#SN-3 ODH Situation in Accel. C.Bonham

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RECEIVED MAY 25 1983 SAFETY SECTION

May 23, 1983

To: Larry Coulson

From: Rich Orr

Subject: ODH SITUATIONS ENCOUNTERED IN ACCELERATOR DIVISION

Attached is a draft copy of a writeup by Charlie Bonham on ODH experience in the Accelerator Division which we agreed to provide to your office.

cc: C. Bonham
H. Casebolt

DRAUGHT

May 17, 1983

ODH SITUATIONS ENCOUNTERED BY THE ACCELERATOR DIVISION

C. Bonham

I. BACKGROUND INFORMATION

The Accelerator Division has assumed a conservative safety policy especially with respect to oxygen deficiency hazards evolving from our use of liquid helium (LHe) and liquid nitrogen (LN_2).

Early in the program, it was realized that available off-the-shelf commercial safety equipment was neither sufficiently reliable nor functional enough to meet the needs of the project in detecting and warning against low partial pressures of oxygen. Thus, two electrical engineers Rich Parry (Accelerator Division) and Paul Czarapata, with Dan Schoo (Research Division) commenced early development of a new inplace oxygen monitor. A commercial detector head was used in conjunction with the reliable and sophisticated laboratory developed electronics package (petents pending).

Simultaneously, the Safety Section searched the commercial market for a small portable oxygen monitor that could be easily carried on the belt of the user. It would not only have to be rugged, but would also have to be fail safe and reliable. They found such an instrument, the Lumidor made in Florida. However, it had problems that were unacceptable to the Laboratory, so our engineering staff provide recommendations to Lumidor that would make their product useful to the project including;

- -A locking "on" power toggle switch.
- -Changing to a rechargeable power system.
- -Incorporation of a 1 second time constant to reduce false alarms.
- -Moved alarm from inside box to outside for louder alarm response.
- -Added a press-to-read switch (saves batteries) - while alarm still remains automatic.
- -A heavy duty belt clip added.
- -Low battery alarm signal was provided.

Concurrently, ODH procedures were slowly and carefully developed and tested. In the case of the Main Ring, these would be superimposed and/or amalgamated with the existing Main Ring procedures. For example, now when the ring is readied for manned occupation, power-off entrances are made with both radiation and cryogenic safety equipment: outer anticontamination suits, booties, gloves, film badge, pocket dosimeter, Elron G-M counter, 5 minute escape packs, personnel oxygen meters. etc. The newly developed procedures tend to be overly conservative. As experience is gained, appropriated modifications to procedures are occassionally made after extensive review.

Training plays an important role in the final preparation of personnel for working in potential ODH areas. The training consists of developing an understanding of both why and how ODH problems could be encountered and their physiological effects. Following the basic lecture, special emphasis is placed upon the use of protective equipment, basic procedures and emergency procedures.

The reader should review Chapter 15.1* of the Fermilab Safety Manual for an overview of the basic Laboratory restraints with respect to ODH. This should make it relatively clear that the ODH problems primarily encountered are those evolving from the reduced partial pressure of oxygen a problem encountered daily in aviation, and a common obstacle faced by mountain climbers in the higher reaches of our planet. Cryogenics may be relatively new, but the hazards of reduced partial pressure of oxygen is not.

II. ODH OCCURRENCES

There have only been a few ODH situations related to the Saver program. Strangely enough, the most serious incident had nothing to do with effluent gases from liquid helium or liquid nitrogen.

1. The CHL Freon Incident (March, 1980)

Prior to the first cooldown, the Central Helium Liquifier group experienced problems with one of the turbines located within the coldbox. It was decided to replace the turbine and in the process, lines were to be cleaned and flushed with Freon.

The coldbox installation includes a large pit below it so that the cold box be lowered for installation and certain maintenance operations. Normally, and in the case of this incident, the cold box was raised over the pit. Two Biomarine oxygen monitors

*Appendix

were located at the base of the cold box, but apparently neither was in the pit.

The Freon was pumped thru the appropriate lines from a 55 gallon drum; conversely, the circulated Freon was to be collected in an empty 55 gallon drum. There had been a shift change (day to swing) in the middle of the operation. Unfortunately, a portion of the Freon was not flowing back into the receiving drum, but was dripping from fittings etc. into the pit area as the 2nd shift continued the operation.

Freon 22 (monochlorodifluoromethane), has a molecular weight of about 86 which makes it approximately three times heavier than air. It vaporizes to a colorless, odorless gas that is relatively non-toxic in concentrations up to 4% (40,000 ppm). Unfortunately it may dilute the oxygen concentration. When the partial pressure of oxygen is reduced to around 90 mm Hg, central nervous system responses become altered and pulse rate and respiration becomes deeper. The victim may pass out.

As we return to the scene of the incident, the technicians had finished their evening meal and the cleaning operation began to wane. Technician "A" decided to take a broom and clean up the pit. Shortly after he entered the pit, he felt very sleepy. He decided to lean against the wall and shut his eyes for a moment of relaxation. That was the last thing he remembered.

His co-worker noticed him slumped over in the pit. The co-worker shouted for help; the Fire Department was called. With lemming-like dexterity, the co-worker, who was also a relative of the victim, entered the pit to effect a rescue. He was generally successful. The Fire Department arrived and helped with the victim.

Then as they were assisting the rescuer from the pit, he too passed out.

This incident would not have happened had procedures been followed. Similarly, it points out the necessity of safety training especially in hazard recognition as well as emergency response. Neither of the nearby commercially made monitors were effected. However, they probably weren't correctly located for representative sampling.

2. Blown Gasket CHL - (minor)

During the first cooldown (spring 1980), a gasket blew on the top cover of the main vessel in the oil removal system (i.e. removal of oil from pumped helium gas). As soon as the gasket blew, the operator immediately shut off the gas to the affected area. No significant release of helium occurred; no area oxygen monitors were activated. The problem occurred because the gasket, supplied with the vessel, was too soft. The problem was repaired by installing a gasket made of 1/8" indium wire which was crushed to approximately .020" thickness by the bolts on 20" diameter cover. There has been no further problems with the indium seal since its installation.

3. Blown gasket on 6" Discharge Line To Coldbox-CHL - (minor)

This problem occurred at the start of the 2nd running period (Feb. 1981). The problem involved a standard 1/16" buna rubber gasket installed in the spool to permit the installation of an optical monitoring device for oil. The failure was caused by lack of parallism in the clamping flange. The problem was corrected by rotating the spool 180° which resulted in parallel flanges. There was no significant release of helium within the building. The area oxygen monitors were not effected.

4. <u>A-1 Refrigerator Building Wet Engine/"U" Tube "O" Ring Seal.</u>

In working with cryogenics, "U" tubes are frequently used to transfer cold liquid/gas across rather short spans. In a sense, they are semi-permanent piping that have the capability of being removed for the convenience of a particular operation. Such an example might be the necessity of replacing a wet engine. The "U-tube" consists of vacuum-jacketed piping, each end of which fits into a ball valve. There is a series of chevron seals which form around the end(s) of the "U-tube"piping. Occasionally, these seals become excessively cold to form-up properly around the piping and then leak. Once a leak starts, sometimes the cold "travels" and effects adjacent seals. The "trick" is to insert the "U"tube' ends rather quickly past the opened ball valve so that the chevron seals are comparatively warm when they effect the seal. If any small leak is present, it is generally correctable by warming the area with a torch. Experience has shown that any leak must be attended to and that they seldom get better-only worse. Many of the "U-tubes" are located in the refrigerator buildings which house both the dry and wet engines, and assorted plumbing which communicated directly below the building to the Main Ring tunnel. Refrigerator buildings are rather small-approximately 5 meters x 5 meters. Since these buildings are instrumented with oxygen monitors which are monitored by the Main Control Room, any helium leaks show up on the trouble panel in the Main Control Room. With this background information, it will be easier to follow some of the following incidents.

At 2300 hrs., Feb. 19, 1982, a seal leaked on the high pressure inlet to the wet engine. The leak vented cold helium gas into the building activating the oxygen monitor.

The building was "crashed" (i.e. a crash button on the exterior of the building shuts off the gas supply to the engine(s)). Oxygen levels were measured as low as 6%; interior room temperature dropped to 15°F. The building doors were opened and the building was allowed to ventilate. The Fire Department was on the scene and ready with Scott air packs, which of course, were not necessary for this incident.

5. <u>E-2 Refrigerator Building "U-Tube" Chevron Seal Leak</u> -(March 4, 19

This incident was somewhat like the incident just cited except in this case, the "U-tube" had been removed from the wet engine. A technician failed to close the ball valve on the valve box completely and did not notice it had a small leak. As the valve became colder the leak become worse. In the same operation, a warm-up purge had been placed on the wet engine but the purge was not properly vented. This was noted from the Control Room via the oxygen monitor and a crew was dispatched to the building to make a correction. The oxygen alarm went off before the crew arrived and a "code 4" was issued. It was handled as a regular emergency, although, it was not a serious incident. The double doors were opened, and the area was allowed to vent. The purge vent was corrected and the leaky ball-valve was heated. The leak slowly ceased. Following this thawing operation, experience has shown that it is necessary to watch a valve for a few minutes to assure that the leak has stopped since even a small leak will get progressively worse--never better.

The next two incidents to be discussed are somewhat different than those described thus far. Both occurred in the Main Ring tunnel, however, neither resulted in any significant release of gas into the tunnel. The first did vent helium into the refrigerator building (as we shall see), the 2nd incident did not produce any measureable reduction in oxygen partial pressure. We have included this failure since it was an interesting failure that pointed the way towards a correction necessary in the spool pieces. The early "A" sector test was the first test of a complete cryogenic system (CHL, the ring compressor and refrigerator systems) and the magnet string. It was not unreasonable to anticipate some failures or problems since the first "A" sector test was almost R&D in scope. However, none really resulted in ODH problems. Much was learned and "A"-sector has been completely updated to that of the rest of the ring. "A" sector changes include: Updated versions of magnets, feed cans, spool pieces, turn around boxes, by-passes, an updated transfer line. Neither of the two incidents (to be discussed) encountered in the early "A" sector tests have appeared in the more recent tests in other sectors.

<u>A25 Feed Can Problem</u> (March 11, 1982)

During a down period, an employee in the Main Ring "A" sector phoned the Main Control Room (MCR) and informed them of a water vapor cloud (water precipitated from the air by cold gas) in the A-25 area. The MCR evacuated the sector of personnel. Almost simultaneously the A-2 refrigerator oxygen monitor alarmed. Crews in the area verified the presence of cold gas and the refrigerator was "crashed". The problem was known to be a helium leak.

It was interesting in the manner in which this emergency was handled. First of all of course, the potentially hazardous area, the refrigerator house, was ventilated and placed under emergency control. The MCR can directly read and make a hard-copy plot of O_2% vrs time of the oxygen alarms. Other alarms within the tunnel and stairwells were not effected. Since it was not a emergency situation, a meeting was first established to review resolution of the problem.

Entry was made into the Main Ring tunnel with Scott Air Packs available, but were unnecessary. The problem proved to be a crack in an epoxy joint associated with the feed can. The new design avoids this problem.

Spool Piece Vacuum Problem (March 3, 1982)

Again in this incident, no ODH problem was encountered nor were oxygen alarms effected. A leak developed between 1Ø helium and the insulation vacuum on one of the R&D spool pieces during the A-sector test. A pressure in the vacuum space developed and opened the three vacuum reliefs. Super-insulation was ejected thru the relief ports and shredded into "confetti" and blown about the tunnel. This in itself was interesting since it again proved the effectiveness of the re-designed 4" vacuum reliefs. With cryogenic work, there is always concern with vacuum reliefs since vacuum spaces often contain super insulation. The concern is the possibility of the super-insulation pluging the reliefs. The spool-pieces have been re-designed following the "A-sector" tests and no further problems have been encountered.

Switchyard Drift Space Assembly Lead Repair Incident (Sept. 30, 1981)

"On Sept. 30, 1981, it was found that the leads (voltage taps) on the new DAS#1 (drift space assembly) were shorting to ground at the connector. It was decided to try and fix it on the next day (Oct. 1, 1981). On Oct. 1, 1981 (Thursday A.M.) the liquid helium was removed from the magnets in preparation for the repair. On trying to effect a repair on the connector, it became evident that too much cold gas evolution to (continue) to try and fix the connector. Fire Department backup was called and Scott Air Packs were used to go down and plug the leak. "A Safety Meeting..." was held where it was decided to try and warm up the south 1Ø phase string and try to fix it again... on Friday morning (Oct. 2, 1981). It was not successful. We are now in the process of warming up the system by flowing warm gas (He) downstairs. Then we will shut off the nitrogen". From log book R.J. Kolar). The repair was subsequently made.

Although, helium was released in the tunnel, it was a controlled situation and remained that way until the repair was completed. The incident pointed the need for additional personnel to receive Scott Air Pack training and qualification in the event other possible confined space repairs.

Failure of Leads on Sub-Cooler-Switchyard (Oct. 11, 1978

A possible design flaw in electrical leads passing thru the sub-cooler caused an arc and sebsequent melting of the shield tube. This allowed liquid helium to enter the insulating vacuum. Apparently super-insulation plugged the vacuum relief ports and the pressure continued to rise to 60 psi. With the rise in pressure, the bellows expanded and ultimately ruptured. The turn-around box was not not sufficiently anchored and its movement from the forces involved also allowed movement of the magnets. (It should be noted that the magnets in the switchyard are suspended from the ceiling rather than support from the floor as in the Main Ring.) By the 3rd of October, repairs were completed on the magnets and the turn-around box in the tunnel, and the sub-cooler upstairs. Cooldown commenced, but there were to be some new problems to be encountered and were probably unrelated to the preceeding incident. The gas engine broke after 83 hours of operation. The rocker assembly support arems broke at the welded pin. The crew had repairs completed in about 24 hours and cooldown commenced on the 8th of November.

In the lead burn thru incident, helium was released in both the tunnel and to a lesser degree in the Control Room area. The oxygen monitoring system was less sophisticated five years ago than now. Whereas the Main Control Room can presently make "hard copies" of measurement from any of the remote oxygen monitors within the system, it wasn't possible in 1978. As a result, there is no information on oxygen levels at either the Switchyard tunnels or the Switchyard service building.

Approximately one month before the Switchyard incident occurred, nearly the identical incident occurred at B-12. B-12 was an above ground structure in the Main Ring where doubler magnet strings were studied and tested. At B-12, one of the power leads from the safety circuit shorted and burned a hole into the vacuum space which became pressurized with helium. The five one inch relief ports became clogged with super-insulation. Forces rapidly developed; some of the bellows deformed, and several magnets toppled off their stands onto the floor. Oxygen alarms went off as cold helium gas filled the test area. Personnel from the nearby but isolated Control Room reported the formation of a large vapor cloud (frozen water vapor) within the tunnel-like test area. Although, no datum was made on oxygen deficiency limits, it is assumed that there was an oxygen deficiency until such time as the area was cleared by the ventilation system and the alarms cleared

III. Purposeful Activities Involving Small to Moderate Helium Releases

In order to cover the spectrum of ODH situations, it would be worthwhile and interesting to cover three other situations:

(1) The changing of the Kautsky main relief valves on cold magnets.

(2) Purposeful inerting of the Protomain tunnel with cold nitrogen gas for Fire Department training. (3) The intentional release of 300 L of liquid helium into the Main Ring tunnel.

(1) Changing of Kautzky Valves on Cold Magnets

Occasionally, it is necessary to change (nitrogen and helium) magnet main relief valves on cold magnets in the beam line. We first developed this technique in the B-12 magnet experimental area. This facility had much more working area than the Main Ring as well as local exhaust/ventilation capability. The Kautsky valve changes were done on occassion and unique tooling and equipment was developed as well as precise procedures for a three man team. A special Kautsky valve change kit evolved which contains special tooling as well as all the other ancillary equipment necessary to perform the task (propane torches, extra "O" rings etc.). Specialized safety equipment provided enhanced personnel protection. A trained team can change two valves in about 5 minutes with little evolution of gas. Oxygen monitors placed directly in the work area do not record any localized oxygen reduction.

(2) The Protomain LN_2 Test

The Protomain exist in the village area of the laboratory. As the name suggests, "Protomain" is a full scale model of a portion Main Ring area and was used in the early development of the accelerator.

The Cryogenic Safety Sub-Committee wished to both test emergency response equipment as well as provide training for the Fire Department crews who might someday respond to a cryogenic emergency. The committee was allocated funding for the test. Approximately 100' of tunnel was instrument ED with thermocouples at various heights and locations within the tunnel. These were tied into strip chart recorders, video cameras were placed at each end of the tunnel to observe the participants. A nitrogen LN_2 tanker supplied the cryogenics. Actually, LN_2 wasn't the ideal choice for the test since the most probable encounter would be with LHe and the two evolved gases behave just the opposite. Cold nitrogen is more dense than air; helium rises, but the cost difference is considerable.

The Protomain proved to be a considerable heat sink and it required several hours to cool it down; -75°F seemed about the lower limit. The oxygen content was around 8%. The cold seemed to stratify about 4' high and as a result a "fog layer" formed below the 4' level.

The results of the test were generally positive. The regulators on the Scott Air Packs continued to function at -75°F. Similarly, the batteries in the transeivers remained active. The footgear was adequate even in pools of LN_2. Visibility was poor. A small strobe lamp was not useful in the "fog zone" which formed about 48" high to the floor. The most benificial portion of the exercise was the development of both understanding and confidence on working in a major cryogenic spill by the Fire Department. This alone made the test worthwhile.

(3) Simulation of Accident Involving the Release of Liquid Helium Into the Main Ring Tunnel

A complete report of the test was prepared by Howard Casebolt and Peter J. Limon and is presented in the Appendix.

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SIMULATION OF ACCIDENT INVOLVING THE RELEASE
OF LIQUID HELIUM INTO THE MAIN RING TUNNEL

Howard Casebolt and Peter J. Limon

I. PURPOSE

The purpose of the test was to show the effects of releasing large quantities of liquid helium into the Main Ring tunnel in a short period of time. The amount of liquid vented was approximately 350 liters in a fraction of a minute at the A-22 location. That amount is equal to one half of a cryoloop.

The test corresponds to a possible accident in which a cart or magnet vehicle hits a spool piece and tears off all of the relief valves on that spool piece. That sort of accident vents more helium into the tunnel than a rupture of the vacuum along with destruction of the relief valves, because when the vacuum is destroyed, the sudden heating results in high single phase pressure, which opens many other relief valves, venting most of the helium into the 8" header.

The test is a realistic simulation of the short term effects (perhaps the first few minutes) of such an accident in the final system. The long term effects which would result in the final system would be more severe, since some fraction of the transfer line from the CHL might also be emptied, venting into the tunnel.

II. SET-UP AND INSTRUMENTATION

The simulation was performed by installing three Kautzky-style valves at the A-22 spool piece, and opening them simultaneously. The single phase and two phase valves pointed down from a height of about one foot off the floor, and the nitrogen relief pointed upstream.

Figure 1 shows the location of the instrumentation in the immediate vicinity of A-22. There were four types of instruments used to measure the effects of the test.

1. Television Monitors: Three cameras were placed in the tunnel at the locations shown in Fig. 1, each about two feet off the floor. Cameras one and two were video taped, but unfortunately only the video tape of camera one was usable, due to instrument failure or operator error. In addition, there was audio at A-22. The impressions are discussed in Section III.
2. Oxygen Analyzers: Eight oxygen analyzers were placed at various places in the tunnel, and were either recorded on a chart recorder at A-2 Service Building or read out in the Main Control Room on a slow time plot. In addition to the six shown in Fig. 1, there were two more at A-35 (+1100') and A-25 (+500') located at approximately head height. Figure 2 shows the output of each of these devices. There are clearly some problems with some of the analyzers. The one at A-22 (head height) rises to a very high level after nine minutes, and then comes back to its original value. This is thought to be due to moisture condensing on the sensor which will cause a high reading. This also means that the actual oxygen level at the sensor might have decreased to a lower value than was indicated because of this same moisture effect. The analyzers at A-22 (+20' - knee height) and at A-25 (knee height) show no response. Although it is known that the analyzers themselves were in working order from a later test, it is possible that the chart recorder had some intermittent problem. In our opinion it is not likely that the analyzer at A-22 (+20') not show some

effect, either temperature or oxygen displacement. Viewing of the video tape shows that the vapor cloud appeared to be above the knee height sensor at that point, however.

3. Four temperature monitors were used as shown in Fig. 1. These were 100Ω platinum resistors, read out on a chart recorder at the A-2 Service Building. The temperature coefficient of the resistors was 0.385 Ω/°C; R = 100Ω at T = 0°C. The estimated reading uncertainty of the data is 50 mvolts, corresponding to a temperature uncertainty (relative) of ~3°C. Figure 3 shows the time response of temperature. We believe that the resistor at A-22-2 was offset by about 10°C since the quiescent temperature in the tunnel was close to 20°C, not 11°C as shown.

4. One leak detector was placed at the bottom of the stairwell at A-25, equipped with a sniffer probe that sampled the tunnel air. Set on the least sensitive scale, 100% helium atmosphere was 88 units. However, it appears that the detector was very non-linear in response at this high level, and should not be taken as an absolute measurement of the helium contamination in the air.

III. DISCUSSION OF RESULTS

A. From the TV monitors, the following conculsions can be made:

1. The helium was completely vented from the magnets in a fraction of a minute, possibly even in a few seconds, creating a swirling cloud of fog in the immediate vicinity of the relief valves, extending 10 or 20 feet upstream and downstream. There was a distinct sound of rapidly flowing liquid, but no loud noise, as there is when there is a high current quench.

2. The cloud had a high degree of internal turbulence, but did not visibly move, as a unit, either up or down the tunnel. After about one minute there was a clear stratification in density of the cloud, with the region near the floor being less dense. After about two minutes, the region near the floor began to clear. The cloud dissipated itself by flowing downstream in a shallow river at the apex of the tunnel. It should be noted that the internal tunnel circulation flows downstream at about three miles per hour. The cloud did not move as a unit but appeared to remain stationary except at the top of the tunnel. After two minutes, there was still fog being generated in the vicinity of the relief valves. It is not known whether there was any remaining cryogenic fluids escaping, or whether this was due to condensation near the cold relief valves, and spool piece. It appears from the video tapes that the nitrogen may still have been venting at this time.

B. Oxygen depletion:

1. From the oxygen analyzers, it appears that the helium gas traveled in bulk at about 200 feet/min. The lowest recorded value of oxygen was 15% at A-21 (100' upstream) and 16% at A-22 and at the top of the A-25 stairwell. Because of possible calibration problems due to moisture, it is probable that the value at A-22 at head height was considerably lower than the recorded 16%.

2. The most striking result, it if is true, is the absence of oxygen depletion at A-22 (20' downstream) at knee height. This analyzer was tested the next day and appeared to be in working condition. If that is so, it means that staying close to the floor, and only 20' from the blowout is quite safe, as

far as oxygen is concerned. In any case, one could move at a swift pace and keep ahead of the depletion region.

3. It is interesting to observe the helium leak detector (Fig. 4). It responded roughly on the same time scale as the oxygen analyzer. Shortly after the tunnel exhaust fan was turned on at B-1 location (+11 minutes), the leak detector shows a large response. We believe that this was due to helium being pulled down from the top of the stairwell just past the detector, which was only two or three feet upstream of the bottom of the stair. Also, at +70 minutes, the leak detector shows a sharp upward response, at a level two orders of magnitude less than the initial response. It is possible that this is helium coming around the tunnel due to the natural circulation in the tunnel. A three mile per hour circulation would correspond to about 75 minutes around the tunnel. It is also possible that this is due to some more mundane event; for example, the liquid nitrogen level in the trap going to a low level. Before there was a clear indication of the downward side of the response, the leak detector began to malfunction, probably due to too high a total pressure.

C. Temperature:

1. Clearly, the most spectacular result is the low temperature in the vicinity of the spill. The temperature fell very fast to -50°C (-75°F) at four foot height, and -70°C (-95°F) at one foot height within 30 seconds. Although the temperature then increased quite quickly, it was still -10°C after five minutes. It is possible that these temperatures could cause injury, particularly to a person's lungs. At ≈-45°C lung tissue begins to freeze. (Ref. NASA.)

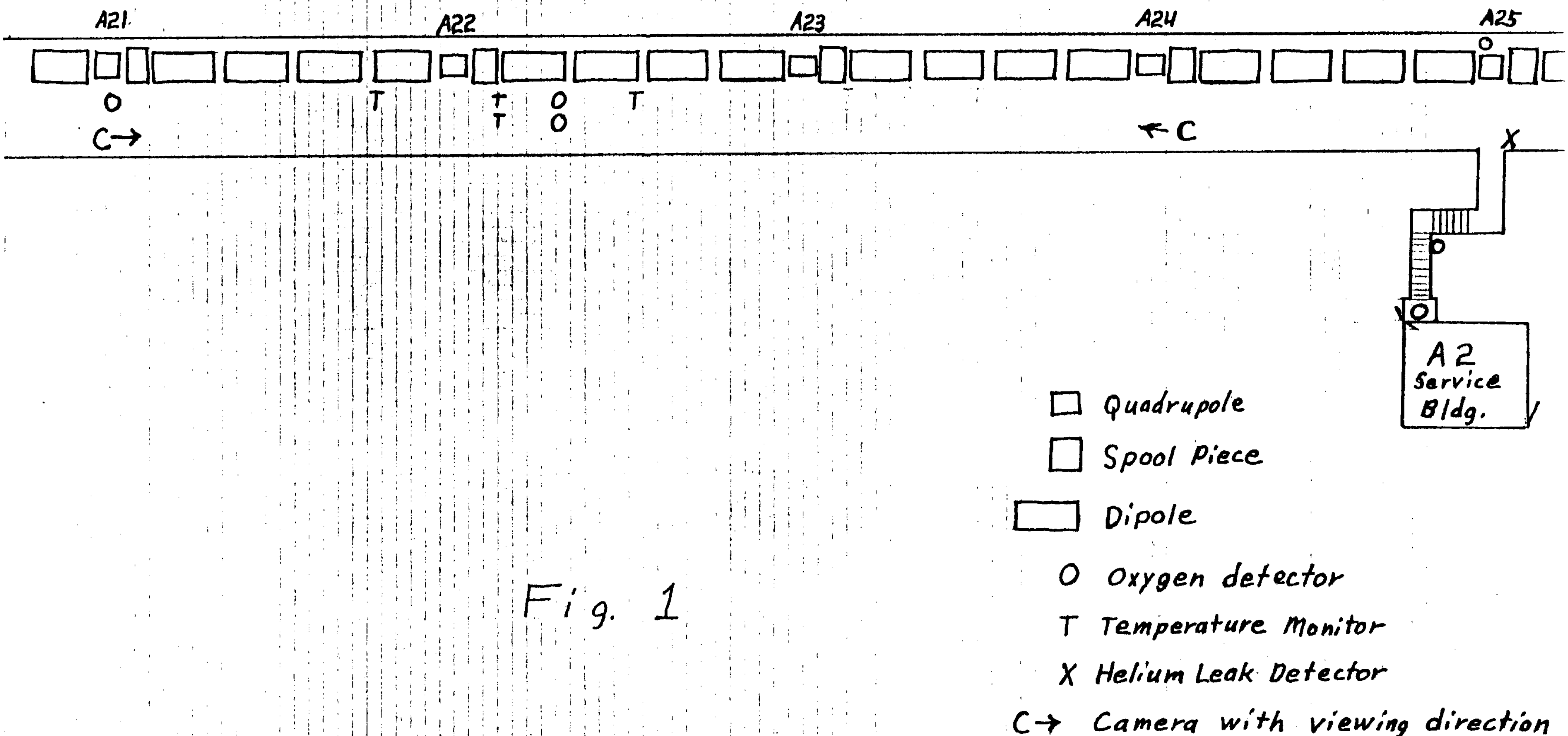
However, 20 feet upstream and 40 feet downstream, the temperature change was only about 10°C. We believe, as mentioned before, that there was a zero offset problem on the thermometer at A-22-2, but that the change in temperature is correct.

2. The large fluctuations in temperature at A-22 are probably due to turbulence in the tunnel air.

IV. CONCLUSION

Although the results of the test show that such an accident is not benign, it also shows that fast action can prevent personal injury. Clearly the first problem encountered in the region of a break of this sort is low temperature with oxygen a secondary problem. An individual who does not move away from the immediate area fast enough, could in one breath damage his lungs. The time response for this particular accident showed that an individual walking rapidly would exit from the first exit. However, accidents that occur closer to an exit would decrease this time interval. In general, the most reasonable response is to move quickly from the area, keeping low, and exit from the second exit removed from the spill area.

It should be mentioned that there was no apparent physical damage to the Saver equipment, the Main Ring, or to the Main Ring tunnel. The only damage that occurred was to an extension cord that was draped around the Kautzky valves. The outer insulation jacket shattered from the cold.


A21
A22
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A2
Service
Bldg.
Quadrupole
Spool Piece
Dipole
O Oxygen detector
T Temperature Monitor
X Helium Leak Detector
C→ Camera with viewing direction

Fig. 1

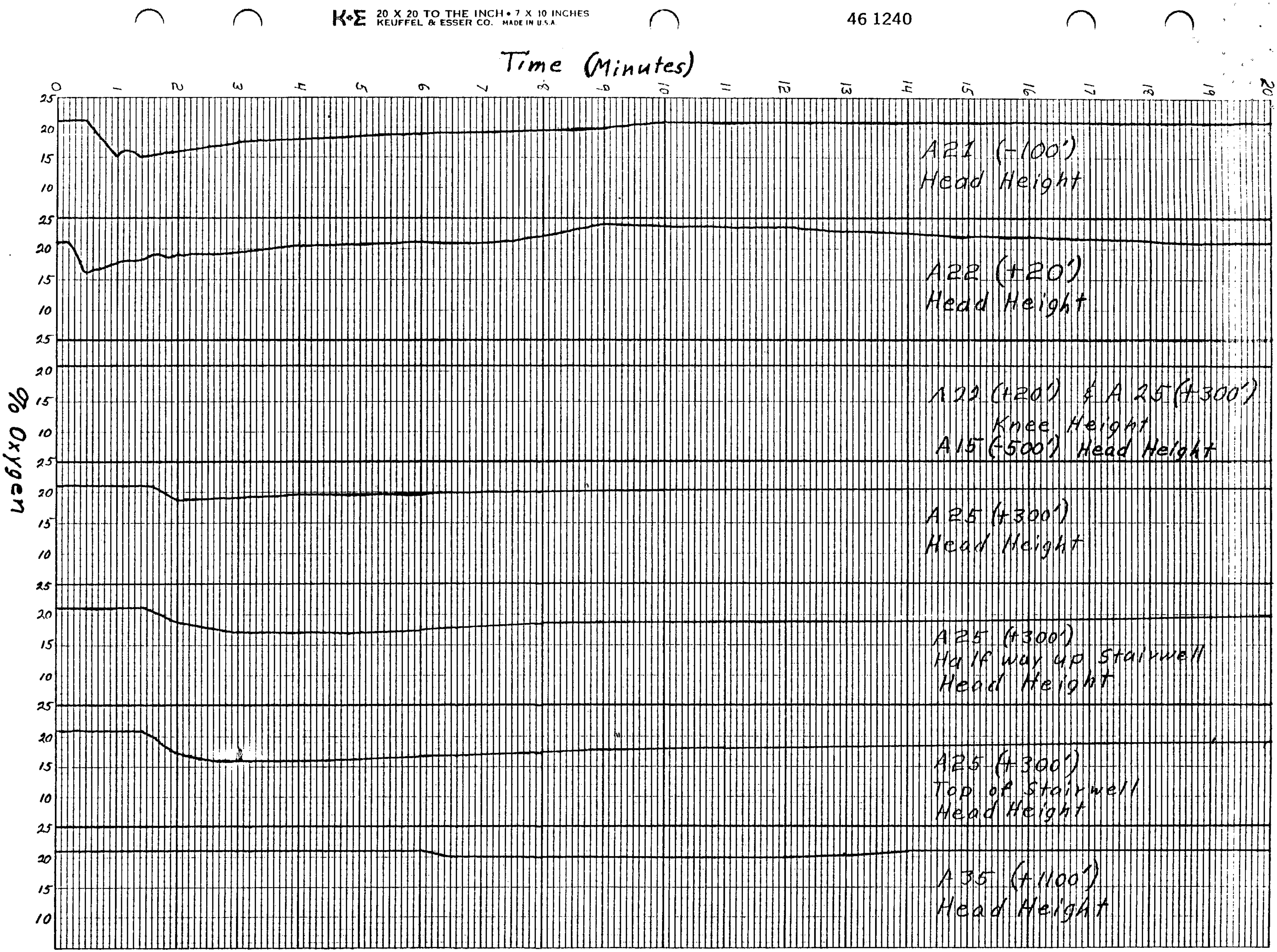
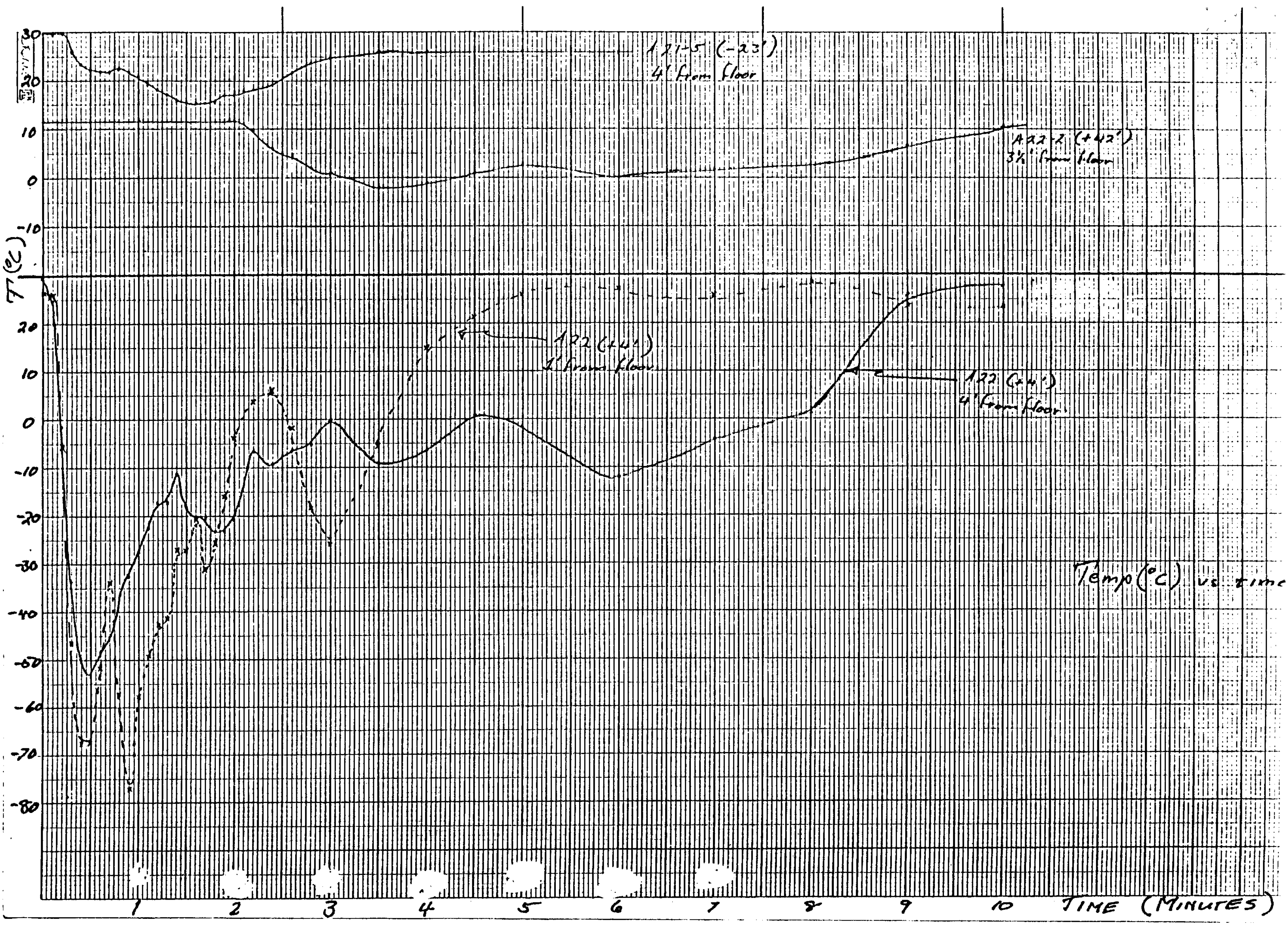

K+E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1240
Time (Minutes)
% Oxygen
A21 (-100')
Head Height
A22 (+20')
Head Height
A22 (+20') & A 25 (+300')
Knee Height
A15 (-500') Head Height
A25 (+300')
Head Height
A25 (+300')
Half way up Stairwell
Head Height
A25 (+300')
Top of Stairwell
Head Height
A35 (+1100')
Head Height

Fig. 2



A21-5 (-23')
4' from floor
A22-2 (+42')
3½' from floor
A22 (+41')
2' from floor
A22 (+41')
4' from floor
Temp (°C) vs time
T (°C)
TIME (MINUTES)

Fig. 3

K+E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1240

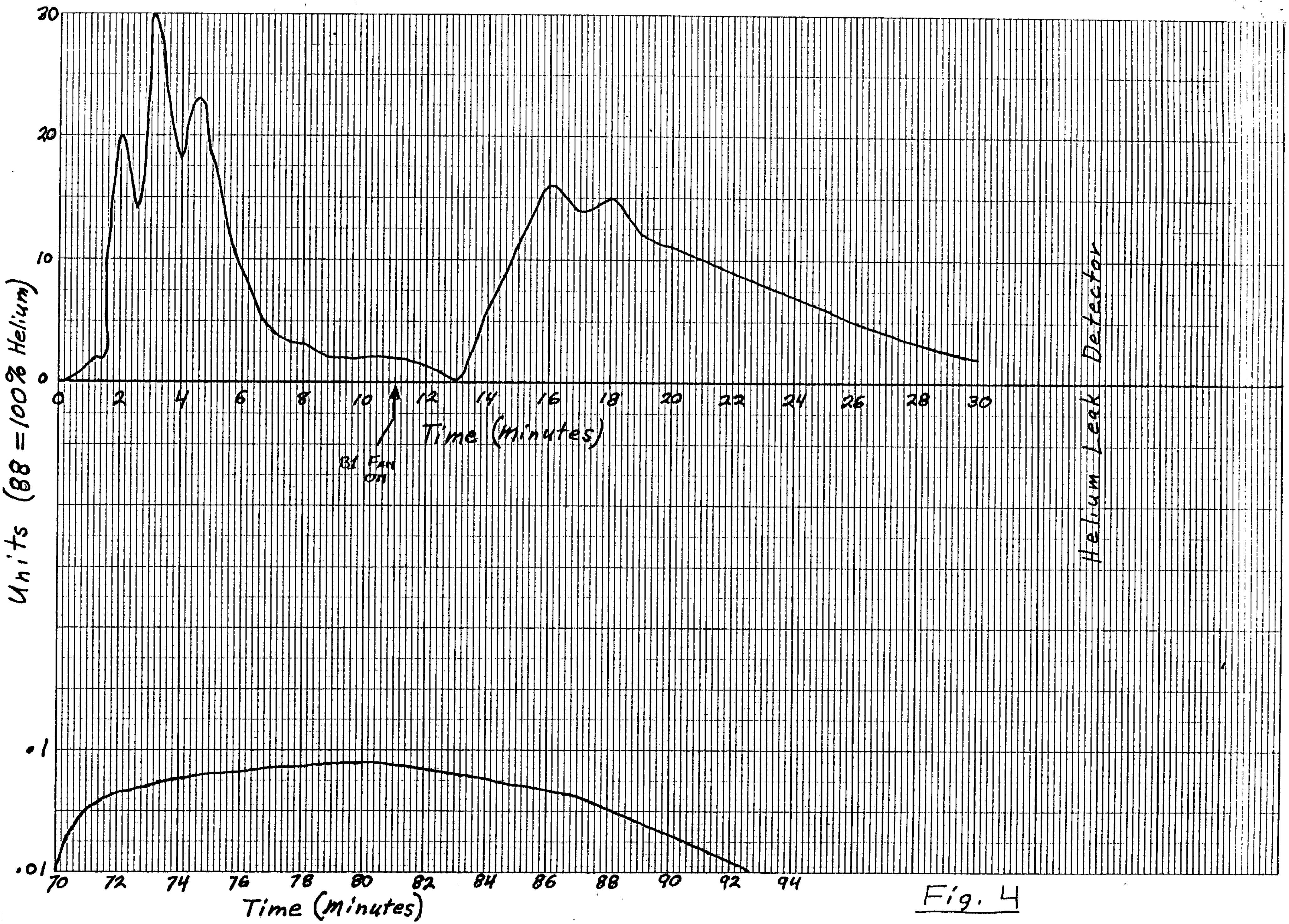


Fig. 4

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RECD
JUN 20 1983
FERMI LAB.

June 17, 1983

To: H. Casebolt

From: R. R. Parry

Subject: Oxygen Cell Life Expectancy

We have been in the oxygen montoring business for over two years now and enough oxygen cells have died to allow us to start getting an idea of their longevity.

A total of 20 cells have expired with a mean life of 45 weeks. This value is deceptive since the range is very large. We have two cells that have lived up to 90 weeks and a few others that died after only 20 weeks. This characteristic is best indicated by the standard deviation statistic of 23.6. As we increase our sample size over the next year, I suspect that the lifetime of the cells can be characterized as a normal distribution.

It is also worthy to note that the cells that have failed, fail in two ways. Either the output is drastically reduced, or the cells output is erratic; slight movements of the cell cause the output to change. Most cell failures fall into this latter category.

J. Anderson
D. Austin
C. Bonham
D. Cossairt
R. Scherr
R. Zifko

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CELL #( 21 )=? C


*** CALCULATE STATISTICS MODE ***
WHAT DATA GROUP (X OR Y)? Y
DATA GROUP IS CELL LIFETIME (WEEKS) THEREFORE CELL # WILL NOT BE USED.
LOW CELL LIFETIME (WEEKS)= 18
HIGH CELL LIFETIME (WEEKS)= 98
RANGE = 80
SUM OF CELL LIFETIME (WEEKS)= 909
MEAN =  45.45
VARIANCE = 558.3657894737
STANDARD DEVIATION = 23.62976490517

***INSERT DATA MODE***
CELL #( 21 )=? P


***PLOT MODE***

LOWER LIMIT OF X=? 1
UPPER LIMIT OF X=? 20
INCREMENTS OF X=? 1
X AXIS LABEL=? CELL NUMBER
Y AXIS LABEL=? OXYGEN CELL LIFETIME (WEEKS)
Y INCREMENT= 1.7
Y AXIS AT X= 1
X AXIS AT Y= 18



                    OXYGEN CELL LIFETIME (WEEKS)
        18        35        52        69        86        103
          +---------+---------+---------+---------+---------+
C  1      I--------------------------------------------*---
E  2      I                     *
L  3      I                                 *
L  4      I                    *
   5      I                     *
N  6      I *
U  7      I           *
M  8      I                               *
B  9      I    *
E  10     I*
R  11     I       *
   12     *
   13     I      *
   14     I           *
   15     I     *
   16     I                        *
   17     I      *
   18     I                                         *
   19     I        *
   20     I     *

***INSERT DATA MODE***
```

```
READY

RUN

X AXIS PROMPT? CELL #
Y AXIS PROMPT? CELL LIFETIME (WEEKS)

***INSERT DATA MODE***
CELL #( 1 )=? R
NAME OF DATA FILE TO BE RETRIEVED ? OXYLIFE

***INSERT DATA MODE***
CELL #( 21 )=? T

***TABLE OF ELEMENTS***
CELL #( 1 )= 1          CELL LIFETIME (WEEKS)( 1 )= 98
CELL #( 2 )= 2          CELL LIFETIME (WEEKS)( 2 )= 56
CELL #( 3 )= 3          CELL LIFETIME (WEEKS)( 3 )= 75
CELL #( 4 )= 4          CELL LIFETIME (WEEKS)( 4 )= 54
CELL #( 5 )= 5          CELL LIFETIME (WEEKS)( 5 )= 56
CELL #( 6 )= 6          CELL LIFETIME (WEEKS)( 6 )= 22
CELL #( 7 )= 7          CELL LIFETIME (WEEKS)( 7 )= 40
CELL #( 8 )= 8          CELL LIFETIME (WEEKS)( 8 )= 72
CELL #( 9 )= 9          CELL LIFETIME (WEEKS)( 9 )= 26
CELL #( 10 )= 10        CELL LIFETIME (WEEKS)( 10 )= 20
CELL #( 11 )= 11        CELL LIFETIME (WEEKS)( 11 )= 32
CELL #( 12 )= 12        CELL LIFETIME (WEEKS)( 12 )= 18
CELL #( 13 )= 13        CELL LIFETIME (WEEKS)( 13 )= 30
CELL #( 14 )= 14        CELL LIFETIME (WEEKS)( 14 )= 40
CELL #( 15 )= 15        CELL LIFETIME (WEEKS)( 15 )= 29
CELL #( 16 )= 16        CELL LIFETIME (WEEKS)( 16 )= 60
CELL #( 17 )= 17        CELL LIFETIME (WEEKS)( 17 )= 30
CELL #( 18 )= 18        CELL LIFETIME (WEEKS)( 18 )= 90
CELL #( 19 )= 19        CELL LIFETIME (WEEKS)( 19 )= 33
CELL #( 20 )= 20        CELL LIFETIME (WEEKS)( 20 )= 28

***INSERT DATA MODE***
```