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CARBON NANOTUBES BASED THERMAL DISTRIBUTION AND TRANSFER BUS SYSTEM FOR 1U CUBESATS and the SPACE ENVIRONMENT ATTENUATION MANIFOLD SHIELD

Abstract

On the road of the development of our first satellite, the NEE-01 PEGASUS, we encountered the need of developing a heat dissipation and transfer system to components that will need such heat in order to avoid freezing while the satellite was in the eclipse part of its orbit.

Many materials and many designs were tested in order to achieve the best thermal transfer rates as indicated by the specifications derived from extensive testing and from the manufacturing specifications of our target components until we achieved the best results using multi walled carbon nanotube sheets to manufacture a thermal transfer bus that met our needs.

Such thermal transfer system will allow the spacecraft to route the internally generated heat, as well as any heat coming from outside that our MLI allows to penetrate the external hull to be efficiently sink to our four battery arrays which we are using as thermal dissipation masses. In order ensure the survival of our COTS electronics longer than any other previous missions that have used this approach we designed a miniature version of a Multi Layer Insulation system, the requirements were to fend off up to 60% of incoming heat, to protect the electronics against alpha and beta particles, to shield them from plasma discharges and to attenuate most of X and gamma radiations. The result was the SEAM/NEMEA Space Environment Attenuation Manifold, a multi stage MLI capable of blocking alpha, beta, X and Gamma radiation and to block up 67% of incoming heat, while retaining internal heat over eclipse phase, NEMEA can also attenuate and even neutralize EMP and Plasma discharge events.

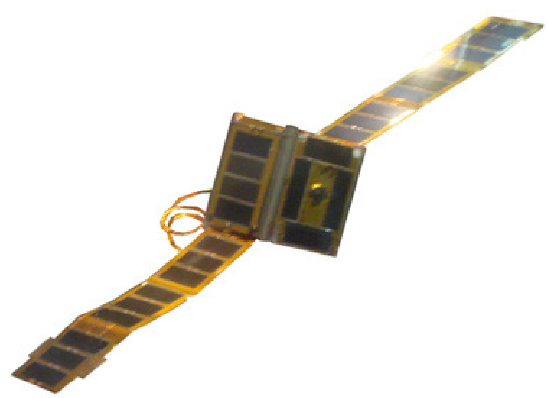
Introduction: EXA is the Ecuadorian Civilian Space Agency, a civilian NGO created in 2007, in charge of the administration and execution of the Ecuadorian Civilian Space Program – ECSP.

As a part of the ECSP, on April 2010 the EXA Directorate approved a project proposed by the Space Operations Director, for building the first Ecuadorian satellite, the project was named Project PEGASUS and with that we moved on to the next phase of the ECSP.

NEE-01 is the Ecuadorian registry number meaning 'Ecuadorian Space Ship – 01' in Spanish, so the spacecraft was christened **NEE-01 PEGASUS**

Project was to be financed entirely by the EXA and the local industry, specifically QUICORNAC, who provided half the funding needed, total budget was of US$30.000 for the research and building phase, as usual in EXA projects, all personnel was working in 'pro-bono' mode, the funding was solely dedicated to hardware, tools, books and facilities.

Team was led by Cmdr. Ronnie Nader and composed by Sidney Drouet, Manuel Uriguen, Hector Carrion, Ricardo Allu and Gonzalo Naranjo.



The NEE-01 PEGASUS in orbital flight configuration with its 2 DSA Multipanel solar wings deployed

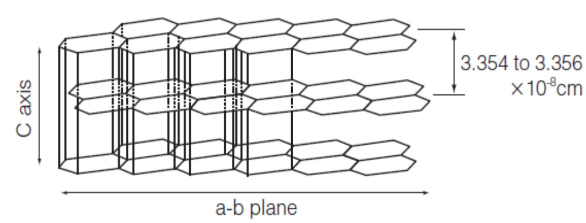
Due the restrictions imposed for the modest budget of the project, one key decision was to use COTS electronics for the spacecraft payloads, this in turn, imposed a high risk of failure for the mission, so we took the approach of investing more resources and research in developing a kind of shield for the spacecraft bus in order to attenuate the space environment effects over our COTS payloads.

Such shield was named SEAM/NEMEA for **S**pace **E**nvironment **A**ttenuation **M**anifold – NEMEA

The shield was designed as a multistage MLI (Multi Layer Insulation), where each phase was designed to tackle a specific aspect of the space environment and designed to work sinergically with the other layers in order to achieve the goal of maintaining a not-so-cosmic environment inside the spacecraft, more into the boundaries of industrial specification operation tolerances of most

Thermal Transfer Bus: However, even achieving this goal will left us with the problem of some high temperature differentials inside the payload, especially during the cold eclipse phase, as the vacuum is not so efficient at distributing heat as air or other fluids, heat from the transmitter circuit will easily building dangerously during illumination phase or our very large battery array can easily freeze on the eclipse phase.

The dominating concept in our design was to make nature help us solve the problem, instead of trying to fight it, so the idea of a heat transport 'highway' on which the molecular random motion could be transmitted efficiently and rapidly from the overheating components to the freezing ones, leveling the temperature gradients between them seemed like a best solution instead of installing radiators and heaters that will consume more power and take up more space.



The molecular geometry of the multi wall carbon nanotubes

We took this approach and began to experiment with thin sheets of aluminum and copper, the best know temperature transfer materials, with mixed results, but in general, good results, copper being the best thermal transfer medium, we find out that the thinner the sheet the fastest the thermal transfer was.

Up to one point in this development we were satisfied with the results, and in terms of numbers and simulations and tests, our problem was basically solved, however, we came across certain information that indicated that a multi walled carbon nanotubes sheet was the best known thermal transfer material, outperforming aluminum 6 times and copper 4 times, as we have settled with our best design being copper based, we decided to invest time and some resources investigating this new option.

We were able to obtain very thin sheets of this multi walled carbon nanotubes from a laboratory in Germany, the sheets were 100µm, 75µm and 25µm in thickness and we installed them over a silicon based thermal transfer substrate from 3M commonly known as thermal transfer tape.

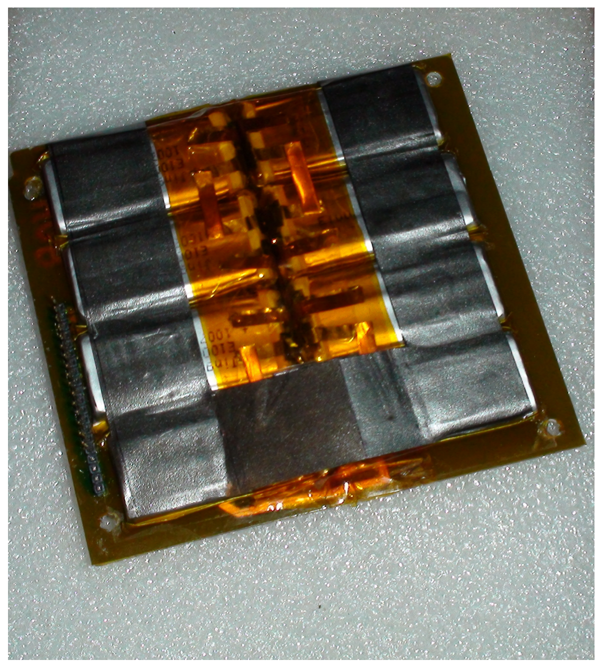
Testing: We setup an experiment to find out which ones were more efficient by cutting a strip of the material of 10cms long by 2cms wide and attaching a thermal contact sensor in one end and a known, verified source of 80C degrees at the other end, the sensor was tied to an online data logger and the results were as follows:

Thickness	Time to reach 65C
100 µm	16 seconds
75 µm	12 seconds
25 µm	7 seconds
Copper 2 mils	48 seconds
Aluminum 2 mils	78 seconds

We repeated this experiment 12 times, ambient temperature was 21C +-2 degrees and atmospheric pressure was 1012 mbars, deviation from the media annotated above was +-4%

From these experiments we could find out that the most efficient sheet was the 25 µm, possibly due that less mass in the thermal transfer bus reduced the thermal inertia or best said, it took less time for the molecular random motion to fill the necessary saturation level for start transferring the motion more efficiently.

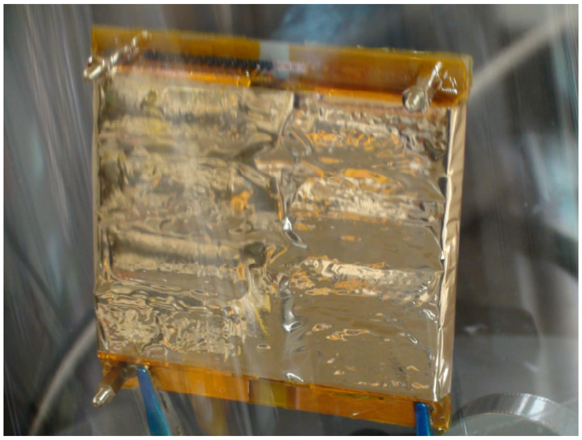
Once those results were digested we designed the geometry of the thermal transfer bus to collect the heat from our thermal sources and shunt it directly to our battery arrays, each one having a mass of 200gr. and with 16 cells each, we shrouded each cell with the CNT sheets and covered them with a Kapton/Mylar protective cover to avoid the heat to radiate back.



One of the NEE-01 PEGASUS battery array prototypes showing the shroud of carbon nanotubes.

As it shows the above picture, 2 tabs of CNT material protrude from the manifold, those we used to connect with the TTB that courses the heat sources in the payload

As annotated before, we discovered later, during some vacuum tests that some important portion of the heat was radiated back so we used the Kapton/Mylar shield in order to attenuate and impede the radiation of heat from the bus, but also to it, as the battery arrays are located just next to the walls of the spacecraft bus and some heat will penetrate the NEMEA shield.



One of the NEE-01 PEGASUS battery array prototypes showing the Kapton/Mylar protective cover while in high vacuum testing

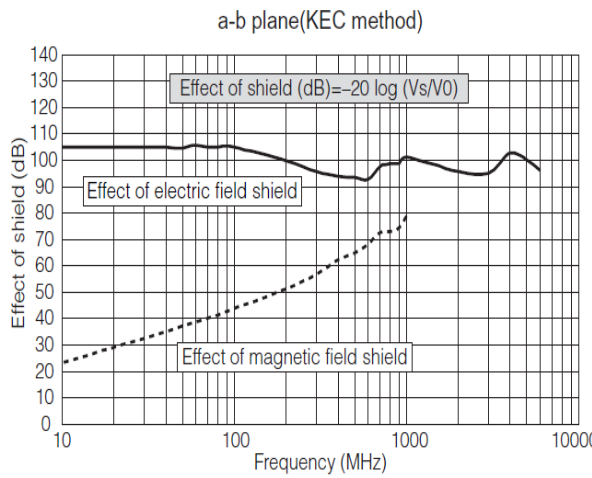
In essence, the idea of a thermal transfer bus inside an spacecraft is to route the heat in a controlled and designed way, minimizing the effects of thermal radiation and using the heat in the most beneficial and uncomplicated way possible.

In essence, the final specifications were:

Parameter	Values
Thickness	0.025 ± 0.010 mm
Density	2.1 g/cm3
Thermal conductivity	1500 to 1700 W/(m·K)
Electrical conductivity	20000 S/cm
Heat resistance	400 ℃

This thermal transfer bus (TTB), coupled with our protective, space environment attenuation shield gives us the necessary level of protection and some degree of control over some variables of the space environment, however we still down know how the carbon nanotubes will interact with the radiation variable, for the radiation amount that the SEMA/NEMEA will let pass inside the S/C. Another interesting question is how it will affect the radiation pattern of the TX module, if it will interact with it, due that the carbon nanotubes conduct electricity too, and for that reason, in hopes of erring on the safe side we covered the exposed areas of the bus with a layer of gold metalized Mylar.

Accordingly to the CNT material provider, these are the electric field specifications:

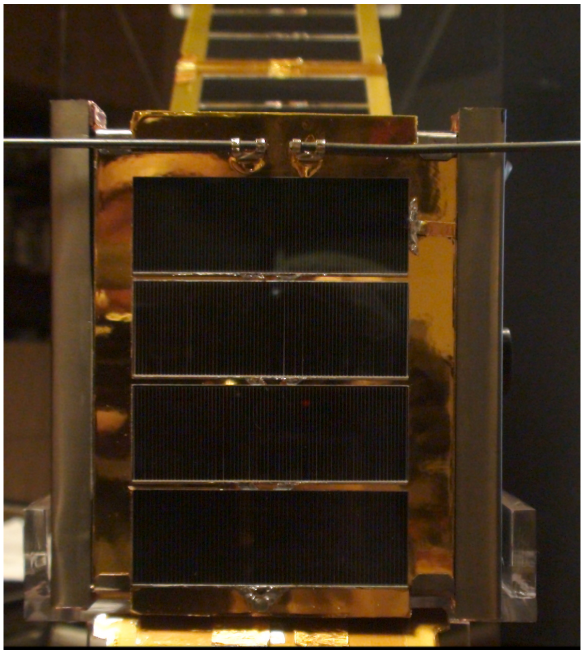


SEAM/NEMEA: As noted on page 2 of this paper, the TTB was coupled to the MLI shield surrounding the spacecraft, which in essence was designed as an scaled-down version of much larger spacecrafts MLIs.

Such manifold was divide into 3 stages or phases, each one modulating some specific aspects of the space environment:

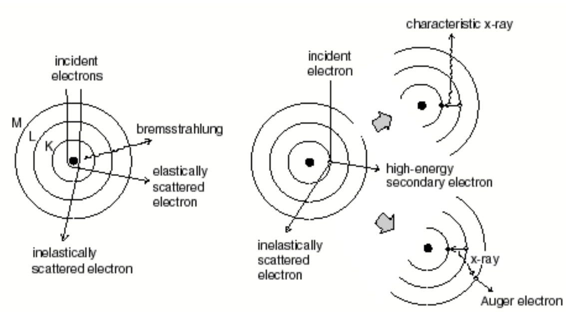
Phase	Function
L0/UPhase	To reflect UV and thermal radiation from sunlight
L1/ βPhase	To handle/deflect/decelerate incoming alpha/beta radiation and EM/plasma fields
L2/γPhase	To handle gamma/X radiation and protons

L0/ UPhase: This phase was designed to be front line of the MLI, reflecting back sunlight with much of its IR component and the UV radiation too, it has a thickness of 0.190mm and it goes over the FR4-06 PCB that holds the solar cells, which in turn are mounted over the UPhase.

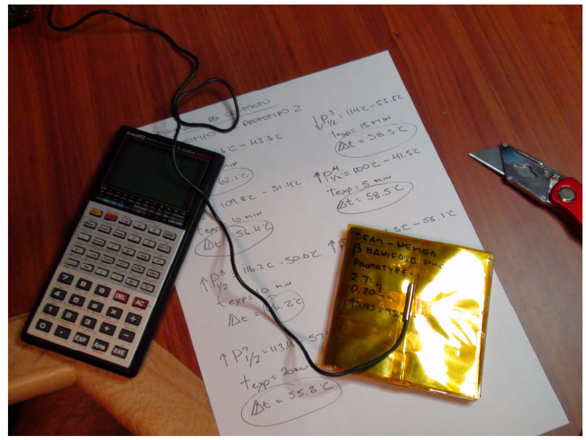


The L0/UPhase of the NEMEA shield mounted over the NEE-01 PEGASUS

L1/ βPhase: This phase goes under the PCB and it is in direct contact with the aluminum structure of the cubesat it is composed of 18 different layers disposed in a patterned array so the main idea is to decelerate incoming electrons without producing or greatly reducing the event of bremsstrahlung. radiation

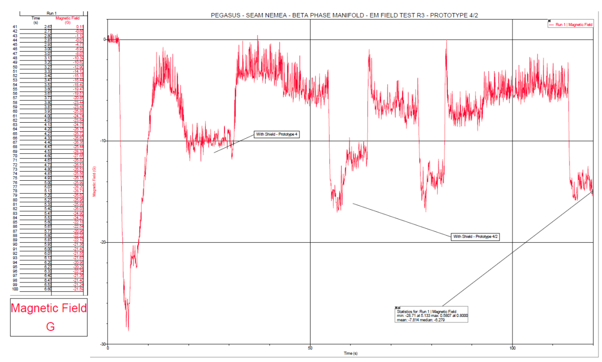


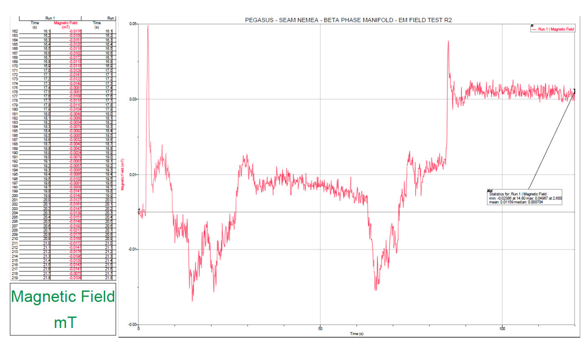
As noted in the picture above, the main idea is to elastically scatter incoming electrons, that is why careful position geometry had to be chosen an tested before a working manifold could be obtained. However, some secondary radiation effects could possibly happen once in orbit, and there is where the γPhase will act as the omega line for those kinds of events.



L1/ βPhase SEAM/NEMEA multi layer insulate.

Another function of the βPhase is to block EM events and plasma environments, experimentation was needed to test our assumptions and for such goal, a plasma chamber was built with a top energy of 35Kvolts, yielding good results:



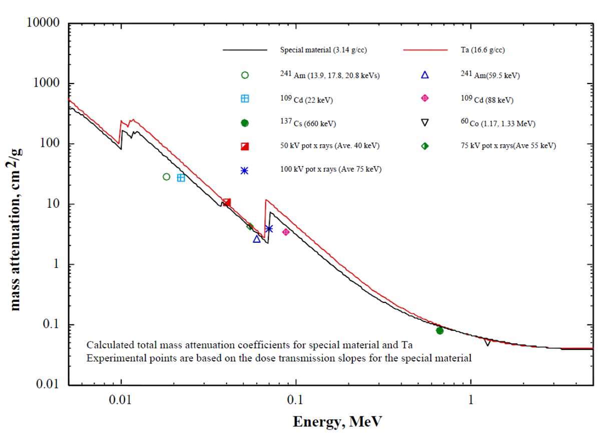


As it can be seen in the above graphs, the lowest points in the curves were caused when the sensor was sorrounded by the βPhase manifold, providing an adequate protection against EM fields.

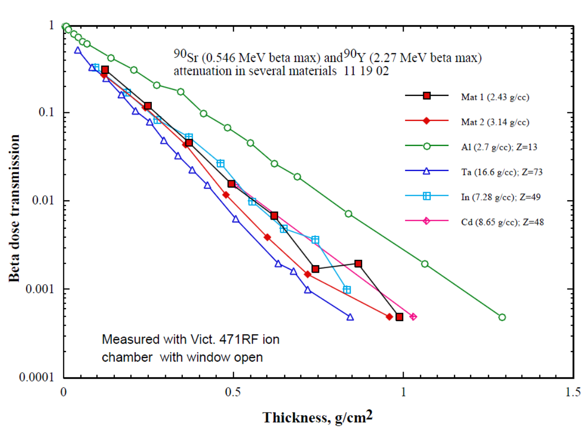
L2/γPhase: This last phase goes inside the aluminum hull of the spacecraft and before the payload; it handles de hard radiation part of the space environment, attenuating the gamma and mid X rays and the high energy protons.

It is 1.25mm thick and is composed by only 4 layers or metallic and a commercial polymer material which role is first to bock mid X rays and them to attenuate low to mid gamma rays up to 60% accordingly to our calculations, and up to 80% accordingly to the provider specifications, which are reproduced below:

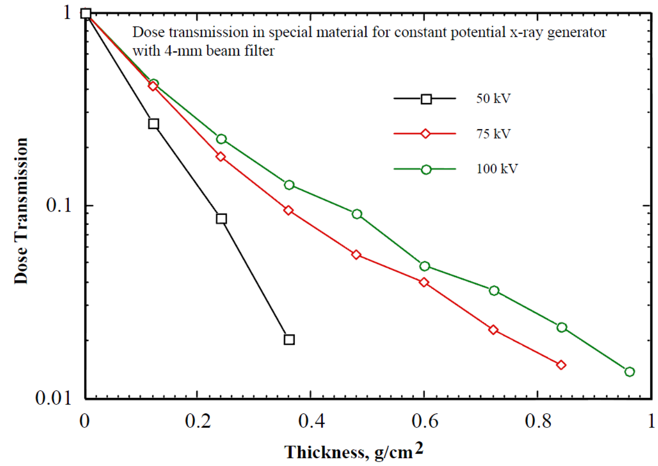
TART model calculations:



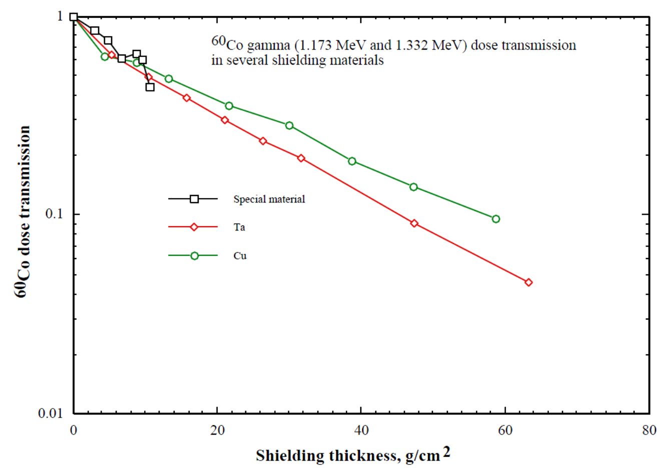
B rays: high energy, radiation source is ^{90}Sr and ^{90}Y:



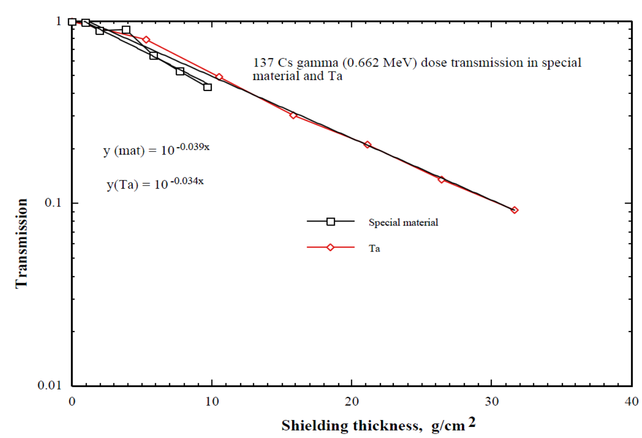
X rays: 50 to 100KeV energy:



Γ rays: high energy, radiation source is ^{60}Co:



Γ rays: mid energy, radiation source is ^{137}Cs:



Γ rays: low energy, radiation source is ^{241}Am and ^{109}Cd:

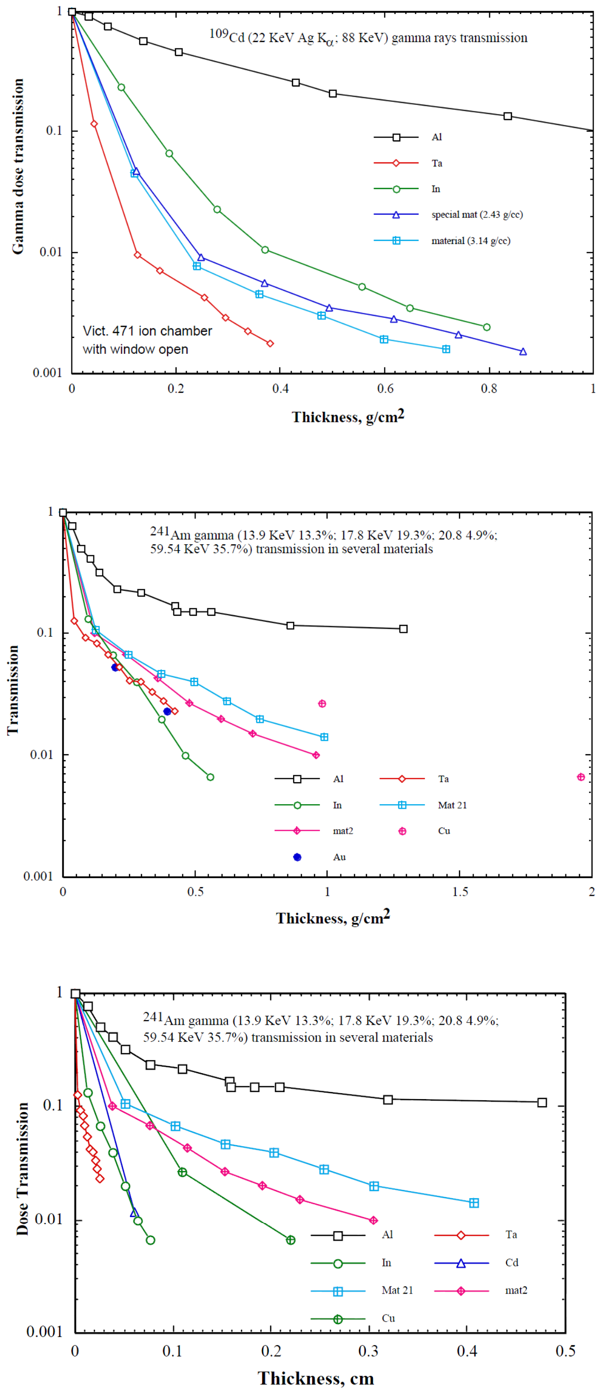
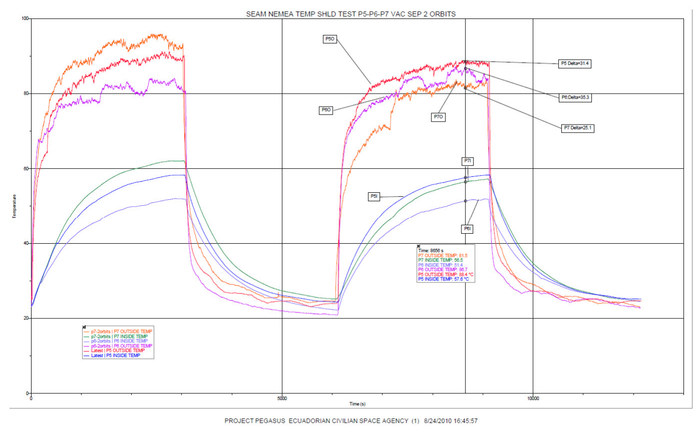


Figure 1. Transmission of ^{241}Am radiation dose through different materials. Results are plotted as a function of material thickness.

As it can be noted on the 2nd graph, the L2 phase also blocks β rays which we use to couple with the L1 phase to reduce any bremsstrahlung radiation that could escape the L1 phase

Thermal protection: the whole manifold was tested with a sunlike thermal radiation source, not including UV rate to produce 120C degrees on the first surface of the manifold, simulating 2 non SSO orbits with almost equal periods or ilumination and eclipse, with the following results:



Acknowledgments: The EXA team that built the NEE-01 PEGASUS and developed the SEAM/NEMEA shield, want to thank our main sponsor, QUICORNAC for its faith and financial support that allowed us to complete this historical project successfully. We also acknowledge the inspiration brought to us by reading the many versions of the Sputnik history and most specially the gallant history of the Amateur Satellite Program.

References:

1- NEE-01 PEGASUS the first Ecuadorian satellite, Paper ID 10055 IAC-2011

2- ECSP: The Ecuadorian Civilian Space Program - Ecuadorian Civilian Space Agency, Aerospace Operations Division - 2007- http://exa.ec.

3- 'Science and Technology in Ecuador' - Books LLC, August 2010, USA

4- The first Ecuadorian Satellite official website http://pegaso.exa.ec

5- NEE-01 PEGASUS – Wikipedia article - http://en.wikipedia.org/wiki/NEE-01_Pegasus

6- The official EXA website: http://exa.ec

7- EXA - BP-37: Guayaquil, Ecuador, April 4/2011 ECUADORIAN SPACE AGENCY UNVEILS ECUADOR'S FIRST SATELLITE http://exa.ec/bp37/index-en.html

8- R. Nader, "The HERMES, Internet-to-Orbit Gateway" UNOOSA, Graz, Austria 2009