"DOSE AND LINEAR ENERGY TRANSFER SPECTRAL MEASUREMENTS FOR THE SUPERSONIC TRANSPORT PROGRAM"

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The Air Force Weapons Laboratory (AFWL) in conjunction with the Federal Aviation Administration is flying radiation monitoring systems on board aircraft provided by the Air Weather Service. The purpose of the package, called the High Altitude Radiation Instrumentation System (HARIS), is to measure the radiation hazard to Supersonic Transport passengers from solar and galactic cosmic rays. The HARIS was fabricated by Solid State Radiations, Inc., and includes gaseous linear energy transfer spectrometer, a tissue equivalent ionization chamber and a geiger meuller tube.

The HARIS is flown on RB-57F aircraft at 60 000 feet from Eielson Air Force Base, Alaska. During solar active periods, crews of the 58th Weather Reconnaissance Squadron are on alert to launch the aircraft during solar flares. Notification for launches and the proper alert status are provided by the Solar Forecast Center located in the North American Air Defense Command Chyenne Mountain Complex in Colorado.

Data from the HARIS are reduced at the AFWL to give rad and rem dose rates measured by the package during the flights. Results presented include ambient data obtained on background flights, altitude comparison data and solar flare data.

The Air Force Weapons Laboratory (AFWL) is conducting a theoretical and experimental program in defining the radiation hazards to man at high altitudes and in space. Experimental efforts have included tissue equivalent ionization chambers (TEICs) for dose measurements and linear energy transfer (LET) spectrometers for energy deposition measurements. Particle spectrometers are also flown to define the physical environment (Ref 1).

In 1965, the AFWL and the Federal Aviation Administration (FAA) agreed to measure the biophysical aspects of the radiation environment encountered by passengers and crews at the high operating altitudes of the Supersonic Transport (SST). The objective of the program is to provide operational data for the Advisory Committee on Radiation Biology Aspects of the SST[1] so that they can recommend appropriate actions to protect the passengers and crews of the SSTs.

To be operati nally relevent, the data must be obtained at the altitudes associated with SST operation - approximately 60,000 feet. Background data taken during solar ambient periods are required and must be obtained at high geomagnetic latitudes, as well as normal latitudes. Measurements must be taken during energetic solar particle events at high geomagnetic latitudes. To measure these events, the program must continue through the upslope, top and downslope of the current solar cycle.

Operational Approach

The AFWL/FAA instrument is called the High Altitude Radiation Instrumentation System (HARIS) and will be discussed in more detail later. It is designed to fly on the RB-57F aircraft of the 58th Weather Reconnaissance Squadron (58th WRS), 9th Weather Reconnaissance Wing, Air Weather Service (AWS). The RB-57F can fly higher than 60,000 feet and can remain at this altitude in excess of five hours if necessary. The HARIS was first flown on background missions near Kirtland AFB, New Mexico (the location of the 58th WRS) in September of 1966.

Initially, the package was mounted beneath the navigator's seat, causing undersirable shielding for the sensors. In February 1968, the HARIS was relocated in the upper pressurized compartment of aircraft (see Fig 1) resulting in shielding much closer to that envisioned for SST passengers and crews. The shielding above the sensors on the RB-57F is 0.5 gm/cm^2 aluminum as opposed to an estimated 3.5 gm/cm^2 for the SST.

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[1]Formerly the Standing Committee on Radiation Aspects of the SST.

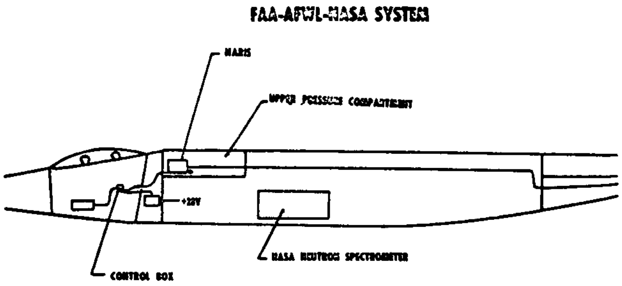

Fig. 1

Kirtland Air Force Base is at 35° geographic latitude and about 45° geomagnetic latitude. This is too far under the earth's magnetic belts to receive significant changes in dose rates from energetic solar charged particle events. In March 1968, one RB-57F and two flight crews of the 58th WRS were deployed to Eielson AFB, Alaska (near Fairbanks, geomagnetic latitude 65° N) to stand alerts for solar flares. At that time the operational portion of the program was given the nickname Operation Cold Flare by USAF. From Eielson, the aircraft can fly as far north as 75° geomagnetic.

Under the initial plan, alert conditions and launch requests were relayed from AFWL to the 9th Weather Reconnaissance Wing Command Post and then to Eielson. The requests were based on information from the Solar Forecast Center (SFC)[2] at the North American Air Defense Command Cheyenne Mountain Complex. The complexity of life support procedures of the RB-57F makes launches fairly slow. On the highest alert condition launches were required no more than three hours after notification.

This system proved too slow in launching the aircraft after flares dispite an increase in support to two aircraft and three flight crews. The launch time was too long and the alert chain too cumbersome. The data gained from proton events in February, March and April of 1969, showed that only very high energy protons - greater than 100 Mev - contributed to the dose rate at SST altitude. The vast majority of such particles come very quickly, so they arrive before the aircraft can be launched.

In an effort to shorten the response time, FAA requested USAF to provide more support for the program. The AWS increased support for the program in June of 1970, to three aircraft and five crews, resulting in a vastly improved alert posture. Under the highest alert condition, an aircraft can reach 60,000 feet one hour after notification. In addition, the alert conditions and launch notifications are sent directly to Eielson by SFC.

Figure 2 shows the current routes used by the aircraft launched to measure solar flares. The shorter Lima route is used by the initial aircraft flying with a reduced fuel load so that it can reach SST altitude more quickly. The longer Mike route is flown by follow-on aircraft and on background missions. Route flown previous to June 1970 was similar to the Mike route.

Instrumentation

The HARIS[3] was developed by Solid State Radiations, Inc. (SSR), Los Angeles, California, under contract to the FAA. AFWL prepared the specifications for the package and monitored the technical aspects of the contract. Four nearly identical instrument packages were fabricated in all. Included in the system are a linear energy transfer spectrometer (LETS), a tissue equivalent ionization chamber (TEIC), a geiger counter (GMT) and a digital recorder.

The choice of sensors was based on the radiation environment at 60,000 feet. The field is a conglomeration of protons, neutrons, electrons, gamma rays, heavy particles and photons. Establishing the physical spectrum would be impractical so the sensors measure the dose rate directly. The TEIC measures the total ionization in the chamber which can be directly related to dose.

The LETS measures the ionization from each individual particle track and can thus establish the quality factor for the radiation. The damage done by an ionization track can increase out of proportion to the number of ions if the track is sufficiently thick. Thus, the total ionization must be multiplied by a parameter (called the quality factor) which takes into account the ionization per unit distance or linear energy transfer (LET). The quality factor can vary with the type of cells being considered but a curve has been established which should allow for any effect (Fig 3, Ref 3).

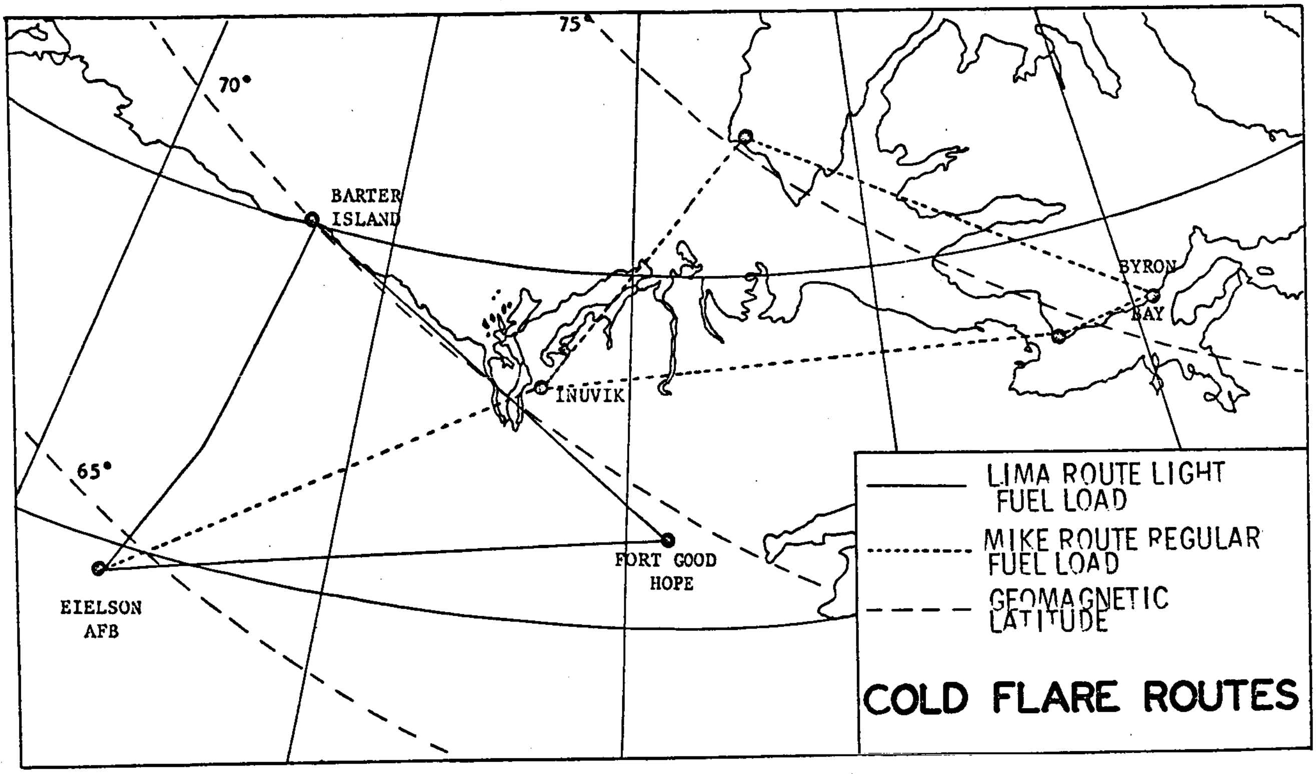

Fig. 2

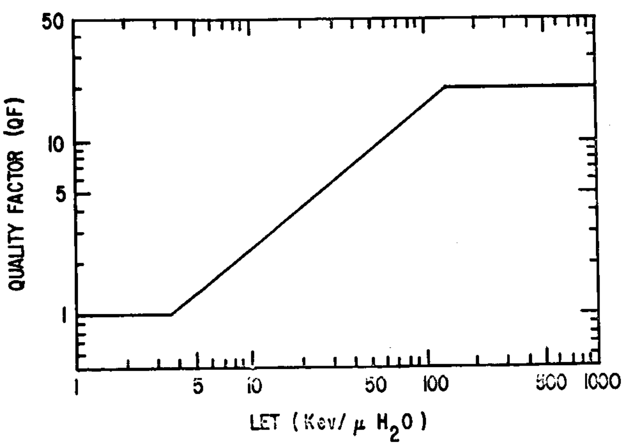

Fig. 3

The geiger counter is used to show consistency in changes in dose rates indicated by the other sensors. Digital readout is used to simplify data reduction.

The LETS is a spherical chamber two inches in diameter with a 3.5 mm lexan wall. It is filled with methane to a pressure giving a path length through the chamber diameter equivalent to four microns of tissue. The anode is a central needle with a high voltage applied between it and the evaporated aluminum coating the inside of the sphere. This voltage is regulated through the use of an Am^{241} alpha source in a side arm counter.

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[2]SFC is a part of the 4th Weather Wing. AWS

[3]A more complete discription of the HARIS is available in Ref 2.

The alpha particles traverse a diameter of the chamber and will deposit a known energy. The voltage can be corrected up or down through the use of these calibration pulses, thus, allowing for changes in the gas pressure or consistency.

Events measured by the LETS are sorted by a ten channel pulse height analyzer according to their LET. The channels increase in width by a factor of two with the channel one lower boundary at .2 Kev/micron and the channel ten upper boundary at 200 Kev/micron. The LETS is accurate in measuring dose rates from about 1.0 mrem/hr to about 2 rem/hr.

The ionization chamber has a moderately tissue equivalent lexan wall 3.2 mm thick. It is the same size as the LETS to allow intercomparison of results. The filling gas is tissue equivalent, pressurized to three atmospheres absolute. The digital readout is logarithmically related to the dose. The TEIC will measure from about 0.3 mrad/hr to about 25 rad/hr.

The digital recorder writes the data on tape every two mintes. Twenty seconds of each cycle is allowed for the electronics to return to normal after the four-second readout period. Then the sensors accumulate data for 96 seconds.

Physically the HARIS is 12" x 8" x 12" and weighs 25 lbs. It draws .5 amp at 28 v DC.

Calibration Procedures for the HARIS

Certain calibration and monitoring procedures have been applied to the HARIS on a routine basis since the summer of 1968. These include internal alpha spectrum analysis and alpha pulse monitoring, gamma calibration and a neutron constancy check. The spectrum from the LETS Am^{241} alpha pulses is examined and the shape of this spectrum along with analysis of the alpha pulses themselves can reveal the relative degradation of the LETS.

HARIS instruments are calibrated on the Cs^{137} gamma range at AFWL before and after deployment to Eielson AFB. These exposures are used primarily to calibrate the TEIC, but they are also a good check on the LETS.

At Eielson, the LETS and TEIC are in turn exposed to a 100 millicurie Am-Be neutron source. These exposures are used as a constancy check and are made, if possible, before and after individual flights. All available check point voltages, as well as the cycle time of the digital tape recorder are monitored.

In addition to the routine checks, proton and neutron calibrations have been performed on the LETS and TEIC to check their response to these particles. In general the sensors respond adequately if they are handled properly.

Data Reduction Procedures

The HARIS digital tape recorder writes the data with bits incorrectly spaced to be used on a computer. A tape to tape converter is used to rewrite the data on a tape which can be read by a Control Data Corporation (CDC) 160a computer. The 160a changes the format of the data and writes it in standard record lengths which can be read by the CDC 6600 computer at AFWL.

The CDC 6600 punches the raw data on cards, as well as in a printout so that erroneous records can be removed. Finally, the flight position and time information is merged with the raw data which is reduced on the 6600 using a standard program. The program prints rad and rem dose rates, GM tube count rates and standard deviations along with position, altitude and time for each reading.

Data from all the sensors can vary greatly given the two-minute recording intervals. To smooth out the variations, the data are averaged over ten record (20-minute) periods. These periods are advanced five records (10-minute) at a time so that each data frame is effectively reduced twice.

The TEIC dose rate is derived by interpolating between the calibration curves obtained for the sensor before and after deployment to Eielson AFB.

To reduce the ten channels of LETS information, a number of counts is first subtracted from each channel readout. These are "background" counts which originate in the instrument from two sources. The first source is internal conversion electrons from the Am^{241} alpha source. The second source is spurious pulses from the electronics of the instrument. "Background" counts are likely to change with time, therefore, the spectrum to be subtracted is established by running the instrument at sea level in the aircraft before the flight.

A rad dose rate is extracted from this spectrum using standard techniques. To obtain a rem dose rate, the spherical shape of the sensor must be allowed for. Rossi's triangle unfolding technique (Ref 4) is used to redistribute the counts in a new spectrum from which the rem dose rate can be obtained.

The TEIC rad dose rate is more reliable than the LETS rad dose rate as a result of uncertainties in the "background" mentioned above. This "background" is concentrated in the lower channels of the LETS readout. The TEIC rad dose rate is used to modify the LETS rem dose rate readout. The lower four channels of the LETS all have a quality factor of one and the fifth channel has a factor of 1.2. The TEIC dose rate, minus the dose rate for the upper five channels of the LETS, is used as the dose rate for the lower five channels. This method eliminates use of the less reliable channels in the final rem dose rate readouts.

Data From Background Missions

Flights made during solar ambient periods generally show rem dose rates right at the bottom of the effective measurement range of the LETS. The error likely at this extreme is quite large - as much as 40 percent for the rem dose rate. The TEIC rad measurement is more accurate with a probable error of 20 percent.

The average measured dose rates to date are .45 mrad/hour and .96 mrem/hour. Considering only measurements from November of 1968 to date, the dose rates have varied only slightly with the solar cycle. The lowest average dose rate measured was in the summer of 1969 at .40 mrad/hour and .85 mrem/hour. The correct average measured rate (January 1971) is .50 mrad/hour and 1.03 mrem/hour.

Data From Solar Flares

HARIS data have been accumulated for solar proton events which occured on the following dates: 25 and 27 February 1969, 30 March 1969, 11 - 16 April 1969, 2 November 1969, 24 January 1971. No huge increases over background were measured for any of these flares. However, it should be noted that the measurements were not taken during the ground level neutron peak of these events except in the case of the 30 March 1969 flare. The specific results from each event are listed here:

25 February 1969: Five and one-half (5 1/2) hours after the flare the instrument measured a rad dose rate of .54 mrad/hour and a rem dose rate of 1.1 mrem/hour. The ambient rates at this time were .42 mrad/hour and .90 mrem/hour.

27 February 1969: (No ground level increase) Six hours after the flare the dose rate was 0.5 mrad/hour and 1.2 mrem/hour.

30 March 1969: This is the only case to date where measurements were taken during the ground level neutron peak. Here the data are presented in graph form (Fig 4).

11 - 16 April 1969: There was no ground level increase during this period but VELA >25 Mev proton counts increased substantially. Measurements taken during this period show no substantial increase.

2 November 1969: Thirteen (13) hours after the flare the rad dose rate measured was 0.55 mrad/hour and the rem dose rate was 1.25 mrem/hour.

24 January 1971: Data from this event are presented in Figure 5. The dose rates given are preliminary as the HARIS instruments are still deployed at Eielson so that post-deployment calibrations have not been performed. Such calibrations should not change the readings more than ten percent, however.

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TIME HISTORY 30 MAR 1969 PROTON EVENT (G.L.E.)

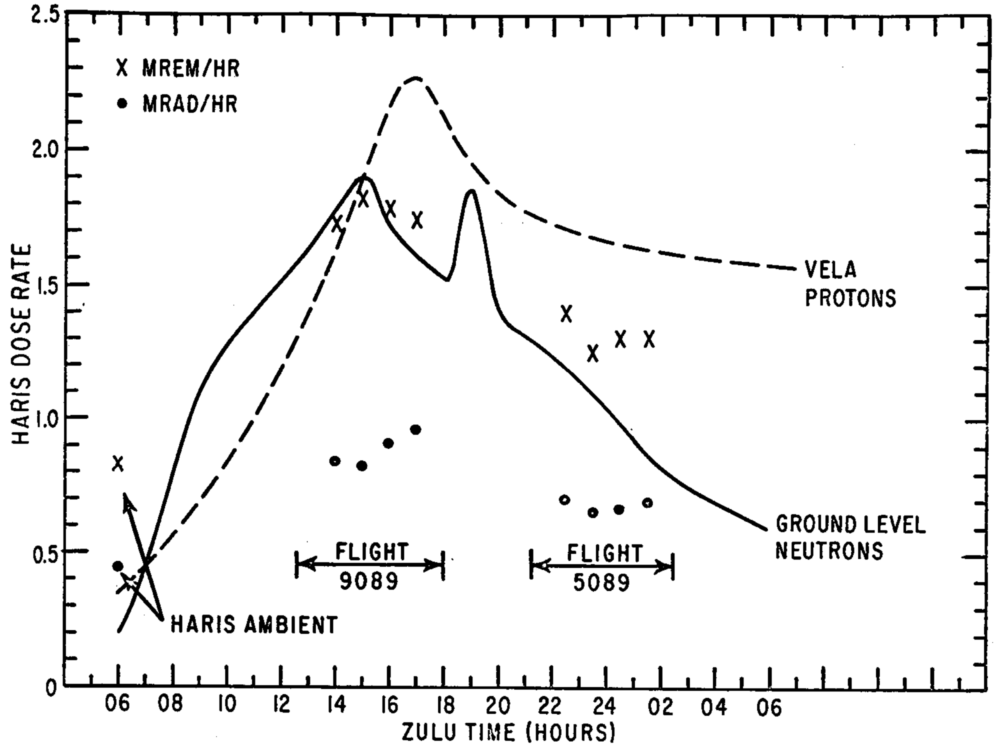

Fig. 4

TIME HISTORY 24 JANUARY 1971 PROTON EVENT