A MASS SPECTROMETER CONCEPT FOR IDENTIFYING PLANETARY ATMOSPHERE COMPOSITION

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DR. SPENCER: Professor Nier has introduced the subject very nicely and told you a lot of details of these systems. I'd like to use my few minutes to speak to a few principles pertinent to some of the considerations which guide people in using mass spectrometers for atmospheric measurements.

The basic problem is not a new one. It is to try to get a sample of the atmosphere and measure it without modifying it. Atomic oxygen is a good example. In most instruments it recombines on the surfaces and is measured as O_2, which is acceptable if the ambient O_2 is negligible (true for most cases). Thus, if you didn't know that there was atomic oxygen up there in the first place, you might conclude that molecular oxygen was present until your fundamental physics told you otherwise. That's fine for the earth, but when we go into other atmospheres, we don't really know what is there, and then it is not quite so obvious. I think that the discussions yesterday, particularly those concerning Jupiter and the trace constituents emphasized the point and illustrate the situation that we find ourselves in, and that is how do we really analyze a sample of the atmosphere in a rather brutal way, which is what the mass spectrometer does, without changing its composition. So, getting a sample is a challenging task, a concern, a consideration that one must be aware of. Obviously, the other things that are a little more apparent in considering a design are the dynamic range that the instrument must have, the mass range that the instrument must cover, the precision of the measurements that are necessary for example, to confirm isotope rations.

A number of systems have evolved, and I want to use some of our more recent work on Pioneer Venus as an example to illustrate some of the problems.

This diagram may not surprise you very much, but it is quite fundamental. (Figure 8-7). Basically, we need some arrangement to sample the atmosphere. We use the term "sample" in the very broadest sense; whether you take a parcel of gas and bring it into the instrument and analyze it or whether it flows through the instrument in the sense that Professor Nier was speaking about really depends on the particular application. Fortunately, in the upper atmosphere, in satellite usage, one can take a sample directly into the ionization region of the mass spectrometer without it having experienced surface collisions and analyze it with perhaps what you might consider the minimum amount of modification. However, the atmospheric sample is not the only gas observed in the source because the surfaces produce gases as well. If you can use the energy of the particles as a differentiator, then you have a very nice tool for differentiating between the particles which are of spacecraft origin or mass spectrometer origin and atmospheric origin. When one goes to lower atmospheres, and I am going to speak generally about more dense atmospheres, then that tool is not available and the chemical effects in the ion source are more difficult to avoid. The sample inlet system that is represented in this block diagram reflects those portions of the system which conduct a sample of the atmosphere, whether it be a batch or a continuous flowing gas, into the ion source of the instrument.

These systems will in general have pumps. There are a variety available, the kind to be used depending upon the particular atmosphere. For Venus, where the atmosphere is dominated by other than inerts, Getter pumps are very handy devices. Ion pumps are useful as well for controlling the inerts.

Most of our activities concentrate on guadrupole analyzers as shown. The rest of the figure should be quite familiar to you.

GENERAL SYSTEM OUTLINE

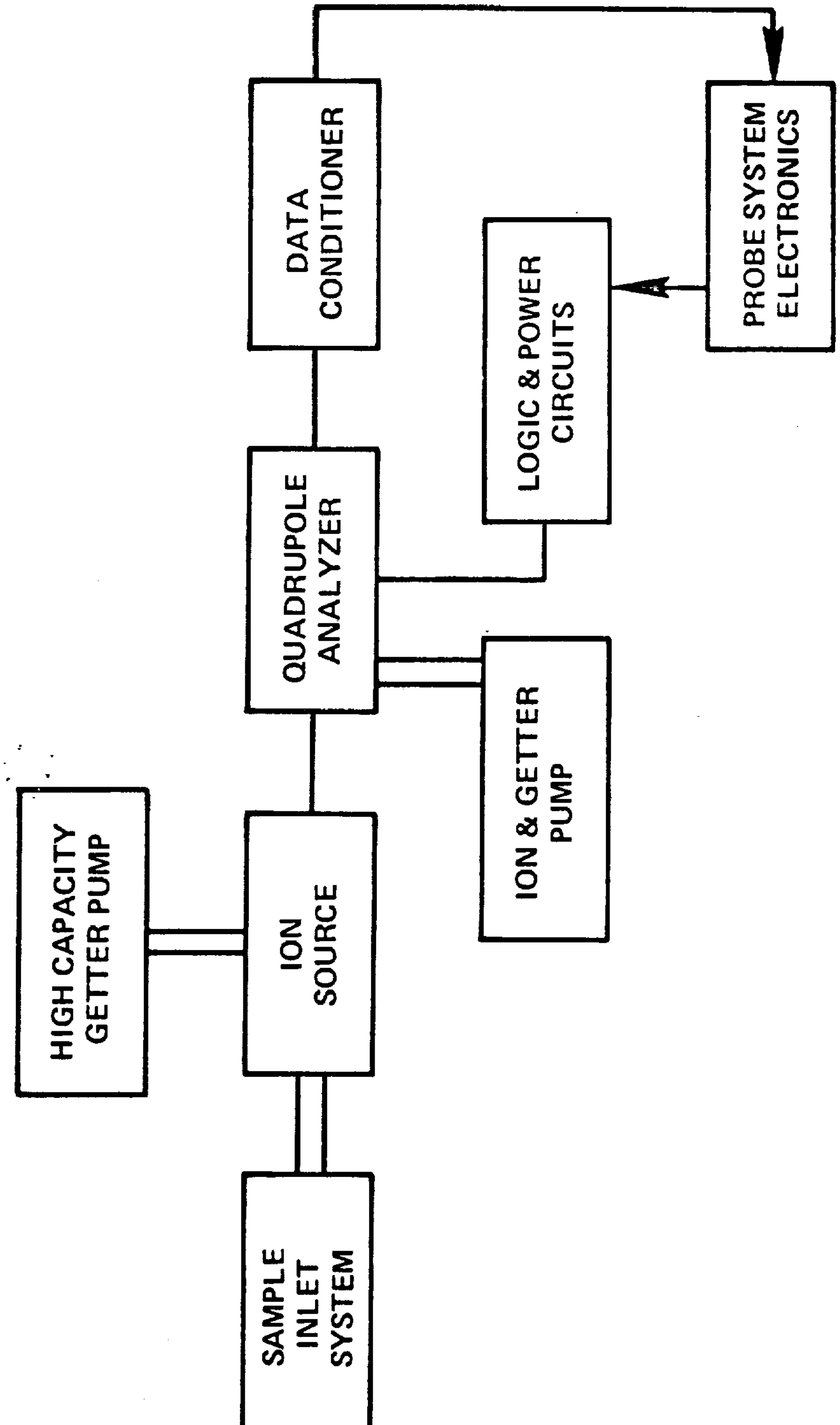

Figure 8-7

The next figure (Figure 8-8), shows what a typical system may look like. The quadrupole and the other elements of the analyzer are shown. In general, the analyzer portion is separated from the ion source region by a relatively low conductance ion orifice. It has its own pumping system to maintain the background gas at a suitably low level. The left portion of the slide shows the ion source and the inlets which are closely associated physically because it's desireable to minimize the amount of surface that is exposed to the gas. The pump (and leaks) are sized to maintain an adequate flow of gas through the ion source. Also shown are three inlets which will be discussed later.

The next slide shows typical weights corresponding to the block diagram (Figure 8-9). It must be noted, however, that these weights are mission dependent. For example, the structure that is required to support the various elements of the instrument will vary from mission to mission and is necessarily closely associated with the sample system.

Although the next figure (Figure 8-10) is a rather poor reproduction, it illustrates a typical instrument installation with sample tubes projecting through the probe wall. In Pioneer Venus, there are some particular temperature and structural problems which require special consideration. The acceleration forces must be supported in some manner by the elements of the system, and that's where some of the weight appears that is not particularly defineable, but which I classify as mission dependent weight.

(Figure 8-11). I mentioned that it is necessary to accommodate to a rather wide range of pressures in the instrument when descending through an atmosphere to the surface. At the same time, it is necessary to optimize, for dynamic range purposes, the pressure in the ionization region. There are a number of devices that can be used to reduce the atmospheric sample to an acceptable pressure level for the mass spectrometer. At the same time, one is concerned about the particular material that

BLOCK DIAGRAM OF PUMP SYSTEM

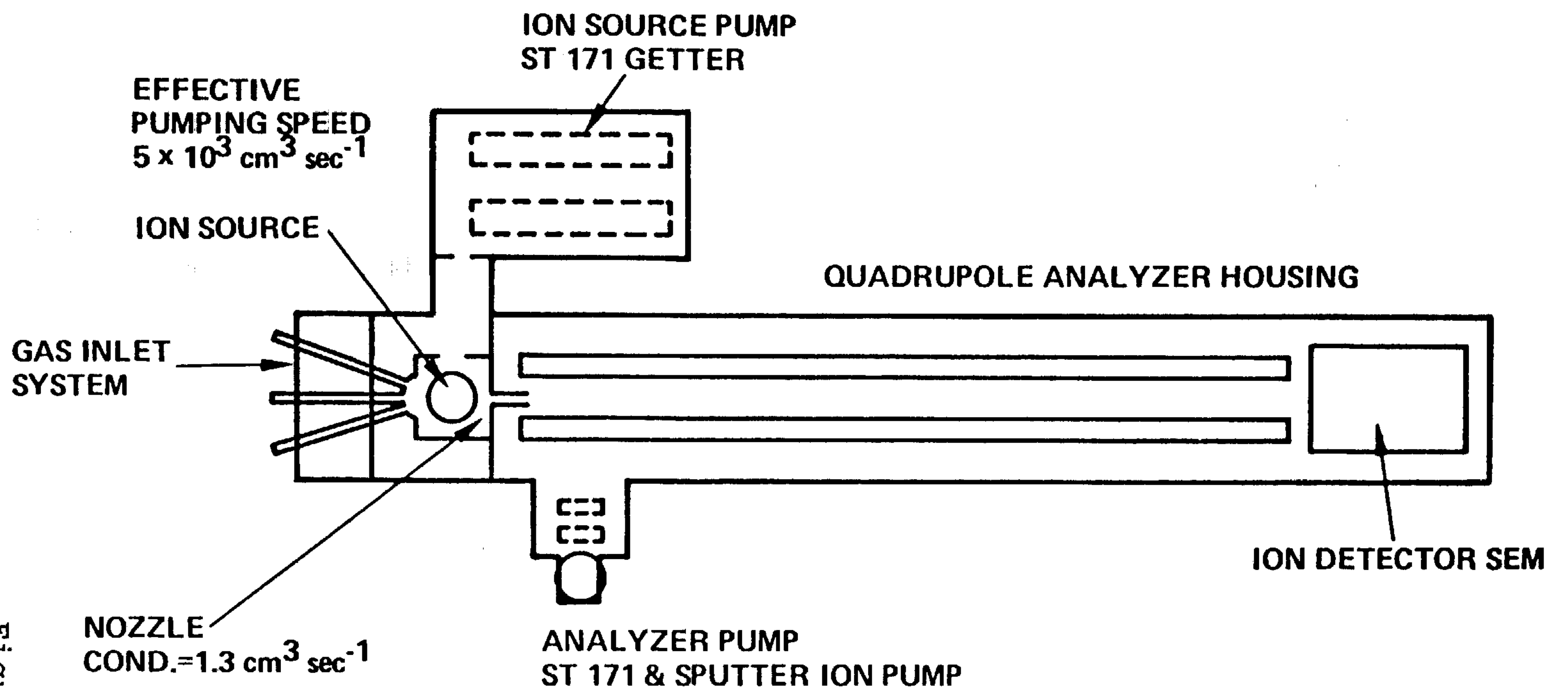

Figure 8-8

INSTRUMENT WEIGHT BREAKDOWN

	KG	LBS
SAMPLE INLET SYSTEM	0.9	2.0
MASS SPECTROMETER	0.5	1.1
ELECTRONICS	1.0	2.2
MECH. STRUCTURE	1.0	2.2
PUMP	≥1.0	2.2
	4.40	9.70

Figure 8-9

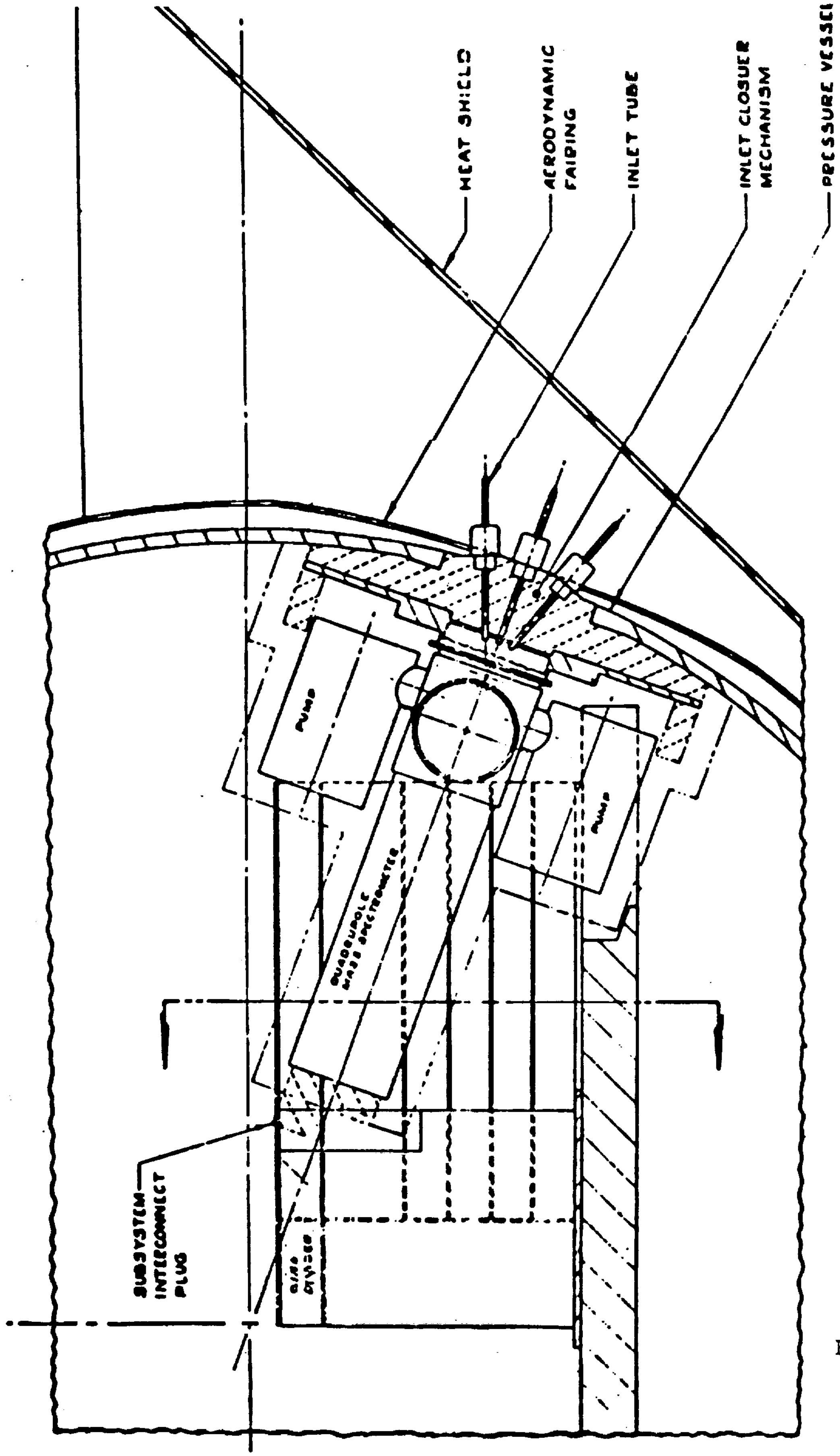
HEAT SHIELD
AERODYNAMIC FAIRING
INLET TUBE
INLET CLOSUER MECHANISM
PRESSURE VESSEL WALL
PUMP
PUMP
QUADRUPOLE MASS SPECTROMETER
SUBSYSTEM INTERCONNECT PLUG

Figure 8-10

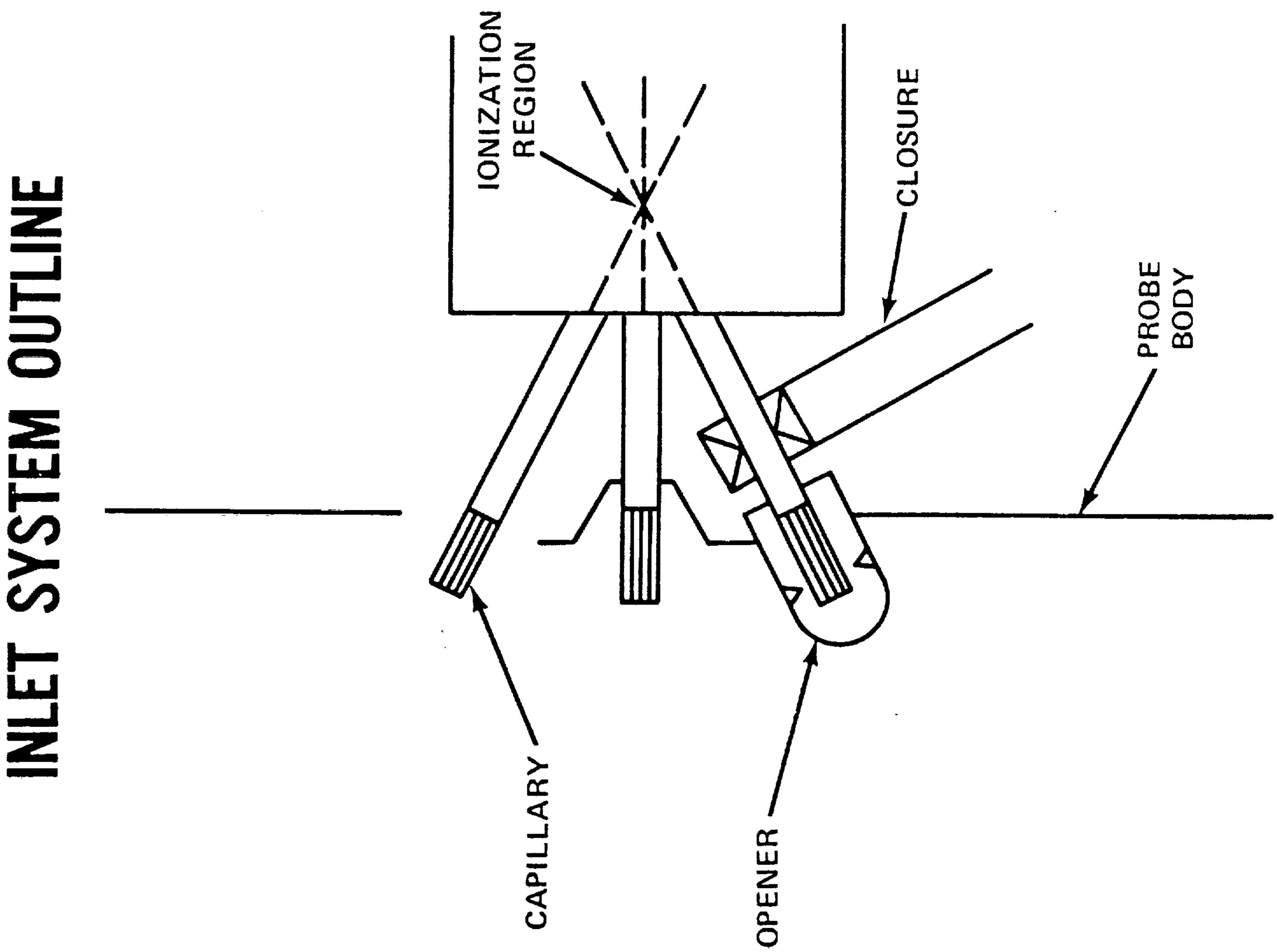
INLET SYSTEM OUTLINE
IONIZATION REGION
CLOSURE
PROBE BODY
CAPILLARY
OPENER

Figure 8-11

the glass is exposed to. Again, one has a choice. One can use glass, quartz, ceramic devices or metals, but the basic consideration is how do these materials react with the gases in the atmosphere.

The approach that we have taken for atmospheric probes is to provide what we believe is a fair amount of redundancy. We take a number of different batches of atmospheric gas during the descent of a probe into the atmosphere and analyze each of them individually. Three channels are shown in the slide, however, for Venus, eight is an appropriate number. The amount of time that the flow can take place for the particular sample really depends upon the particular mission. It could be either nearly continuous or brief. The system must also be very clean so one can have confidence that gases are not being carried there which will alter the analysis. The example illustrated here shows three capillaries with an opener for uncovering and exposing each. There is also a device which terminates the sample by sealing off the tube at the end of a selected flow period. Considering a number of sample tubes, the times of the various samples can be spaced through the atmosphere to accommodate for example the considerations that John Lewis was speaking about yesterday where different strata in the atmosphere might prompt one to look for different groups of gases.

Figure 8-12 illustrates one measurement scheme during a particular sample. The vertical scale represents the operating pressure level in the ionization region. In general, it is not constant, but for the purposes of this discussion, it makes little difference. I think you can see essentially what happens; at some time through an internally generated signal, the device is exposed to the atmosphere and the gas permitted to flow into the instrument. One can select, depending upon the particular altitude range or the particular localized study, scans of selected mass numbers. Scans can be continuous, where you look at

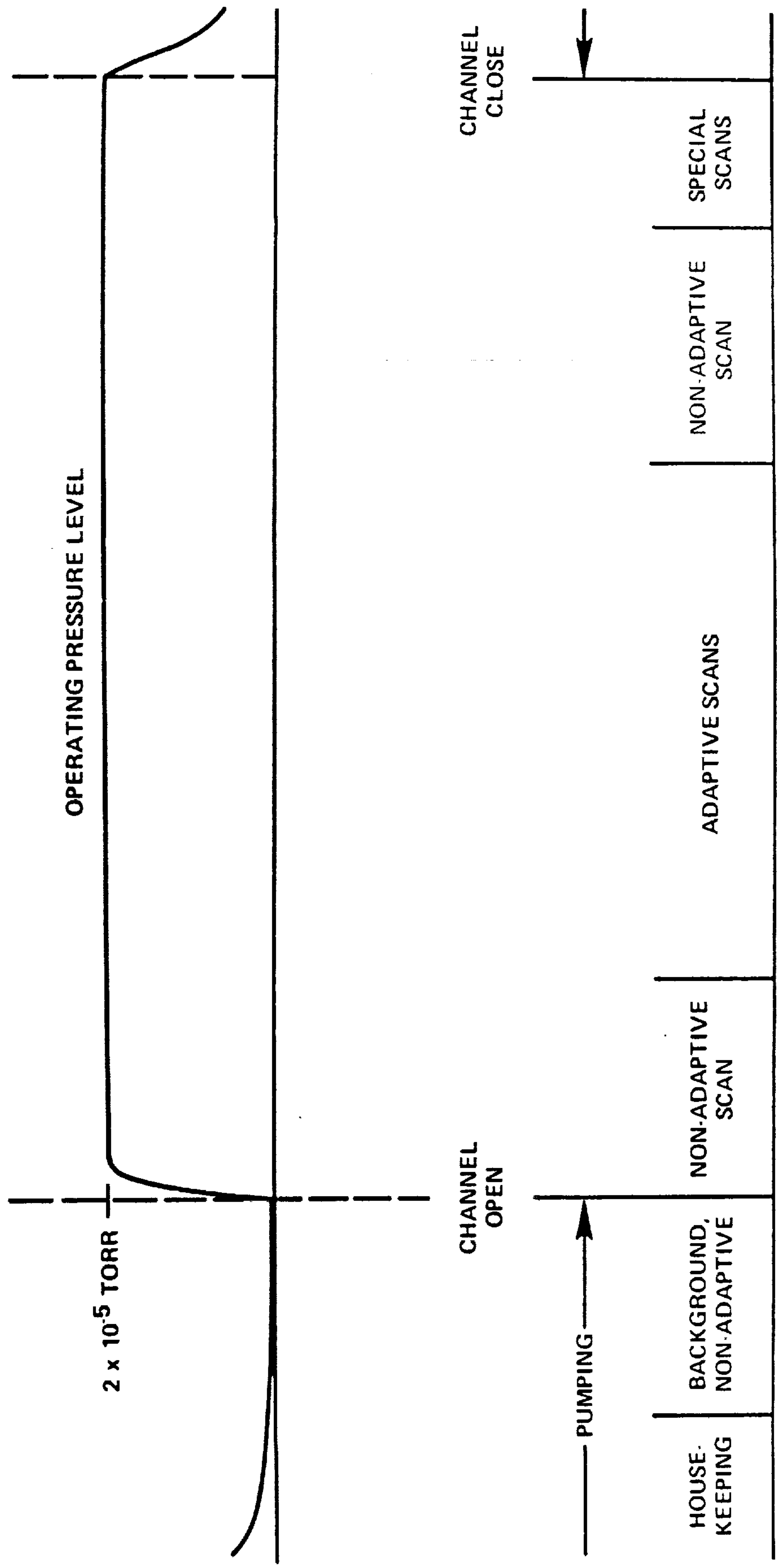
OPERATING PRESSURE LEVEL
2 x 10^-5 TORR
CHANNEL CLOSE
CHANNEL OPEN
PUMPING
HOUSE-KEEPING
BACKGROUND, NON-ADAPTIVE
NON-ADAPTIVE SCAN
ADAPTIVE SCANS
NON-ADAPTIVE SCAN
SPECIAL SCANS

Figure 8-12

every mass, which I have labeled here non-adaptive, for purposes of identification. You may want to study the altitude distribution of the gases. The data system can be used a little more effectively by using an adaptive approach that looks at preselected masses.

At the end of some period of time, the channel itself can be closed and the instrument then sealed off from the atmosphere. The capillary in this case, or whatever the leak happens to be, is sealed off and the high-pressure gas that is now remnant in the capillary and ion source is removed. The pump system is thus able to reduce the remaining gas in the system to a background level. This is a particularly important concept, because the surfaces of the instrument of the ion source do retain gases, which must be expected, especially in an unknown and hostile atmosphere such as Venus; and presumably for other planets where there may be a number of exotic components in one form or another. They may react with and be retained by the surfaces of the ion source. One would like to know, for example, that one doesn't carry a particular gas that may result from some surface chemical reaction at one altitude to some lower altitude. This arrangement permits one to look at that background.

I included the last but didn't really intend to talk about it (Figure 8-13); however, a talk about mass spectrometers would not really be complete without showing a spectrum. People would not think that you were being very honest. This is a nest spectrum from a laboratory study that we have done that illustrates the capabilities of small quadrupoles. You can see the typical things - the number of gases and the resolution. It gives you a feel for the dynamic range of instruments and peak shapes.

I think I will close, then, with just one remark. I have been speaking to you about things that are real in terms of instruments. We, collectively, have done a lot of development over the years towards these instruments, and I think we have

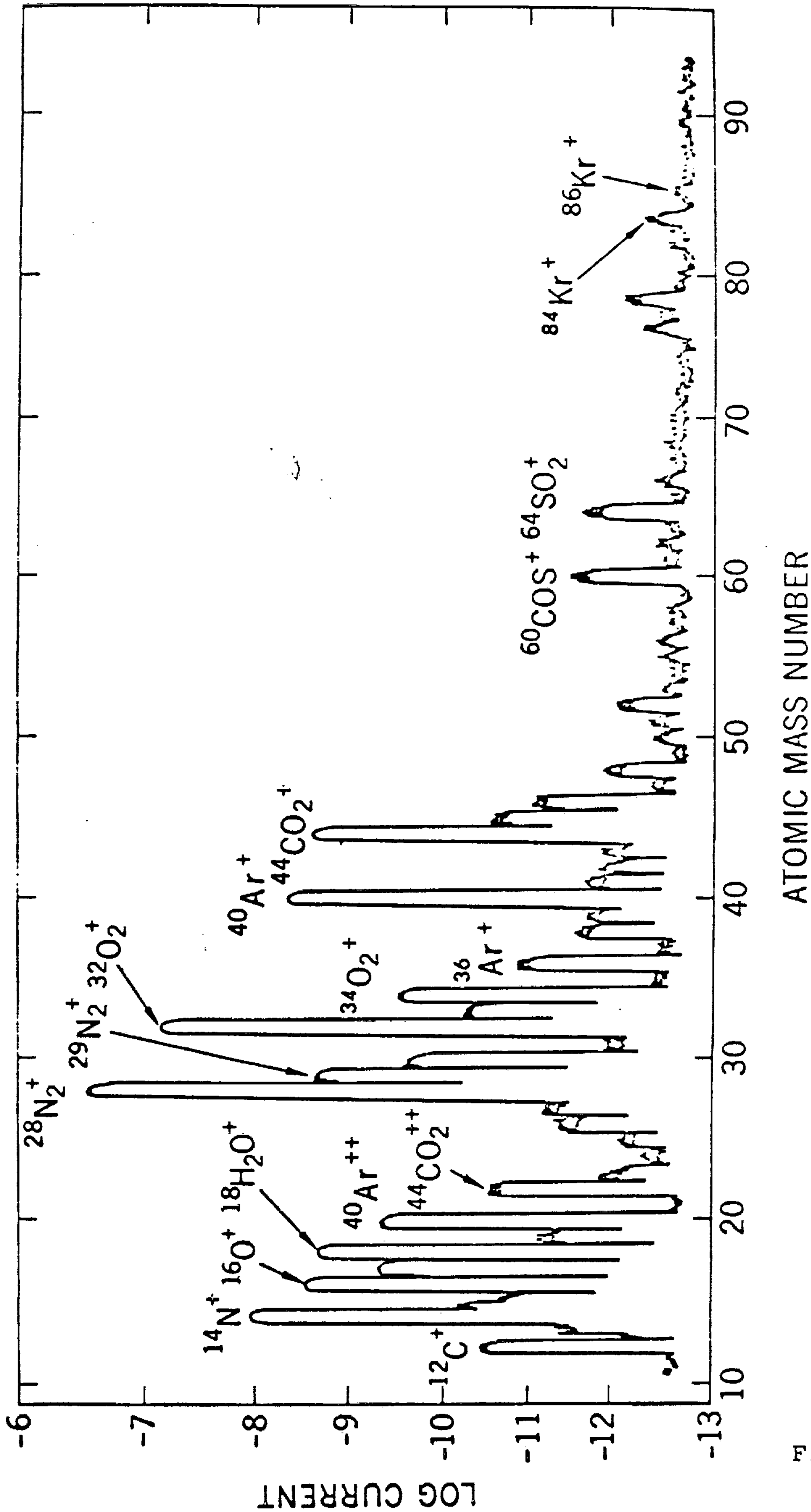
LOG CURRENT
-6
-7
-8
-9
-10
-11
-12
-13
10
20
30
40
50
60
70
80
90
ATOMIC MASS NUMBER
$^{12}C^+$
$^{14}N^+$
$^{16}O^+$
$^{18}H_2O^+$
$^{40}Ar^{++}$
$^{44}CO_2^{++}$
$^{28}N_2^+$
$^{29}N_2^+$
$^{32}O_2^+$
$^{34}O_2^+$
$^{36}Ar^+$
$^{40}Ar^+$
$^{44}CO_2^+$
$^{60}COS^+$
$^{64}SO_2^+$
$^{84}Kr^+$
$^{86}Kr^+$

Figure 8-13

come to quite an advanced state. I think we are ready for missions to the planets. These instruments are in many cases built and operating. Many of them are tested. Many of the principles have been tested and have been found lacking in some regards. The test that Professor Nier speaks about on A.E. will be carried forward also. We too will be doing a similar, but somewhat more advanced experiment on the next A.E. satellite with a system that is particularly designed for planetary upper atmosphere use. We are not speaking about what might be, we are speaking about what in fact can be, and what is being done.