Subject: NOTES ON A BOOSTER CONTROL SYSTEM

I. Introduction

The following note describes some general relationships between events in the booster control system. Flow charts are given to indicate detailed relationships. The descriptions are relatively detailed but are meant only to show trends in present thinking. As prototypes are developed and parameters frozen, control concepts will change.

II. Scope and Constraints

The Booster System controls the transport and acceleration of a proton beam from the output of the 200 MeV Linac to the 10 GeV beam transport system. It supervises the measurement and monitoring of the parameters required for efficient operation.

This system must operate in four modes. (1) Exercise Mode. In this mode the Booster System components will operate under simulated normal conditions or special test conditions. There will not be any input from the linac. (2) Linac Test Mode. A proton beam will be transported into the 200 MeV transfer hall for the purpose of analyzing the linac output. The components of the system that are not engaged in this activity will function under simulated normal conditions or special test conditions. (3) Booster Test Mode. A proton beam will be accelerated to 10 GeV and dumped for the purpose of analyzing system performance. (4) Operating Mode. A proton beam will be accelerated to 10 GeV and delivered to the 10 GeV transport system.

The switching between modes will normally be sequential (1, 2, 3, 4, 1, 2, etc.) but is not limited to this sequence. Normally, the system will stay in one mode for periods greater than an hour.

In the Exercise Mode, Linac Test Mode, or Booster Test Mode the system is self-contained and will not require external commands. When it is in the Operating Mode, the system will receive commands from a Supervisory System and local human intervention will not be required. In this mode the system will transmit, automatically, on request, status and monitored information to the Supervisory System.

When the Booster System is in the Linac Test Mode, Booster Test Mode, or Operating Mode, it will issue commands and status requests to the Linac System.

To centralize human decisions and interaction there will be one location for man-machine communications. The system requires one man at this location unless it is in the operating mode when it does not require any.

Since this system exists as an early link in a chain of systems, its reliability should exceed that of succeeding links for efficient operation. The system will operate 24 hours per day, 7 days per week with a minimum of scheduled down time for system maintenance. Therefore, the system must have a high level of redundancy and self-checking to minimize system down time.

To minimize overall engineering costs by eliminating redundant effort on the construction of simulators, the command generating aspects of the system should be implemented early in the prototype stage of other system components. The system will operate in the Exercise Mode throughout construction.

III. Exercise Mode

The system enters this mode during "down time" to provide simulated signals to booster equipment. It monitors equipment status and displays this to the operator on demand. Special test programs will be available for use during maintenance of apparatus.

IV. Linac Test Mode

The Booster System enters this mode to evaluate the output of the Linac System. The relevant parameters of the output are:

1) Mean Energy
2) Energy Distribution
3) Particle Distribution in Horizontal Phase Space
4) Particle Distribution in Vertical Phase Space

A series of magnetic elements provide the components to perform the evaluation. Items 3 and 4 can be modified by these components. Many of these components are also used in the other modes to transport the 200 MeV protons to the injection point. There are approximately 50 components in the 200 MeV transfer hall. The particle distribution in physical space will be characterized by three values: 1) the mean, 2) the full width at half maximum, and 3) the full width at 10% of maximum. The angular distribution will be determined by two sets of position data separated longitudinally.

With an appropriate spectrometer, 1 and 2 can be determined by measuring a magnetic field and physical distribution. This is a preliminary measurement since the best spectrometer available is the Booster Ring itself. Therefore, six values in each plane plus four for the energy distribution are required. Intermediate physical distributions are required to provide additional checks on the transport components. This would require another four locations giving twelve additional values in each plane. Because the transducers that measure these distributions will not generate the data in the required reduced form, approximately three times as many values will be transmitted to the data reduction subsystem. This gives 40 values for particle distribution. It is not necessary to measure all these on the same pulse. To observe changes during the pulse, a time resolution of 2 μsec is required. The required accuracy is ±1% or six bits. The 50 magnetic components need current control with a resolution and resetability of ±.05% or ten bits. To accomplish beam dynamics calculations, it is necessary to know the current in each component. This needs to be measured to ±.05% or ten bits.

During these measurements, timing commands will be transmitted to the linac for synchronization. The Booster System will request status information from the Linac System. The Booster System will command the Linac System output mean energy and energy distribution.

V. Booster Test Mode

The Booster System enters this mode to evaluate System performance. The parameters that characterize the output of the Booster are:

1) Proton Energy Distribution
2) Two transverse phase space distributions
3) The phase distribution and frequency of the bunch structure
4) The intensity of the beam

The operation of the booster is subdivided into three regions that are reasonably distinct; injection, acceleration, and extraction. Acceleration includes transition and extraction includes synchronization.

Injection is characterized by:

1) Injection efficiency
2) Capture efficiency
3) Emittance of circulating beam in both planes
4) Bunching factor

To isolate functions it is necessary to measure and correct:

1) Closed orbit
2) Median plane
3) Launch position and angle
4) Magnitude of injection orbit bump

Acceleration is characterized by:

1) Emittance in both planes
2) Bunching factor
3) Mean energy

To isolate functions it is necessary to measure and correct:

1) Beam size vs. B
2) Beam position vs. B
3) Coherent betatron oscillations

4) Coherent phase oscillations (particularly in the region of transition)

Extraction is characterized by:

1) Emittance in both planes
2) Bunching factor
3) Mean energy
4) Bunch phase
5) Extraction efficiency

The parameters in the ring that are available to achieve the above are:

1) Ring Magnet Power Supply
    a. A.C. magnitude
    b. D.C. magnitude
    c. A.C. phase
2) Orbit Correcting Magnets
    a. 48 horizontal
    b. 48 vertical
3) Orbit Bumps
    a. Scraper bump
    b. Injection bump
    c. Extraction septum bump
4) Accelerating Voltage
    a. Amplitude
    b. Frequency and phase

VI. Operating Mode

The system enters this mode as the normal operating mode. Local human intervention is not required. This system is automatic and receives commands from a central control system. It is self-checking. That is, it continues to monitor and control the required functions as in the other modes. It provides alarm on fault and then details the fault to the central control system on request.

VII. System Logical Relationships

The attached figures show the logical relationships required to implement the above. The first figure shows the relationships between the modes. They are in the normal 1, 2, 3, 4, 1, 2, 3, ... sequence with a fallback path for errors. The relationships between events within the modes are shown in Figures 2, 3, 4, and 5.

VIII. Interface

The I-O with the Linac System will be:

A. Input

1) Linac System Ready

B. Output

1) Booster Enable

2) Change DE

3) Pretrigger (energize rf, etc.)

4) Beam trigger

5) Pulse length

The I-O with the 10 GeV transfer system will be:

A. Input

1) Transfer system ready

2) Change energy

3) Emittance fault (area too large)

B. Output

1) Kicker trigger

2) Booster system ready

The I-O with the Main Ring System will be:

A. Input

1) Magnet field ready for injection

2) Main Ring System ready

3) Change Phase

B. Output

1) Booster System ready

The I-O with the central control system will be:

A. Input

1) Request for parameter change

2) Request analysis

3) Request status

B. Output

1) Change complete

2) Results of analysis

3) Status

IX. Data Rates

Typical data rates to control points for synchronized and unsynchronized data are given in Table 5. The highest data rates occur in the region of injection. At this time the parameters associate with injection need to be transferred as well as the initial points for the rf system function generators. In the first 100 μsec the frequency program requires 2 values, the amplitude program requires 1 value, the Linac receives a trigger and the injection bump receives a trigger. Using the word structure described in TM-4, this requires 13 16-bit words. In order that 10 injection parameters be measured in this period, 20 additional control words are required (an address and timing for each point). Using a safety factor of 2 for future expansion, 66 words will be required in 100 μsec or 3 μsec per word.

Appendix A

Typical Software Routines

1) Align 200 MeV transport
2) Measure transverse phase space
3) Measure intensity listrogram
4) Measure closed orbit
5) Correct closed orbit
6) Display X vs B + correct
7) Display or print last 24 hr. record
8) Display or print selected system record
9) Display or print machine status
10) Etc.

TABLE I

Control Point	Number Points	Word Length	Data Rate Words/ Pulse	Data Rate Words/ Sec.
200 MeV Transfer Mag.	50	10 bits		1
Injection	8	10 bits	1	
Correction Mags	96	7 bits		2
RF Frequency	1	14 bits	50	
RF Amp	1	10 bits	25	
Cavity Current	1	10 bits	25	
Mag P.S.	2	12 bits	2	

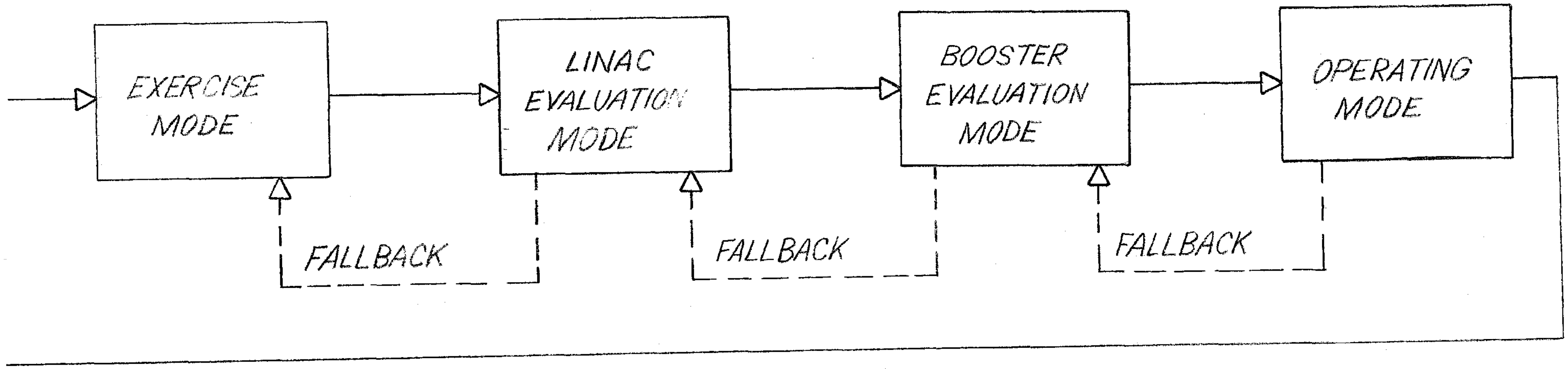


FIG. 1
MODE INTERRELATIONSHIPS

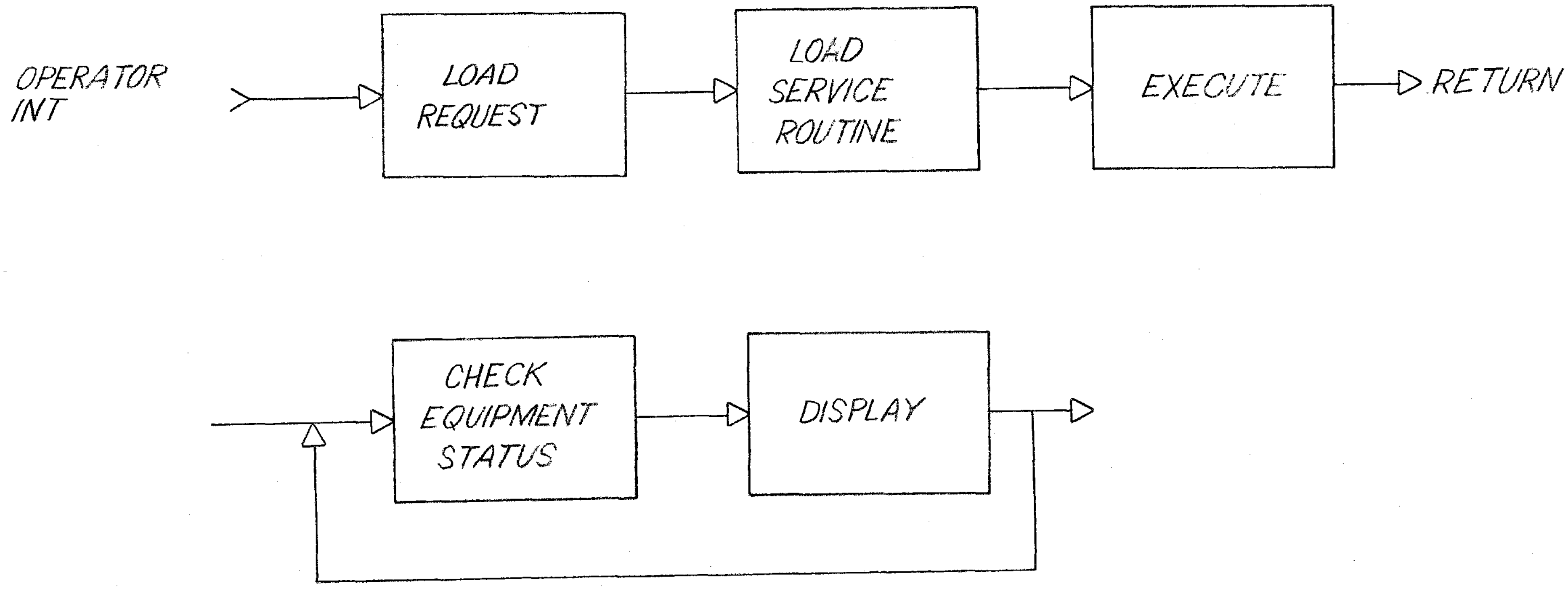


FIG. 2
EXERCISE MODE

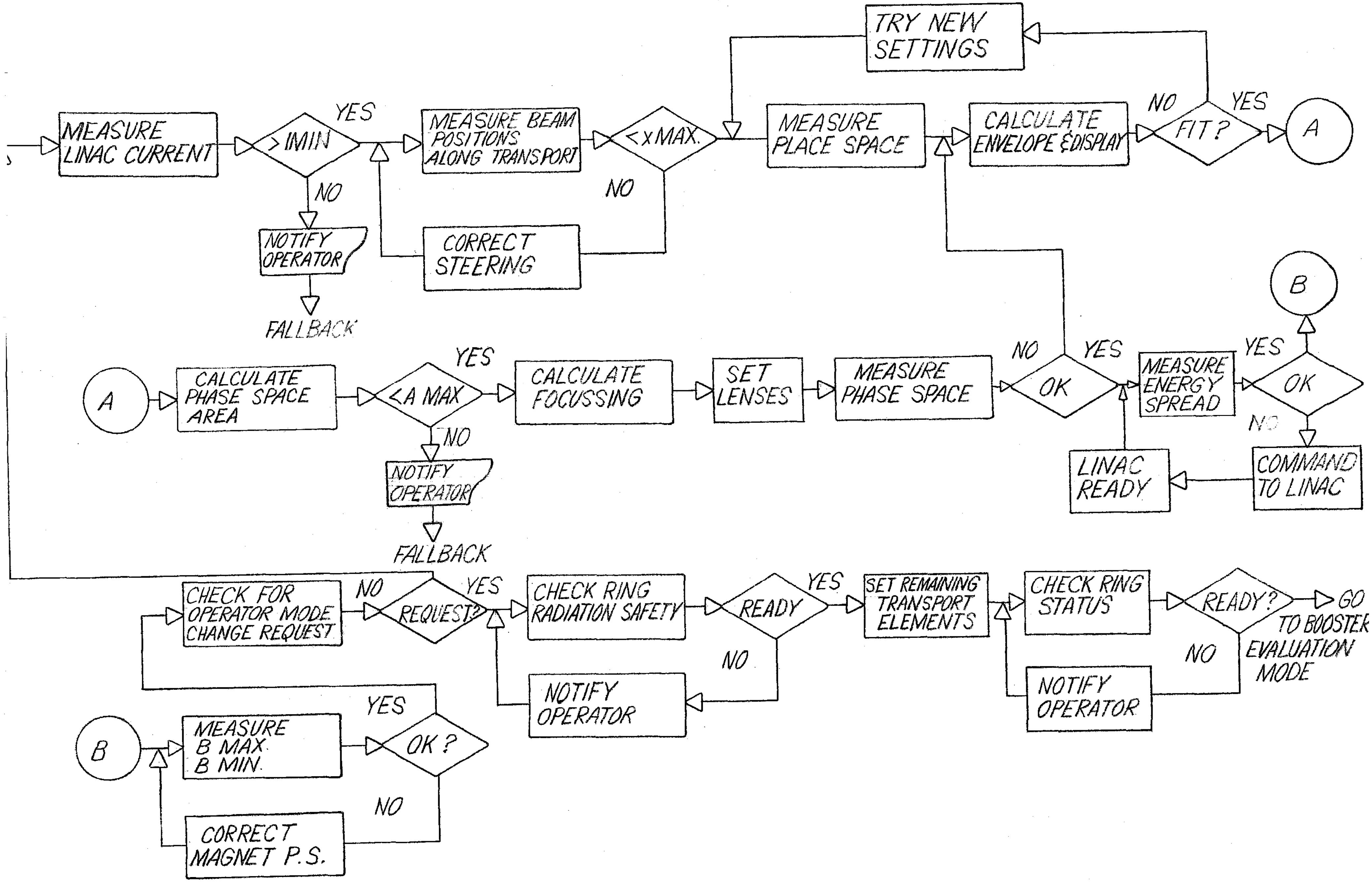
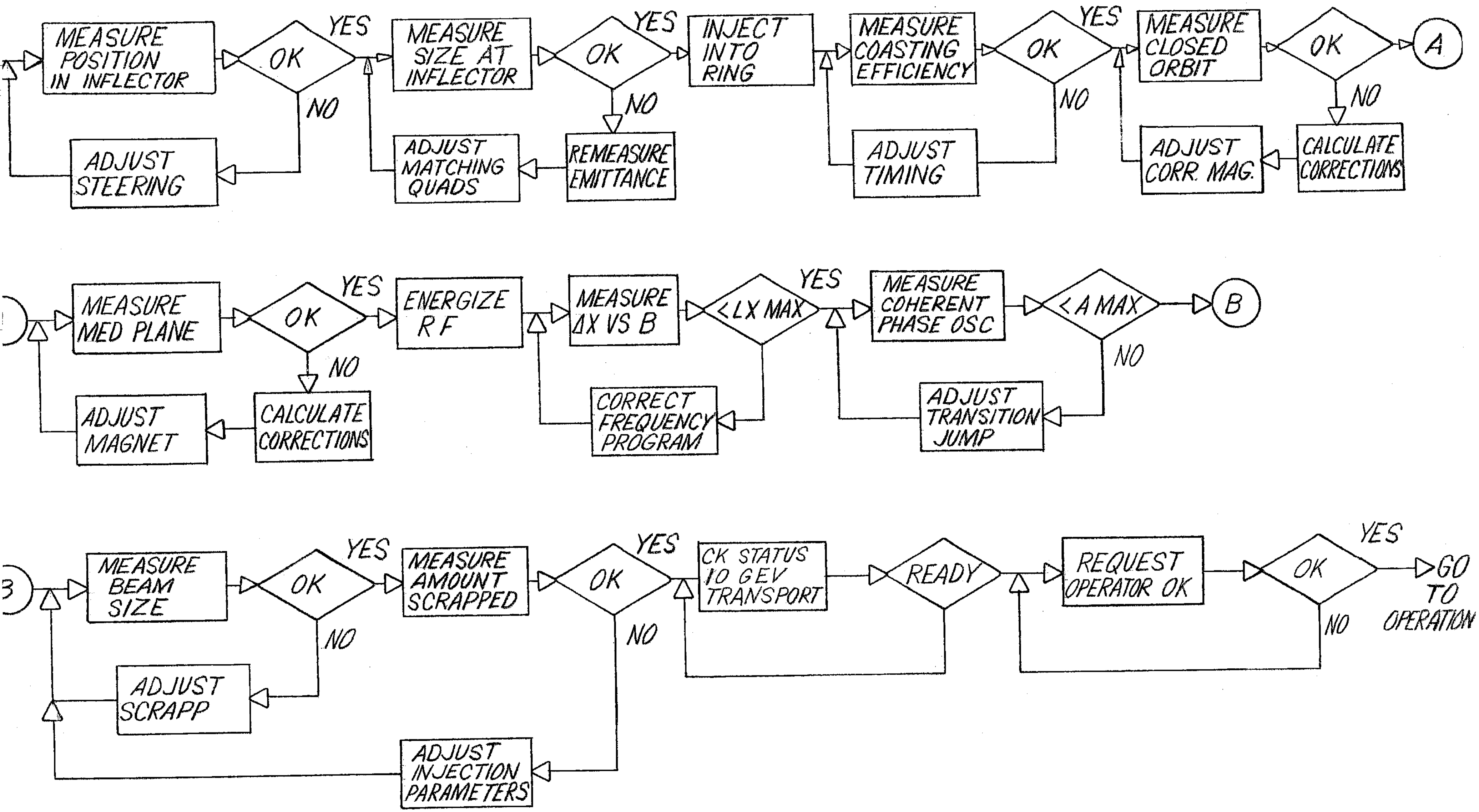


FIG 3
LINAC EVALUATION MODE



IF ITH LOOP IS ITERATED MORE THAN NI TIMES, ALARM AND RETURN

FIG 4
BOOSTER EVALUATE MODE

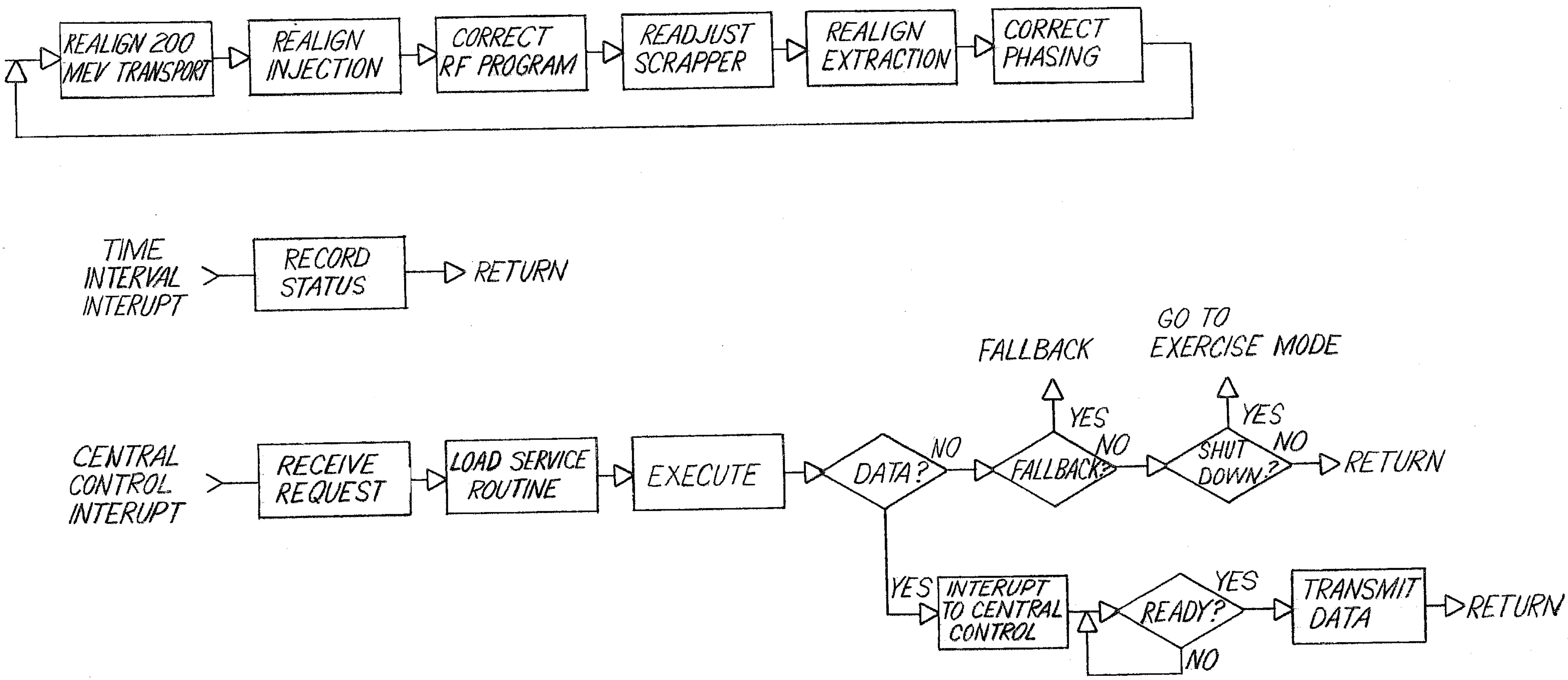
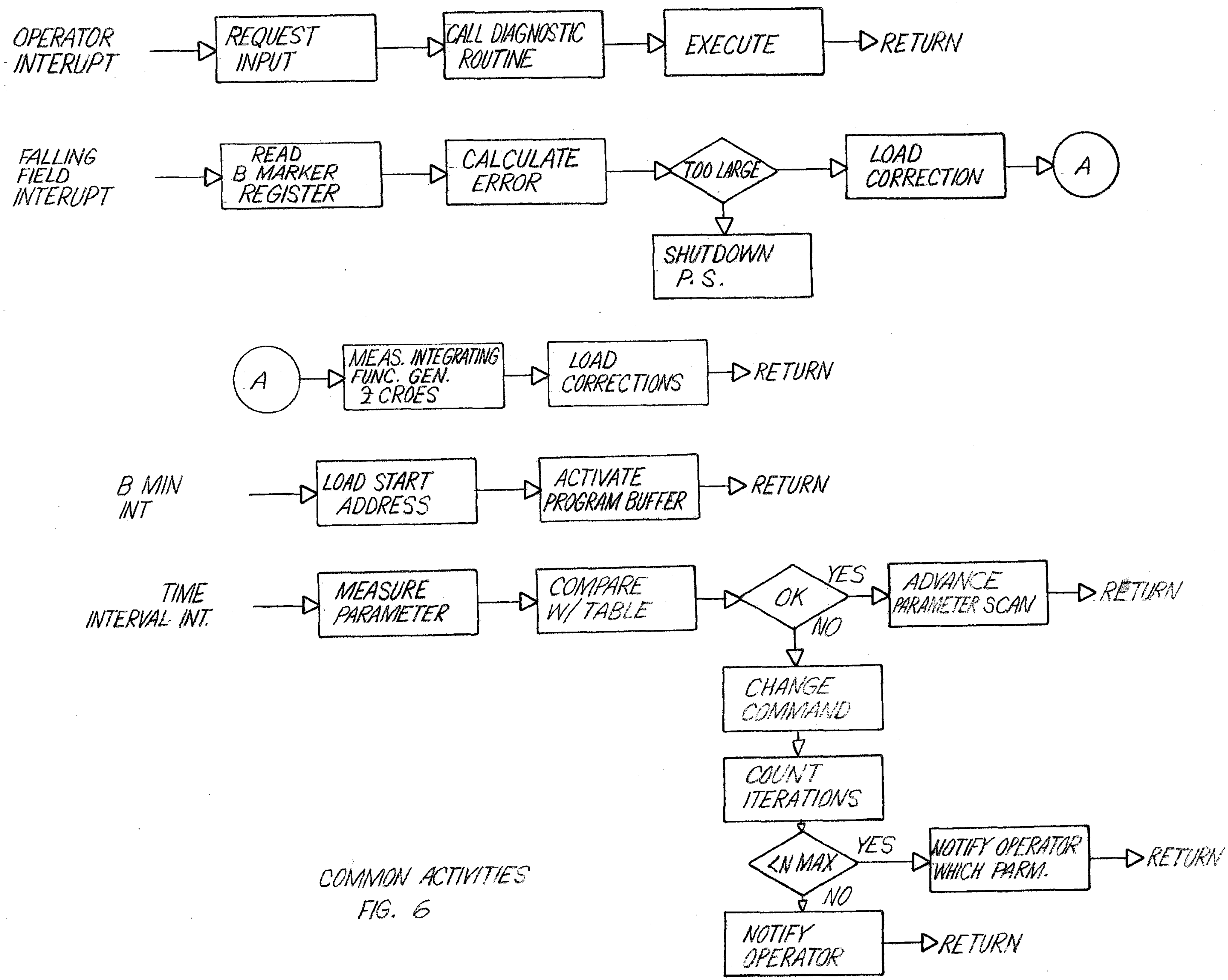


FIG. 5
OPERATING MODE



COMMON ACTIVITIES
FIG. 6