PROCEEDINGS OF SCIENCE

Haleakala Neutron Monitor Redeployment

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The Pacific Ocean region presents a significant gap in the equatorial coverage of the global Neutron Monitor (NM) network, hindering the detection of Solar Neutron Particles (SNP) and Galactic Cosmic Rays (GCR). To address this issue, we are redeploying the Haleakala Neutron Monitor (HLEA) on the island of Maui. HLEA was established in 1991 but was subsequently decommissioned in 2006 due to funding constraints. Its strategic location at a high altitude on Haleakala mountain, situated in the middle of the Pacific Ocean, offers unique advantages for SNP detection. The reinstatement of HLEA represents an invaluable opportunity to extend ground coverage for SNP and GCR detection, enhance the global NM network, and contribute to a deeper understanding of high-energy particle interactions. By harnessing the potential of this revitalized NM station, we aim to enrich space weather research and improve the efficacy of space weather monitoring systems, thereby enhancing our preparedness and resilience against space weather hazards.

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1. Introduction

The global Neutron Monitor (NM) network plays a vital role in monitoring space weather (SW) phenomena, providing essential data on Solar Neutron Particles (SNP) and Galactic Cosmic Rays (GCR) that have significant implications for space missions, astronauts' safety, and terrestrial infrastructure. However, a substantial gap in the equatorial coverage of the NM network exists in the Pacific Ocean region, spanning a longitudinal expanse of 162 degrees from Princess Sirindhorn NM in Thailand, to Mexico City NM. This gap restricts our ability to detect and study high-energy particles in this critical area, hindering our understanding of SW hazards and the potential impacts on our technological systems.

To address this challenge, we are undertaking the ambitious initiative of redeploying the Haleakala Neutron Monitor (HLEA) on the island of Maui. HLEA was initially established in 1991 as part of the University of New Hampshire (UNH) NM system, providing valuable data on GCRs and SNPs. Unfortunately, due to funding constraints, it was decommissioned in 2006. However, recognizing the strategic significance of its location, situated at a high altitude on Haleakala mountain and positioned in the middle of the Pacific Ocean, we view the reinstatement of HLEA as an invaluable opportunity to extend ground coverage for SNP and GCR detection and enhance the global NM network.

The high-altitude location of HLEA (approximately 3 km or 3052 m) offers several advantages for SW research. The increased altitude results in a higher neutron count rate compared to sea-level NMs, improving the detection sensitivity to GCR variations. Moreover, the low latitude of HLEA (latitude 20.71 degrees) facilitates SNP detection as it allows for extended exposure to the Sun, maximizing the Sun's elevation and enhancing the sensitivity to SNP events.

HLEA will also provide information about FDs for GCRs with rigidity above ~13 GV [1], which are important for understanding solar modulation effects on GCRs during the 11- and 22-year solar cycle modulation and Forbush decreases (FDs). Additionally, the sensitivity of HLEA to SNP events has been demonstrated through its historical detection of three SNP events (a list can be found in [2]). Thus, HLEA, when restored, would continue to play a significant role in SNP detection.

For demonstration purposes, Fig. 1 shows the five-minute average count rate for 2003 November

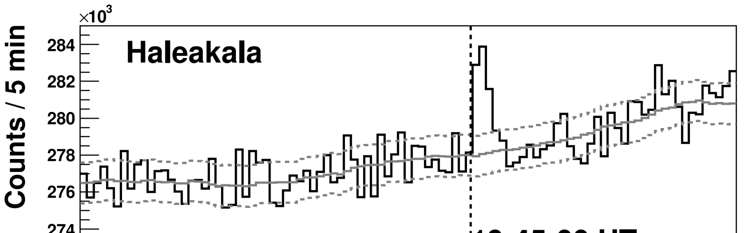

Figure 1: Most recent SNP event observed by the old Haleakala NM station in 2003 November 4. Picture taken from [3]: *Five-minute averages of the counting rate observed by the Haleakala The smooth solid line is the averaged background, and the dashed lines are* ±1σ *from the background.*

4, measured by the old HLEA station: as seen, at 19:45 UT, the detector measured a ≈ 2% increase over the background due to SNPs [3]. The significance of the SNP excess reported in [3] is 7.5 σ.

If the number of tubes were to be reduced by a factor of three (see Sec. 1.1), the uncertainty on the background counts would scale roughly as $\sqrt{3}$, resulting in a significance of 4.3 σ, a little bit less than the significance of the excess observed by Mexico City NM, for the same event.

Note also that SNP events have been detected by smaller NMs [4]. Therefore, a scaled-down version of HLEA would still be highly sensitive to SNP events with an amplitude of 2% or more over the background.

By reinstating HLEA and reintegrating it into the global NM network, we aim to significantly enhance our understanding of high-energy particle interactions in the near-Earth space environment. This improved understanding is crucial for mitigating potential risks posed by SW phenomena to astronauts, aircrews of transpolar flights, and critical electronic devices both in space and on the ground.

1.1 The HLEA Detector

HLEA Detector will be installed inside a 20’ shipping container, 20’ long, 8’ wide, and 8’ 6" high. Figure 2 shows a model of the HLEA shipping container with double doors and two banks of 3-tubes on each side, for a total of 6-tubes.

Figure 3 shows a picture of the HLEA proposed location, adjacent to the Chicago building and near the DKIST telescope. The location and configuration of the proposed HLEA NM has been carefully planned to minimize the project’s overall footprint and ground disturbance.

The container would be placed on removable concrete footings 6" above grade. The electrical power and data lines for the container would be pulled from the main panels from the nearby buildings.

The proposed project was submitted to the Department of Land and Natural Resources (DLNR) Office of Conservation and Coastal Lands (OCCL), which has reviewed and accepted the application. The first stage of redeployment and testing has already started.

The HLEA detector is being revitalized with the use of the original polyethylene, Figure 4 shows some of the selected polyethylene moderators and proportional BP-28 counter tubes that

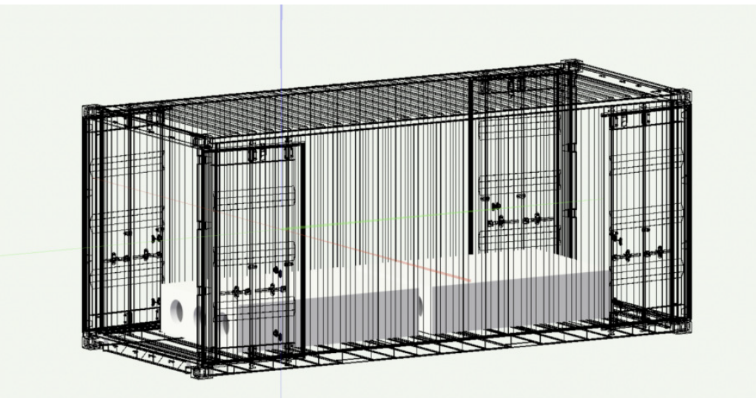

Figure 2: Model of the HLEA shipping container with double doors and two banks of 3-tubes on each side.

Figure 3: Picture of the HLEA proposed location adjacent to the Chicago building and near the DKIST telescope.

Figure 4: Polyethylene blocks that will be reused from the old HLEA NM.

were part of the previous HLEA station. These counter tubes have been safely stored since the decommissioning of HLEA in 2006. The HLEA detector will feature a total of six tubes, which will be physically grouped into banks to ensure redundancy and improved data reliability.

Each tube bank in the HLEA detector will be equipped with its own high-voltage power supply, providing independent operation for enhanced stability. The banks will be placed on a polyethylene and wood platform, ensuring a 4π surrounding thermal neutron reflector system for efficient neutron detection. To further enhance data acquisition and transmission capabilities, each tube bank will have its own dedicated harness and ethernet/Wi-Fi router.

To maintain accurate timing and environmental monitoring, a GPS unit, precision barometer (0.1 mbar), and thermometer will be incorporated into the HLEA detector system. These components will support the full array of tubes and provide crucial information for data analysis. The HLEA detector will be remotely rebootable, and a backup uninterruptible power supply (UPS) will

Figure 5: Tested BP-28 counters in IfA library.
396, 248 and 348 are in long-term test
217, 337, 422, 239, 176 and 425 to be long-term tested

Figure 6: Tested BP-28 counters in container.421, 391, 246 are corroded. 392 pulls down HW. 400, 356, and 397 show high noise levels. 230, 173, 243, 394, and 197 are good.

be employed to ensure continuous operation during power outages.

Regarding temperature control, the operating temperature range of an NM-64 detector is relatively large. However, to ensure optimal performance and data accuracy, the building housing the HLEA detector may require thermal control. Meteorological data from 2020 suggests that environmental controls will be minimal, with typical day/night excursions of approximately ±7°C and summer/winter excursions ranging from 0°C to 15°C. These temperature variations are relatively small compared to those experienced in New Hampshire (either Durham or Mount Washington).

During this past year, we performed some tests in Haleakala to estimate the present conditions of the moderators and of the counters. We ran and completed some tests with modern electronic readout boards in collaboration with the Bartol Research Institute at the University of Delaware. The 21 BP-28 tubes were carefully examined and checked. Some signs of leaks and corrosion were found on 3 counters (421, 391, and 246) that were labeled as compromised. All the other tubes were in good condition and passed the test for further analysis on electric noise levels and uniformity of response. We performed some preliminary tests with new electronic readout boards on the good tubes. After testing, the tube counters were ranked, and 9 of the best tubes were moved from the cargo container to the IfA library. Three of these tubes were connected to the readout electronics for a long-term operation test and for temporal stability checks, Figure 5. All cylindrical moderators were cleaned and stacked back inside the cargo container with the BP-28 counters inside, Figure 6.

Figure 7 shows the typical Boron Trifluoride BP-28 tube spectra. Both primary at 2.3 MeV and secondary at 2.8 MeV peaks are clearly visible. The well-known incomplete energy deposition of ${}^3Li^7$ and ${}^2He^4$ is clearly seen as a shoulder on the left side of the primary peak, as can also be seen on the right panel of Figure 7. On the right side of the secondary peak, a high channel noise is clearly seen. The spectra were fitted to measure the width of the primary peak, which enables the qualification of the uniformity of the tube response along with the 191 cm wire, and the level of noise can be used to estimate the counter quality.

After studying the BP-28 spectra properties, we selected 9 best counters, and 3 of them were connected to the rack (Figure 5) for long-term stability tests. Figure 8 shows the results of two weeks of testing for tubes 348, 396, and 248. Tube 348 demonstrated sporadic noise during the first

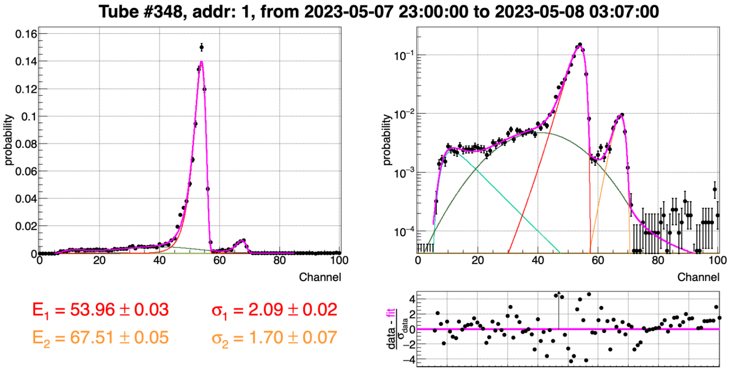

Figure 7: Fitted BP-28 tube spectra. Left: linear scale. Right: logarithmic. Bottom right: pull distribution. Positions and widths of the primary and secondary peaks are indicated.

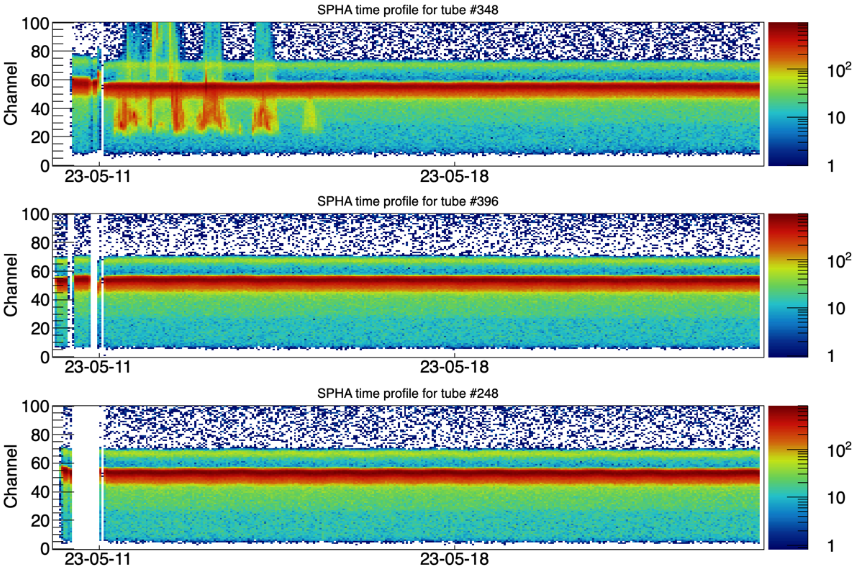

Figure 8: BP-28 tube counts over time. Long-term tests for 3 tubes. Top: tube 348. Middle: tube 396. Bottom: tube 248

week; however, later on, the spectra stabilized. The other tubes were stable over time. We plan to continue our long-term qualification tests for the remaining tubes.

1.2 Electronic Boards, Test, and Calibration

For the new front-end electronics (FEE), we will use a setup identical to that of the Durham NM station at UNH. The FEE is composed of a single printed circuit board (PCB), a preamplifier, a shaper, a discriminator, and an optical isolator. The system is designed such that onboard threshold adjustments can be performed. The transistor-transistor logic output has a width proportional to the pulse height and allows for time-over-threshold analysis of each tube's pulse. Finally, an optical isolator and a driver allow long cable runs to counters.

The parts list and the PCB layout of the FEE boards remain unchanged from the construction of the supporting electronics for Durham, Mount Washington Observatory, and Leadville NMs. These hardware and software systems are applicable to other NM installations and are available for us to be used as part of our collaboration. Using the same setup will allow us to speed up the process of redeployment.

The new boards (with spares) will be procured and populated at UNH with assistance from UH staff. Each board will be tested with a pulse generator to ensure proper operation, dynamic range, and impedance. Each board will be thermally stressed to induce infantile failures. All testing and calibration processes will be performed at UNH. The new boards and FEE will then be shipped to Hawaii at Haleakala and will be integrated with the proportional count tubes.

1.3 Integration and Data Acquisition System

The integration of the HLEA detector will occur at UNH. The complete structure without the counter tubes and the electronics will be assembled at UNH; after that, the container will be shipped to Maui and deployed to the summit. Once at the summit, the tubes and the electronics will be integrated into the counters, and the data-taking will start. The full installation will take place before the Spring of 2024.

The data acquisition will be developed on a remote stand-alone National Instruments cRIO computer (a compact real-time embedded industrial controller) and commercially supported LabView software. This enables remote instrument monitoring, data transfer, and UTC time (coordinated universal time) synchronization via the internet. The data from each tube will be recorded independently, including real-time histogram diagnostics. The National Instruments cRIO computer is equipped with a field-programmable gate array (FPGA), eight reconfigurable module slots, and ethernet ports. The setup is equipped with National Instruments interface modules for counters, ADCs, and digital I/O. The cRIO processor provides UTC time stamps, performs rate computations, and buffers data for automated FTP (file transfer protocol). Finally, a web server is also available.

Data collected electronically at HLEA will be recorded on the internal hard drives of two independent computers inside the station. Data will be transferred to the investigators at UH on a daily basis, where they will be examined for anomalies and prepared in an archival format. UNH will provide an off-site backup of all raw and processed data. Data will consist primarily of ten-second count rates from each tube. One-minute averages of the data will also be saved and electronically transferred. Each minute, the GPS time, detector temperatures, and barometric pressure will be recorded. Remote connection to the entire HLEA setup, including temperature, pressure, and switching system commands, will be established. Additional information, such as the pulse height spectrum of each NM tube, will be recorded for a few minutes on a daily basis for offline analysis and monitoring purposes. A monitoring system will be developed and displayed at the SW control center at UH, where the unusual activity will generate alerts in the SW monitoring. This will consist of a graphical interface where all of the above information will be displayed.

Extensive data-taking and end-to-end tests will be performed on the HLEA detector, studying each proportional counter tube, all the electronics and software, and inspecting the data quality. Official data-taking will start after one week of successful end-to-end tests.

Raw data will be archived at UH and mirrored at UNH for backup. A reduced data set will be sent to the Neutron Monitor Database (NMDB). NMDB provides public access to NM measurements from stations around the world through a webpage interface accessible to the public (`https://www.nmdb.eu/`). The system provides access to real-time and historical data. The public data will be in the form of hourly averages of uncorrected counts, pressure-corrected counts, and barometric pressure. Meteorological conditions at the station at the time the data were taken will be included together with terms and conditions of use, including appropriate acknowledgment of NSF funding. Data not archived in the NMDB can be obtained by directly requesting them from the host institution.

1.4 Conclusion

In conclusion, the revival of the Haleakala Neutron Monitor (HLEA) marks a pivotal step in addressing the existing gap in equatorial coverage within the global NM network. This gap has been limiting our ability to effectively detect and study SNP and GCR, which are integral to understanding SW phenomena.

By reestablishing the HLEA on Maui's Haleakala mountain, we are strategically positioned to observe these high-energy particles. HLEA's advantageous placement at a higher altitude and its location in the heart of the Pacific Ocean contributes to its unique capacity for SNP detection and GCR monitoring.

The HLEA detector's core components, the original proportional counter tubes and polyethylene moderators, have been carefully conserved. These elements are being reintegrated into the setup to ensure reliable and accurate performance. Housed within a specially designed 20' shipping container, the detector's impact on the environment is minimized and earned the approval of the DLNR OCCL, allowing us to advance to the project's next phases. HLEA is poised to extend our ability to detect SNP and GCR events. This effort strengthens the global NM network and opens avenues for a more profound understanding of SW.

Aknolodgement

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