DRAFT

RECOMMENDATIONS REGARDING THE FORBUSH LEGACY DATA AT THE CARNEGIE INSTITUTION OF WASHINGHTON.

By

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

The Forbush legacy data at the Carnegie Institute of Washington have been examined to determine their residual scientific value. The areas of possible scientific value are enunciated, followed by the results of a focused examination of the extent to which the legacy data are capable of providing new understanding now, or in the future. It was demonstrated that the original photographic record contains important information that was never made public, and which is highly relevant to modern day scientific studies. It also has considerable significance for the study of space weather. Ten recommendations are made, that can be summarized thus. **Recommendations 1-6**. *That the photographic records for all five ionization chambers for the period 1935-1960 be recognized as a primary data record of high scientific value that should be preserved in their present form until a satisfactory method to preserve them in electronic form is developed and proven. That a rigorous form of quality control be utilized throughout.* **Recommendations 7-8.** *That a small amount of the data worksheets in the archive be retained for both scientific and historic purposes.* **Recommendations 9-10.** *That a substantial quantity of the material presently in the archive can be culled. That on the basis of the above recommendations, it is expected that the archive can be reduced to approximately a quarter of its original size (about 9 boxes, approximately 24x 14x12 inches, each.*

2. TERMS OF REFERENCE

Following correspondence between Mr. S. Hardy (Carnegie Institution); Ms. H.E.Coffey (the National Geophysical Data Center, NOAA), and Dr. M.A.Shea, it was recognized that an expert opinion was desirable regarding the value of the substantial amount of "legacy data" that was stored at the Carnegie Institution following the death of Dr. S. E. Forbush. Having built and operated an ionization chamber similar to those employed by Forbush, and being aware of the various forms of errors and artifacts that arise in such data, the author was asked to examine the stored data. I was asked to provide an assessment of the scientific value of the material, and if appropriate, provide recommendations regarding its preservation.

Based on the correspondence between Ms. Coffey, Dr. Shea, and Mr. Hardy, the author has worked to the following terms of reference.

(1) Assess the scientific content of the material in the Forbush legacy data, with particular attention to the possibility that there may be, as yet, unexploited information therein.

(2) Assess the physical state, and the degree of organization of the legacy data to determine how it could be preserved.

(3) As appropriate, to cull material that have no residual legacy value.

(4) Make recommendations regarding legacy data that should be retained in a national data archive.

3. SCIENTIFIC SETTING

<u>3.1. The Past</u>. The discovery of the cosmic radiation in 1911 generated a great deal of scientific interest and research. While it was relatively easy to measure over the short tem (days), the comparison of data recorded over greater periods of time was impossible using the technology of the day. By 1930 this had been partially rectified and studies of the longer term (months) began appearing in the literature. Major deficiencies remained, however, and as a consequence, the Carnegie Institute of Washington commissioned the development of a new recording ionization chamber by the University of Chicago, and MIT. Six were constructed, and became known as the Carnegie Type C Ionization Chambers. Their design proved to be most successful, ushering in an unprecedented level of stability and reproducibility.

Five were deployed worldwide by the Department of Terrestrial Magnetism of the Carnegie Institute of Washington. They were located at Cheltenham, VA (USA); Christchurch, New Zealand; Godhavn, Greenland; Huancayo, Peru; and Mexico City, Mexico. They were subsequently operated under the supervision of Scott. E. Forbush until about 1970 (CHECK).

Using the CIW ionization chambers, Forbush almost single-handedly established the manner in which the cosmic radiation in the energy range 1-100GeV varies with time. By 1940 he had proved the existence of a diurnal (daily) variation, and made the pioneering discovery of the "Forbush Decrease" (a sudden decrease in cosmic ray intensity coincident with a large geomagnetic storm). In the 1940's he established that the Sun, on rare occasions, generated short lived bursts of cosmic rays. In the 1950's he demonstrated that the cosmic ray intensity varied with an 11-year cycle, in anti-phase to solar activity.

John A. Simpson developed the "neutron monitor" in the late 1940s, and soon established that it was more stable, and more sensitive than the CIW ionization chambers. Stimulated by the "International Geophysical Year", 1957-8, a large number of neutron monitors were established world wide, and they rapidly became the “cosmic ray detector of choice”. When augmented by continuous measurements by satellite borne instruments in the late 1960’s, the days of the CIW ionization chambers were over. The network was shut down progressively (it seems) between 1960 and 1970.

Dr. Forbush died in 1971(CHECK) and all his working papers and records were put into storage. It is those records that are assessed herein. As far as the author can determine, very few in the cosmic ray community knew of their existence.

3.2 The Present. Using the data from the world-wide neutron monitor network; satellite instrumentation; and the cosmogenic record of the cosmic ray changes prior to the commencement of the instrumental record, the understanding of cosmic ray phenomena has progressed greatly since the “Ionization Chamber Era”. As stated in the first term of reference, we need to

> -Assess the scientific content of the material in the Forbush legacy data, with particular attention to the possibility that there may be, as yet, unexploited information therein.

Our present day understanding and interests can be summarized thus

- A high degree of phenomenological, and theoretical understanding of the cosmic ray modulation processes (Diurnal variation; Forbush Decrease; 11- and 22- year variation) since, say, 1955;

- The use of solar energetic particle (SEP) events to study the configuration of the interplanetary magnetic fields in the inner solar system. In the case of the SEP events seen by ground level instrumentation (the “ground level event”-GLE) data integration times as low as 1 minute have been shown to yield totally new and important information that was not apparent from the coarser 15 minute and often 1 hour data provided by Forbush, and by many members of the neutron monitor network until the 1980’s.

- Recognition that the cosmic radiation generated by the Sun (the GLE and the SEP events) would, in extreme events, damage our terrestrial and spaceborne infrastructure, and constitute a hazard for manned space travel.

Against that background the Forbush legacy data has the potential to provide new and important information as follows

3.2.1 Information regarding cosmic ray modulation during periods of lower solar activity

The sunspot record shows that solar activity rose steadily between circa 1900, and the 1950s. The neutron monitor, and satellite eras have both been restricted to this period of very high solar activity. Our knowledge of the Sun indicates that it will return to low levels of solar activity within the next several decades, and this may have considerable and serious implications for the modern technological infrastructure of mankind, and space travel. As a consequence there is a developing level of interest in the manner in which the cosmic ray intensity reaching the Earth from the galaxy may change in response to this lower level of solar activity.

The Forbush legacy data are the only source of continuous cosmic ray data for the period of increasing solar activity prior to the 1950s, and it is certain that those data will be a vital input to studies of the manner in which cosmic ray phenomena respond to changes in the level of solar activity.

3.2.2 Information about the configuration of the interplanetary magnetic field.

Forbush only published the data for five GLE between 1942and 1956, and at best, he published 15- minute averages. Modern studies of the neutron monitor data show that a great deal of important information resides in finer time resolutions- 1 to 2 minutes for preference. The primary Forbush record was a photographic trace showing each day's results with a potential accuracy of 2 minutes. There is no record that Forbush ever examined the data with this time resolution.

The Forbush legacy data are the only source of higher time resolution data for the four GLE that occurred prior to 1956. There were only about 12 (CHECK) large GLE in the whole historical record, and therefore obtaining higher resolution for these four events could provide a very significant increase in our knowledge of the cosmic ray events, and of the interplanetary magnetic fields.

3.2.3 Information about the Rate of Occurrence of GLE.

The occurrence of GLE appears to be highly skewed to the past. Thus there were seven large GLE in the 18 years between 1942 and 1960; and only five comparable events (CHECK) in the subsequent 45 years. This suggests that the rate of occurrence of GLE decreased for the years of high solar activity since 1960. This counter-intuitive result is supported by the inference from the glaciological record that very large SEP were considerably more frequent during periods of low solar activity- during the Gleissberg Minimum of circa 1890, and during the last 15 years of the Maunder Minimum. (1645-1715).

Forbush was a very conservative scientist. Examination of the primary data tapes (below) shows that all four of the GLE he reported were ~30 standard deviations above the noise, AND were seen at all three of the high latitude stations he operated. There is no record that he ever investigated whether there were smaller events, or events that were not seen at all three stations. (GLE were not his main interest). It is known that he never reported one smaller event (a 6% event in one of his instruments on 4 May 1960), but was later identified in the Godhavn data record following an enquiry from the author of this report in 1960.

The Forbush legacy data provides the only source of information regarding the occurrence of additional, smaller GLE before 1951; i.e, for the period of increasing solar activity when GLE already appear to be more frequent. Confirmation of this

association has major implications regarding space weather, and the understanding of the physics of the process whereby the Sun accelerates cosmic rays.

4. ASSESSMENT OF THE LEGACY DATA

There were 34 boxes (24x14x12 inches)(CHECK) of legacy data. Due to other commitments, and sickness, the author examined the data over the period June 2004 to June 2006. The details of the examination process are given in the Appendix. This section is restricted to stating the conclusions reached after detailed consideration of all the items in the 34boxes, and the data already published either by the Carnegie Institution, or in the scientific literature. The Appendix also provides a brief outline of the operation of the Carnegie Type C Ionization Chambers.

4.1. The Primary Data Records.

The ionization chamber integrated the cosmic ray ionization current on a capacitor, and the resulting voltage was measured by an electrostatic galvanometer that focused a light beam on a 58mm wide strip of photographic paper, that was continually advanced by a clockwork mechanism at 20mm per hour. The resulting 480 mm strips of photographic paper was taken off each day, developed and fixed. They were subsequently analyzed and stored at DTM. The other primary data of importance were the instrument operators log books that recorded the accuracy of the time recorded on the photographic record; the occasional tests for the sensitivity of the galvanometer; and details of any malfunctions and adjustments.

To the authors considerable surprise, the original primary photographic records for essentially the whole 37 year program, for Cheltenham, Christchurch, Godhavn and Huancayo, were in the archive. Forbush clearly recognized the desirability of being able to re-examine the data at a much later date. The daily strips were annotated with the date and time; joined to make a continuous strip for each month; folded at each midnight; and made into a concertina like stack with a full day visible at a time. Each month of data was carefully stored between robust cardboard or composition board strips. The data were in remarkably good condition. The archive had clearly been stored in a dry place- there was absolutely no adhesion of the sheets. The photographic material was in excellent condition- there was no sign of poor fixing, or fading. The contrast on most strips was excellent, and should permit machine based reading.

At the time of writing, all of the station operators log books have not been identified, although it is believed that they will be located. Failure to locate them would be an inconvenience, but not a fatal problem.

4.1.1 Examination of GLE (refer 3.2.3 above) To determine whether there may be new, unrecognized information in these tapes, the author examined each of the known GLE in the three high latitude ionization chambers. It was immediately obvious that they contained much more information than Forbush ever published. The two "western solar disk" GLE exhibited minute to minute fluctuations that, in terms of the current model, will provide absolutely vital information. It is safe to say that if the detailed high time resolution data from one of the GLE had been published, the development of our understanding of the GLE, and the properties on the interplanetary magnetic field would have been changed in the 1960s. Today, that record will be a major contributor to what the author expects will be a major change in our understanding of the GLE. **This examination demonstrated in the most positive way that there is major value remaining in these primary records that has not been utilized to date.**

4.1.2 Search for unrecognized GLE (refer 3.2.2 above) The author then scanned some of the earliest records from 1936 and 1937, to test the hypothesis that there might be unrecognized GLE in the record. (It takes about 5 hours to scan a years data, so the author limited this investigation to about 1.5 years).Two traces were found in the record from one station with the characteristics of a GLE; however they occurred during the "setting up" period of the instrument, and may be a consequence of a testing procedure. Further study will be required to resolve this. Nevertheless, my considered opinion from this examination is that it is highly likely that careful examination of the records for 1936-1951 (i.e., prior to the commencement of the neutron monitor record) will locate small unrecognized GLE with time profiles similar to the others recognized by Forbush. Further, it is my considered opinion that the event of 4May 1960 (see section 3.2.3) would not have been recognized by Forbush without the concurrent information from elsewhere in the world. It looked so different on the primary record (because of its short duration) than all the other GLE that he had seen that it is likely that he would have regarded it as a "unresolved artifact"- due to instrumental malfunction, or outside influence of some kind. It is only now, with our improved understanding of the GLE process, that an interpreter would be likely to recognize it for what it is. Further, it is only in the last 20 years that it has been recognized that some GLE may only be seen above the instrumental threshold at one location in the world. Thus the primary record warrants scanning without the expectation that a GLE will be seen at all three high level ionization chambers. **In summary, this examination, although not as positive as the case of the GLE, provides strong support that there may be major value remaining in these primary records that has not been utilized to date, for a period of time when solar conditions were different from those of the "neutron monitor era".**

4.2 The Secondary Data Records.

The deflections of the galvanometer were read off the photographic record for each hour and tabulated, hour by hour. The same was done for the atmospheric pressure, and the presence and amplitude of "bursts" in the record (nuclear reactions in the walls of the chamber). The ionization data were corrected for pressure change; the bursts subtracted; and averaged to yield bihourly data. These were published by the Carnegie Institution for the period .

After some years of operation, Forbush recognized that there were long term drifts in the several instruments that did not correlate with one another. He concluded that these were due to changes in radioactive contamination, and instrumental factors. He used his detailed knowledge of the instruments, and the information in the station log books, to remove the long term drifts from the data, and published the correction factors. He made it clear that he was dissatisfied with the result, but that it was the best he could do based upon his detailed knowledge of the data, and the instruments. Based on my own personal experience with an ionization chamber, I am confident that no one would be able to achieve what Forbush could not do in this regard. The balloon borne ionization record 1934-1969 provides the long term changes in the cosmic ray intensity that could not be measured with the Carnegie ionization chambers, so the deficiency in long term stability in the Forbush data is of no great consequence.

In the author's opinion, Forbush has done all that is possible to remove the long term drifts from the data. His tabulated and published bihourly data , plus the long term corrections, provide the best possible reduction of the data, and the author is of the view that there is no value in retaining the intermediate data processing material.

The only exception is for the largest Forbush decreases in the period 1936-1951. The neutron monitor data have shown that there may be several hours difference between the commencement of Forbush decreases at different points on the Earth's surface. These differences provide information on the direction of the interplanetary magnetic field, and the properties of the interplanetary shock waves that produce them.

RECOMMENDATIONS

Based upon the detailed examination of the Forbush legacy data, and for the reasons given in the preceding sections, the author makes the following recommendation;

High Priority Recommendations

(1) That the photographic records from Cheltenham (Fredericksburg), Christchurch, Climax (limited period), Godhavn, and Huancayo be recognized as a data source with major potential to provide new information, now, and as research proceeds in the future.

(2) That those records themselves, for the interval 1935-1960, be stored for at least two further decades, or until recommendation (4) has been fully implemented and tested in detail.

(3) That the existence of the legacy archive be made known to the research community, and access given for research purposes.

(4) That a means of scanning the records be developed and tested. In view of the fluctuating density of the photographic records; the variable contrast; the presence of "bursts" that must be recognized and removed; and the presence of corrupted data due to instrument malfunction, some form of quality control will be necessary. A time resolution of 2 minutes would be desirable, and possible insofar as the quality of the records is concerned.

(5) That the station operating log books be retained as an integral part of the photographic record discussed above.

(6) That a brief “handbook” be provided (by the author of this report) that will allow others to understand the nature of the photographic record, and the pitfalls therein. By restricting the records being preserved to brief intervals of time, the majority of the problems in the interpretation of the data have been eliminated

Second Level of Priority Recommendations

(7) That, where possible, the hourly data be located for the six or so major Forbush decreases that occurred in the interval 1935-1950, and be stored in an electronic manner.

(8) That the archive be examined for material of historic value (as distinct from scientific value)

Reduction in Size of the Archive

(9) Already, the author of this report has identified ephemeral scientific material that has been removed. Based on the above recommendations, it is expected that another 6 boxes, of thereabouts, can be removed, and this can be achieved by the author in the near future if desired.

(10) On the basis of the above recommendations, and with appropriate consolidation, the author expects that the highest priority archive (Recommendations 1-6) would occupy the following space
- Six or seven boxes (24x14x12 inches) of primary photographic records.
- Two boxes of primary ancillary data.

The secondary priority material would occupy very little space- some 100 pages at maximum.

APPENDICES.

A1. The Assessment Process Used.

A2. Brief Description of the Carnegie Type C Ionization Chamber.

The Carnegie Type C Ionization chamber (also known as the Compton- Bennet ionization chamber), was designed to measure time dependent changes of ~0.3% over several years, and for this reason it was a difference instrument. The ionization current from the 19 litre main chamber was balanced by a current of opposite sign from the “compensation (or balance) chamber” containing a radioactive source (Uranium) inside the main chamber. This greatly reduced the chambers’ sensitivity to environmental effects, and to a number of instrumental effects (changing voltages; changing gas pressure in the chamber) yielding good stability on the short to medium term (~5 years). The position of the Uranium source was adjustable to allow the balance to be adjusted to keep the instrument “on scale”. Over time, this was done on all chambers other than the one at Cheltenham.

The ionization chamber was shielded by 100 mm of lead to restrict its response to the higher energy component of the secondary cosmic radiation. The net ionization current (the cosmic ray, less the balance current in opposition) was integrated on the capacitance between the centre electrode of the chamber, and earth. The voltage across this capacitance was measured by an electrostatic galvanometer that focused a light beam on a 58mm wide strip of photographic paper, that was continually advanced by a clockwork mechanism at 20mm per hour. A light spot provided the prevailing value of atmospheric pressure. At the end of each hour, the central electrode was connected to earth for three minutes The 480 mm strips of photographic paper were taken off each day, developed and fixed. They were subsequently analyzed and stored at DTM. The other primary data of importance were the instrument operators log books that recorded the accuracy of the time recorded on the photographic record; the occasional tests for the sensitivity of the galvanometer; and details of any malfunctions and adjustments.

The sensitivity of the galvanometer was calibrated at regular intervals, and was a vital number used in the conversion of the observed deflection of the light beam on the photographic strip, to percent change in ionization.

The Uranium source contributed ~ 15% of the ionisation current in the main chamber [*Compton, Wollan, and Bennett*, 1934], the amount being determined by the position of the source in the balance chamber. This resulted in a poorly know change in the current in the main chamber due to the source. Forbush clearly recognised [*Forbush*, 1954, 1958] that the decay of radioactive contamination in either chamber, and the variable contribution from the Uranium source, would result in long term drifts of either sign in the recorded data. The size, and stability of such background effects could be established by operating the ionization chambers in a moderately deep mine or tunnel, as was done initially as part of the construction and commissioning of one chamber [*Compton, Wollan, and Bennett*, 1934]. There is no record, however, that this was done again for any of the chambers to examine the long term effects. Without any other independent means to calibrate the long term stability of the instruments, Forbush was restricted to investigating periodic or episodic variations that could be validated by correlation with other phenomena. In recent years *McCracken and Heikkila* [2003} have circumvented this problem using the high altitude ionization chamber obtained by H.V.Neher, between 1933-1967, in conjunction with the Forbush data..

It should be noted that the ionization currents were exceedingly small. The resistances between the central electrode; the main and balance chambers (at opposite potentials with respect to earth); and earth, were required to be $\sim 10^{18}$ ohms. The gas pressure was maintained at 60 atmospheres (CHECK) to increase the ionization current, and loss of pressure was a recurrent problem. The station log books record that the ionization chambers themselves , and the electrometers, were interchanged at various times, presumably because of difficulties with the electrical insulation, and pressure leaks. In the authors view, the changes in sensitivity were removed, as far as was possible, by Forbush with full knowledge of the minutiae of these changes, and that it would futile to try to improve on what he achieved.

The ionization current was a function of the atmospheric pressure and correction was made at DTM for that prior to tabulation in their published records. Note that this pressure sensitivity is still present in the photographic record. There is anecdotal evidence that the record from Godhavn (Greenland) was affected by snow accumulation in the winter.