds with a tri-cut platelet. It was possible to dry 40 µl droplet in 6 seconds with only a few bubbles appearing.

General Observations of Boiling. In observation of boiling during droplet drying, two previously stated droplet drying theories were substantiated. First, in boiling a droplet, bubbles form around the edge and boiling does not occur toward the center without significantly increased RF heating.

Second, 380°C gas suppressed boiling of a RF heated droplet. This showed that the gas, with a much higher than liquid boiling temperature, acts as a cooling gas through

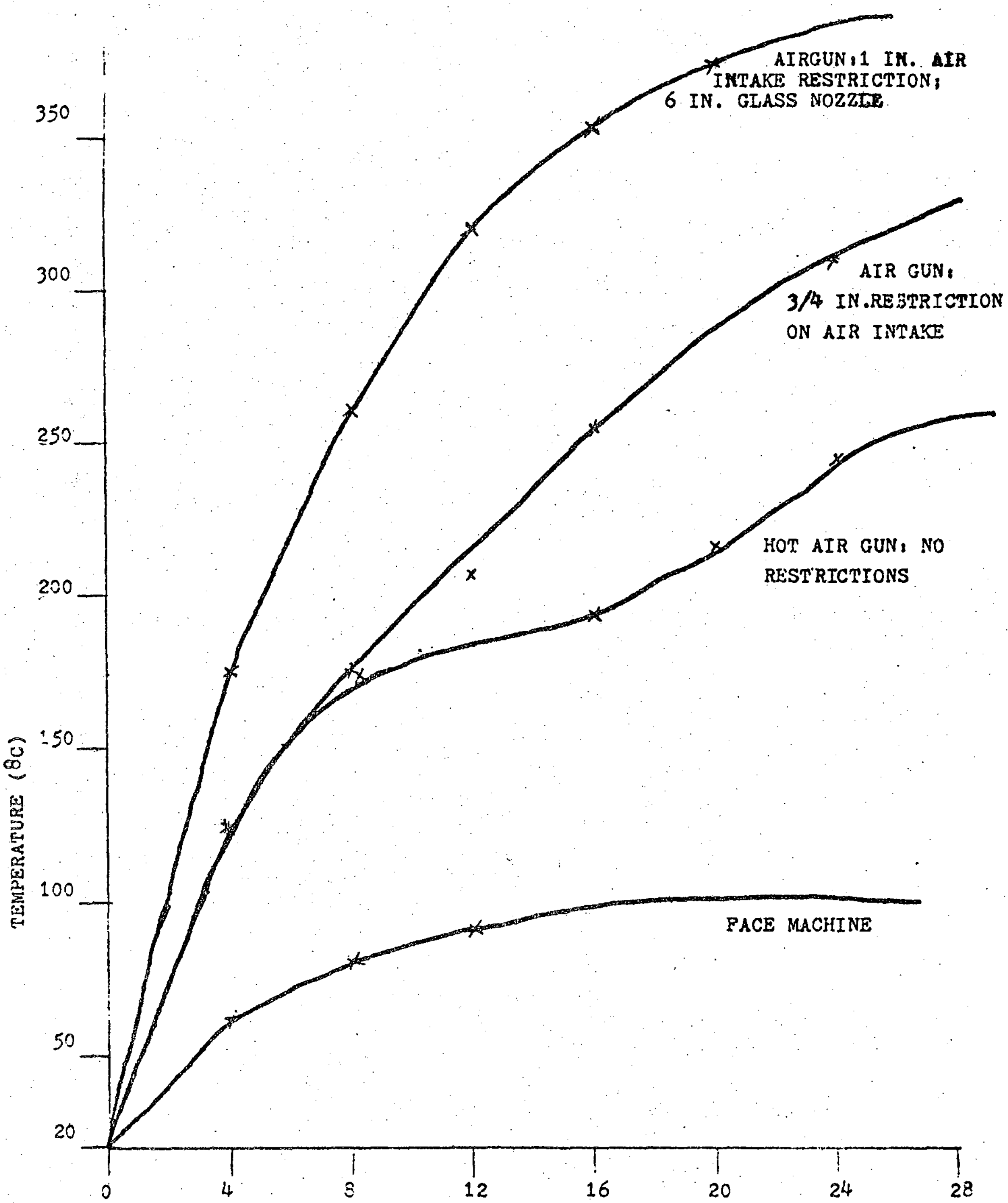


FIGURE 10 PLATELET HEATING RESPONSE TO AIR GUN AND FACE HOT AIR JET

TIME (SEC.)

Table 3 Experimental Results

For the following results the droplet size is 20-30 μl and the platelet type is regular.

Dry'g Time Sec.	Resistor Setting %	Initial Platelet Temp.	Air Gun	Boiling	
28	0	Cold	yes	none	
21	0	Warm	"	"	
30	50	Cold	no	edge	
24	50	Warm	"	"	
9	70	"	"	"	
12	50	"	yes	none	

Table 4 Experimental Results

For the following results the droplet size was 20-30 µl.

Dry'g Time Sec.	Resitor Setting %	Initial Platelet Temp.	Air Gun	Boiling	Platelet Type
9	70	Warm	no	edge	regular
5.5	70	Warm	yes	none	regular
9.5	50	Cold	"	"	tri-cut
8	50	Warm	"	"	"
5	70	"	"	"	"
5.5	75	Warm	"	"	"
6	80	Cold	"	"	"
4.5	80	Warm	"	"	"

Table 5 Experimental Results

Dry'g Time Sec.	Resis-tor Set'g	Initial Platelet Temp.	Air Gun	Drop-let Size µl	Boiling	Platelet Type
12	70%	Cold	no	40	none	regular
10.5	70%	Warm	"	"	"	"
9	75%	"	"	"	"	"
11	70%	Cold	yes	"	"	"
7	59%	Warm	yes	"	"	"
8	70%	Warm	"	"	"	"
8.5	80%	Cold	"	"	boiling	"
5	80%	Warm	"	"	boiling	"
6	*	Cold	"	"	slight	"
6	*	Warm	"	"	"	"

* Turned to 100% resistor setting for 1 second, then reduced to 70%.

its evaporation of the droplet. This also shows that a much higher gas temperature could be used when RF heating is not being used. Additionally, it was observed that boiling was gentle, without bumping or flashing, in the form of fine bubbles.

Conclusions. The results in Tables 3, 4, and 5 demonstrate that more intense heating can be applied to droplet drying, without problems, to achieve shorter times and accelerate the operation of the FACE machine. The results of the tri-cut platelet show that intense heating can be applied horizontally without boiling, as long as air is supplied from above. With 600°C helium instead of 380°C air, improvement over the results of Tables 3, 4, and 5 should be quite possible. To allow boiling is not intolerable: the possible loss of 1 or 2% of yield, an estimate based on my professional judgement and experience, since the boiling is gentle, is more than compensated by a savings in radioactive loss by faster fraction collection and drying. The experiments were executed in an attempt to avoid boiling, further experiments would show possible gains by tolerance of boiling.

ANALYSIS OF CHROMATOGRAPHIC SEPARATION

The FACE machine chromatographic column is shown, with specifications, in Figure 11. The column separates the metal ions in the wash solution according to their valences. The rabbit is washed with 140 μl of 12M HCl, and the wash solution is run through the column, collected on a platelet as the first column fraction, and dried. The column is then eluted with 160 μl of 6M HCl, which is split into the second and third fractions. About 90% of the divalent- and trivalent-metal ions leave the column in the first fraction. Element 104 (with any other four valent metal) is removed from the wash solution by the column and is eluted in the second and third washes. The differentiation of the ions is based upon the differences in binding strength to the ion-exchange resin; in chloride complexing strengths; and in stoichiometric complexing ratios. The reaction and equilibrium equations for the column are as follows:

$$M^{+4} + 6Cl^{-} \rightleftharpoons MCl_6^{=}$$

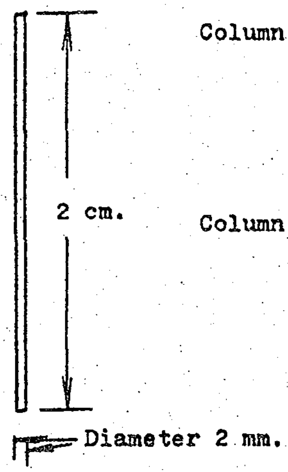
$$K_4 = \frac{[MCl_6^{=}]}{[M^{+4}][Cl^{-6}]}$$

$$2RCL + MCl_6^{=} \rightleftharpoons 2Cl^{-} + R_2MCl_6$$

$$M^{+3} + 4Cl^{-} \rightleftharpoons MCl_4^{-}$$

$$K_3 = \frac{[MCl_4^{-}]}{[M^{+3}][Cl^{-\,4}]}$$

$$RCl + MCl_4^{-} \rightleftharpoons Cl^{-} + RMCl_4$$



Column Material: Crushed polytrifluorochloroethylene powder coated with trioctylmethylammonium chloride. The Mesh size is a 240 screening.

Column Volume: 50µl total volume, 30µl free volume.

FIGURE 11 CHROMATOGRAPHIC COLUMN SPECIFICATIONS

R = organic amine group

K_n = equilibrium for n-valent metal ion

M = metal ion

Column Binding. Four valent metals form bi-negative complexes. Such complexes bind ionically to two cations of the resin, with approximately twice the binding energy of the mononegative complexes formed by three valent metals.

Anion Complexing. The strength of complexes increases with valence, thus generally at any given chloride concentration the four valent metal will be more strongly complexed than the three valent metal.

Chloride Stoichiometry. The selective uptake and elution of the ions is also due to the dependence of complexing on different powers of chloride concentraions, to the 6th power for the four valent metals versus to the 4th power for the three valent metals. This effect makes it possible for the four valent metal to attach to the resin in 12M HCl and to disassociate in 6M HCl. For the following reaction:

$$M^{+4} + 4Cl^- + 2RCl \rightleftharpoons R_2MCl_6$$

The ratio of resin complexing strength at 12 M HCl and 6M HCl solution concentration is:

$$\frac{(R_2MCl_6)}{(M^{+4})}_{12M} \Bigg/ \frac{(R_2MCl_6)}{(M^{+4})}_{6M} = \left[\frac{12}{6}\right]^4 = 16$$

Thus the change of chloride concentration has a stronger effect on four valent anion complexes. Also, the equilibrium concentration of four valent complexes will decline by a factor of 64 resulting in its elution.

Conclusions. From the experimental results, it appears that the column is adequate for purposes now desired. Separation appears to be clear cut, any retained valence-3 metal ions in fraction 2 is probably due to liquid retained between resin beads. The solution is likely to equilibrate in a few seconds with the resin. As the solution will be stagnant for 4 seconds or more before it is displaced, the shortening of droplet drying will not affect column performance appreciably. Since the void volume of the column is now slightly less than 2 droplet volumes, the difference in exposure to resin for different portions of each droplet could be corrected by increasing column volume from 50 µl to 65 µl. Solution residing above the resin bed is inactive. So that a larger bed would allow better contact without change in the actual retention time.

Minimum Drying Modification Proposal

In analyzing the response of a platelet to the FACE machine heating jets, both air and helium, it was observed that the temperature of the gas streams were lower than optimal. The maximum gas temperatures are approximately 110°C for the hot air and 200°C for the helium. The helium jet would be a much more effective droplet drying agent if its temperature were raised to 600°C. The heat from the helium jet is very unlikely to induce bulk boiling of the droplet. Experiments with 380°C gas show only surface evaporation.

The helium temperature is controlled by a thermocouple attached to the gas heating chamber housing. The helium gas, initially at 600°C, is cooled in passing through the metal ring nozzle - which is not insulated or heated, is initially quite cold, has a high heat capacity, and loses heat to the surroundings by convection and radiation. The 200°C temperature is not reached until the nozzle has been in operation for about 60 seconds.

The hot air below the platelet reaches 110°C. At the present flow and temperature, the hot air heats the platelet only to 85°C. Hotter air, used in conjunction with hot helium, could provide enough heat to complete the drying in 4 seconds and still avoid bulk boiling.

To accelerate the drying of droplets, the metal nozzle ring of the helium jet should be wrapped with an electrical-resistor heating element and insulated with care that it does not obstruct the jet or column. This would permit maintaining the helium jet at a constant temperature of 600°C. The hot air temperature should be increased, by either stronger heating or restricted flow, so that it reaches 125°C within 4 seconds. The more intense heating which will result, should match or outdo the 4-second drying time achieved in the airgun-RF heating experiments for a larger-than-average drop, since the proposal is to use helium at 600°C rather than at 380°C. With a shorter drop-drying time of 4 seconds, time (e.g., 12 seconds) can be allotted for flaming at the droplet drying station, allowing the elimination of the flaming station.

The flaming station results in a time delay of 33 seconds for the first and second fractions, and 25 seconds for the third fraction; once in the flaming station, the platelet can not be moved independently. If flaming were conducted without moving and cooling the platelets, the flaming time could be cut from the present 15 seconds to 10-12 seconds. A dual-feed combination hot-air nozzle and Busen burner, equipped with an ignitor, could be installed to supply both the hot air for droplet drying and the heating by burner for the flaming operation.

To reduce heat conduction to the arm of Turntable 3, the platelet should rest on an insulating washer.

It should be noted that, with 600°C helium, adeqaute pyrolysis and removal of residual water of hydration might even make the flaming operation unnecessary.

In summary, consolidation of the flaming station with the droplet drying station, with the increased gas temperatures, would allow elimination of the flaming-station time delay and more rapid drying of each droplet.

Extensive Drying Modification Proposal

The minimum FACE machine modification proposal is the most expedient, but not the optimum, method of droplet drying. The method proposed here is a more radical change.

For the reasons given in the minimum-modification proposal, the helium-gas ring nozzle needs to be insulated and wrapped with an electrical-resistor heating element to provide 600°C helium.

It is also desired to heat the platelet in such a way that heat is provided to the edge of the droplet rather than underneath. This method would permit more intense heating without bulk boiling. When using hot air, a temperature limit exists, above which the droplet becomes superheated and bulk boiling begins (with a risk of liquid ejection). RF heating, directly and instantaneously, generate heat at the edge of the platelet, where it encounters the edge of the droplet. The heat transfer path from the platelet to the droplet surface is shorter at the droplet edge than at its center. Thus, heating the droplet edges reduce the bulk heating.

Because RF heating allows a precise amount of energy to be induced into the metallic platelet with millesecond timing, it can also be used as a substitute for flaming and can bring the platelet to flaming temperatures in as little as 0.5 seconds.

A temperature below that of a Bunsen burner, approximately 450°C to 600°C, would suffice to oxidize the non-volatile organic residue, while reducing the risk of losing desired product isotopes.

For RF heating, the platelet will rest on an insulating ceramic washer set in a fiberglass-reinforced (or other) high-temperature-resistant plastic. The need for non-metalic arms is to avoid RF inductance anywhere except for the platelet. Stray inductance of the helium-gas ring nozzle will necessitate fractionally higher power input, but this will not prevent platelet heating and the lost energy will aid in keeping the ring hot. With the RF coil below the platelet, the current induced in the platelet will shield the helium ring nozzle from the RF flux.

The power output of a RF heating coil is proportional to the square of the coil current and the square of the coil turns. The RF induction coil should consist of 2 to 5 coil turns, have a diameter of about 25 mm, and be located immediately underneath the Turntable 3 arm holding the platelet.

In summary, the RF heating method will allow more intense heating, better heating control, and faster (1-second) flaming.

ANALYSIS OF CHEMICAL LOSS

Introduction

Most of the atoms of element 104 produced in the target are lost before reaching the alpha-detectors by both radioactive decay and chemical loss in sample processing. FACE processing yield is approximately 5%, thus any small improvement will mean a great increase in FACE machine output.

The chemical and radioactive losses are independent which, when multiplied together, give the overall FACE machine yield. Approximately 60-70% of the element 104 is lost through chemical processes. This estimate is based on an experiment with hafnium 181. This experiment is described in the previously mentioned report on the chemistry of element 104.

There are five stages to consider in the handling of element 104 and nobelium in the analysis of the loss of these two elements. These stages are: collection of elements 104 and nobelium on the rabbit; the transfer of the radioactive nuclides to the column; elution and collection on a platelet; flaming the platelet; and finally, alpha counting of the platelet.

Hafnium Experiments. Hafnium 181 was used to test these chemical losses. The isotope is beta emitting with a half-life of 42.4 days, so radioactive loss during the experiment is not significant.

The chemical loss was 66% of hafnium deposited on the rabbits. Of the 66% loss, 20% was accounted for by hafnium left on the rabbit, indicating incomplete dissolution.

The remaining 46% loss was unaccounted for. The following loss mechanisms after rabbit washing are possible: precipitation or adsorption onto the Tygon transfer lines; possible precipitation or adsorption onto the glass walls of the column; incomplete desorption from the column; and finally volatilization in either the drying or flaming operations on the platelets.

Rabbit Washing. Element 104 is deposited with the salt aerosol on the rabbit. The chemical state of the element 104 atoms is not known. When the rabbit is washed, a few films of wash solution remains on the rabbit, adhering to the surface rather than being transferred to the column.

To reduce loss on the rabbit face, a wash solution of 1M HNO_3 and 11-12M HCl should be used. The HNO_3 will not bind or precipitate any solute, since all nitrates are very soluble in an aqueous solution. Also, it will insure the oxidation and dissolving of all element 104 on the rabbit, mild aqua regia being a strong stripping agent.

The nitric acid will also reduce the surface tension of the wash solution, greatly aiding in mechanical transfer to the column, and better wetting of the rabbit surface.

When the solution is finnally dried, it should aid in oxidizing any trace organics present.

Tygon Tubing. Tygon tubing is a polyvinyl chloride polymer with trinolyl phosphate plasticizer, typically 20-40%, to make it flexible. This plasticizer is leachable even in aqueous solutions of pH 7, significant enough to exclude Tygon from use on solutions for human use in ingestion or intraveneous injection. In the FACE machine, the concentration of heavy metal chlorides is extremely small, so that even an extremely weak solution of phosphates has the potential to complex a large part of the element 104 present. Hafnium is known to form an insoluble strong phosphate compound which precipitates from solution. Trinonyl phosphate has the following formula, $(C_7H_7O)_3PO$, molecular weight 377. As an ester, trinonyl phosphate is hydrolyzed by acid, so the high acidity of the wash solution is likely to promote rapid dissolution of the phosphate and perhaps other organics. (Plasticizers, in the Tygon tubing and oligomers in the plastic storage bottles are the probable cause of the need for flaming step to remove organics.)

The writer recommends polyethylene or even Teflon tubing, even though it is less flexible. It should be pretreated by boiling in HCl and thorough washing afterwards with distilled water.

Possible Loss on Chromatographic Vessel Walls

Glass, an alkali silicate, dissolves quite slowly in strong acids, producing an alkali chloride salt and silicic acid. The etched glass surfaces may then adsorb various salts or ions. However, heavy metals in a strong HCl solution are not expected to precipitate onto the glass walls, and the possibility of chemical loss in the column is not very likely.

The column material is 0.25 F trioctylmethylammonium chloride, dispersed by ortho-xylene onto an inactive flurocarbon powder. When hafnium 181 was run on the column, the second fraction eluted more hafnium, 57% of the amount charged, and the third fraction eluted 29%. It is therefore possible that 10 to 20% is being retained as an anion complex bound to the stationary phase.

Losses from the Platelet

Evaporation and flaming are suspected as a cause of chemical loss. The chemical properties of element 104 are expected to be homologous with zirconium or hafnium. The chemical behavior of hafnium was considered in the design of the FACE machine, and possible pathways of loss for hafnium would be mechanisms of loss for element 104.

Hafnium and zirconium tetrachlorides are volatile, and sublime under one atmosphere pressure at 331°C and 319°C, respectively. The vapor pressure of hafnium is estimated to double for every 10°C. The vapor pressure at 100°C is then 10^{-6} atmospheres, and loss through droplet batch distillation is not expected for hafnium or element 104.

When the droplet is being brought to dryness, the final dehydration is ill-defined. The tetrachloride of element 104 is expected to hydrolyze to 104 oxychloride, in analogy to the behavior of hafnium tetrachloride. This compound is not very volatile and should remain on the platelet as it is heated to higher temperature during flaming.

In the flaming operation, residual contamination can be expected to dehydrate, and organics to oxidize. The dynamics of this change with its out gassing of H_2O and CO_2 is not known. Whether there is flaking of the dried precipitate and scattering when the platelet is being dehydrated or moved is not known. Therefore is would be desireable to monitor the hafnium 181 radioactivity before and after each processing step, to verify the retention during processing.

ANALYSIS OF RADIOACTIVE LOSS

The analysis of radioactive loss will be investigated step by step in the FACE machine.

Collection of Element 104 on the Rabbit. The half-life of element 104 is 65 seconds, and the half-life of nobelium is 26 seconds. This gives exponential decay coefficients of k_1=0.01066 for element 104, and k_2=0.02666 for nobelium.

Let P be the production rate of element 104. Let Rf be the amount of element 104, and No, the amount of nobelium. The rate of increase in the amount of element 104 on the rabbit, minus the rate of decay of the material already on the rabbit:

$$\frac{d(Rf)}{dt} = P - k_1(Rf)$$

The solution to this equation is:

$$(Rf) = P/k_1(1-e^{-k_1 t})$$

The rate of increase of nobelium on the rabbit is equal to the rate of decay of element 104 minus the rate of decay of nobelium:

$$\frac{d(No)}{dt} = k_1(Rf) - k_2(No)$$

The solution to this equation is as follows:

$$(No) = P\left[1/k_2 - \frac{e^{-k_1 t}}{k_2-k_1}\right] + P\left[1/k_2 - 1/(k_2-k_1)\right]e^{-k_2 t}$$

The following table illustrates the increase of element 104 and nobelium on the rabbit.

t (sec.)	Rf/P	(Rf/P)/t	No/P
0	0	0	0
15	13.86	0.92	1.00
30	25.68	0.86	3.35
45	35.74	0.79	6.35
60	44.32	0.74	9.60
75	51.64	0.69	12.80
90	57.87	0.64	15.83
105	63.18	0.60	18.62
120	67.71	0.56	21.14
180	80.04	0.44	28.12
	93.81	0.00	37.51

The ratio of No to Rf after 120 seconds is 0.31, and the infinite time ratio is 0.40. The actual ratio is 1.1$\pm$ 0.4. Why this is so is not explained. This will be used in the calculations which follow. $(No)_o$ will be the initial amount of nobelium and $(Rf)_o$ will be the initial amount of element 104, after the rabbit is removed from the aerosol collection station.

First Fraction. After element 104 is collected on the rabbit, the amount at any time in the future is a simple exponential function as follows:

$$(Rf) = (Rf)_o e^{-k_1 t}$$

The amount of element 104 that will be detected by the alpha detectors is the amount of 104 remaining when the platelet is retrieved by an arm. The rate of increase of nobelium, expressed as before, yields the following equation.

$$(No) = (No)_o e^{-k_2 t} + \frac{k_1 (Rf)_o}{k_2 - k_1} e^{-k_1 t} - e^{-k_2 t}$$

For calculation, it is assumed that all the nobelium present in the column (either initially as such, or produced from element 104 by decay) is immediately eluted onto the platelet. This means that any nobelium eluted onto the next platelet is from decay of element 104 in the column subsequent to the previous elution. It is also assumed that no element 104 is eluted in the first column fraction. Eighty seconds after the rabbit has been removed from the aerosol collection station, the first fraction is collected and dried on the platelet. At this moment, the amount of nobelium on the platelet is given by the following formula:

$$(No) = (No)_o(0.11851) + (Rf)_o(0.2050)$$

The amount 33 seconds later when the platelet is retrieved by an arm after flaming is as follows:

$$(No) = \left[(No)_o(0.11851) + (Rf)_o(0.2050)\right] e^{-k_2(33)}$$

or $$(No) = (No)_o(0.0492) + (Rf)_o(0.0851)$$

The first alpha-detector will recieve the following amount of nobelium:

$$(No) = (No)_o(0.0492) + (Rf)_o(0.0851)$$

This, with $(No)_o = 1.1\ (Rf)_o$, $(No) = (Rf)_o(0.14276)$.

Second Fraction. In calculating the amount of element 104 and nobelium in the next two fractions, it is assumed that each fraction will receive 50% of the element 104 on the resin. This 50% fraction is the chemical division of the element 104 assuming an infinite half-life. The real division will be different due to the radioactive decay of element 104, and to the exact column behavior.

All the nobelium produced in the column between the first platelet and the second platelet is assumed to be eluted onto the second platelet. At the time beginning with column droplet collection onto the second platelet, the amount of element 104 on the column is as follows:

$$(Rf) = (Rf)_o e^{-k_1(80)} = (Rf)_o(0.4262)$$

The rate of increase of nobelium is equal to the rate of decay of element 104 minus the rate of decay of nobelium. The equation is as follows:

$$\frac{d(No)}{dt} = k_1(Rf) - k_2(No)$$

$$(No) = 0 \quad \text{for } t=0$$

$$(Rf) = (Rf)_o(0.4262) \text{ for } t=0$$

The solution of this equation is as follows:

$$(No) = \frac{k_1(Rf)_o(0.4262)}{k_2-k_1} \left[e^{-k_1 t} - e^{-k_2 t}\right]$$

The nobelium present on the second platelet 33 seconds later when the second elution is finished, i. e. 133 seconds after the beginning of the current FACE batch is:

$$(No) = 0.082(Rf)_o$$

After the elution is finished, the rate of increase of No is again equal to the decay of the element 104 minus the rate of decay of the nobelium.

The conditions at this time are:

$$(No) = 0.082(Rf)_o$$

$$(Rf) = (Rf)_o e^{-k_1(113)} (0.5) = (Rf)_o(0.1499) \quad t=0$$

After an additional 33 seconds, when the platelet is moved to the alpha counter, the values are:

$$(No) = \left[(0.082)(Rf)_o\right]e^{-k_2(33)} + \frac{k_2}{k_2-k_1} (Rf)_o(0.1499) \left[e^{-k_1(33)} - e^{-k_2(33)}\right]$$

$$(Rf) = (Rf)_o e^{-146k_1}(0.5) = (Rf)_o(0.10545)$$

$$(No) = (0.0340)(Rf)_o + (0.02882)(Rf)_o = (0.0628)(Rf)_o$$

Third Fraction. In a total of 58 seconds all the remaining element 104 is eluted, along with all nobelium produced, onto a platelet and dried, flamed, and retrieved by the platelet. The amount of element 104 on the final platelet is as follows:

$$(Rf) = (Rf)_o(0.5)\ e^{-171k_1} = (0.0808)(Rf)_o$$

The amount of nobelium present is:

$$(No) = \frac{k_1}{k_2-k_1}(Rf)_o(0.1499) \left[e^{-58k_1} - e^{-58k_2}\right]$$

$$= (0.66625)(Rf)_o(0.1499)(0.21304) = (Rf)_o(0.0212)$$

In summary, the results for the three platelets are as follows:

First Fraction	$(No) = (No)_o(0.0492)+(Rf)_o(.085)$
Second Fraction	$(Rf) = (Rf)_o(0.10545)$
	$(No) = (Rf)_o(0.0628)$

Third Fraction $(Rf) = (Rf)_o(0.0808)$

$(No) = (Rf)_o(0.0213)$

Since element 104 will ultimately result in two alphas in the energy band of interest, the counts on each platelet will be as follows:

C_n = Counts of fraction n

z = detector geometry factor

First Fraction $C_1 = Z(No)_o(0.0492)+(Rf)_o(0.0851)$

Second Fraction $C_2 = Z(Rf)_o(0.2737)$

Third Fraction $C_3 = Z(Rf)_o(0.183)$

Total Counts (assuming $(No)_o/(Rf)_o = 1.1$) = $Z(Rf)_o(0.59592)$

The relative ratio of counts for the three fractions is as follows for the two $(No)_o/(Rf)_o$ ratios.

	Calculated Counts		Observed Counts*	
$(No)_o/(Rf)_o$	0.3	1.1	Increment	Cumulative
First Fraction	0.42	0.58	1	1
Second Fraction	1.00	1.00	2	3
Third Fraction	0.62	0.62	3	6

If the flaming step is eliminated, the final fraction quantities are as follows:

First Fraction $(No) = (No)_o(0.1185)+(Rf)_o(0.2050)$

Second Fraction $(No) = (Rf)_o(0.082)$

$(Rf) = (Rf)_o(0.1499)$

Third Fraction $(No) = (Rf)_o(0.0288)$

$$(Rf) = (Rf)_o(0.1055)$$

The counts are as follows, assuming $(No)_o/(Rf)_o = 1.1$.

First Fraction	$C_1 = Z(Rf)_o(0.3354)$
Second Fraction	$C_2 = Z(Rf)_o(0.3818)$
Third Fraction	$C_3 = Z(Rf)_o(0.2398)$
Total Counts	$= Z(Rf)_o(0.9570)$

Thus the calculated increase in total counts would be 60.5% with the elimination of the flaming step.

III. THE FACE COMPUTER OPERATIONS

Computer "software" is loaded into the PDP-9 to allow programing to be done in FACE language. The FACE programs which operate the FACE machine in experimental runs are written in the FACE computer language.

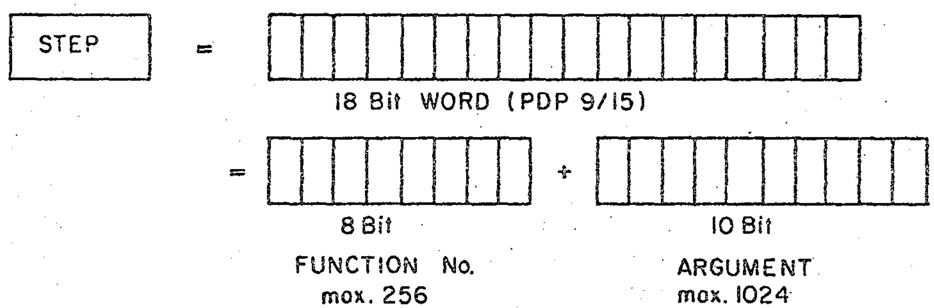
Programming in FACE is done through a teletype terminal.

General Structure of a FACE Program

The general structure of the programs is illustrated in Figures 3 and 4. Each FACE program is composed of operations, up to 20 in number, which in turn are composed of steps, numbering more than 1000 total, for all operations. Each operation also has its own internal indicator, or internal flag, specifically dedicated and limited to switching that operation in and out. The internal flag for Operation 1 is set by a teletype command "GO" which initiates all programs. All other operations have their internal flags set or cleared by pre-programmabe steps.

When a progam starts, the computer goes to Operation 1 and executes Step 1, Step 2, Step 3, ect., until it reaches the end of the operation. If the next operation's flag is set, Operation 2 is executed; if not, the computer moves to the flag for Operation 3, and so on through Operation 20. If all the internal flags are unset, the program terminates. Otherwise, the computer goes through Exit and on to Continue. After a 50 msec. pause, the sequence of operations is repeated. The 50-msec. cycle time is an important figure to remember,

FIGURE 12 F.A.C.E. PROGRAMING STRUCTURE



CLASSES OF FUNCTIONS	ARGUMENT CONTAINS
COUNTERS	CONTENT OF COUNTER
PRINT COMMAND FOR TELETYPE	STEP No., OPERATION No., COUNTERS etc.
JUMPS	No. OF STEPS
CHECKS ON SENSORS	SENSOR No.
CAMAC COMMAND	DEVICE No.
HALTS AND EXITS	OPERATION No., STEP No., etc.
SET AND CLEAR FLAGS	FLAG No.
SUBROUTINES	SPECIAL ARGUMENTS
TIMERS	TIME IN UNITS OF 50 ms
HARDWARE ORIENTED	DEVICE No.

XBL737-3728

for several purposes to be explained later. Execution of steps is not necessarily in numerical order; certain functions in a given step will cause the computer to skip forward or backward several steps within any one operation. Internal flags are set or cleared through pre-programmed commands in the steps. Certain functions in a given step will cause the computer to skip forward or backward several steps within any one program. External flags, which are addressable, displayable, and usually related to the machine operation, will be discussed later.

Steps

Each function is identified by a specidic number. Associated with each function is an argument specifying the element number (flag, counter, sensor, of step) or the measure (time, number of steps) required to execute the function.

The teletype reports a step in the following format:

Step No.	Function No.	Argument	Meaning
23	49	1	Zero counter one.
24	101	10	Count to "10" time units (50 msec. each, or 500 msec. total)

Each of the functions will be explained at a later point.

Teletype Commands and Programming

There are 18 teletype (TT) commands. Each teletype command is identified by a two-letter mneumonic code. The teletype commands listed in Table 1 are used to load, alter, and execute a program. To use a teletype command, you type the two-letter code and then press the ALT key. The name stands for alternative mode, but in this machine language, the key is arbitraily selected as a "load" key to instruct the computer. The computer will request more information if needed to execute the command.

Teletype Programming

To start a program, the following teletype command would be typed by the computer:

GO=0/1

The "1" has the effect of correcting the "0". To start the program, you type:

GO

The program then begins with Step 1, Operation 1.

To illustrate how to program via the teletype, the programming of Operation 1 of the FACE program will be shown.

First, you give the command IS and acknowledge (type ALT key). Unless you have been programmin in another operation, the computer will assume Operation 1 is involved, and will type

IS OP=1/

You again acknowlege, and the computer will add to the line:

IS OP=1/ STEP=0/

The step number is the one just ahead of the point where your program step is to be inserted.

Table 6

TT Commands

CF-change or list state of flag.

CO-continue where halt occurred.

CS-change or list a step.

DS-delete a step

GO-start operation 1, step 1. (does not zero counters)

HT-halt Rube Goldberg

IS-insert a step

LO-list steps in an operation.

ON-turn on an operation.

SS-single step execution.

TT-tape in. (not implemented)

TO-tape out (not implemented)

LI-list integrator.

OF-turn off an operation. (not implemented)

NW-number of washes

CX-change status of XTAL

CC-change or list contents of a counter.

OI-operation in (from paper tape).

OO-operation out (to paper tape).

PI-program in from disk.

PO-program out to disk.

After you acknowledge, the computer responds with

IS OP=1/ STEP=0/ FUN#=0/

At this point, you type in the function (58) and acknowledge. The computer will then respond by adding the argument

IS OP=1/ STEP=0/ FUN#=0/58 ARG=0/

You type in 3 for the argument, so that a complete line follows:

IS OP=1/ STEP=0/ FUN#=0/58 ARG=0/3

With acknowledgement, the computer will store the command as Step 1 in Operation 1.

Starting the process again, the computer will respond to IS with the resulting line:

IS OP=1/

Afterwards with acknowledgement, the computer responds:

IS OP=1/ STEP=1/

After this, you again program the function, then the arguement. The full programming of Operation 1 of the FACE program would appear as follows:

IS OP=1/ STEP=0/ FUN#=0/58 ARG=0/3
IS OP=1/ STEP=1/ FUN#=0/58 ARG=0/6
IS OP=1/ STEP=2/ FUN#=0/62 ARG=0/4
IS OP=1/ STEP=3/ FUN#=0/62 ARG=0/5
IS OP=1/ STEP=4/ FUN#=0/57 ARG=0/1

To see what you have in Operation 1, you type LO (list operation). If the teletype command were the first one, the computer would respond with:

LO OP=1/

Acknowledgement causes the computer to print out the program sequence:

LO OP=1/

STEP	FUN#	ARG
1	58	3
2	58	6
3	62	4
4	62	5
5	57	1

To delete a step, say Step 4, you would type:

DS

The computer would respond with:

DS OP=1/

You would again acknowledge, and the computer will respond:

DS OP=1/ STEP=5/

Step function and argument numbers are proposed by the computer, depending on the teletype command. You would type "4" and acknowledge. The final line is as follows:

DS OP=1/ STEP=5/4

After acknowledgement, Step 4 will be delted and ensuing steps will be advanced. A LO command and acknowledgement of line 1 will yield the print-out:

LO OP=1/

STEP	FUN#	ARG
1	58	2
2	58	6

3	62	4
4	57	1

In deleting or inserting a step or steps, the following steps will move either up or down to fill or open the gap.

To reinsert a step, the following command sequence would be used:

LO OP=1/

STEP	FUN#	ARG
1	58	2
2	58	6
3	62	4
4	62	5
5	57	1

To change a step, you type

CS

and the computer responds:

CS OP=1/

With acknowledgement, the computer would add:

CS OP=1/ STEP=4/

In this case, it is STEP=4/. Another acknowledgement would give:

CS OP=1/ STEP=4/ FUN#=62/

You could now change the FUN# by typing in another number and acknowledging, or keep it the same by just acknowledging it. The computer would respond with:

CS OP=1/ STEP=4/ FUN#=62/ ARG=5/

Typing in "6" and then acknowledging, followed by a LO OP=1/, a teletype command statement would give the following print out:

```
CS  OP=1/  STEP=4/  FUN#=62/  ARG=5/6
LO  OP=1/
STEP FUN# ARG
  1   58   3
  2   58   6
  3   62   4
  4   62   6
  5   57   1
```

IS, DS, CS, and LO are four basic programming teletype commands used to write FACE language programs.

Since an operation may be many steps long, its listing can be terminated by a P control command (depressing both the control key and P key) if desired. When a control P command is used to terminate any action, the computer prints a two-line statement to signify completion. Control P has the disadvantage that no HLT statement will be made and all load information in counters and flags is lost.

<u>Program Running and Storage</u>

Programs can be loaded by being typed in, read in from paper tape, or read in from disk. The TI and TO commands are not implemented.

To <u>read</u> in from paper tape, you type the command

OI

After typing the ALT mode key, the computer responds with:

OI OP=1/

The operation number desired is typed in. For all OP= / statements, as any step is loaded, the number printed by the computer will be 1, unless for any earlier step in the sequence, another number has just been specified. In that case, OP= / statement will then list that number instead of 1.

To print the program on paper tape, command OO is typed:

OO

The computer responds

OO OP=1/

If the operation is not Operation 1, the operation number is desired is typed in. The paperpuch is turned on and the ALT mode key is typed. The paper tape is then produced.

Whereas the paper tape loads or prints one operation at a time, the PI and PO commands involving disk storage can store and load entire programs composed of many operations.

To store a program on a disk, the PO command is typed, and the computer responds with:

PO PROGRAM OUT TO DISK

The program is now on the disk. This command wipes out a pre-existing program on the disk.

As mentioned before, the GO command starts a program running.

To load a stored program, typing in PI and pressing the ALT mode key produces the following response:

PI PROGRAM IN FROM DISK

The program is now loaded to run.

To halt a program, you type the command

HT

The computer halts operation and prints the operation and step number at which the halt occurred.

HLT 1002

The first digit is the operation number and the last three digits are the step number. The HT command will be ignored if the teletype is occupied with printing other function outputs; there must be a pause for HT to be used.

Other Teletype Commands

Besides these basic operating teletype commands, there are other commands to assist in programming, debugging, and running the FACE machine.

To list or change the state of a flag, you type CF, followed by ALT mode. The computer response is:

CF

You then type the desired flag number and its status is shown:

CF # = 5 = 1/

If the flag needs to be set or cleared, you can then type the appropriate signal. 1 stands for a set flag, and 0 stands for a cleared flag.

To restart a program where a previous halt (HLT) occurred, you use the command CO. This allows the programmer to restart the program after making a mechanical correction in the operation of the FACE machine or a correction in a program parameter. The teletype command ON wiht ALT mode ackowledgement has the computer reponse

ON OP=1/

After you specify the operation and press the ALT mode key, the computer will respond as follows:

ON OP=1/3 STEP=1/

After you specify the step and press the ALT mode key, the computer will execte the specific operation starting with the specified step. With this command, you can start any operatation at any step. The GO command starts the program only at the first operation at the first step.

To do <u>single-step</u> execution, you type SS, then ALT. The computer responds:

SS OP=1/

After you type the desired operation number and acknowledge, the computer responds:

SS OP=1/ STEP=1/

Changing the step number if necessary, and acknowleging the computer response three more times, will give the following computer printout:

SS OP=1/ STEP=1/ FUN#= / ARG= /

With the third acknowledgement, the computer will execute the step. All teletype commands with the following format will <u>increment</u> the step number by one automatically:

OP= / STEP= / FUN#= / ARG= /

Thus, another SS command will respond with the same operation,

SS OP=3/

and upon acknowledgement, with:

SS OP=3/ STEP=2/

The SS teletype command is extemely usefull in debugging a new program, or interpreting an unfamiliar program, by following it through step by step.

To <u>read out</u> the total amount of accelerator beam received by the target apparatus in coulomb units, you type the command LI, then acknowledge. The computer responds, for example:

INT 26213 X10-00009 COULOMBS

INT indicates the integral or cumulative amount, and this amount is printed as five digits times a power of 10. Thus, the example figured corresponds to $2.6213x10^{-5}$.

Command NW controls <u>how many fractions</u> the chromatographic column output is to be divided into for purposes of computer memory allocation. The machine has twenty alpha-detector sensors. The computer will group the detectors as follows (for a particular group of rabbits):

				*				*		*						*				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	2	3/4			6	7/8			10		12/13		14	15/16			18	19/20		1

* non-operable alpha counter in need of repair in an hypothetical situation

The NW=3 command tells the computer to assemble the sensor outputs in groups of three; and for data collection purposes to sum all data for the number-1 labeled sensor (the first chemical fraction) as one data output and similarily for the number 2 and 3-labeled sensors. This TT command is for the data analysis by the computer, not for operation of the FACE machine. NW, though a mnemonic for number of washes, is more accurately referred to as number of column fractions (usually 3 effluents) which is determined by the FACE program.

CX is the TT command to change the status of the crystal (XTAL). CX is typed in with ALT mode and the computer responds with:

CX #=

The desired crystal number is typed in and with ALT mode the computer responds:

CX # = 3 = 1/

The first number (3) gives the silicon-crystal detector number. The last number (1 or 0) tells whether the crystal is operable (1) or not (0). To change the crystal status, the alternative number (0 or 1) is typed after the /. This command gives the computer the needed information for the NW command to group the counters as explained above.

Command CC lists the contents of a counter, which in certain cases can be changed. A CC command, with the ALT mode, will have the computer respond with:

CC #=

The desired counter number (e.g., 8) is typed in, and ALT mode is depressed. The computer responds with:

CC # = 8 = 0/

OF is a TT command not now implemented which could be used to turn off an operation.

Functions and Arguments

As has already been seen, each step involves a function and an argument. The various FACE functions are listed in Table 2. The argument indicates which one (the element number in a sequence), or how much (time, number of steps).

Functions number 1 through 40 are for counters 1 through 40. If the values of the counter is equal to the argument of the function of the same number, the computer will omit the following step, and will skip from step N to step N+2. For instance, in the following example:

31 22 10
32 59 8
33 52 0

When the computer reaches Step 31 and the value in counter 22 is 10, the computer will go to Step 33, otherwise, to Step 32.

Function 41 is more complex. The FACE machine has a collection of sensors assigned numbers 1 through 67. Sensors (discussed in a following section) are either set or cleared as a machine operation is completed and thus reflect the existing states of the particular element. An example is given by the listing:

Table 7

Functions

FUN#	FUN DESCRIPTION	ABBR.	FUN ARG.
1	Skip if counter #1=argument	SKC1	max.=1024
2	Skip if counter #2=argument	SKC2	max.=1024
.	. . . . .	.	.
.	. . . . .	.	.
.	. . . . .	.	.
40	Skip if counter #40=argument	SKC40	max.=1024
41	Skip if sensor # in counter is set	SK3	
42	Print step and content of cntr.#3	PS3	
43	Stop+reset+start+electrometer+tape	SEL	
44	Put value of electrometer on tape	TEL	
45	Put x-tal in proper sum on scope and increment counter #3	SUM	
46	X-tal I.D. on tape with time and content of counter 1	ION	
47	Beam off on tape with time and content of counter 1	BOF	
48	Beam on tape with time	BON	
49	Zero a counter	ZC	counter no.
50	Increment a counter	IC	counter no.
51	Print value of a counter	PC	counter no.
52	Print operation and step no.	PS	none
53	Jump forward N steps	JF	N
54	Jump backward N steps	JB	N
55	Skip if sensor set	SKS	sensor. no.
56	CAMAC command	COM	command no.
57	Halt operation	HOP	operation no.
58	Start an operation at step one	SOP	operation no.

FUN#	FUN DESCRIPTION	ABBR	FUN ARG.
59	Exit and return forward N steps	RF	N
60	Exit and return backward N steps	RB	N
61	Clear a flag	CF	flag #
62	Set a flag	SF	flag #
63	Check flag	SKF	flag #
64	Load arguments of the next N steps	LD	N
65	Call subroutine	CS	step # of subroutine
66	Return from subroutine to next step after function 65	RS	none
67	HOP and print OP and STEP	HOPS	restart step#
68	Continue OP after HOP	COP	OP #
69	ID-x-tal-off on tape	IOF	if the arg. 0 it is taken as the I.D.
70-100 unsused			
101	Delay N time increments using cntr. #1	DL1	N(increment= 50 msec.)
102	Delay N time increments using cntr. #2	DL2	N(increment= 50 msec.)
.			
.			
.			
140	Delay N time increments using cntr. #40	DL40	N(increment= 50 msec.)
141	Skip N steps if X-tal #1 incorrect	SKX1	N
142	Skip N steps if X-tal #2 incorrect	SKX2	N
.			
.			
.			
160	Skip N steps if X-tal #20 incorrect	SKX20	N

37 41 0

38 59 8

39 52 0

For Function 41, no argument is needed. If the sensor of the same number as the value in Counter 3 is set, then Function 41 will cause the computer to skip a step. For example, counter 3 has a value of 12 and Sensor 12 is set, then the computer will go to Step 39, otherwise, the computer will go to Step 38. Function 41 is only found in Operation 5 of the FACE program.

Function 42 prints the step of the operation and content of counter 3. For example:

38 42 0

Step 38 would print 0038 and then the value of counter 3.

Function 43 stops, resets, and starts the electrometer and tape.

Function 44 puts the value of the electrometer on tape.

Function 45 puts the alpha detector crystal data on the scope and increments counter 3.

Function 46 puts the crystal identity on tape with the time and content of counter 1.

Function 47 turns the beam on, and the time of Function 47 execution is stored on tape.

Function 48 turns on beam with time stored on tape.

Function 49 zeroes a counter. It is used especially in conjunction with Functions 101 to 104 (discussed below) for timing purposes.

Function 50 increments a counter by unity. It is used in loops for repetitive actions. A typical loop will be illustrated with Functions 55 and 60.

Function 51 prints the value of a counter. It is not used in the entire FACE program. It is however valuable for diagnostic purposes.

For example, the following steps:

11 49 1

12 50 1

13 51 1

would first zero counter one, then increment the value to one, then print CTR 1001. The first 1 stands for the counter number.

Function 52 is a diagnostic function. The presence of Function 52 will print the step number.

37 52 0 (A step in a hypothetical Operation 4)

The computer, when it comes to this step, will print the following:

4037

The first number is the operation; the rest of the digits are the step number. This function will give information about the computer's operation of FACE. Table 12 gives Function 52 print-outs in terms of their diagnostics for FACE mechanical malfunction.

Functions 53 and 54 tell the computer to shift forward (53) or backward (54) the number of steps specified in the argument. Great care must be taken in using Function 54 which may enable the computer to loop (or lock-up) endlessly. Usually, in lock-up, the operation cannot even be halted manually and the entire program must be aborted, because the loop may take only a few milleseconds, whereas about 2 seconds are needed to insert an HLT command.

Function 55 enables the computer to be "informed" of the FACE machine status, by inspecting one of the sensors (explained in another section).

Function 56 is the function which turns on and off FACE machine equipment, sets or clears sensors. Each mechanical operation has two associated arguments. There is an even argument number which turns on the mechanical operation, and an odd argument number (the even number plus one), which turns it off. For instance, 250 turns on linear valve 1; 251 turns it off. Each sensor has only a single address number which clears the sensor if clearable and sets it if settable. The following example illustrates both function of Function 56.

34	56	292
35	56	224
36	49	1
37	101	20
38	56	225

Step 34 will clear sensor 292. Step 35 will turn on the main FACE instrument air supply. Steps 36 and 37 will provides a time lag of 1 second. Step 38 will turn off the air

Table 8

CAMAC Command Listing (Function # 56)

Decimal	Octal	FACE Machine Element
000 to 046	000 to 056	Amplifiers for Alpha Counters
048 to 090	060 to 132	Magnets for Alpha Counting sample arms
096 to 138	140 to 212	Alpha counting sample arms
140	214	Table one release, labled spare one
142	216	Spare Two
144	220	Main air to rabbit control system and Counter arms
146	222	Shoot rabbit from FACE to target, 90° valve
148	224	Main Inst. air (low pressure for column, ect.)
150	226	Main air for all pneumatic relays
152	230	Hot air jet under plate at column position
154	232	PK
156	234	Slosyn Syringe #1 Dispense
158	236	Slosyn Syringe #2 Dispense
164	244	Motor 3
166	246	Motor 4
168	250	Linear Valve 1
170	252	Linear Valve 2
172	254	Linear Valve spare
174	256	Shoots rabbit from target to FACE
176	260	Removes rabbit from irrad. or reverse of 177
177	261	Moves soln. #2 in opposite direction of 176

Decimal	Octal	
178	262	Drops rabbit in soln. # 2 from rabbit storage column at target
179	264	Reverse motion from 178
180	264	Spare 4
182	266	Spare 5
184	270	Solonoid spare
186	272	Beam
256 to 276	400 to 424	Set microswitch for arms #1 through 21
277	425	Turntable #3 (90^{o} position microswitch)
278	426	Upper drum step counter and position indicator
279	427	Lower drum step counter and position indicator
280	430	Piston in shoot position micrsw.
281	431	Piston in irrad. position microsw.
288	440	Clear Photocell #1
289	441	" " #2
290	442	" " #3
291	443	" " #4
292	444	" " #5
293	445	" " #6
294	446	" " #7
295	447	" " #8
296	450	Level sensor in column
297	451	Drop Counter
320	500	Plate is in Turntable #3 sensor
321	501	Plate slide mechanism sensor
322	502	Lower plate hopper (almost out of plates) sensor

Decimal	Octal	
323	503	Upper plate hopper sensor
324	504	Turntable #1 position microswitch
325	505	Turntable #2 position microswitch
332	514	Turntable #3 (30^o turn microsw., sets at off position)
404	624	Rabbit ram (removes rabbit from turntable #2 to Turntable #1)
406	626	Pneumatic Ram (Seats rabbit against dissolver)
408	630	Flamer On
410	632	Air pressure on dissolver
412	634	Close dissolver vent
416	640	Spare pneumatic relay:Slosyn 3/ Dissolver
418	642	Open line between dissolver and column
420	644	Air pressure on column
422	646	Open valve from Slosyn #1 syringe
424	650	Open valve from Slosyn #2 syringe
426	652	Close vent to column
428	654	Spare pneumatic relay
486	746	Turn Turntable #1 CCW (counting table)
488	750	Turn Turntable #2 CCW (rabbit table)
490	752	Turn Turntable #2 CW (rabbit table)
492	754	Turn Turntable #3 30^o (sample table)
494	756	Helium Jet #1 on
496	760	Helium Jet #2 on
498	762	Slosyn 3

supply. Arguments associated with Functions 55 and 56 are listed in Tables 8 and 9 with their associated FACE machine sensors or mechanical elements. Function 56 is a CAMAC command and Table 8 is a CAMAC command listing by argument number in both decimal and octal.

Function 57 clears an internal flag associated with the operation, which has the same number as the Function. For example:

51 57 2

Step 57 will cause the computer to by-pass Operation 2, that is to discontinue or terminate.

Function 58 sets an internal flag associated with the operation having the same numbers as the function's argument. This turns on an operation. For example:

59 58 3

60 57 2

Step 59 would set the internal flag for Operation 3, which would turn on Operation 3 and Step 60 would turn off Operation 2.

Functions 59 and 60 allow the computer to exit to the next operation, and at the same time set the re-entry point for return to the present operation as a specified number of steps forward (59) or backward (60) in relation to the step performed just before the exit occurs.

Functions 61, 62, and 63 concern the use of flags to communicate information between operations.

Function 61 clears a flag, Function 62 sets a flag, and Function 63 instructs the computer to skip a step if the flag is set. The flags store and communicate information about execution of the FACE operations. The completion of a FACE program sequence or FACE machine task can result in a flag being either cleared or set. Another operation is informed whether that task has been done by having a step where the set or cleared flag is checked, and a step is skipped or not skipped, depending on the flag status. This would be used as follows, which is from Operation 12 in the FACE machine program.

13	63	2
14	53	2
15	53	3
16	58	14
17	57	12
18	58	13
19	57	12

In Step 13, Function 63 checks Flag 2 to see if it is set. If it is set, the computer skips to Step 15 which in turn jumps to Step 18, which turns on Operation 13. Step 19 then turns off Operation 12. If in Step 13, Flag 2 is not set , the computer skips the Step 14 which sends the computer to Step 16. In Step 16, Operation 14 is turned on and then, in Step 17, Operation 12 is terminated.

Functions 64, 65, and 66 are used for subroutines. The following example illustrates the use of these three

" for number sequence only"

functions:

11	59	6		(cont.)		
12	49	1		21	15	30
13	101	20		22	65	12
14	49	2		23	64	4
15	101	20		24	12	3
16	66	0		25	13	20
17	64	4		26	14	4
18	12	2		27	15	20
19	13	30		28	65	12
20	14	2				

Steps 12 through 15 are the steps making up the subroutine. Step 11 instructs the computer to go to Step 17. Function 64 in Step 17 instructs the computer to load the arguments of the next four steps, 18 to 21, into the arguments of the 4 steps of the subroutine. The function number of the step instructs the computer into which subroutine step to load the argument number.

Function 65 transfers the computer to the subroutine. Function 66 at the end of the subroutine returns the computer to the next step after the step containing Function 65.

Steps 18 to 21 change Steps 12 to 15 as follows:

Step 11 causes a skip of 6 steps to Step 17.

Step 17 initiates the loading of arguments from the next four steps.

Step 18 loads argument 2 into Step 13, etc.

Step 22 transfers the computer to Step 12 so as to execute the subroutine.

Step 16 returns the computer to Step 23 (next after 22).

Step 23 initiates the loading of arguments from the next four steps, etc.

Although the illustration does not show a programming advantage in using this subroutine, cases arise in the actual FACE program where a fairly long subroutine has only a few arguments that need to be changed between repetitions.

Function 67 halts the computer execution of the program and prints the step and operation number of the step containing the 67 function. For example:

34 67 0 (a hypothetical step in an operation 9)

would print out:

9034

After a step containing a Function 67 halts the program, a following step containing a Function 68 will restart the program. For example:

35 67 0

36 68 3

Step 35 will stop the program, Step 36 will restart the program with Operation 3.

Function 69 puts the identification number of the alpha-detector which has been turned off on the magnetic tape to inform the computer to close the data file for that detector.

There are no Functions 70 through 100.

Functions 101 to 140 will exit and return from continue and increment the counter. The following steps are given as an example:

77 49 5

78 105 20

Step 77 will zero counter five. Step 78 will increment counter 5 by one and exit and return to Step 78 via continue. This function will repeat this operation until counter 5 is equal to 20. The cycle time is 50 msec. Since the argument of Function 105 is 20, the total time delay will 20 times 50 msec., or one second. Counters are not zeroed before use. The initial values of the counter after a TT command of "GO" is not zero.

To be used as a timer, Function 49 must be executed to zero the counter that the timer function will use. An example using the timer function for counter 13 follows:

33 49 13

34 113 30

Step 33 sets counter 13 equal to zero. Step 34 will delay the execution of the current operation by 30x50 msec.= 1.5 seconds. The computer will execute the other executable steps in other on-going operations, and return to increment counter 13 every 50 msec. When counter 13 is equal to 30, the computer will execute Step 35.

Function 141 through 160 ensure that the silicon-crystal alpha detector is the correct on to read the sample. These functions are used in Operation 5 of the FACE program only. Functions 141-160 search for the proper file in which data from the current silicon-crystal alpha detector is to be stored. This search terminates after the proper detector is erased.

FACE MACHINE SENSORS

To facilitate computer monitoring of the mechanical functioning of the FACE machine, it is equipped with 36 mechanical sensors and 8 photocell sensors. In the CAMAC program, each sensor is assigned one bit in the sensor words read by the PDP-9. Each sensor either is set (on, symbol one) or cleared (off, signal zero) by a CAMAC function 56 command, and a change in the sensor's status is observed with a 55 function. The Function 55 skips a step if the sensor corresponding to its argument is set; otherwise, the computer proceeds to the next step in the program. When a sensor is cleared in a program command, the computer program may later check to see if the sensor is set. A set sensor usually signifies the completion of some mechanical operation in the FACE machine. In the opposite case, the sensor is set and the computer then later checks to observe that the sensor has been cleared by a mechanical operation in the FACE machine. By using the sensors, the FACE program is informed when mechanical operations have been completed and when to proceed to the next step. Also several FACE machine operations can be coordinated through information from the sensors.

Alpha-Detector Arms--Sensors 1-21

Sensors 1 through 20 are used for position-sensing of the respective alpha-detector arms numbers 1 through 20. Sensor 21 is for sensing contact between an arm and a center contact ring around the platelet station, where the platelet are retrieved by the arms. The arm sensor is unsettable when the arm is in the retracted position, and is settable when the arm is extended. An electromagnet over the arm in retracted position keeps the sensor switch closed so it can not be opened (set) by a CAMAC command. Sensor 21 is settable when the arm is in electrical contact with the center platelet pickup station's rim.

It is important that an arm complete its mechanical task of extending and picking up a platelet, but it is also important that one arm does not collide with another disabled arm still extended. The arms are forcefully extended and retracted by air pressure and a collision can be quite damaging to the arms. The arms should be operated with extreme care to avoid damaging them.

Sensor 1-20, when settable, communicate that the respective arm is still extended and, until retrieved, that no further arm extensions should take place. Sensor 21 communicates that an arm is extended, with the alpha-detector head over the platelet, and the arm's electromagnets will be turned on to pick up the platelet.

<u>Turntable 3--Sensors 22, 67</u>

Sensors number 22 and 67 monitor mechanical switches. Sensor 67 indicates whether a 30° rotation increment of the Turntable 3 has been completed. Sensor 22 checks whether Turntable 3 is in a 90° position. Turntable 3 has four arms that are 90° apart. Each station around Turntable 3, the platelet hopper, droplet drying station, flaming station and platelet retrieval station, are 90° apart, and to insure that Turntable 3 is in alignment with these stations, Sensor 22 is provided.

When sensors 22 and 67 are not in position, they are settable. Sensor 67 will remain set until Turntable 3 has rotated 30°, and then the sensor will be cleared. Sensor 22 is settable when out of alignment with the 90° station positions. When in alignment, the sensor will clear. Sensor 22 is a switch, located at a 90° position at the drying station, which is closed mechanically by a Turntable 3 arm when in 90° alignment.

Rabbit Transfer and Target Apparatus Loading Sensors 25, 26, and 33, through 39

Rabbits are transferred from the FACE machine pneumatically to the target apparatus and back. Their movement is monitored with photocells 1 through 7, corresponding to sensors 33-39.

The flip-flops associated with the photocells are cleared by a CAMAC command, and are set by interruption of a light beam across the path of the rabbit.

Photocell number 6 is set by the rabbits in the shooting reservoir waiting to be shot to the target area. When photocell 6 is clearable, there are no more rabbits in the reservoir. Photocell 7 is set by a rabbit which is leaving the shooting mechanism on its way to the target apparatus, thus indicating that the shooting mechanism has operated correctly.

Photocells 1 and 2 are near the top and bottom, respectively, of the target-apparatus rabbit reservoir. Photocell 3 is beneath the reservoirs. When a rabbit arrives in an empty reservoir, it sets two photocells. When the target-apparatus rabbit reservoir is full, Photocell 1 is unclearable, and no more rabbits are sent to the reservoir. Photocell 1 also tells the computer program that the rabbit has arrived and is not clogged in the transfer tube; also, it tells the computer that the next rabbit can be sent over.

Photocell 2, when clearable, indicates that the target apparatus is low on rabbits. Photocell 3, clearable in the retracted position, indicates that the rabbit shuttle contains a rabbit. Also, extending the rabbit-loading shuttle will set Photocell 3.

Photocell 4 will indicate either the dropping of a rabbit into the irradiation position, or the shooting of a rabbit to the FACE machine. The rabbit which drops down into the irradiation piston is, after irradiation, shot back out the same way into another transfer tube back to the FACE machine.

Photocell 5 is set when the rabbit arrives at Turntable 2 and indicates that the rabbit has avoided being stuck in the transfer tube.

The rabbit irradiation piston has two mechanical sensors, one for the retracted shoot position, number 25. When the irradiation piston is being retracted to shoot the rabbit to the FACE machine, sensor 26 has just been cleared and sensor 25 will be cleared. Similarly, the extension of the irradiation piston will clear sensor 25.

<u>Turntalbe 1 and 2 -- Sensors 59,60</u>

Turntable 1 is monitored by mechanical sensor 59 and Turntable 2 by mechanical sensor 60. Each of these sensors is settable when the turntable is rotating between turntable positions. Turntable 1 rotates in one 30^{o} increment, Turntable 2 in two 30^{o} increments. The sensors are used to count the increments through which the turntables rotate. When the turntables are in position, the sensors are cleared and unsettable.

<u>Chromatographic Column-Sensors 41 through 44</u>

Sensor 44 is the level sensor, and is settable if the column vessel becomes empty.

Sensor bits 41, 42, and 43 are for the column drop-counter sensor, and make up a three digit binary number (maximum counts is seven drops). One CAMAC command number clears all three sensor bits. The drop-counter sensor detects a current pulse when a drop leaving the chromatographic column strikes a platinum wire between the column and the platelet.

When the first drop is detected by the drop-counter, bit 41 is set to 1; when the second drop is counted, bit 42 is set to 1, and 41 is cleared; and so on. The following table illustrates the counting of drops.

	Bit Numbers		
	43	42	41
First Drop	0	0	1
Second Drop	0	1	0
Third Drop	0	1	1
Fourth Drop	1	0	0
Fifth Drop	1	0	1
Sixth Drop	1	1	0
Seventh Drop	1	1	1

Platelet Delivery Sensors-- 57, 58, and 40

These three sensors monitor the platelet hopper inventory and verify the transfer of the platelet from the hopper to Turntable 3.

Sensors 57 and 58 are the lower and upper platelet hopper sensors. Both are photocells which are interrupted by a stack of platelets in the hopper. As the platelets are used by the FACE machine, the level drops and the sensor can be set. This allows the FACE program to print a Function 52 statement and notify the FACE machine operator of the impending shortage.

Sensor 40 (photocell 8) is located 30° clockwise from the droplet drying station. The photocell is interrupted and set by the presence of a platelet, verifying successful transfer from the hopper to Turntable 3.

FIGURE 13   SCHEMATIC REPRESENTATION OF THE CHEMISTRY PROGRAM

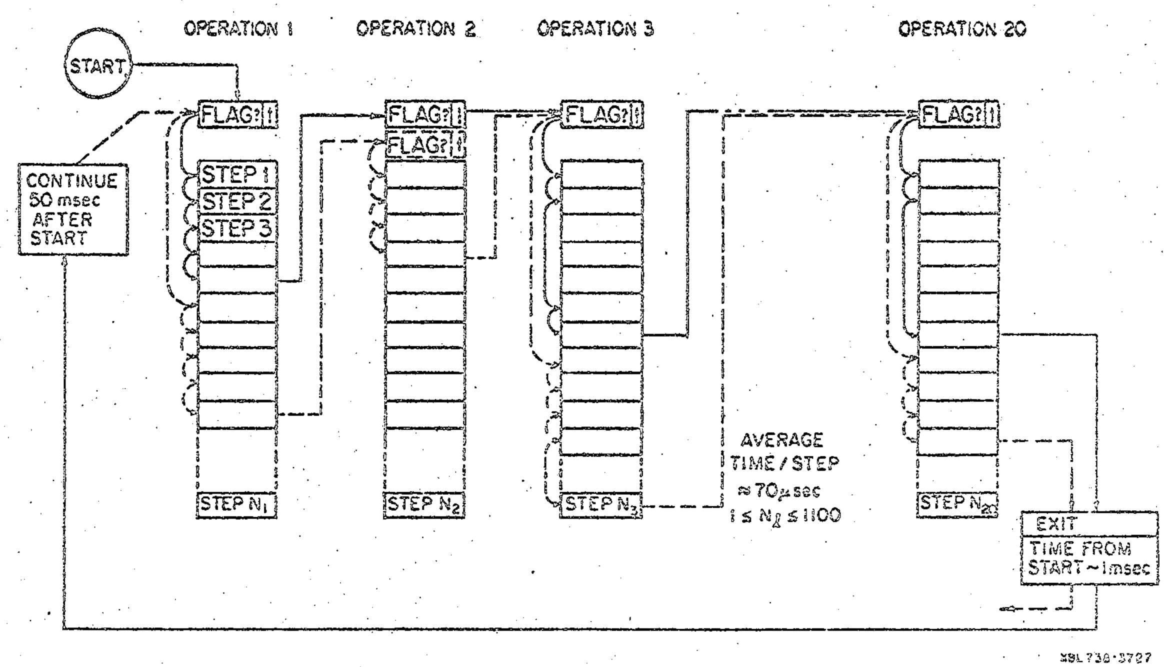


Table 9

Sensor Number and Argument List

Function #55 Argument no. & Sensor no.	CAMAC #56 Argument no. Decimal	Equipment Identification
1	256	Alpha-detector Arm #1
2	257	" " " #2
3	258	" " " #3
4	259	" " " #4
5	260	" " " #5
6	261	" " " #6
7	262	" " " #7
8	263	" " " #8
9	264	" " " #9
10	265	" " " #10
11	266	" " " #11
12	267	" " " #12
13	268	" " " #13
14	269	" " " #14
15	270	" " " #15
16	271	" " " #16
17	272	" " " #17
18	273	" " " #18
19	274	" " " #19
20	275	" " " #20
21	276	Center Contact Sensor
22	277	Turntable #3 (90° position microswitch)
23	278	Turntable #1 Step counter and position indicator
24	279	Turntable #2 Step counter and position indicator
25	280	Load piston in shoot position
26	281	Load piston in irradiation position
27 through 30 not implemented		
33	288	Photocell #1
34	289	" #2
35	290	" #3
36	291	" #4
37	292	" #5
38	293	" #6
39	294	" #7
40	295	" #8
41	297	Drop counter #1
42	297	" " #2
43	297	" " #3
44	296	Level Sensor for column
57	322	Lower platelet hopper sensor

Function #55 Argument no. & Sensor no.	CAMAC #56 Argument no. Decimal	Equipment Identification
59	324	Turntable #1 position microsw. (30^o) sets in non-aligned position
60	325	Turntable #2 position microsw. (30^o) sets in non-aligned position
61 through 66 not implemented		
67	332	Turntalbe #3 position microsw. (30^o) sets in non-aligned position

PROGRAM GUIDES

The FACE machine is run with a program written in the FACE language. The FACE program is composed of 15 operations. The FACE program, when running, is often executing two or more processes or operations simultaneously. For example, while a fraction is being collected on a platelet, another platelet might be undergoing flaming. The simultaneous running of the operations is coordinated through the use of flags and counters.

In reality, the computer can execute only one step at a time, but because of the computer's speed, the execution of the operations appears to be simultaneous to the FACE machine operator. All the executable steps in each Operation, which has been turned on are executed every 50 milleseconds.

Each step requires, on the average, 60 microseconds. Approximately 800 steps can be executed in every 50 milleseconds cycle without a time problem. The exit and return functions, numbers 59 and 60, allow the computer to go on to the next operation and will provide the operation, in which the computer is exiting from, a 50 millesecond pause. Timer functions also provide an exit and return.

To illustrate the general structure of the FACE program, Figure 13 is provided, showing the interrelations between the operations via the 58, 61, 62, and 63 functions. In each rectangle, which represent an Operation, is a listing of each step which involves a flag function, and whether that flag involved is being set, cleared, or checked for whether it is set or cleared. Also listed in each rectangle is the number of steps in the Operation and whether it halts itself. The arrows connecting the Operation rectangles indicate which Operations turn on which Operation. The arrow represents a 58 function.

Table 10 lists the purpose of each Flag, by Flag number. Table 11 lists the location of each Flag by Flag number. Table 11, under each Flag number, lists where each flag is cleared, set, or checked.

In Operations 3, 4, and 5, there are Function 52 statements provided to help diagnose frequent mechanical failures. If there is a failure of a certain type in the operation of the FACE machine, the computer will execute a 52 function. The Function 52 print out of the operation and step number will enable the operator to look up that number on Table 12 and see what the problem is.

Table 13 lists the location of the counter functions steps which are not used for timing.

These tables and the figure will enable the FACE machine user to understand the FACE program, by pointing out the more important interconnecting functions.

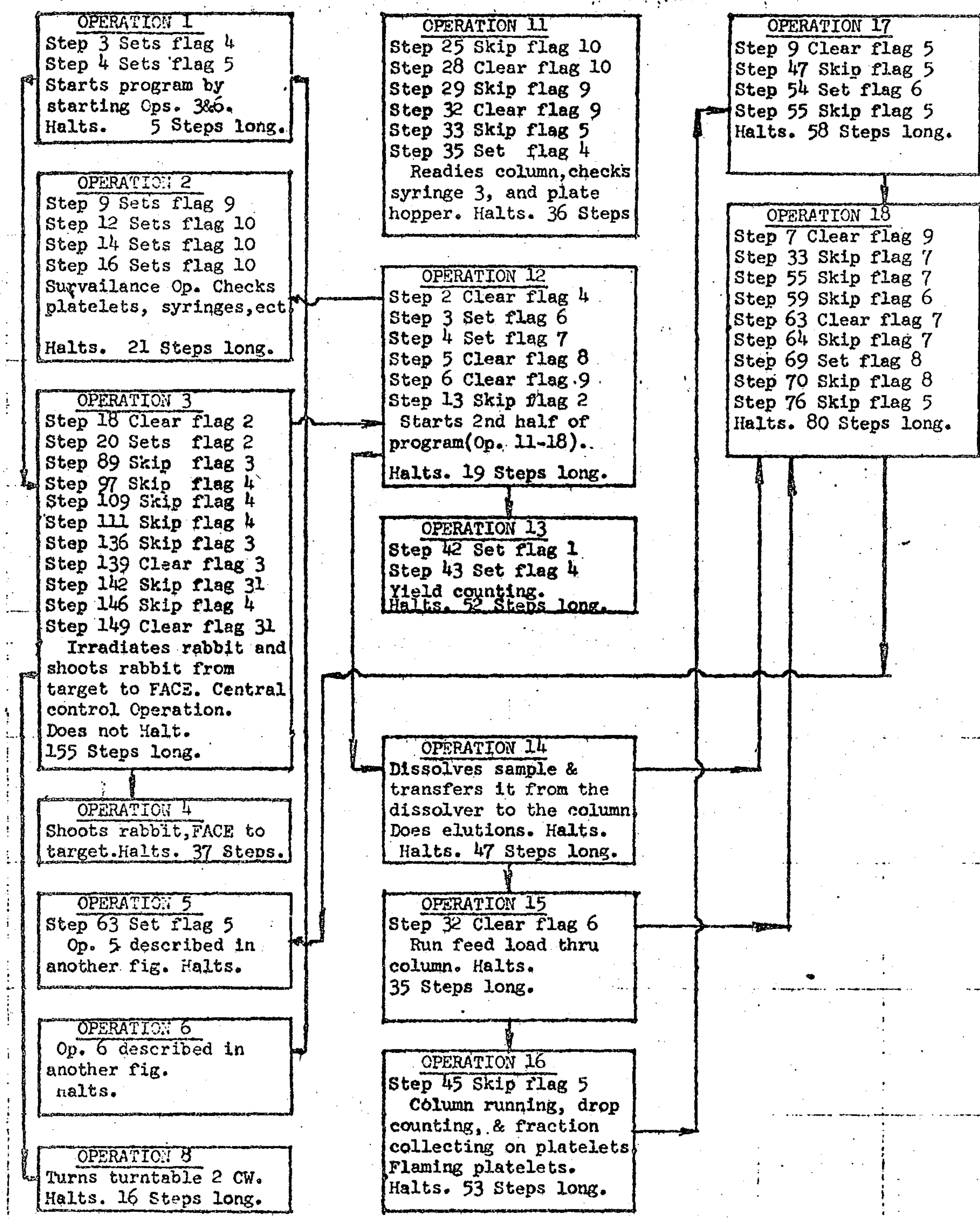


Figure 14 Schematic Representation of the FACE Program

Table 10 Flag Purposes

Flag 1. Vestigial.

Flag 2. Flag 2 is set by Op. 3 for when the counter 6 equals 1 and the flag is cleared when counter 6 is equal to any other number. The set Flag 2 in Op. 12 will decide that the rabbit will be a yield rabbit and that Op. 13 will be executed.

Flag 3. Flag 3 is set by teletype and aborts the rabbit. Causes irradiation to be bypassed. Op. 3 skips steps 89-97 which is the timer for irradiation. Flag 3 also starts Op.8. Op. 8 discharges aborted rabbits.

Flag 4. Flag 4 is set by Op.'s 1, 11, and 13. Flag 4 tells the machine that it is ready for next rabbit if set. After next rabbit is started, Op. 12 clears Flag 4. An unset Flag 4 in Op. 3 causes the computer to lock up in steps 112-111 and will not execute the program.

Flag 5. Flag 5 is set in Op.'s 1 and 5. It skips in Op. 11, 16, 17, and 18. It is cleared in Op. 17. Flag 5 insures that Op. 5 is completed so that the counters are ready when wet chemistry starts.

Flag 6. Flag 6 sets in Op. 12 and Op. 17. It clears in Op. 18, and skips in Op. 18. Op. 12 sets the flag to prevent use of Helium jets until things are ready as notified by Op. 15.

Flag 7. Flag 7 sets in Op. 12, and is cleared in Op. 18. It skips in Op. 18. Flag 7 communicates whether the plate position has been checked. An internal communication in Op. 18 started every time by Op. 12.

Flag 8. Flag 8 sets in Op. 18, and is cleared in Op.12. It skips Op. 18. It is an infracommunicating flag in Op. 18. It tells the latter portion of Op. 18 that three platelets have been discharged and to call counters. Op. 12 clears to start second half of program.

Flag 9. Set in Op. 2, Flag 9 is cleared in Op.'s 11, 12 and 18. It skips in Op. 11. After every run, Op. 2 is run to check system. Flag 9 is set if lower plate hopper is empty. Op. 11 stops with set flag. Op. 12 clears for new run. Platelets in hopper in Op. 18 will clear flag.

Flag 10. Flag 10 is set in Op. 2 and is cleared in Op. 11. Op. 2 sets flag, if any of the Slosyns are empty. It causes Op. 11 to halt. Clearing of flag is after correction of problem.

Flags 11-30. These flags are used in Op. 5 & 6. Use is straight forward.

Flag 31. Flag 31 stops rabbit production. It is set by teletype.

Table 11. Flag Function Location

FLAG 1

Function	Location
61 Clear	------
62 Set	Op. 13 Step 42
63 Check	------

FLAG 2

Function	Location
61 Clear	Op. 3 Step 18
62 Set	Op. 3 Step 20
63 Check	Op. 12 Step 13

FLAG 3

Function	Location
61 Clear	Op. 3 Step 139
62 Set	------
63 Check	Op. 3 Steps 89,136

FLAG 4

Function	Location
61 Clear	Op. 12 Step 2
62 Set	Op. 1 Step 3 Op. 11 Step 4 Op. 13 Step 43
63 Check	Op. 3 Steps 97, 109, 111, 146

FLAG 5

Function	Location
61 Clear	Op. 17 Step 9
62 Set	Op. 1 Step 4 Op. 5 Step 63
63 Check	Op. 11 Step 33 Op. 16 Step 45 Op. 17 Steps 47, 55 Op. 18 Step 76

FLAG 6

Function	Location
61 Clear	Op. 15 Step 32
62 Set	Op. 12 Step 3 Op. 17 Step 54
63 Check	Op. 18 Step 59

FLAG 7

Function	Location
61 Clear	Op. 18 Step 63
62 Set	Op. 12 Step 4
63 Check	Op. 18 Steps 33, 55, 64

FLAG 8

Function	Location
61 Clear	Op. 12 Step 5
62 Set	Op. 18 Step 69
63 Check	Op. 18 Step 70

FLAG 9

Function	Location
61 Clear	Op. 11 Step 32 Op. 12 Step 6 Op. 18 Step 7
62 Set	Op. 2 Step 9
63 Check	Op. 11 Step 29

FLAG 10

Function	Location
61 Clear	Op. 11 Step 28
62 Set	Op. 2 Step 12, 14, 16
63 Check	Op. 11 Step 25

FLAGS 11 to 30 : Flags 11 through 30 are set in Op. 5 and skiped and cleared in Op. 6.

FLAG 31
Function Location

61 Clear Op. 3 Step 149

62 Set ------

63 Check Op. Step 142

Table 12- Interpretation of Functions 67 and 52 Print Statements

Operation 3

Number	Message
3034	No rabbits in loader (starts Op. 4)
3045	Loader is not in loader position
3056	Piston has not moved into load-shoot position (before irradiation)
3064	Rabbit has not dropped into piston
3082	Piston is not in irradiation position
3108	Piston is not in load-shoot position (after irradiation)
3110	Lower drum is not in place (waits for Flag 4)
3123	Rabbit is stuck in loader or piston
3134	Rabbit is slow or stuck in tube
3140	Halt after aborting rabbit
3144	Interruption of rabbit production
3150	Required no. of runs has been made
3152	Required no. of rabbits has been produced

Operation 4

Number	Message
4009	No more rabbits in reservoir, load last two rabbits
4022	Rabbit stuck in 90° valve
4028	Rabbit slow or stuck in tube

Operation 5

The second message number is the restart step no. The two numbers are always printed together.

Number	Message
5008/9	Arm #n is stuck ½-way
5013/14	Arm #n is already out
5016/17	Arm #n is trying to come out, but another arm is already out
5031/32	Arm #n which is out, is slow or stuck
5039/40	Read switch #n is malfunctioning
5053/54	Arm #n which is in, is slow or stuck

Table 13 Counter Function Location List (Not Including Timers)

Counter 1

Operation	Step	Fun.#	Arg.
Op. 3	10	49	1
Op. 3	50	50	1
Op. 3	150	1	10
Op. 3	153	50	1

Counter 2

Operation	Step	Fun.#	Arg.
Op. 3	11	49	2
Op. 3	148	50	2
Op. 12	12	50	2

Counter 3

Operation	Step	Fun.#	Arg.

Counter 4

Operation	Step	Fun.#	Arg.
Op. 3	86	49	4
Op. 3	94	50	4
Op. 3	95	4	130

Counter 5

Operation	Step	Fun.#	Arg.
Op. 3	87	49	5
Op. 3	88	50	5
Op. 3	92	5	21
Op. 3	115	49	5
Op. 3	116	50	5
Op. 3	120	5	10
Op. 3	126	49	5
Op. 3	127	50	5
Op. 3	131	5	40

Counter 6

Operation	Step	Fun.#	Arg.
Op. 3	12	49	6
Op. 3	14	50	6
Op. 3	15	6	1
Op. 3	21	49	6
Op. 3	154	50	6

Counter 7

Operation	Step	Fun.#	Arg.
Op. 4	23	49	7
Op. 4	24	50	7
Op. 4	25	7	40

Counter 8

Operation	Step	Fun.#	Arg.
Op. 5	24	49	8
Op. 5	25	50	8
Op. 5	46	49	8
Op. 5	47	50	8

Counters 9, 10, 11, 12, and 13

Counter 14

Operation	Step	Fun.#	Arg.
Op. 12	1	49	14
Op. 18	2	50	14
Op. 18	13	14	1
Op. 18	61	14	3
Op. 18	67	14	3

Counter 15

Operation	Step	Fun.#	Arg.
Op. 16	1	49	15
Op. 16	34	50	15
Op. 16	35	15	7
Op. 16	48	49	15
Op. 17	1	49	15
Op. 17	43	50	15

Counter 16

Operation	Step	Fun.#	Arg.
Op. 16	2	49	16

Counter 17

Operation	Step	Fun.#	Arg.
Op. 8	1	49	17
Op. 8	11	50	17

Counter 17 Continued

Operation	Step	Fun.#	Arg.
Op. 8	12	17	4
Op. 13	1	49	17
Op. 13	36	50	17
Op. 13	37	17	2
Op. 18	1	49	17
Op. 18	30	50	17
Op. 18	31	17	1
Op. 18	49	17	2

Counter 39

Operation	Step	Fun.#	Arg.
Op. 2	3	50	39
Op. 2	17	49	20
Op. 2	20	49	39
Op. 2	7	49	39

IV. CONCLUSIONS

The considerable achievement, that is the FACE Automactic Apparatus, can be made even more usefull through improvement of its low element 104 throughput yield.

Chemical loss, which results in 70% approximately of the element 104 to be missing in addition to the radio-active loss factor, needs to be systematically investigated with a hafnium 181 sample followed through the FACE machine processing steps. This will allow the identification of the crucial steps in which chemical loss occurs and subsequent analysis and elimination. This thesis has reviewed possible causes, with the Tygon tubing being particularly suspect.

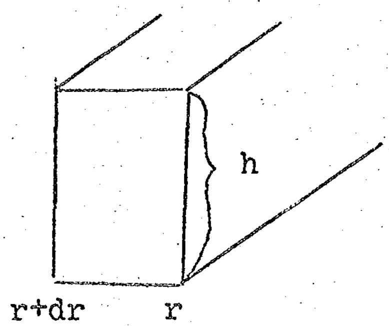
To reduce radioactive loss, or accelerate the FACE machine operation (the same thing), the time consuming steps of droplet drying and flaming need to be shorten. At the present time great gains can achieved by more intense heating. The present heating is too mild for very rapid drying (4 seconds or less per droplet). The experiments were limited by the maximum temperatures generatable by the equipment. Futher gains are still to be achieved by even more intense heating. The important restriction, is to apply the heat at or near the gas-liquid interface to avoid violent boiling.

Flaming shows promise of being eliminated by either the new drying conditions or a few per cent addition of HNO_3 to the HCl solutions used in the column.

In summary, the throughput can be at least doubled, in consideration of improved droplet drying now demonstrated to be possible, and further improvements are very likely.

Appendix A Platelet Thermal Dynamics

In order to mathematically model the thermal behvior of a RF heated platelet, a differential heat balence equation is derived as follows:



$$Heat_{in} - Heat_{out} = Heat_{Acc.}$$

$$h2\pi(r+dr)k\frac{dT}{dr}\bigg|_{r+dr} - h(2\pi r)k\frac{dT}{dr}\bigg|_{r} - g\left[2\pi(r+dr)^2 - 2\pi r^2\right]\left[T-T_\infty\right]$$

$$= h\left[2\pi(r+dr)^2 - 2\pi r^2\right]\alpha\frac{dT}{dt}$$

T = temperature

r = radius

k = thermal conductivity of platelet

h = thickness of platelet

g = thermal coefficient of heat transfer to the air

T_∞ = temperature at infinity

α = Platelet metal heat capacity

consolidating terms:

$$(r+dr)k\frac{dT}{dr}\bigg|_{r+dr} - rk\frac{dT}{dr}\bigg|_{r} - \frac{g}{h}(2rdr)(T-T_\infty) = 2rdr\,\alpha\frac{dT}{dt}$$

$$k\frac{\partial\left(r\frac{\partial T}{\partial r}\right)}{\partial r} - \frac{g}{h}2r(T-T_\infty) = 2r\alpha\frac{\partial T}{\partial t}$$

The right hand term is set equal to zero in the assumption of steady state:

$$\frac{\partial T}{\partial t}=0$$

$$k\frac{\partial(r\frac{\partial T}{\partial r})}{\partial r} - \frac{g}{h}2r(T-T_{\infty}) = 0$$

Dividing through by k:

$$\frac{\partial(r\frac{\partial T}{\partial r})}{\partial r} - \frac{2g}{kh}r(T-T_{\infty})=0$$

Variable substitution:

$$\theta=T-T_{\infty}$$

$$\frac{\partial(r\frac{\partial \theta}{\partial r})}{\partial r} - \frac{2g}{kh}r\theta=0$$

Further differentiating the right most quantity:

$$r\frac{\partial^2\theta}{\partial r^2}+\frac{\partial\theta}{\partial r} - \frac{2g}{kh}r\theta=0$$

Variable substitution:

$$\theta=y$$
$$r=x$$

$$xy'' + y' - \frac{2g}{kh}xy=0$$

$$xy'' + y' - \frac{2gxy}{kh} = 0 \qquad z = (2g/kh)^{\frac{1}{2}}x$$

The order of the Bessel solutions to the above equation is zero, that is p=0.

The solution to the equation is as follows:

$$y = Z_0(iz) = c_1 I_0(z) + c_2 K_0(z)$$

$I_0(z)$ is known as the modified Bessel function of the first kind, of order zero.

$$I_0(z) = \sum_{m=0}^{\infty} \frac{(z/2)^{2m}}{(m!)^2}$$

$K_0(z)$ is known as the modified Bessel function of the second kind, of order zero.

$$K_0(z) = \frac{\pi}{2} i\, H_0^{(1)}(iz)$$

FACE Automatic Apparatus Program Appendix B

Operation 1. Starting Operation.

This operation is only run once to start the program by turning on Operations 3 and 6 and setting flags 4 and 5.

OP 1

STEP	FUN#	ARG	
1	58	3	Start operation 3 at step one
2	58	6	Start operation 6 at step one
3	62	4	Set a flag, flag 4
4	62	5	Set flag 5
5	57	1	Halt operation one

Operation 2. Watch-Dog and Clock Operation.

Checks to see if hopper has enough platelets and if slo-syns are almost empty. Also provides a second delay in program.

OP 2

STEP	FUN#	ARG	
1	55	58	Skip to step 3 if sensor 58 is set, low on plates,Upper plate hopper
2	52	0	Print operation and step no.
3	50	39	Increment counter 39
4	56	282	Clear sensor 27,upper limit Slosyn Syringe 1#
5	56	283	Clear sensor 28, upper limit Slosyn Syringe #2
6	56	333	Discontinued, does nothing
7	56	322	Clear sensor 57, Lower plate Hopper(almost out of plates)
8	56	323	Clear sensor 58, Upper plate Hopper(low on plates)
9	55	57	Skip to step 11 if sensor 57 is set
10	62	9	Set flag 9
11	55	27	Skip if sensor 27 is set,to step 13
12	62	10	Set flag 10
13	55	28	Skip if sensor 28 is set to step 15
14	62	10	Set flag 10
15	55	68	Discontinued, does nothing
16	62	10	Set flag 10
17	39	20	Skip if counter 39 equals 20 to step 19
18	60	15	Exit and return backwards 15 steps to step 3
19	50	40	Increment counter 40
20	49	39	Zero counter 39
21	60	18	Exit and return backwards 18 steps to step 3

Operation 3. Rabbit Control Operation.

Irradiates the rabbit at the target apparatus and then transfers the rabbit to the FACE machine.

STEP	FUN#	ARG	
1	56	187	Turn off beam
2	56	176	Removes rabbit from irrad.,target soln. #3
3	49	5	Zero counter no. 5
4	105	16	Count to 16 with counter 5, 800 ms.
5	56	174	Shoots rabbit from target to FACE, Target soln. 1
6	49	5	Zero counter 5
7	105	50	Count to 50 with counter 5, 2.5 sec.
8	56	175	Stop shoot rabbit from target to FACE, target soln. 1
9	58	8	Start operation 8 at step one
10	49	1	Zero counter one
11	49	2	Zero counter two
12	49	6	Zero counter six
13	50	1	Increment counter 1 by one
14	50	6	Increment counter 6 by one
15	6	1	If counter 6 is equal to 1 skip to step 17
16	53	2	Jump forward 2 steps to step 18
17	53	3	Jump forward 3 steps to step 20
18	61	2	Clear flag 2
19	53	3	Jump forward 3 steps to step 22
20	62	2	Set a flag , flag no. 2
21	49	6	Zero counter 6
22	56	288	Clear photocell No. 1
23	56	290	Clear photocell No. 3
24	56	291	Clear photocell No. 4
25	55	35	Check photocell No. 3, skip to step 27 if set
26	53	2	Jump forward 2 steps to step 28
27	53	12	Jump forward 12 steps to step 39
28	49	5	Zero counter 5
29	105	10	Count to 10 with counter no. 5, 500ms.
30	56	290	Clear photocell 3

STEP	FUN#	ARG	
31	55	35	Skip to step 33 if photocell No. 3
32	53	2	Jump forward 2 steps to step 34
33	53	6	Jump forward 6 steps to step 39
34	52	0	Print operation and step no.
35	58	4	Start operation 4 at step one
36	49	5	Zero counter 5
37	105	200	Count to 200 with counter 5, 10 sec.
38	60	16	Exit and return backwards 16 steps to step 22
39	56	280	Set microswitch for piston in shoot position, at target
40	56	281	Set microswitch for piston in irrad. position, at target
41	56	286	
42	56	287	
43	55	32	Skip if sensor 32 is set
44	53	2	Jump forward 2 steps to step 46
45	67	39	HOP and print OP and STEP, restart step 39
46	56	176	Removes rabbit from irrad. or takes rabbit from soln. 3 for loading with command 261 oct.
47	49	5	Zero counter 5
48	105	20	Count to 20 with counter 5, 1 sec.
49	56	280	Set microswitch for piston in shoot position, at target
50	56	281	Set microswitch for piston in irrad. position, at target
51	55	25	Skip if sensor 25 is set, piston in shoot position.
52	53	4	Jump forward 4 steps to step 56.
53	55	26	Skip if sensor 26 is set, piston in irrad. position.
54	53	2	Jump forward 2 steps to step 56
55	53	2	" " " " " " 57
56	67	49	HOP and print OP and STEP, restart step 49
57	56	178	Drop rabbit into soln. 2 from rabbit storage column
58	49	5	Zero counter 5
59	105	20	Count to 20 with counter 5, 1 sec.
60	56	179	Reverse motion of CAMAC command 178, 262 Octal
61	49	5	Zero counter 5
62	105	20	Count to 20 with counter 20, 1 sec.
63	55	36	Skip to step 65 if photocell No.4 is set

STEP	FUN#	ARG	
64	67	57	HOP and print OP and STEP , restart step 57
65	56	288	Clear photocell No. 1
66	55	33	Check if photocell No. 1 is set, if set skip to step 68
67	58	4	Start operation 4 at step one
68	56	177	Moves soln. No. 2 in direction opposite for 260 (octal). loads rabbit into irrad. step.
69	49	5	Zero counter 5
70	105	40	Count to 40 with counter 5, 2 sec.
71	56	281	Set micro switch for piston in irrad. position at target
72	55	26	Skip to step 74 if sensor 26 (piston in irrad. position) is set
73	53	10	Jump forward 10 steps to step 83
74	56	176	Removes rabbit from irrad. or takes rabbit from soln. 3 for loading with command 261. pushes soln. in.
75	49	5	Zero counter 5
76	105	20	Count to 20 with counter 5,1 second
77	56	177	Moves soln. No. 2 in direction opposite for 260. Loads rabbit into irrad. step.
78	49	5	Zero counter 5
79	105	40	Count to 40 with counter 5, 2 sec.
80	55	26	Skip if sensor 26 is set to step 82,(Piston in irrad. position)
81	53	2	Jump forward 2 steps to step 83
82	67	71	HOP and print OP and STEP, 71 restart step
83	56	186	Turn on beam
84	48	0	Beam on tape with time.
85	43	0	Stop + reset+ start electro-meter+tape
86	49	4	Zero counter 4
87	49	5	Zero counter 5
88	50	5	Increment counter 5
89	63	3	Skip to step 91 if flag 3 set.
90	53	2	Jump forward 2 steps to step 55
91	53	6	Jump forward 6 steps to step 97
92	5	21	If counter equal to 21 skip to step 94
93	60	5	Exit and return backwards 5 steps to step 88
94	50	4	Increment counter 4 by one
95	4	130	If counter 4 is equal to 130 skip to step 97

STEP	FUNC#	ARG	
96	54	9	Jump backward 9 steps to step 87
97	63	4	Skip to step 99 if flag 4 is set.
98	60	1	Exit and return backward one step
99	56	187	Turnoff beam
100	47	0	Beam off on tape with time and content of counter one
101	44	0	Put value of electrometer on tape
102	53	1	Jump forward one step to step 103
103	56	176	Remove rabbit from irrad. or take rabbit from soln. 3 for loading with Octal command 261.
104	49	5	Zero counter 5
105	105	16	Count to 16 with counter 5, 800 ms.
106	56	280	M23, piston in shoot position microswitch
107	55	25	Skip to step 109 if sensor 25 is set,shoot position microsw.
108	67	93	HOP and print OP and STEP
109	63	4	Skip to step 111 if flag 4 set
110	52	0	Print operation and step no.
111	63	4	Skip to step 113 if flag 4 set
112	60	1	Exit and return backwards 1 step to step 111
113	56	291	Clear photocell No.4
114	56	174	Shoot rabbit from target to FACE
115	49	5	Zero counter 5
116	50	5	Increment counter 5
117	55	36	Skip to step 119 if photocell no. 4 is set
118	53	2	Jump forward two steps to step 120
119	53	5	Jump forward 5 steps to step 124
120	5	10	If counter 5 is equal to 10 skip to step 122
121	60	5	Exit and return backward 5 steps to step 116
122	56	175	Stop shoot rabbit from target tc FACE
123	67	106	HOP and print OP and STEP restart step 106
124	56	292	Clear photocell no. 5
125	56	174	Shoots rabbit from target to FACE
126	49	5	Zero counter 5
127	50	5	Increment counter 5 by one
128	55	37	Skip to step 130 if photocell 5 is set
129	53	2	Jump forward 2 steps to step 131
130	53	5	Jump forward 5 steps to step 135

STEP	FUN#	ARG	
131	5	40	Count to 40 with counter 5, 2 sec.
132	60	5	Exit and return backwards 5 steps to step 127
133	56	175	Stop shoot rabbit from target to FACE
134	67	117	HOP and print OP and STEP restart step 117
135	56	175	Stop shoot rabbit from target to FACE
136	63	3	Skip to step 139 if flag 3 is set
137	53	4	Jump forward 4 steps to step 141
138	58	8	Start operation 8 at step one
139	61	3	Clear flag 3
140	67	146	HOP and print OP and STEP
141	58	12	Start operation 12 at step one
142	63	31	Skip to step 144 if flag 31 is set
143	53	7	Jump forward 7 steps to step 150
144	67	149	HOP and print OP and STEP restart step 149
145	53	7	Jump forward 7 steps to step 152
146	63	4	Skip to step 148 if flag 4 set
147	60	1	Exit and return backwards 1 step
148	50	2	Increment counter 2
149	61	31	Clear flag 31
150	1	10	If counter 1 is equal to 10 skip to step 152
151	53	2	Jump forward 2 steps to step 153
152	67	0	HOP and print OP and STEP restart step 0
153	50	1	Increment counter 1
154	50	6	Increment counter 6
155	60	140	Exit and return backwards 140 steps to step 15

Operation 4. Rabbit Reservoir Operation.

Rabbits are transferred from FACE machine to target reservoir until it is filled.

OP 4

STEP	FUN#	ARG	
1	56	146	Shoots rabbit from FACE to target area, 90° valve
2	49	7	Zero counter no. 7
3	107	13	Count to 13 with counter 7, 650 milleseconds
4	56	147	Stops shoot rabbit from FACE
5	49	7	Zero counter seven
6	107	10	Count to 10, 500 ms. , with counter 7
7	56	293	Clear photocell No. 6
8	53	2	Jump forward 2 steps to step no. 10
9	67	7	Halt operation (HOP) and print OP and STEP, restart no. 7
10	56	170	Turn on linear valve no. 2
11	49	7	Zero counter 7
12	107	6	Count to 6 with counter 7, 300 ms.
13	56	171	Turn off linear valve no. 2
14	49	7	Zero counter 7
15	107	6	Count to 6 with counter 7 , 300 ms.
16	56	294	Clear photocell No. 7
17	56	289	Clear photocell No. 2
18	56	146	Shoot rabbit from FACE to target area, 90° valve
19	49	7	Zero counter no. 7
20	107	20	Count to 20 with counter 7, 1 sec.
21	55	39	Check photocell no. 7
22	67	14	HOP and print OP and Step, restart step no. 14
23	49	7	Zero counter 7
24	50	7	Increment counter 7 by one
25	7	40	If counter 7 is equal to 40 skip to step 27
26	53	3	Jump forward 3 steps to step 29

STEP	FUN#	ARG	
27	56	147	Stop shoot rabbit from FACE to target area, 90° valve
28	67	16	HOP and print OP and STEP, restart step 16
29	55	34	Skip step to step 31, if photocell No. 2 is set
30	60	6	Exit and return backwards six steps
31	56	147	Stop shoot rabbit from FACE, 90° valve
32	49	7	Zero counter 7
33	107	6	Count to 6 with counter 7, 300 ms.
34	56	289	Clear photocell No.2
35	55	34	Check photocell No. 2, skip to step 37 if set
36	60	31	Exit and return backward 31 steps to step 5
37	57	4	Halt operation 4

Operation 5. Alpha-detector Arm Operation.

This operation runs the alpha-detector arms to pick up FACE machine wash samples and count their alpha decays.

OP 5

STEP	FUN#	ARG	
1	53	66	Jump forward 66 steps to step No. 67
2	56	276	
3	56	258	
4	55	21	Skip if sensor 21 is set to step 6
5	53	6	Jump forward six steps to step 11
6	41	0	Skip if sensor # in counter #3 is set
7	53	12	Jump forward 12 steps to step No. 19
8	42	0	Print step and content of counter #3
9	67	2	HOP and print operation and step, restart step 2
10	54	8	Jump backward eight steps to step 2
11	41	0	Skip if sensor # in counter #3 is set
12	53	4	Jump forward four steps to step 16
13	42	0	Print step and content of counter #3
14	67	2	HOP and print OP and STEP, restart step 2
15	54	13	Jump backward 13 steps, to step 2
16	42	0	Print step and content of counter #3
17	67	2	HOP and print OP and STEP, restart step 2
18	54	16	Jump backward 16 steps to step 2
19	56	5	Turn off amplifier 3
20	56	53	Turnoff magnet 3
21	49	8	Zero counter 8
22	108	6	Count to 6, 300 milliseconds
23	56	100	Turn on arm 3
24	49	8	Zero counter 8
25	50	8	Increment counter 8 by one
26	55	21	Skip if sensor 21 is set, to step 28
27	53	7	Jump forward seven steps to step 34
28	8	40	Skip if counter 8 is equal to 40 to step 30

OP 5 cont.

STEP	FUN#	ARG	
29	60	4	Exit and return backward 4 steps to step 25
30	56	101	Turn off arm 3
31	42	0	Print step and content of counter #3
32	67	23	HOP and print op and STEP, restart step 23
33	54	10	Jump backwards 10 steps to step 23
34	56	258	
35	59	1	Exit and return forward one step to step 36
36	41	0	Skip if sensor # in counter #3 is set
37	53	2	Jump forward 2 steps to step 39
38	53	4	Jump forward 4 steps to step 42
39	42	0	Print step and content of counter #3
40	67	34	HOP and print OP and STEP, restart step 34
41	54	7	Jump backward 7 steps to step 34
42	56	52	Turn on arm 3
43	49	8	Zero counter 8
44	108	6	Count to 6, 300 ms., with counter 8
45	56	101	Turn off arm 3
46	49	8	Zero counter 8
47	50	8	Increment counter 8 by one
48	41	0	Skip if sensor # in counter #3 is set
49	53	7	Jump forward 7 steps to step 56
50	8	40	If counter 8 is equal to 40, skip to step 52
51	60	4	Exit and return backward to step 47
52	56	100	Turn on arm 3
53	42	0	Print step and content of counter #3
54	67	45	HOP and print OP and STEP
55	54	10	Jump backwards ten steps to step 45
56	49	8	Zero counter 8
57	108	4	Count to four, 200 ms.
58	56	4	Turn amplifier 3 on
59	46	0	X-tal I.D. on tape with time and content of counter 1

OP 5 cont.

STEP	FUN#	ARG	
60	45	0	Put x-tal in proper sum on scope and increment counter 1
61	49	23	Zero counter 23
62	62	13	Set flag 13
63	62	5	Set flag 5
64	56	313	
65	57	5	Halt operation 5
66	66	112	Return from sub-routine (to next step after fun. 66)
67	141	15	Skip 15 steps to step 83 if x-tal #1 incorrect
68	64	12	Load argments of the next 12 steps
69	3	256	Change argument of step 3 to 256
70	19	1	" " " " 19 " 1
71	20	29	" " " " 20 " 29
72	23	96	" " " " 23 " 96
73	30	97	" " " " 30 " 97
74	34	256	" " " " 34 " 256
75	42	48	" " " " 42 " 48
76	45	97	" " " " 45 " 97
77	52	96	" " " " 52 " 96
78	58	0	" " " " 58 " 0
79	61	21	" " " " 61 " 21
80	62	11	" " " " 62 " 11
81	65	2	Call sub-routine, step 2 first step in sub-routine
82	142	15	Skip 15 steps to step 97, if x-tal #2 incorrect
83	64	12	Load arg. of the next 12 steps
84	3	257	
85	19	3	
86	20	51	
87	23	98	
88	30	99	
89	34	257	
90	42	50	
91	45	99	
92	52	98	
93	58	2	
94	61	22	
95	62	12	
96	65	2	Call sub-routine, first step no. 2
97	143	15	Skip 15 steps to step 112 if x-tal #3 incorrect
98	64	12	Load arg. of the next 12 steps

OP 5 cont.

STEP	FUN#	ARG	
99	3	258	
100	19	5	
101	20	53	
102	23	100	
103	30	101	
104	34	258	
105	42	52	
106	45	101	
107	52	100	
108	58	4	
109	61	23	
110	62	13	
111	65	2	Call sub-routine, first step 2
112	144	15	Skip 15 steps to step 127, if x-tal #4 incorrect
113	64	12	Load arguments of the next 12 steps
114	3	259	
115	19	7	
116	20	55	
117	23	102	
118	30	103	
119	34	259	
120	42	54	
121	45	103	
122	52	102	
123	58	6	
124	61	24	
125	62	14	
126	65	2	Call subroutine, first step no. 2
127	145	15	Skip 15 steps to step 142 if x-tal #5 incorrect
128	64	12	Load arguments of the next 12 steps
129	3	300	
130	19	9	
131	20	58	
132	23	104	
133	30	105	
134	34	260	

OP 5 cont.

STEP	FUN#	ARG	
135	42	56	
136	45	105	
137	52	104	
138	58	8	
139	61	25	
140	62	15	
141	65	2	Call subroutine , first step number 2
142	146	15	Skip 15 steps to step 157 if x-tal #6 incorrect
143	64	12	Load arguments of the next 12 steps
144	3	301	
145	19	11	
146	20	59	
147	23	106	
148	30	107	
149	34	261	
150	42	58	
151	45	107	
152	52	106	
153	58	10	
154	61	26	
155	62	16	
156	65	2	Call subroutine, first step no. 2
157	147	15	Skip 15 steps if x-tal #7 incorrect
158	64	12	Load arguments of the next 12 steps
159	3	302	
160	19	13	
161	20	61	
162	23	108	
163	30	109	
164	34	262	
165	42	60	
166	45	109	
167	52	108	
168	58	12	
169	61	27	
170	62	17	
171	65	2	Call subroutine, first step number2

OP 5 cont.

STEP	FUN#	ARG	
172	148	15	Skip 15 steps to step 187 if x-tal #8 incorrect
173	64	12	Load arguments of the next 12 steps
174	3	303	
175	19	15	
176	20	63	
177	23	110	
178	30	111	
179	34	263	
180	42	62	
181	45	111	
182	52	110	
183	58	14	
184	61	28	
185	62	18	
186	65	2	Call subroutine, first step no. 2
187	149	15	Skip 15 steps to step 202 if x-tal #9 incorrect
188	64	12	Load arguments of the next 12 steps
189	3	304	
190	19	17	
191	20	65	
192	23	112	
193	30	113	
194	34	264	
195	42	64	
196	45	113	
197	52	112	
198	58	16	
199	61	29	
200	62	19	
201	65	2	Call subroutine, first step NO. 2
202	150	15	Skip 15 steps to step 217 if x-tal #10 incorrect
203	64	12	Load arguments of the next 12 steps
204	3	305	
205	19	19	
206	20	67	
207	23	114	
208	30	115	

OP 5 cont.

STEP	FUN#	ARG	
209	34	265	
210	42	66	
211	45	115	
212	52	114	
213	58	18	
214	61	30	
215	62	20	
216	65	2	Call subroutine, first step No. 2
217	151	15	Skip 15 steps to step 232 if x-tal #11 incorrect
218	64	12	Load arguments of the next 12 steps
219	3	306	
220	19	21	
221	20	69	
222	23	116	
223	30	117	
224	34	266	
225	42	68	
226	45	117	
227	52	116	
228	58	20	
229	61	31	
230	62	21	
231	65	2	Call subroutines, first step no. 2
232	152	15	Skip 15 steps if x-tal #12 incorrect
233	64	12	Load arguments of the next 12 steps
234	3	307	
235	19	23	
236	20	71	
237	23	118	
238	30	119	
239	34	267	
240	42	70	
241	45	119	
242	52	118	
243	58	22	
244	61	32	
245	62	22	
246	65	2	Call subroutine, first step no. 2

STEP	FUN#	ARG	
247	153	15	Skip 15 steps to step 262, if x-tal #13 incorrect
248	64	12	Load arguments of the next 12 steps
249	3	308	
250	19	25	
251	20	73	
252	23	120	
253	30	121	
254	34	268	
255	42	72	
256	45	121	
257	52	120	
258	58	24	
259	61	33	
260	62	23	
261	65	2	Call subroutine, first st4p No. 2
262	154	15	Skip 15 steps to step 277 if x-tal #14 incorrect
263	64	12	Load arguments of the next 12 steps
264	3	309	
265	19	27	
266	20	75	
267	23	122	
268	30	123	
269	34	269	
270	42	74	
271	45	123	
272	52	122	
273	58	26	
274	61	34	
275	62	24	
276	65	2	Call subroutine, first step no. 2
277	155	15	Skip 15 steps to step 292, if x-tal #15 incorrect
278	64	12	Load arguments of the next 12 steps
279	3	310	
280	19	29	
281	20	77	
282	23	124	
283	30	125	
284	34	270	
285	42	76	

OP 5 cont.

STEP	FUN#	ARG	
286	45	125	
287	52	124	
288	58	28	
289	61	35	
290	62	25	
291	65	2	Call subroutine, step 2 first step in subroutine
292	156	15	Skip 15 steps to step 307.,if x-tal #16 incorrect
293	64	12	Load arguments of the next 12 steps
294	3	311	
295	19	31	
296	20	79	
297	23	126	
298	30	127	
299	34	271	
300	42	78	
301	45	127	
302	52	126	
303	58	30	
304	61	36	
305	62	26	
306	65	2	Call sub routine, first step of sub routine step 2
307	157	15	Skip 15 steps to step 322, x-tal #17 incorrect
308	64	12	Load the next 12 arguments of the next 12 steps
309	3	312	
310	19	33	
311	20	81	
312	23	128	
313	30	129	
314	34	272	
315	42	80	
316	45	129	
317	52	128	
318	58	32	
319	61	37	
320	62	27	
321	65	2	Call sub-routine, first step no. 2

STEP	FUN#	ARG	
322	158	15	Skip 15 steps to step 337, if x-tal #18 incorrect
323	64	12	Load the arguments of the next 12 steps
324	3	313	
325	19	35	
326	20	83	
327	23	130	
328	30	131	
329	34	273	
330	42	82	
331	45	131	
332	52	130	
333	58	34	
334	61	38	
335	62	28	
336	65	2	Call sub-routine, first step no.2
337	159	15	Skip 15 steps to step 352, if x-tal #19 incorrect
338	64	12	Load arguments of the next 12 steps
339	3	314	
340	19	37	
341	20	85	
342	23	132	
343	30	133	
344	34	2u4	
345	42	84	
346	45	133	
347	52	132	
348	58	36	
349	61	39	
350	62	29	
351	65	2	Call sub-routine, first step no. 2
352	160	15	Skip 15 steps to step 367, if x-tal #20
353	64	12	Load arguments of the next 12 steps
354	3	315	
355	19	39	
356	20	87	
357	23	134	
358	30	135	
359	34	275	

OP 5 cont.

STEP	FUN#	ARG	
360	42	86	
361	45	135	
362	52	134	
363	58	38	
364	61	40	
365	62	30	
366	65	2	Call subroutine, first step no.2
367	54	366	Jump backwards 366 steps, to step no. 1

Operation 6. Data Retrieval Operation.

Operation turns off alpha-detectors and collects alpha decay data.

OP 6

STEP	FUN#	ARG	
1	49	9	Zero counter No. 9
2	109	20	Count to 20 with counter No.9, one second
3	63	11	Skip a step if flag is set, flag no. 11
4	53	7	Jump forward seven steps to step No. 11
5	50	21	Increment counter No. 21 one
6	21	20	If counter No. 21 is equal to 20 skip
7	53	4	Jump forward four steps to step No. 11
8	56	1	
9	69	0	ID-x-tal - off on tape, if the arg. is #0,it is taken as the ID.
10	61	11	Clear flag No. 11
11	63	12	Skip a step, to step No. 13, if flag No. 12 is set.
12	53	7	Jump forward seven steps to step No. 19
13	50	22	Increment counter No. 22 by one
14	22	20	Skip a step, to step No. 16 , if counter No. 22 is equal to 20
15	53	4	Jump forward four steps to step No. 19
16	56	3	
17	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID.
18	61	12	Clear flag No. 12
19	63	13	Skip a step, to step No. 21, if flag No. 13 is set
20	53	7	Jump forward seven steps to step No. 27
21	50	23	Increment counter twenty three by one
22	23	20	If counter twenty three is equal to 20, skip to step No. 24
23	53	4	Jump forward four steps to step No. 27
24	56	5	
25	69	0	ID-x-tal-off on tape, if the arg. is 0#, it is taken as the ID.
26	61	13	Clear flag No. 13
27	63	14	Skip a step to step No. 29, if flag No. 14 is set
28	53	7	Jump forward seven steps to step No. 35
29	50	24	Increment counter 24 by one
30	24	20	If counter 24 is equal to 20, skip to step No. 32
31	53	4	Jump forward four steps to step No. 35

STEP	FUN#	ARG	
32	56	7	
33	69	0	ID-x-tal-off on tape, if the arg. is #0,it is taken as the ID
34	61	14	Clear flag No. 14
35	63	15	Skip a step to step No.37, if flag No. 15 is set
36	53	7	Jump forward seven steps to step No. 43
37	50	25	Increment counter No. 25 by one
38	25	20	If counter 25 is equal to 20, skip a step to step No. 40
39	53	4	Jump forward four steps to step No. 43
40	56	9	
41	69	0	ID-x-tal-off on tape, if the arg. is #0,it is taken as the ID
42	61	15	Clear flag No. 15
43	63	16	Skip a step forward to step No. 45, if flag No. 16 is set
44	53	7	Jump forward seven steps to step No. 51
45	50	26	Increment counter No. 26 by one
46	26	20	If counter 26 is equal to 20 skip a step to step No. 48
47	53	4	Jump forward four steps to step No. 51
48	56	11	
49	69	0	ID-x-tal-off on tape, if the arg. is 0#,it is taken asthe ID
50	61	16	Clear flag No. 16
51	63	17	Skip a step forward to step No. 53, if flag No. 17 is set
52	53	7	Jump forward seven steps to step No. 59
53	50	27	Increment counter No. 27 by one
54	27	20	If counter No. 27 is equal to 20, skip to step No. 56
55	53	4	Jump forward four steps to step No. 59
56	56	13	
57	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
58	61	17	Clear flag No. 17
59	63	18	Skip a step to step No. 61 if flag No. 18 is set
60	53	7	Jump forward seven steps to step No. 67
61	50	28	Increment counter No. 28 by one
62	28	20	If counter 28 is equal to 20 skip to step No. 64
63	53	4	Jump forward four steps to step No. 67
64	56	15	
65	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID

STEP	FUN^A	ARG	
66	61	18	Clear flag 18
67	63	19	Skip to step No. 69, if flag 19 is set
68	53	7	Jump seven steps to step No. 75
69	50	29	Increment counter No. 29 by one
70	29	20	If counter 29 is equal to 20 skip to step No.72
71	53	4	Jump forward four steps to step No. 75
72	56	17	
73	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
74	61	19	Clear flag 19
75	63	20	If flag 20 is set, skip to step No. 77
76	53	7	Jump forward seven steps to step No. 83
77	50	30	Increment counter 30 by one
78	30	20	If counter 30 is equal to 20, skip to step No. 80
79	53	4	Jump forward four steps to step No. 83
80	56	19	
81	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
82	61	20	Clear flag 20
83	63	21	If flag 21 is set, skip to step No. 85
84	53	7	Jump forward seven steps to step No. 91
85	50	31	Increment counter 31 by one
86	31	20	If counter 31 is equal to 20,skip to step No. 88
87	53	4	Jump forward to step No. 91
88	56	21	
89	69	0	ID-x-tal-off on tape. if the arg. is #0, it is taken as the ID
90	61	21	Clear flag 21
91	63	22	If flag 22 is set, skip to step No. 93
92	53	7	Jump forward seven steps to step No. 99
93	50	32	Increment counter 32 by one
94	32	20	If counter 32 is equal to 20 skip to step No. 96
95	53	4	Jump forward four steps to step No. 99
96	56	23	
97	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
98	61	22	Clear flag 22

OP 6 cont.

STEP	FUN#	ARG	
99	63	23	If flag 23 is set, skip to step No. 101
100	53	7	Jump seven steps to step No. 107
101	50	33	Increment counter 33 by one
102	33	20	If counter 33 is equal to 20 skip to step No. 104
103	53	4	Jump to step No. 107
104	56	25	
105	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
106	61	23	Clear flag 23
107	63	24	If flag 24 is set, skip to step No. 24
108	53	7	Jump forward four steps to step No. 115
109	50	34	Increment counter No. 34 by one
110	34	20	If counter 34 is equal to 20 skip to step No. 112
111	53	4	Jump forward four steps to step No. 115
112	56	27	
113	69	0	ID-x-tal-off on tape, if the arg. is#0. it is taken as the ID
114	61	24	Clear flag 24
115	63	25	If flag 25 is set, skip to step No. 117
116	53	7	Jump seven steps to step No. 123
117	50	35	Increment counter 35 by one
118	35	20	If counter 35 is equal to 20,skip to step 120
119	53	4	Jump forward four steps to step No. 123
120	56	29	
121	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
122	61	25	Clear flag 25
123	63	26	If flag 26 is set, skip to step No.125
124	52	7	Jump forward seven steps to step No. 131
125	50	36	Increment counter 36 by one
126	36	20	If counter 36 is equal to 20, skip to 128
127	53	4	Jump forward four steps to step No. 131
128	56	31	
129	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
130	61	26	Clear flag 26
131	63	27	If flag 27 is set, skip to step 133
132	53	7	Jump forward seven steps to step No. 139

STEP	FUN#	ARG	
133	50	37	Increment counter 37 by one
134	37	20	If counter 37 is euqal to 20, skip to step No. 136
135	53	4	Jump forward to step No. 139
136	56	33	
137	69	0	ID-x-tal-off on tape, if arg. is #0 , it is taken as the ID
138	61	27	Clear flag 27
139	63	28	If flag set skip to step No. 141
140	53	7	Jump forward to step No. 147
141	50	38	Increment counter No. 38 by one
142	38	20	If counter 38 is equal to 20 skip to 144
143	53	4	Jump four steps to step No. 147
144	56	35	
145	69	0	ID-x-tal-off on tape , if the arg. is #0, it is taken as the ID
146	61	28	Clear flag 28
147	63	29	If flag 29 is set, skip to step 149
148	53	7	Jump forward seven steps to step 155
149	50	39	Increment counter 39 by one
150	39	20	If counter 39 is equal to 20, skip to step No. 152
151	53	4	Jump forward four steps to step No. 155
152	56	37	
153	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
154	61	29	Clear flag 29
155	63	30	If flag 30 is set skip to step No. 157
156	53	7	Jump forward seven steps to step No. 163
157	50	40	Increment counter 40 by one
158	40	20	If counter 40 is equal to 20 skip to step 160
159	53	4	Jump forward four steps
160	56	39	
161	69	0	ID-x-tal-off on tape, if the arg. is #0, it is taken as the ID
162	61	30	Clear flag 30
163	63	1	If flag 1 is set skip to step No. 165
164	53	7	Jump forward seven steps to step No. 171
165	50	20	Increment counter 20 by one
166	20	120	If counter 20 is equal to 120 skip to step No. 168
167	53	4	Jump forward four steps to step No. 171
168	56	41	Skip to step No. 170 if sensor No. in counter #3 is set
169	69	21	ID-x-tal-off on tape
170	61	1	Clear flag 1
171	60	170	Exit and return backward 170 steps to step No. 1

Operation 8. Rabbit Discharge Operation.

Turns turntable 2 eight positions to discharge washed rabbits.

OP 8

STEP	FUN#	ARG	
1	49	17	Zero counter 17
2	56	312	
3	56	490	Turn Turntable 2# CW (rabbit table)
4	56	325	Turntable 2# (position microswitch)
5	55	60	Skip if microswith is set, go to step No. 7
6	60	2	Exit and return backward two steps, to step No. 4
7	56	325	Turntable 2# (position microswitch)
8	55	60	Skip if microswitch is set, go to step No. 10
9	59	2	Exit and return forward two steps, step No. 11
10	60	2	Exit and return backward two steps, step No. 8
11	50	17	Increment counter No. 17 by one
12	17	4	Skip if counter is equal to four, to step No. 14
13	60	9	Exit and return backward nine steps to step No. 4
14	56	491	Turn off Turntable 2# CW (rabbit table)
15	56	313	
16	57	8	Halt operation No. 8,

Operation 11. Column Preparation Operation.

Readies column, checks syringe number 3, and cheks plate hopper.

Rinses column.

OP 11

STEP	FUN#	ARG	
1	56	420	Apply air pressure on column.
2	56	426	Close vent to column
3	56	296	Set level sensor in column
4	55	44	Check column level sensor, if still set skip to step 6
5	59	2	Exit and return forward 2 steps to step 7
6	60	3	Exit and return backwards 3 steps to step 3
7	56	421	Stop applying air pressure to column
8	56	426	Open vent to column
9	56	428	Turn on spare pneumatic relay
10	56	498	Turn on Slosyn 3
11	49	11	Zero counter 11
12	111	20	Count to 20 with counter 11, 1 sec.
13	56	499	Turn off Slosyn 3
14	56	429	Turn off spare pneumatic relay
15	56	420	Apply air pressure to column
16	56	426	Close vent to column
17	49	11	Zero counter 11
18	111	20	Count to 20 with counter 11, 1 sec.
19	56	296	Set level sensor for column
20	55	44	Check sensor 44 levelsensor for column if set, if set skip to step 22
21	59	2	Exit and return forward 2 steps to step 23
22	60	3	Exit and return backward 3 steps to step 19
23	56	421	Turn off air pressure to column
24	56	427	Open vent to column
25	63	10	Skip a step to step 27 if flag 10 is set
26	59	2	Exit and return forward 2 steps to step 28
27	67	28	HOP(halt operation) and print OP(operation) and STEP (step), restart step 28

OP 11 cont.

STEP	FUN#	ARG	
28	61	10	Clear flag 10
29	63	9	Skip if flag 9 is set, to step 31
30	59	2	Exit and return forward 2 steps to step 32
31	67	32	HOP and print OP and STEP restart step 32
32	61	9	Clear flag 9
33	63	5	Skipto step 35 if flag 5 is set
34	60	1	Exit and return backwards one step to step 33
35	62	4	Set flag 4
36	57	11	Halt operation 11

Operation 12. Second Half of Program Control Operation.

Initially zeros counters, sets and clears flags to start second half of program. Decides whether rabbit will go to yield counting or to chemistry.

OP 12

STEP	FUN#	STEP	
1	49	14	Zero counter 14
2	61	4	Clear flag 4
3	62	6	Set flag 6
4	62	7	Set flag 7
5	61	8	Clear flag 8
6	61	9	Clear flag 9
7	49	39	Zero counter 39
8	49	40	Zero counter 40
9	58	2	Start operation 2 at step one, after execution return to step 10
10	49	12	Zero counter 12
11	112	16	Zero counter 16
12	50	2	Increment counter 2 by one
13	63	2	Skip a step if a flag 2 is set to step 15
14	53	2	Jump forward 2 steps
15	53	3	Jump forward 3 steps
16	58	14	Start operation 14 at step one, after execution return to step 17
17	57	12	Halt operation 12
18	58	13	Start operation 13 at step one and return to step 19
19	57	12	Halt operation 12

Operation 13. Rabbit Yield Operation.

Transfers rabbit from turntable 2 to turntable 1, and then to yield alpha-counter to measure deposited radioisotopes on the rabbit.

OP 13

STEP	FUN#	ARG	
1	49	17	Zero counter 17
2	56	312	
3	56	488	Turn turntable #2 CCW (rabbit table) on.
4	56	325	Set turntable #2 microswitch for position
5	55	60	Check Turntable #2 microswitch , if set skip to step 7
6	60	2	Exit and return 2 steps to step 4
7	56	325	Set Turntable #2 microswitch
8	55	60	Check Turntable #2 microswitch, if set skip to step 10
9	59	2	Exit and return forward 2 steps to step 11
10	60	2	Exit and return backwards 2 steps to step 8
11	56	489	Turn off turntable #2
12	49	12	Zero counter 12
13	112	2	Count to 2 with counter 12, 100 ms.
14	56	325	Set Turntable #2 microswitch
15	55	60	Check Turntable #2 microswitch, if set skip to step 17
16	59	2	Exit and return forward 2 steps to step 18
17	60	2	Exit and return backward 2 steps to step 15
18	56	324	Set Turntable #1 position microswitch
19	55	59	Check Turntable #1 position microswitch, if set skip to step 21
20	59	2	Exit and return forward 2 steps to step 22
21	52	0	Print operation and step no.
22	56	404	Rabbit ram(removes rabbit from turntable #2 to table #1) turn on
23	49	12	Zero counter 12
24	112	20	Count to 20 with counter 12, 1 sec.
25	56	405	Turn off rabbit ram
26	49	12	Zero counter 12
27	112	8	Count to 8 with counter 12, 400 ms.
28	56	486	Turn turntable #1 CCW (counting table)
29	56	324	Set turntable #1 position microswitch
30	55	59	If turntable #1 position microswitch is set skip to step 32

OP 13 Cont.

STEP	FUN#	ARG	
31	60	2	Exit and return backwards 2 steps to step 29.
32	56	324	Set turntable #1 position microswitch
33	55	59	If turntable #1 position microswitch is set skip to step 35
34	59	2	Exit and return 2 steps forward to step 36
35	60	2	Exit and return 2 steps backwards to step 33
36	50	17	Increment counter 17 by one
37	17	2	If counter 17 is equal to 2 skip to step 39
38	60	9	Exit and return backwards 9 steps to step 29
39	56	487	Turn off turntable #1
40	49	12	Zero counter 12
41	112	15	Count to 15 with counter 12, 600 ms.
42	62	1	Set flag 1
43	62	4	Set flag 4
44	56	40	Turn on amplifier 21
45	46	21	X-tal I.D. on tape with time and content of counter one.
46	49	20	Zero counter 20
47	56	313	
48	56	140	Turn on table one release ram
49	49	12	Zero counter 12
50	112	15	Count to 15 with counter 12, 750 ms.
51	56	141	Turn off table one release ram
52	57	13	Halt operation 13

Operation 14. Rabbit Wash Operation.

Rotates turntable 2 to place rabbit in wash station. Washes rabbit in wash station. Washes rabbit with first wash and transfers it to the column, and washes the rabbit with the second wash.

OP 14

STEP	FUN#	ARG	
1	56	312	
2	56	490	Turn on turntable #2 CW (rabbit table)
3	56	325	Set truntable #2 position microswitch
4	55	60	Check Turntable #2 microswitch, if set skip to step 6
5	60	2	Exit and return backward 2 steps to step 3
6	56	325	Set turntable #2 position microswitch
7	55	60	Check Turntable #2 microswitch, if set skip to step 9
8	59	2	Exit and return forward 2 steps to step 10
9	60	2	Exit and return backwards 2 steps to step 7
10	56	491	Turn off turntable #2 CW
11	49	12	Zero counter 12
12	112	4	Count to 4 with counter 12, 200 ms.
13	56	325	Set turntable #2 position microswitch
14	55	60	Check turntable #2 microsw.,if set skip to step 16
15	59	2	Exit and return forward 2 steps, to step 17
16	60	3	Exit and return backwards 3 steps to step13
17	56	313	
18	56	406	Turn on pneumatic ram (seats rabbit against dissolver).
19	49	12	Zero counter 12
20	112	5	Count to 5 with counter 12, 250 ms.
21	56	416	Turn on spare pneumatic relay
22	56	498	Turn on Slosyn 3
23	49	12	Zero counter 12
24	112	15	Count to 15 with counter 15, 750 ms.
25	56	499	Turn off Slosyn 3

OP 14 cont.

STEP	FUN#	ARG	
26	56	417	Turn off spare pnuematic relay
27	49	12	Zero counter 12
28	112	60	Count to 60 with counter 12, 3 sec.
29	58	18	Start operation 18 at step one and return to step 30
30	56	418	Open line between dissolver and column
31	56	412	Close dissolver vent
32	56	410	Turn on air pressure on dissolver
33	49	12	Zero counter 12
34	112	150	Count to 150 with counter 12, 7.5 sec.
35	56	411	Turn off air pressure on dissolver
36	56	413	Open dissolver vent
37	56	419	Close line between dissolver and column
38	58	15	Start operation 15 at step one and return to step 39
39	49	11	Zero counter 11
40	111	10	Count to 10 with counter 11, 500
41	56	416	Turn on spare pneumatic relay
42	56	498	Slosyn 3, turn on
43	49	11	Zero counter 11
44	111	15	Count to 15 with counter 11, 750ms.
45	56	499	Turn off Slosyn 3
46	56	417	Turn off spare pnuematic relay
47	57	14	Halt operation 14

Operation 15. Column Running Operation.

Transfers second wash to column after first wash is run through the column. The second wash is then run through column.

OP 15

STEP	FUN#	ARG	
1	56	426	Close vent to column
2	56	420	Apply air pressure to column
3	49	12	Zero counter 12
4	112	35	Count to 35 with counter 12, 1450 ms.
5	56	296	Set level sensor in column
6	55	44	If level sensor set skip to step 8.
7	59	2	Exit and return 2 steps forward at step 9
8	60	3	Exit and return backwards 3 steps to step 5
9	56	421	Stop applying air pressure to column
10	56	427	Open vent to column
11	49	12	Zero counter 12
12	112	30	Count to 30 with counter 12, 1500ms.
13	56	412	close dissolver vent
14	56	418	Open line between dissolver and column
15	56	410	Apply air pressure on dissolver.
16	49	12	Zero counter 12
17	112	60	Count to 60 with counter 12, 3 sec.
18	56	413	open dissolver vent
19	56	411	Stop air pressure on dissolver
20	56	419	Close line between dissolver and column
21	56	407	Turn off pneumatic ram(seats rabbit against dissolver)
22	56	426	Close vent to column
23	56	420	Apply air pressure to column
24	49	12	Zero counter 12
25	112	20	Count to 20 with counter 12, 1 sec.
26	56	296	Set level sensor in column

OP 15

STEP	FUN#	ARG	
27	55	44	If level sensor set skip to step 29
28	59	2	Exit and return forward 2 steps to step 30
29	60	3	Exit and return backwards 3 steps to step 26
30	56	427	Open vent to column
31	56	421	Stop air pressure to column
32	61	6	Clear flag 6
33	58	18	Start operation 18 at step one and return to step 34
34	58	16	Start operation 16 at step one and return to step 35
35	57	15	Halt operation 15

Operation 16. Column Running and Fraction Collection Operation.

Collects column on platelets.

OP 16

STEP	FUN#	STEP	
1	49	15	Zero counter 15
2	49	16	Zero counter 16
3	56	421	Turn off air pressure to column
4	56	427	Open vent to column
5	56	426	Close vent to column
6	49	12	Zero counter 12
7	112	2	Count to 2 with counter 12
8	56	158	Slosyn #2 dispense
9	49	12	Zero counter 12
10	112	20	Count to 20 with counter 12
11	56	159	Slosyn #2 stop dispense
12	56	425	Close valve from Slosyn #2 syringe
13	56	426	Close vent to column
14	56	420	Turn on air pressure for column
15	49	12	Zero counter 12
16	112	20	Count to 20 with counter 12
17	56	296	Set level sensor in column
18	56	297	Set drop counter
19	55	44	Skip to step 21 if level sensor is set
20	60	17	Exit and return backwards 17 steps to step 3
21	49	12	Zero counter 12
22	112	1	Count to 1 with counter 12
23	55	41	If drop 1 set skip to step 25
24	60	7	Exit and return backwards 7 steps
25	56	296	Set level sensor in column
26	56	297	Set drop sensor & counter
27	55	44	Skip to step 29 if level sensor is set
28	60	24	Exit and return backwards 24 steps to step 4
29	49	12	Zero counter 12
30	112	1	Count to 1 with counter 12

OP 16 cont.

STEP	FUN#	ARG	
31	55	41	Check drop 1 sensor,if set skip to step 33
32	59	2	Exit and return forward 2 steps to step 34
33	60	8	Exit and return backwards 8 steps to step 25
34	50	15	Increment counter 15 by 1
35	15	7	If counter 15 is equal to 7 skip to step 37
36	60	19	Exit and return backwards 19 steps to step 17
37	50	16	Increment counter 16 by 1
38	16	1	If counter 16 is equal to 1 skip to step 40
39	53	2	Jump forward 2 steps to step 41
40	53	10	Jump forward 10 steps to step 50
41	56b	408	Flamer on
42	49	12	Zero counter 12
43	112	40	Count to 40 with counter 12, 2 sec.s
44	56	409	Flamer off
45	63	5	Skip to step 47 if flag 5 is set
46	60	1	Exit and return backwards to step 45
47	58	18	Start operation 18 at step one, and return to step48
48	49	15	Zero counter 15
49	60	32	Exit and return backwards 32 steps to step 17
50	56	421	Turn off air pressure on column
51	56	427	Open vent to column
52	58	17	Start operation 17 at step one and return to step 53
53	57	16	Halt operation 16

Operation 17. Flaming Operation.

OP 17

STEP	FUN#	ARG	
1	49	15	Zero counter 15
2	53	6	Jump forward 6 steps to step 8
3	56	408	Flamer on
4	49	12	Zero counter 12
5	112	40	Count to 40 with counter 12
6	56	409	Flamer off
7	66	54	Return from subroutine(to next step after fun#65)
8	65	3	Call subroutine, first step number 3
9	63	5	Skip a step if Flag 5 is set
10	60	1	Exit and return to step 9
11	58	18	Start operation 18 at step 1, and return to step 12
12	56	421	Stop air pressure on column
13	56	427	Open vent to column
14	56	424	Open valve from Slosyn #2 syringe
15	49	12	Zero counter 12
16	112	20	Count to 20 with counter 12
17	56	158	Slosyn #2 syringe dispense
18	49	12	Zero counter 12
19	112	20	Count to 20 with counter 12
20	56	159	Stop Slosyn #2 syringe dispense
21	56	425	Close valve from Slosyn #2 syringe
22	56	426	Close vent to column
23	56	420	Apply air pressure to column
24	49	12	Zero counter 12
25	112	20	Count to 20 with counter 12
26	56	297	Set drop counter
27	56	296	Set level sensor in column
28	55	44	If level sensor set, skip to step 30
29	60	17	Exit and return backwards to step 12
30	49	12	Zero counter 12
31	112	1	Count to 1 with counter 12
32	55	41	If drop 1 set skip to step 34
33	60	7	Exit and return backwards 7 steps to step 26
34	56	296	Set level sensor
35	56	297	Set drop counter
36	55	44	If level sensor set skip to step 38

OP 17 cont.

STEP	FUN#	ARG	
37	60	24	Exit and return 24 steps to step 13
38	49	12	Zero counter 12
39	112	1	Count to 1 with counter 12
40	55	41	If drop one counter set skip to step 42
41	59	2	Exit and return forward to step 43
42	60	8	Exit and return backwards to step 34
43	50	15	Increment counter 15 by one
44	15	7	If counter 15 is equal to 7 skip to step 46
45	60	19	Exit and return backwards 19 steps to step 26
46	65	3	Call subroutine step 3
47	63	5	Skip a step to step 49 if flag 5 is set
48	60	1	Exit and return a step to step 47
49	58	18	Sart operation 18 at step one and return to step 50
50	58	11	Start operation 11 at step one and return to step 51
51	49	12	Zero counter 12
52	112	400	Count to 400 with counter 12, 20 sec.
53	65	3	Call subroutine step 3
54	62	6	Set flag 6
55	63	5	Skip to step 57 if flag 5 is set.
56	60	1	Exit and return 1 step to step 55
57	58	18	Start operation 18 at step 1 and return to step 58
58	57	17	Halt operation 17

Operation 18. Platelet Dispensing Operation.

Dispenses platelets and controls Turntable 3 rotation.

OP 18

STEP	FUN#	ARG	
1	49	17	Zero counter 17
2	50	14	Increment counter 14 by one
3	59	10	Exit and return forward 10 steps tosstep 13
4	56	322	Set lower plate hopper (almost out of plates) sensor
5	55	57	If lower plate hopper sensor set,skip to step 7
6	52	0	Print operation and step no.
7	61	9	Clear flag No. 9
8	56	396	Feed plate to turn table 3
9	49	13	Zero counter 13
10	113	20	Count to 20 with counter 13
11	56	397	Stop feed plate to turn table 3
12	66	67	Return from subroutine (to next step after fun. #65)
13	14	1	If counter 14 is equal to 1 skip to step 15
14	53	2	Jump forward 2 steps to step 16
15	65	4	Call subroutine , step 4
16	56	495	Turn off helium jet #1
17	56	497	Turn off helium jet #2
18	56	153	Turn off hot air jet under plate at column position
19	49	13	Zero counter 13
20	113	5	Count to 5 with counter 13
21	56	312	turn off ADC
22	56	492	Turn turntable #3 30°(sample table)
23	56	332	Set turntable #3 position microswitch
24	55	67	Skip to step 26 if position microswitch sensor for table #3 is set.
25	60	2	Exit and return backwards 2 steps
26	56	332	Set turntable #3 position microswitch
27	55	67	If turntable #3 sensor is set, skip to step 29
28	53	2	Jump forward 2 steps to step 30

OP 18 cont.

STEP	FUN#	ARG	
29	60	2	Exit and return backwards 2 steps to step 27
30	50	17	Increment counter 17 by one
31	17	1	If counter 17 is equal to 1 skip to step 33
32	53	17	Jump forward 17 steps to step 49
33	63	7	Skip a step to step 35 if flag 7 is set
34	53	15	Jump forward 15 steps to step 49
35	56	320	Set plate is on turntable 3 sensor
36	55	55	If plate on turntable sensor set, skip to step 38
37	59	2	Exit and return forward 2 steps to step 39
38	59	11	Exit and return forward 11 steps to step 49
39	56	493	Turn off turntable #3 30°(sample table)
40	67	44	HOP and print OP and STEP
41	57	15	Halt operation 15
42	57	16	Halt operation 16
43	57	17	Halt operation 17
44	56	492	Turn on turntable #3
45	68	15	Continue OP after HOP
46	68	16	Continue OP after HOP
47	68	17	Continue OP after HOP
48	59	3	Exit and return forward 3 steps to step 51
49	17	2	If counter 17 is equal to 2 skip to step 51
50	60	27	Exit and return backwards 27 steps to step 23
51	56	493	Turn off turntable #3
52	49	13	Zero counter 13
53	113	10	Count to 10 with counter 13
54	56	313	Turn on ADC
55	63	7	Skip a step to step 57 if flag 7 is set
56	53	3	Jump forward 3 steps to step 59
57	56	152	Turn on hot air jet under plate at column position
58	56	494	Helium Jet #1 on
59	63	6	Skip to step 61 if flag 6 is set
60	56	496	Helium Jet #2 on
61	14	3	If counter 14 is equal to 3 skip to step 63
62	53	2	Jump forward 2 steps to step 64

OP 18 cont.

STEP	FUN#	ARG	
63	61	7	Clear flag 7
64	63	7	Skip to step 66 if flag 7 is set
65	53	2	Jump forward 2 steps to step 67
66	65	4	Call subroutine step 4
67	14	3	If counter 14 is equal to 3 skip to step 69
68	53	2	Jump forward 2 steps to step 70
69	62	8	Set flag 8
70	63	8	Skip to step 72 if flag 8 set
71	57	18	Halt operation 18
72	56	277	Set turntable #3 (90° position microswitch)
73	55	22	Check turntable #3 microswitch (90° position)
74	53	2	Jump forward 2 steps to step 76
75	67	66	HOP and print OP and STEP
76	63	5	Skip a step if flag 5 is set to step 78
77	60	1	Exit and return backwards 1 step to step 76
78	56	312	Turn off ADC
79	58	5	Start operation 5 at step one
80	57	18	Halt operation 18

Appendix C Comparison Chart of the Physical Properties of Air and Helium

Temperature		Density x 10^4 (g/cm.^{3})			C_p (cal./gm-^oC)		
^oF	^oC	Air	Helium	He/Air	Air	Helium	He/Air
400	204.4	7.40	1.02	0.1379	0.245	1.24	5.061
600	315.6	5.99	0.86	0.1382	0.251	1.24	4.940
800	426.7	5.05	0.70	0.1394	0.257	1.24	4.825
1000	537.8	3.25	0.60	0.1852	0.263	1.24	4.715

Temperature		u x 10^5 (centipoise)			(stokes)		
^oF	^oC	Air	Helium	He/Air	Air	Helium	He/Air
400	204.4	2589.	2745.	1.06	0.35	2.70	7.72
600	315.6	2976.	3125.	1.05	0.50	3.75	7.55
800	426.7	3333.	3467.	1.04	0.66	4.91	7.43
1000	537.8	3661.	3807	1.04	0.84	6.30	7.48

Temperature		k x 10^6 (cal./cm^{2}sec^{o}C)			(cm^2/sec.)		
^oF	^oC	Air	Helium	He/Air	Air	Helium	He/Air
400	204.4	3.05	15.46	5.07	0.52	3.72	7.20
600	315.6	3.66	17.60	4.81	0.74	5.32	7.15
800	426.7	4.11	19.69	4.79	0.97	7.12	7.36
1000	537.8	4.57	21.57	4.72	1.22	9.16	7.52

Appendix C Continued

	$D_{AB}P$		
Temperature °K	Air-H_2O	Helium-H_2O	Ratio He/Air
313.0	0.288	0.902	3.223

* Fundamentals of Momentum, Heat and Mass Transfer, by Welty, Wicks, and Wilson. Publisher: John Wiley & Sons, Inc.

CHAPTER 1
SYSTEM INTRODUCTION

The PDP-9® programmed data processing system is a general purpose computer, incorporating FLIP CHIP hybrid integrated circuits throughout. The PDP-9 features:

- High performance at low cost
- Demonstrated reliability
- Simple input/output interfacing
- Extensive software

Flexible, high capacity, input/output provisions coupled with a complete line of peripheral equipment allow system planning to satisfy a variety of applications. PDP-9 can be easily configured to perform equally well the role of central data processing facility, control element, or satellite processor. The ease with which its modular hardware and software adapt to the requirements of data acquisition, process control, and on-line processing in real-time environments makes it the ideal small scale system for scientific and industrial use.

The PDP-9 system is a single address, fixed word length (18 bits), parallel binary computer. The minimum system configuration(see frontispiece) has 8192 words of core memory storage; paper tape input at 300 cps and output at 50 cps; console teleprinter keyboard input and printer output at 10 cps; and a real-time clock.

The system readily interfaces to optional peripherals such as punched card equipment, line printers, magnetic tape transports, analog-to-digital converters, digital-to-analog converters, CRT displays, data communication equipment, and magnetic drum and disc systems. Equipment of special design is easily adapted for interfacing to the PDP-9. The FLIP CHIP module line offers proven reliability plus simple, inexpensive fabrication of compatible interface controls for special equipment, or for the special-purpose equipment itself. Peripherals can be interfaced to the system as processing requirements expand, without modification of the central processor.

CHARACTERISTICS

Complete cycle time of 1 μsec for the random access, ferrite core memory.

Real-time clock generates a clock pulse every 16.7 msec (every 20 msec for 50 Hz systems) to increment a time counter stored in system memory. The counter initiates a program interrupt when a programmed preset time interval is completed. The clock can be enabled or disabled under program control.

® PDP is a registered trademark of the Digital Equipment Corporation.

True direct addressing is provided for all 8192 18-bit word locations in the basic core memory module configuration or any memory module appended to the system. The system allows indirect addressing up to the memory expansion limit of 32,768 locations. Core memory is expanded in increments of 8192 words. Memory parity can be optionally included. With the parity option, memory cycle time is approximately 1.2 μsec. System software expands to make efficient use of all available core memory storage.

Power failure protection can be optionally implemented to protect against data loss due to internal power interruptions. With this option, the PDP-9 is unaffected by power interruptions of less than 25 msec duration. In the event of a longer interruption, the option can save the active register contents and automatically restart the interrupted program at a specified address when power is restored. Without the "power failure protection" option, power interruptions of 10 msec duration, or longer, may result in loss of active register contents and memory contents.

Automatic readin is provided of binary-coded programs from paper tape via the paper tape reader. A user-initiated and hardware-implemented control transfers 18-bit words (three tape lines) from tape to a block of sequentially addressed core memory locations, and executes the instruction defined by the last word without further user intervention.

A built-in test program, user-initiated and hardware-implemented, circulates a self-incrementing count through all central processor registers for the purpose of validating both their operation and the internal transfer paths. The user can monitor and verify register operation by observing the respective register display on the control console.

All input/output transfers are executed in parallel bytes up to 18 bits in length. The system's I/O facilities can service data transfer rates up to one million bytes per second.

Bidirectional input/output bus is provided for program controlled data/command transmissions between the central processor and up to 256 external devices. All program controlled I/O transfers pass through the central processor's accumulator (AC), the 18-bit primary arithmetic register. Memory referencing instructions convey data between the AC and system core memory. IOT (input/output transfer) instructions select appropriate devices and effect the data transfer between the AC and information registers in the devices.

Four buffered data channels allow fast, non-overlapping data transmission between system core memory and four devices interfaced to the I/O bus. Data channel transfers occur via the memory buffer (MB) register in the central processor and do not disturb the contents of other major registers in the processor. Thus, a data channel transfer suspends rather than interrupts execution of the program in progress. The maximum transfer capacity of the data channel facility is between 250,000 and 333,333 words per second, depending on the mix of input and output transfers (each output transfer steals four machine cycles; each input transfer steals three cycles). Provisions are made in system memory for word counter registers and current address registers unique to each data channel. The data channel facility can be expanded for multiplexed servicing of up to four additional devices.

Direct memory access channel (DMA) bypasses the central processor, allowing direct, cycle stealing, data transmission between core memory locations and external devices via a separate entry port to system memory module(s). DMA transfers have priority over all other system actions. An optional multiplexer/adapter will interface to and allocate priority of service among up to three devices.

Program interrupt control frees the program in progress from the necessity of monitoring the status of peripheral devices. The program continues until a device signals a request for service. A subroutine, entered automatically upon the processor's granting of the interrupt request, stores the interrupted program's status, determines the device making the request, and transfers control to the appropriate service subroutine. At completion of the device servicing, the interrupted program is restored to control. The program interrupt control facility is suitable for those peripheral devices having low data rates.

Multilevel automatic priority interrupt option (API) affords immediate access to device handling and data handling subroutines on a ranked priority basis. Of the eight priority levels added by this option the four higher levels are assigned to device use, and the lower four are assigned to software use. The priority levels are fully nested; i.e., a higher priority request can interrupt in-process servicing of a lower priority. The restoration of an interrupted service subroutine does not require additional programming considerations. Likewise, the return to an interrupted main program segment is easily implemented.

The granting of priority interrupt requests, at completion of the current instruction, is rated above program and program interrupt activity and below data channel or direct memory access channel activity, or real-time clock counting.

The API system has 32 channels of which 28 are allocated to external device interrupting (hardware priority levels) and 4 are allocated to programmed interrupting (software priority levels). A channel assignment defines the core memory location of the unique entry to an interrupt subroutine. Device channels function independently of priority; up to eight device channels may be assigned to the same priority level. Device channels also may be multiplexed without limit, in which case the channel address defines the entry to a search routine rather than unique entry to one routine.

Additional provisions include dynamic reallocation of device priority level assignments (device control must be designed with logic circuits to accomplish reassignment) and programmed raising of the active interrupt to a priority level higher than the normal assignment, when the situation requires exclusion of interrupt requests at specific priority levels. The API is program enabled or disabled. Specific devices can be inhibited from interrupting by appropriate control inputs to their interfaces.

The basic machine has fixed-point hardware capability and floating-point software capability for performing binary arithmetic in 1s and 2s complement notations. Floating-point software offers choice of 6 or 9 decimal digit precision. The program library supplied includes extensive repertoire of multi- and single-precision subroutines.

Add or subtract (complementary addition) is performed in 2 μsec with fetch of operand from effectively addressed core memory location. Overflow indication is furnished for 1s complement addition where absolute value of algebraic summed result exceeds capacity of the accumulator ($2^{17} - 1$). Algorithms for 2s complement addition and subtraction treat overflow from accumulator as a carry into a 1-bit register called the "link".

Extended arithmetic element option offers fast, flexible, hardware execution of the following as signed or unsigned functions:

> Shifting the contents of the primary arithmetic registers (AC or MQ), right or left, in 2 to 17 μsec.
>
> Normalizing the quantity in the primary arithmetic registers; i.e., shifting the contents left to remove leading binary 0s for the purpose of preserving as many significant bits as possible. Time required is 2 to 17 μsec.
>
> Multiplication in 3 to 11 μsec.
>
> Division, including integer and fractional, in 3 to 12 μsec. Divide overflow indication is furnished when division would produce quotient exceeding $2^{17} - 1$ magnitude.

DESIGN

The compactness of the PDP-9 affords maximum computing facility in a minimum of space; its modular construction provides for ease of system growth to meet future processing requirements -- external devices and additional core memory append with minimum effort and no effect on the central processor. (Section 4, Interface, presents complete details on interfacing special purpose or user-designed external devices to the PDP-9 input/output facilities.) PDP-9 is completely self-contained, and does not require special air conditioning or humidity control. Internal power supplies generate all required operating voltages from a single input source of 115-volt, 60-Hz single-phase power. Systems can be supplied to operate with 50 Hz power at a variety of voltage levels.

CONFIGURATIONS

The basic PDP-9 configuration (figure 1-1) consists of the following.

1. Central processor with integrated control console, work shelf and chair.
2. Core memory stack of 8192 18-bit words. Includes interface connection for direct memory access of memory locations by high data rate peripherals.
3. Three peripheral devices: a 300 character/second paper tape reader; a 50 character/second paper tape punch; and an input/output teleprinter, Teletype Model KSR 33. (Teletype Model KSR 35 can be optionally supplied and is recommended for applications where extreme use is to be made of the teleprinter's output function.)
4. Real-time clock.
5. Input/output facilities: I/O bus, four data channels, direct memory access channel, program interrupt control, I/O status word provision, and conditional skip on external device status.

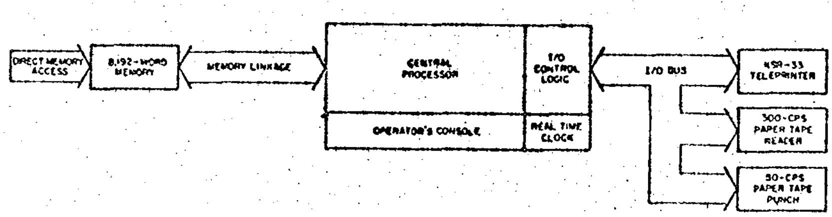


Figure 1-1 Basic PDP-9

The PDP-9 expands into a variety of configurations by:

Increasing system core memory from the basic-supplied 8192 words up to 32,768 words in increments of 8192 words. Memory parity may be optionally added.

Adding peripheral equipment selected from the PDP-9 line, or interfacing the system to special purpose or user-designed equipment.

Interfacing a basic or expanded PDP-9 to a data processing complex.

Incorporating central processor options to increase the system's computing and data handling power.

Figure 1-2 illustrates a typical expanded PDP-9 system.

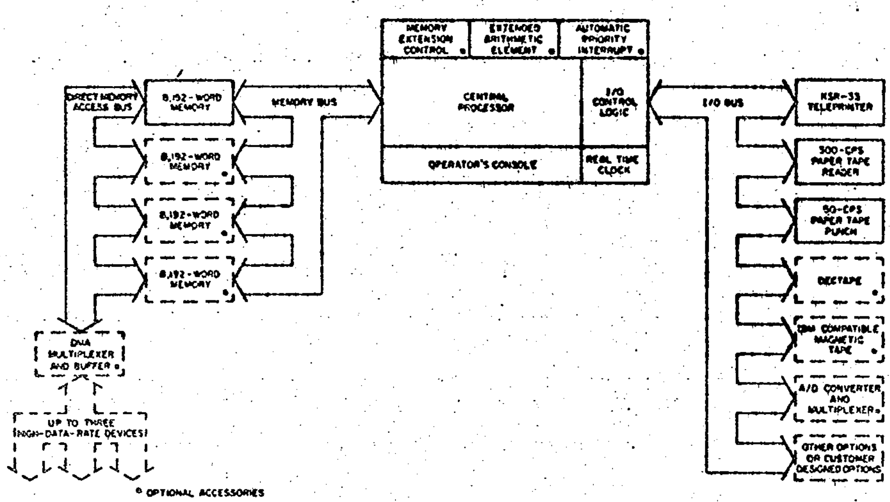


Figure 1-2 Expanded PDP-9 System Configuration, Block Diagram

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