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RICH SYSTEM

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REGISTRAZIONE DELLE MODIFICHE / *CHANGE RECORD*

EDIZIONE *ISSUE*	DATA *DATE*	AUTORIZZAZIONE *CHANGE AUTHORITY*	OGGETTO DELLA MODIFICA E SEZIONI AFFETTE *REASON FOR CHANGE AND AFFECTED SECTIONS*
1	20/02/04		First Issue
2	08/07/2005		Updated version New thermal control concept (Section 5) New power dissipation (Section 6.1) Updated analysis results (Section 8)

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ACRONYM LIST

AD	Applicable Document
BOL	Begin Of Life
CGS	Carlo Gavazzi Space
EOL	End Of Life
GMM	Geometrical Mathematical Model
I/F	Interface
ISS	International Space Station
MLI	Multi Layer Insulation
MPA	Minimum Propulsion Attitude
RICH	Ring Image Cherenkov Counter
RD	Reference Document
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TCS	Thermal Control Subsystem
TMM	Thermal Mathematical Model
TRP	Temperature Reference Point
w.r.t.	With respect to

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1. SCOPE

This document describes the thermal mathematical and geometrical models of RICH (Ring Image Cherenkov Counter), a subdetector included in AMS-02 experiment. These models were built to investigate the thermal behavior of RICH during all mission phases. Analysis results are presented as well.

2. RELEVANT DOCUMENTS

The following documents are to be considered relevant to the RICH program.

2.1 APPLICABLE DOCUMENTS

AD	Doc.Number	Issue/Date	Rev.	Title/Applicability
AD 1	AMS02-TN-CGS-004	Issue5 02/03/2005		Preliminary thermal requirements for AMS-02 internal interfaces
AD 2	SSP57213			Alpha Magnetic Spectrometer (AMS-02) Hardware Interface Control Document (ICD)

2.2 REFERENCE DOCUMENTS

AD	Doc.Number	Issue/Date	Rev.	Title/Applicability
RD 3	AMS02-RP-CGS-006	Issue2 08/03/2005		AMS-02 Launch to Activation Thermal Analysis Report

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3. PURPOSE

This report contains the description of the Thermal Mathematical Model (TMM) and the Geometrical Mathematical Model (GMM) developed to study the thermal behavior of RICH

Steady state and transient thermal analysis have been performed using the SINDA/FLUINT network analyzer, to investigate the thermal behavior of RICH detector installed on AMS-02, during the design orbital cases, considering worst hot and cold conditions, properly selected by AMS-02 thermal team at system level.

A Thermal Mathematical Model has been generated, consisting of **3317** nodes for the representation of the following items:

- Secondary structure (216 nodes)
- Rectangular cell grids (35 nodes for each bar)
- Triangular cell grids (113 nodes for each sector)
- Lower panel (17 nodes)
- PCBs around the octagonal structure (24 nodes)
- Panels around the octagonal structure (72 nodes)
- External environment (4 nodes for conduction, 12 for radiation)

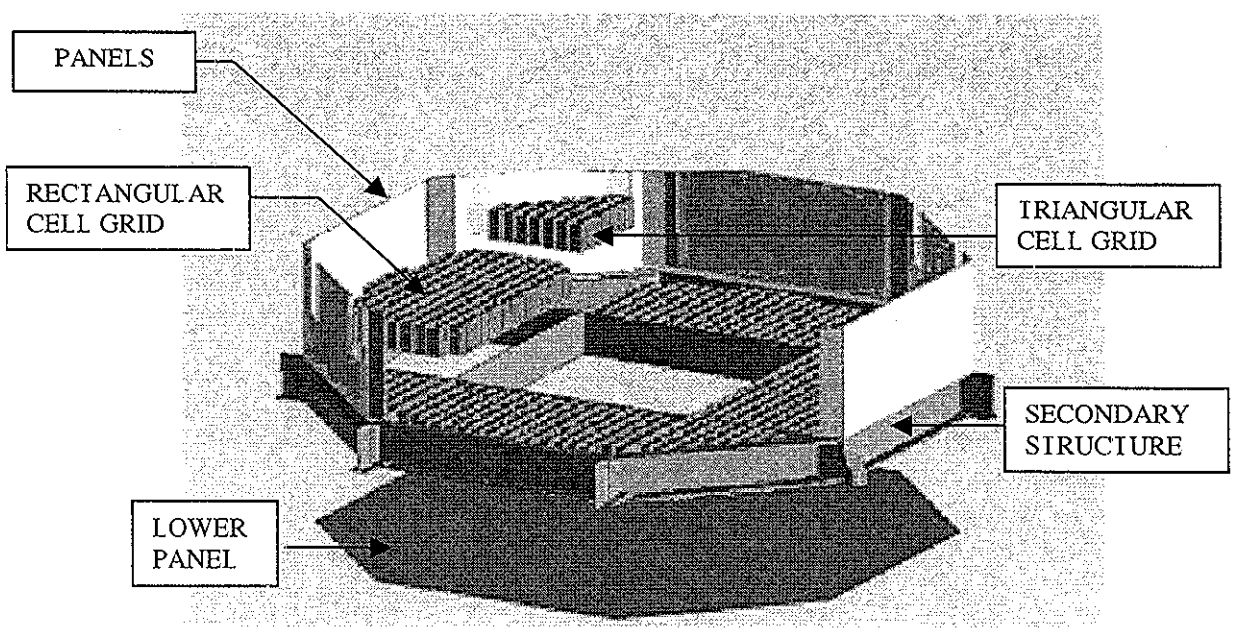

Fig 3-1 Rich assembly exploded view

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4. REQUIREMENTS

4.1 TEMPERATURE REQUIREMENTS

The following temperatures are assumed as design limits for the RICH PMTs [AD 1]

Operating Range:	-30°C ÷ +50°C
Non Operating Range:	-35°C ÷ +60°C

4.2 SHORT-TERM TEMPERATURE STABILITY

A stability of 7°C is required over the orbit period.

4.3 TEMPERATURE GRADIENTS

There is a design limit of 15°C for the temperature gradient among the different RICH PMTs.

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5. THERMAL CONTROL CONCEPT

In order to respect the requirement on the maximum temperature gradient among the different PMTs, a radiator is not the most effective solution. The impinging fluxes are very different on the sides of RICH and so radiators would contribute in increasing the gradient.
In order to uniform the temperatures in the different RICH sectors the detector is completely surrounded by Multi Layer Insulation (MLI), while the dissipated power is rejected through the USS02 mounting points and the heat leakage through the MLI.

Radiative links between the inner and outer layer of MLI have the following form:

GR=eps* x A

where eps* is equal to 0.05 and A is the relevant node Area.

The external layer of MLI blanket is made of white Beta-cloth and its thermal optical properties both BOL and EOL are listed in the following table:

Beta-cloth	BOL (cold analysis)	EOL (hot analysis)
α	0.2	0.47
ε	0.9	0.86

Tab. 5-1 Beta-Cloth thermal optical properties

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6. THERMAL LOADS

6.1 INTERNAL LOADS

Totally 20.4W are dissipated on 680 PMTs (30mW each). Since the PMTs are not modelled, their dissipation is directly applied on the grid bars.
In each rectangular cell grids there are 16 bars and 144 PMT. The dissipation of the rectangular cell grid of each sector is 4.32W.
In each triangular cell grid there are 8 bars and 26 PMTs. The dissipation of the triangular cell grid of each sector is 0.78 W.

Additional 29.4 W are dissipated on the PCBs around the octagonal structure (5.7W on each long side; 1.1W on 2 short side and 2.2W on the others short side).

The RICH dissipation is reassumed in the following table:

	Dissipation [W]
Rectangular cell grid	4.32 x 4
Triangular cell grid	0.78 x 4
PCBs on long side	5.7 x 4
PCBs on short side	1.1 x 2 2.2 x 2
TOTAL	**49.8**

Tab. 6-1 RICH power budget

6.2 EXTERNAL LOADS

RICH is located in AMS-02 experiment , which experiences typical external ISS payloads environmental conditions. In particular, ISS orbiting in its Low Earth Orbit experiences typical fluxes of LEO satellites:

→ Solar visible radiation
→ Albedo (given by the fraction of the Sun energy diffusely reflected by Earth)
→ Infrared Earth contribution.

RICH location makes it subjected not only to these direct impinging fluxes, but also to reflections of the aforementioned contributions by other ISS elements.

RICH impinging heating rates, radiative links and sink temperatures have been generated at system level by AMS-02 thermal team.

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7. THERMAL MODELLING

7.1 PHYSICAL PROPERTIES

7.1.1 MATERIALS AND MATERIAL PROPERTIES

The following table shows the RICH materials and the conductivities used in the thermal mathematical model:

Component	Material	Conductivity [W/m /K]
Secondary structure	Aluminum	155
Panels	Aluminum	155
Lower Panel	Polycarbonate	0.2
Cell Grids	Aluminum	155

Tab. 7-1 Summary of used materials

The dependence from temperature of the above mentioned quantities has been neglected.

7.1.2 CONTACT CONDUCTANCES

The following values have been used to introduce in the model the thermal joint conductance between different parts:

- **500 W/m^{2}K** : contact conductance between different parts of the secondary structure
- **200 W/m^{2}K** : contact conductance between secondary structure and lower panel
- **500 W/m^{2}K** : contact conductance between secondary structure and panels
- **500 W/m^{2}K** : contact conductance between secondary structure and beams

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7.2 THERMAL MATHEMATICAL MODEL

The main division in thermal submodels (used in the SINDA code) is listed in the following table:

	SUBMODEL NAME	DESCRIPTION	NUMBER OF NODES
SECONDARY STRUCTURE	PRIMARY	Primary beams	40
	SECNINT	Secondary beams	16
	SECNEXT		24
	EXTLIN	External beams	68
	EXTANG		68
	LOWPANEL	Polycarbonate panel	17
RECTANGULAR CELL GRIDS	BEAM1	Rectangular cell grid (RAM direction)	560
	BEAM1001	End bar in RAM rectangular cell grid in PORT direction	35
	BEAM1002	End bar in RAM rectangular cell grid in STRB direction	35
	BEAM2	Rectangular cell grid (STARBOARD direction)	560
	BEAM2001	End bar in STARBOARD rectangular cell grid in RAM direction	35
	BEAM2002	End bar in STARBOARD rectangular cell grid in WAKE direction	35
	BEAM3	Rectangular cell grid (WAKE direction)	560
	BEAM3001	End bar in WAKE rectangular cell grid in STRB direction	35
	BEAM3002	End bar in WAKE rectangular cell grid in PORT direction	35
	BEAM4	Rectangular cell grid (PORT direction)	560
	BEAM4001	End bar in PORT rectangular cell grid in WAKE direction	35
	BEAM4002	End bar in PORT rectangular cell grid in RAM direction	35
TRIANGULAR CELL GRIDS	ABEAM101÷A BEAM108	Triangular cell grid (RAM/STARBOARD direction)	113
	ABEAM201÷A BEAM208	Triangular cell grid (STARBOARD/WAKE direction)	113
	ABEAM301÷A BEAM308	Triangular cell grid (WAKE/PORT direction)	113
	ABEAM401÷A BEAM408	Triangular cell grid (PORT/RAM direction)	113
	ELTBOARD	PCBs around the octagonal structure	24
PANELS	RADLIN	Panels on the long sides (in RAM, WAKE, PORT and STARBOARD directions)	36
	RADANG	Panels on the short sides (in RAM/PORT, WAKE/PORT, RAM/STRB and WAKE/STRB directions)	36
	USS	External conductive environment	4
	SINK	External radiative environment	12
	Total number of nodes		**3317**

Tab. 7-2 Submodel lists and number of nodes

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7.2.1 SECONDARY STRUCTURE NODAL BREAK-DOWN

Rich secondary structure is an octagonal frame composed by 5 different kind of beam, each one included in a different submodel, as show in the table below.

BEAM	SUBMODEL NAME
Primary	PRIMARY
Secondary internal	SECNINT
Secondary external	SECNEXT
External linear	EXTLIN
External angular	EXTANG

Tab. 7-3 Secondary Structure submodels

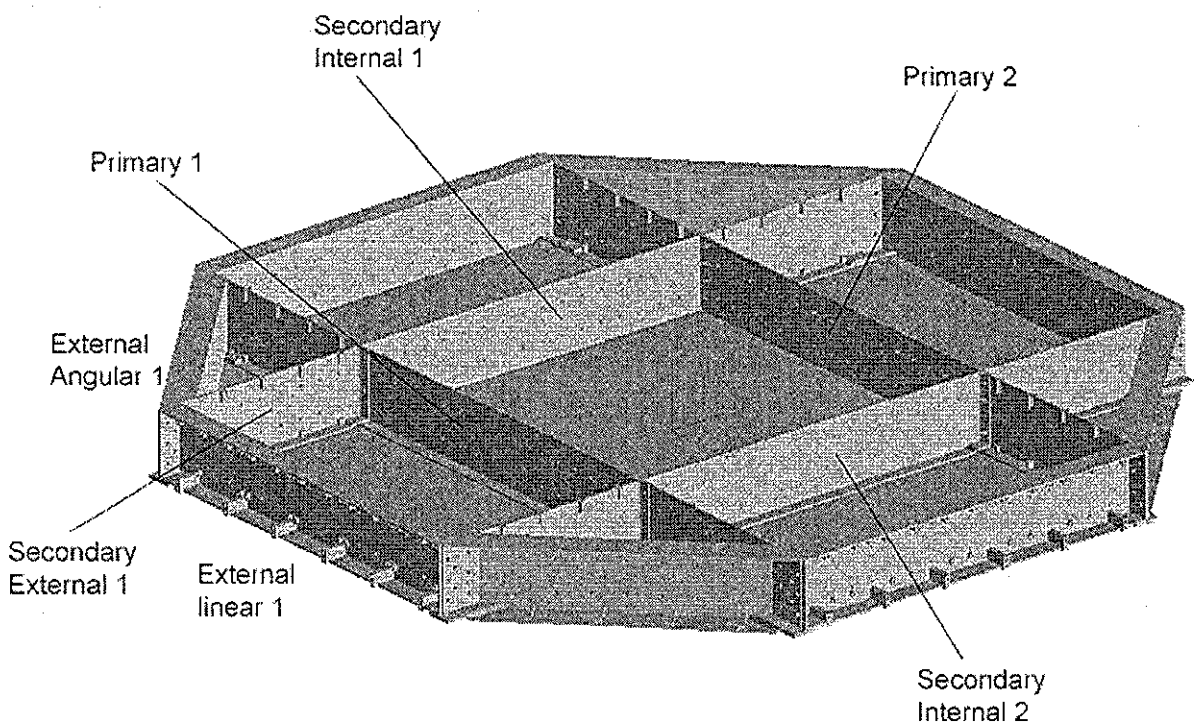

Fig. 7-1 Secondary Structure

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7.2.1.1 PRIMARY

Primary beam nodes are listed in the following table, with their thermal capacitance.

NODE NUMBER	DESCRIPTION		THERMAL CAPACITANCE J/°C
101÷102	Primary Internal RAM	central	153.7
103÷105	Primary Internal RAM	central	172.0
106÷107	Primary Internal RAM	central	153.7
111÷112	Primary Internal RAM	base	61.5
113÷115	Primary Internal RAM	base	39.1
116÷117	Primary Internal RAM	base	61.5
1001-1006	Primary internal RAM	arithmetic	-
201÷202	Primary Internal WAKE	central	153.7
203÷205	Primary Internal WAKE	central	172.0
206÷207	Primary Internal WAKE	central	153.7
211÷212	Primary Internal WAKE	base	61.5
213÷215	Primary Internal WAKE	base	39.1
216÷217	Primary Internal WAKE	base	61.5
2001-2006	Primary internal WAKE	arithmetic	-

Tab. 7-4 Primary nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

7.2.1.2 SECONDARY

There are two kind of secondary beam: 2 internal (L shaped), and 4 external (T shaped);

7.2.1.2.1 INTERNAL

Two different beams are included in *SECNINT* submodel. The first digit in node's ID indicates beam's position: 1 for STARBOARD side, 2 for PORT side.
Secondary internal nodes included in the model are listed in the following table:

NODE NUMBER	DESCRIPTION		THERMAL CAPACITANCE J/°C
101÷103	Secondary Internal STRB	central	167.3
104÷106	Secondary Internal STRB	base	39.1
1001-1002	Secondary internal STRB	edge	19.5
201÷203	Secondary Internal PORT	central	167.3
204÷206	Secondary Internal PORT	base	39.1
2001-2002	Secondary internal PORT	edge	19.5

Tab. 7-5 Secondary internal nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

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7.2.1.2.2 EXTERNAL

Four different beams are included in *SECNEXT* submodel. The first digit in node's ID (x in Tab. 7-6) indicates beam's position: the beams are numbered clockwise starting from RAM-STARBOARD side.
Secondary external nodes included in the model are listed in the following table:

Node number	Node Description		Thermal Capacitance (J/°C)
x01-x02	Secondary External x	central	148.3
x03-x04	Secondary External x	base	61.0
x001	Secondary External x	edge	34.3
x002	Secondary External x	arithmetic	-

Tab. 7-6 Secondary external nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

The following picture shows the position of arithmetic and diffusive nodes on the primary, secondary internal and secondary external beams.

● Diffusive Node
■ Arithmetic Node

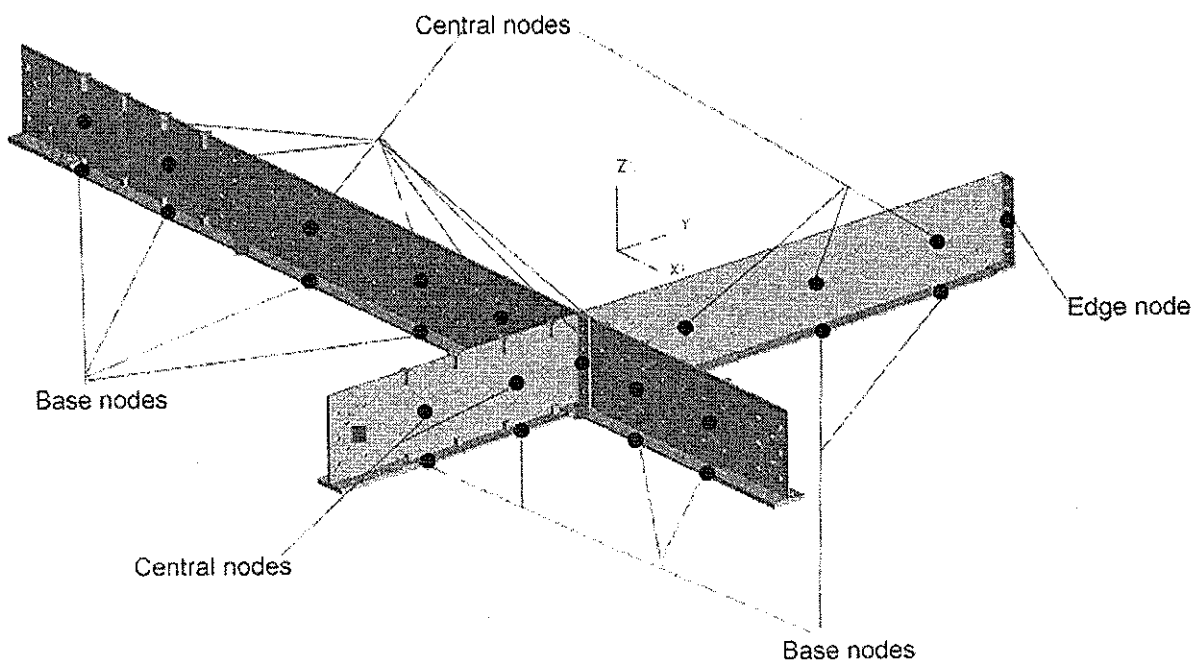

Fig. 7-2 Primary and Secondary nodalization

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7.2.1.3 EXTERNAL LINEAR

Four different beams are included in *EXTLIN* submodel. The first digit in node's ID (x in Tab. 7-7) indicates beam's position: the beams are numbered clockwise starting from RAM side.
External linear nodes included in the model are listed in the following table:

Node number	Description		Thermal Capacitance (J/°C)
x11÷x13	External linear x	central	164.3
x21÷x23	External linear x	upper	61.4
xX31÷x33	External linear x	lower	61.4
x001-x002	External linear x	edge	31.2
x1÷x6	External linear x	arithmetic	-

Tab. 7-7 External linear nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

7.2.1.4 EXTERNAL ANGULAR

Four different beams are included in *EXTANG* submodel. The first digit in node's ID (x in Tab. 7-8) indicates beam's position: the beams are numbered clockwise starting from RAM-STARBOARD side.
External angular nodes included in the model are listed in the following table:

Node number	Description		Thermal Capacitance (J/°C)
x11÷x13	External angular x	central	110.4
x21÷x23	External angular x	upper	51.4
x31÷x33	External angular x	lower	51.4
x001-x002	External angular x	edge	57.3
x1÷x6	External angular x	arithmetic	-

Tab. 7-8 External angular nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

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7.2.2 LOWER PANEL NODAL BREAK-DOWN

Lower Panel is a 1 millimeter thick polycarbonate panel. In Fig. 7-3 is shown its nodal breakdown.
Arithmetic nodes are used to connect the panel to main structure.
Lower panel nodes included in the model (*LOWPANEL* submodel) are listed in the following table:

Node number	Description	Thermal Capacitance (J/°C)
1÷4	External nodes	870.0
5	Central node	902.0
101÷112	Arithmetic nodes for structure connection	-

Tab. 7-9 Lower panel nodes numbering

Thermal capacitance has been computed considering a specific heat of 1674 J/Kg°C for polycarbonate.

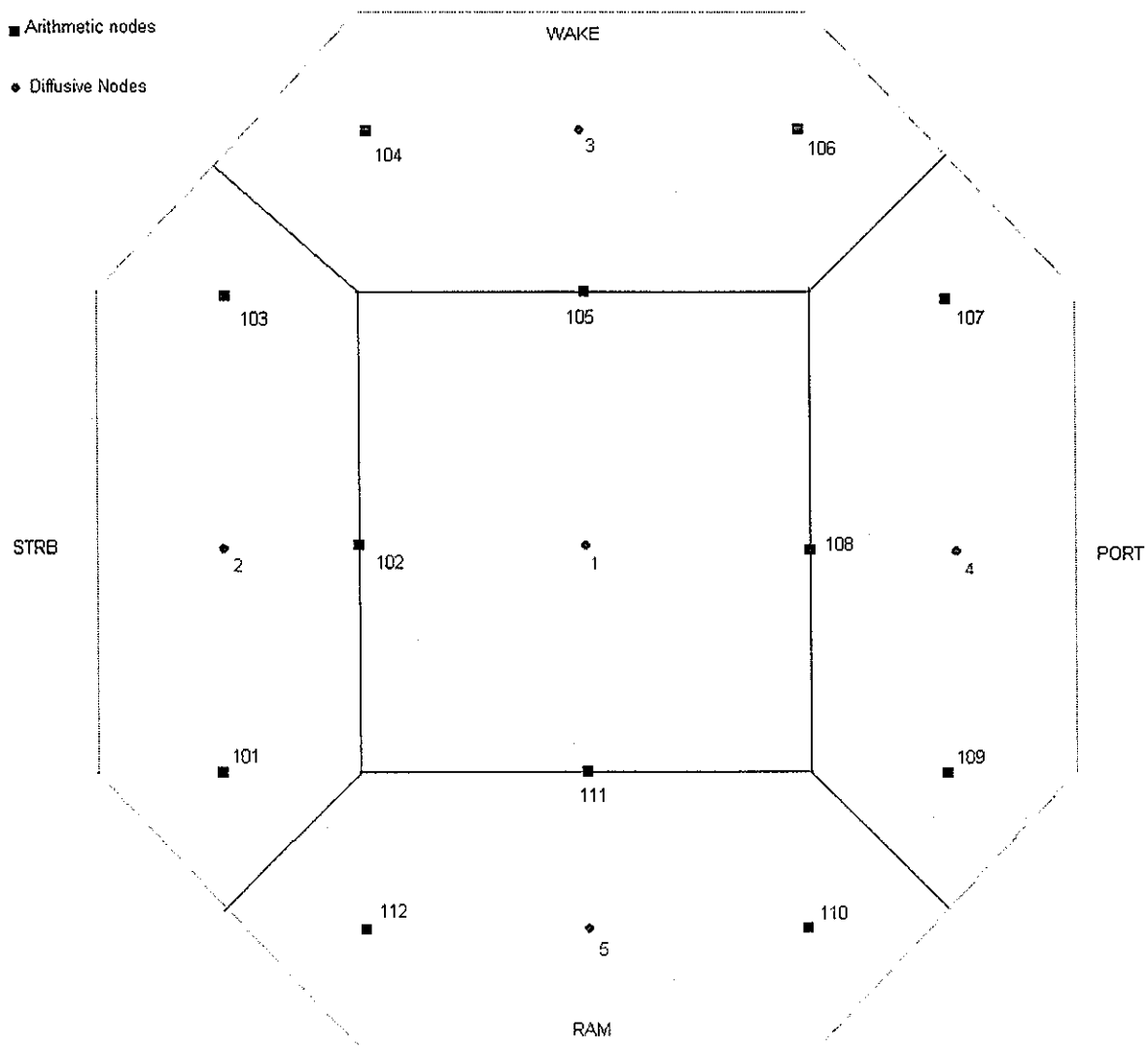

Fig 7-3 Lower panel nodal break-down

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7.2.3 RECTANGULAR CELL GRIDS

Each rectangular cell grids sector is represented by three different submodels: one for the 16 central beams (*BEAMx* where x=1,...., 4 indicates the cell grid position, clockwise starting from RAM), two for the shorter end beams directly connected to the secondary external bars (*BEAMx001* and *BEAMx002,* where x=1,...., 4). Beams nodal breakdown is shown in the following figure and table.

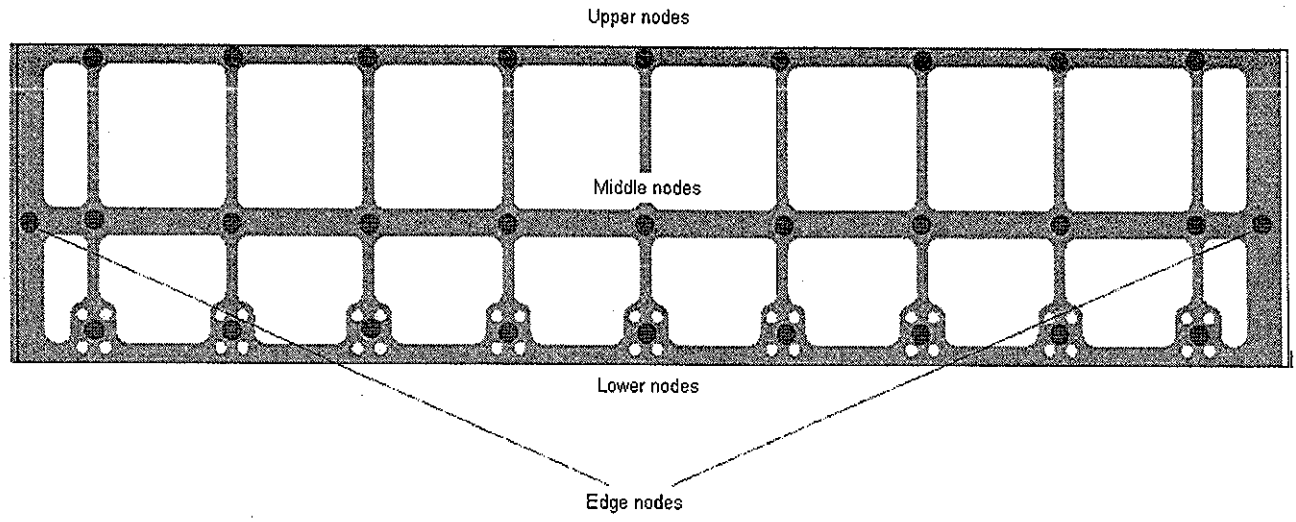

Fig. 7-4 PMT's beam in rectangular cell grids nodal breakdown

The first 3 digit in node's ID (xxx in Tab. 7-10) indicates beam's number, from 101 to 116.

Node number	Description	Thermal Capacitance (J/°C)
xxx11-xxx19	Upper Nodes	18.9
xxx12÷xxx18	Upper Nodes	2.9
xxx21-xxx29	Middle Nodes	26.7
xxx22÷xxx28	Middle Nodes	4.3
xxx31-xxx39	Lower Nodes	18.7
xxx32÷xxx38	Lower Nodes	2.7
xxx101-xxx102	Edge Nodes	13.4

Tab. 7-10 PMT's beam in rectangular cell grids nodes numbering

On every upper and middle node 0.013W is applied to simulate PMTs' dissipated power (26 mW for each PMT).

Different submodels are used for the external beams in each rectangular cell grid: these beams are directly connected to the main structure and they have PMT only on one side

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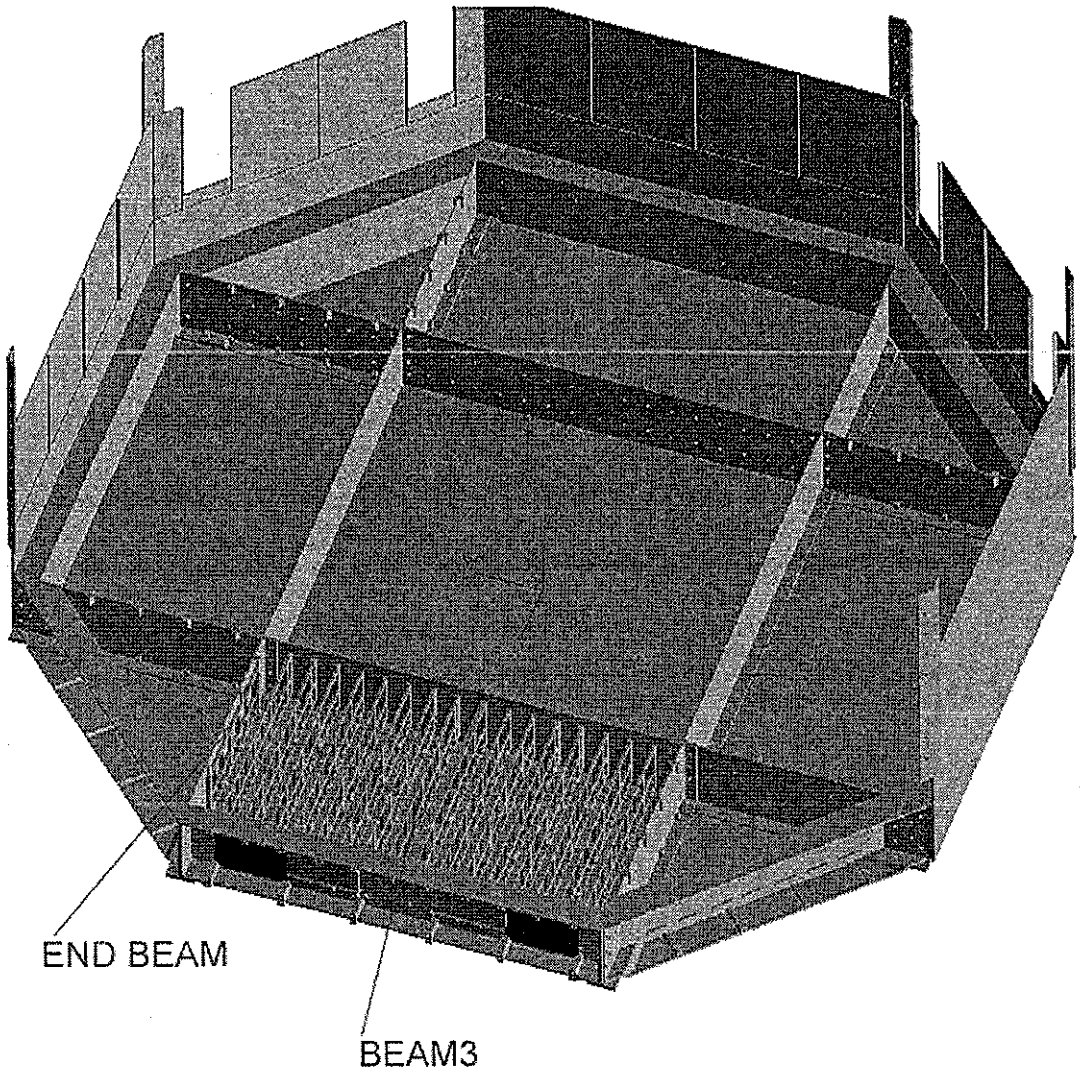

Fig. 7-5 - PMT End Beam position

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7.2.4 TRIANGULAR CELL GRIDS

The nodal breakdown is the same used for the the rectangular cell grids beams. In this case PMT beams have different length, as shown in the picture below.
Every beam constitutes a different submodel, named ABEAMX0Y, where X indicates the sector where the beam is located, and Y the position in the sector (X=1, ..., 4 clockwise starting from RAM-STARBOARD side).

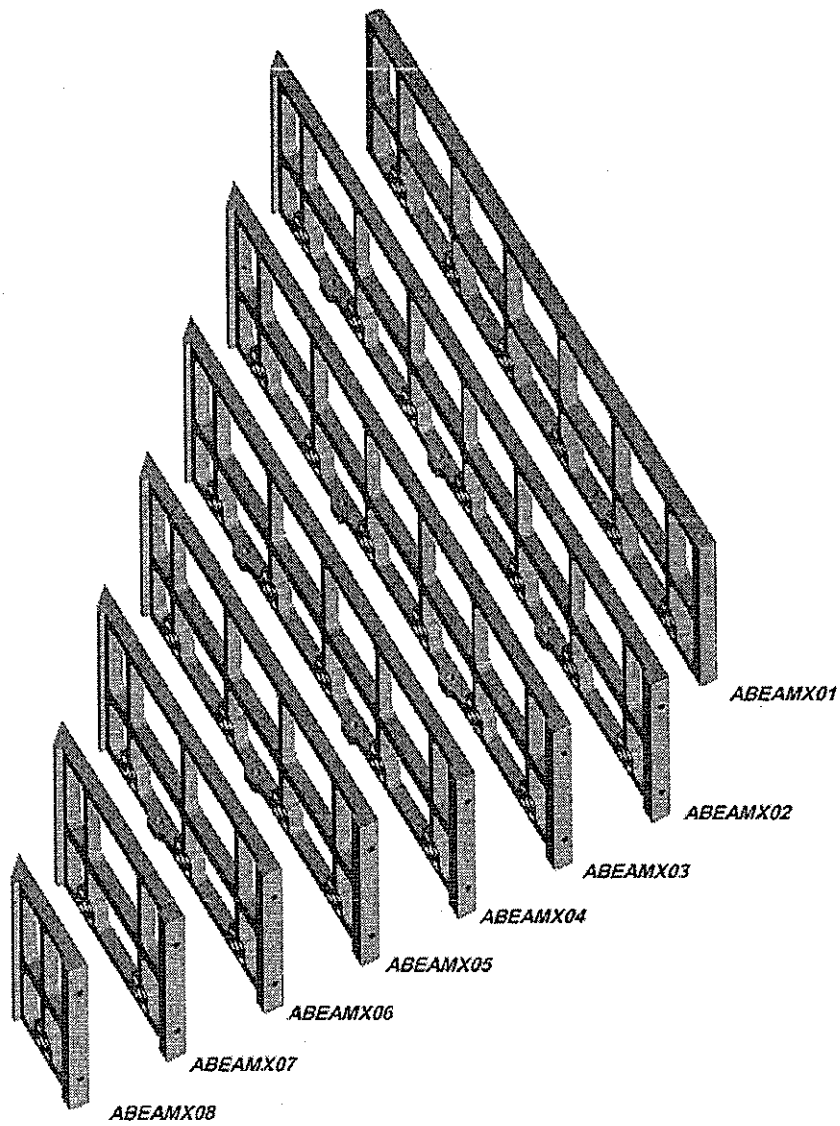

Fig. 7-6 Triangular cell grids.

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7.2.5 ELECTRONIC BOARDS

Some electronic boards are connected on angular and linear external beam.
Electronic board nodes included in the model are listed in the following table, with their properties.

Node number	Description	Thermal Capacitance (J/°C)
x01÷x05	Boards on linear beams	5.15
111 311	Boards on angular beams (RAM/STARBOARD and WAKE/PORT)	340.8
211 411	Boards on angular beams (WAKE/STARBOARD and RAM/PORT)	340.8

Tab. 7-11 Electronic boards nodes numbering

Electronic boards have also radiative conductor with secondary structure and panels. Radiative conductors have been computed using Thermal Desktop software

7.2.6 PANELS NODAL BREAK-DOWN

There are 8 panels connected to external linear and angular beams. They're named respectively "linear panels" and "angular panels"

	SUBMODEL NAME
Linear	RADLIN
Angular	RADANG

Tab. 7-12 Panels submodels

7.2.6.1 LINEAR PANELS

Four panels are included in *RADLIN* submodel. The first digit in node's ID (x in Tab. 7-13) indicates panel's position: the panels are numbered clockwise starting from RAM side.
Linear panel nodes included in the model are listed in the following table:

Node number	Description	Thermal Capacitance (J/°C)
x04÷x06	Central Nodes	399.2
x11÷x16	Arithmetic nodes for structure connection	-

Tab. 7-13 Linear panels nodes numbering

Thermal capacitance has been computed considering a specific heat of 900 J/Kg°C for aluminum

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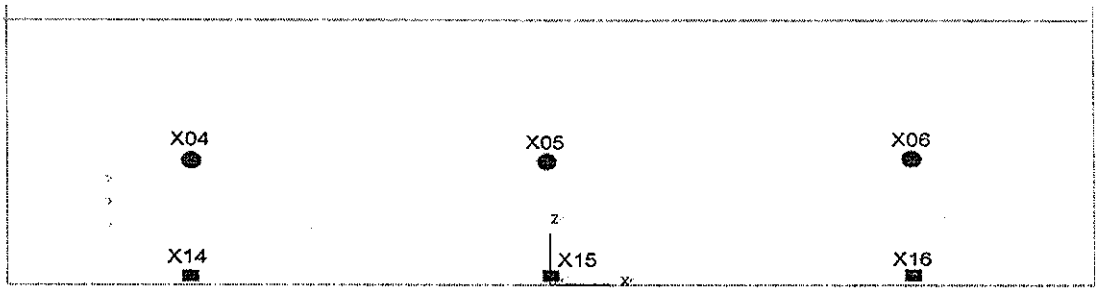

Fig. 7-7 Linear panels nodal break-down

7.2.6.2 ANGULAR PANELS

Four panels are included in *RADANG* submodel. The first digit in node's ID (x inTab. 7-14) indicates panel's position: the panels are numbered clockwise starting from RAM-STARBOARD side.
Angular panel nodes included in the model are listed in the following table:

Node number	Description	Thermal Capacitance* (J/°C)
x04÷x06	Central Nodes	276.0
x11÷x16	Arithmetic nodes for structure connection	-

Tab. 7-14 Angular panels nodes numbering

The angular panels nodal break-down is the same as the linear one (*Fig. 7-7*)

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8. ANALYSIS RESULTS

The analysis has been performed using I/F thermal data, properly selected by AMS-02 thermal team at system level

I/F thermal data are constituted of :

→ Conductive I/F temperatures for mechanical interfaces
→ Merat temperatures for each of the external facing surfaces
→ Impinging heat fluxes (absorbed) for each of the external facing surfaces
→ Radiative links between each of the external facing surfaces and sink nodes

Since the PMTs are not modelled but the temperature ranges to be respected are given for the PMTs themselves, in operative cases +5°C of temperature gap have been considered between the PMT and the bar to which it is clamped on.

In the following sections analysis results are presented for the AMS-02 Launch to Activation Sequence. It has been divided into 4 phases, significant from the thermal point of view:

- Phase 1: Sts unmated attitude
- Phase 2: Sts docked to the ISS, AMS-02 in the cargo bay
- Phase 3: Sts docked to the ISS, AMS-02 in hand-off position
- Phase 4: AMS-02 on ISS truss

In the following section the selected orbits will be identified by the following parameters:

- Beta angle
- Yaw, Pitch and Roll angles (Attitude)
- STS location (free flying, docked, undocked)
- Environment (hot or cold)

Hot environment is characterized by:

- Altitude: 150 nm
- Albedo: 0.4
- Planet IR: 266.5K
- Solar Flux: 451.5 BTU/hr/ft^2

Cold environment is characterized by:

- Altitude: 270 nm
- Albedo: 0.2
- Planet IR: 245.5K
- Solar Flux: 419.1 BTU/hr/ft^2

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8.1 PHASE 1: STS UNMATED ATTITUDE

The thermal environment attitudes described throughout this section are based on the Orbiter structural coordinate reference system (with the Orbiter +Z-axis pointing out of the payload bay, +Y-axis pointing out the starboard wing, and +X-axis pointing aft).
The following table contains a list of shuttle attitudes that AMS experiment is required to analyze in the shuttle-alone configuration.

Attitude	Duration	Payload Recovery time at +ZLV to repeat attitude (β≤60 degrees)	Payload Recovery time at PTC to repeat attitude (β>60 degrees)
+ZLV (±XVV, ±YVV)[1] for β≤60 degrees	Continuous	N/A	N/A
PTC for β >60 degrees[2]	Continuous	N/A	N/A
-Z Solar Inertial [3] (End of Mission)	36 hours	Analysis will be ran continously	Analysis will be ran continously

Tab. 8-1 STS unmated attitudes

The design cases for RICH detector during STS unmated attitudes are as follows:

URL identifier	BETA	Attitude	STS	Environment
STS_21	75	PTC	free flying	HOT
STS_18	0	ZLV-YVV	free flying	COLD
STS_63	75	-Z Solar Inertial	free flying	COLD

Tab. 8-2 RICH detector design cases during STS unmated phases

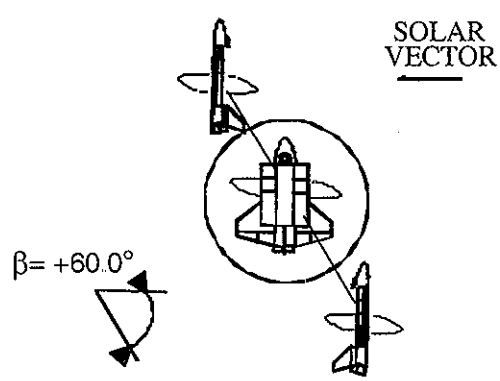

Fig. 8-1 PTC STS unmated attitude

[1] BOL thermal optical properties have been used
[2] BOL thermal optical properties have been used
[3] EOL thermal optical properties have been used

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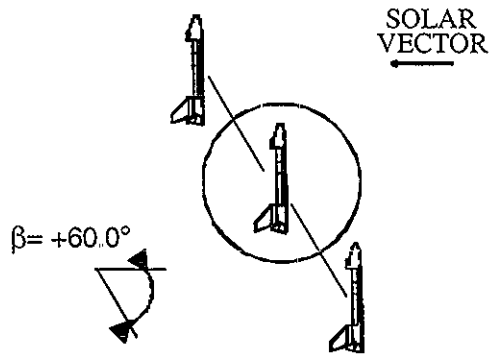

Fig. 8-2 –Z Solar Inertial STS unmated attitude

The following graphs show the temperatures of the RICH PMTs (maximum or minimum) on the eight octagon sections. It is worthwhile to notice that RICH is not-operative during this phase.

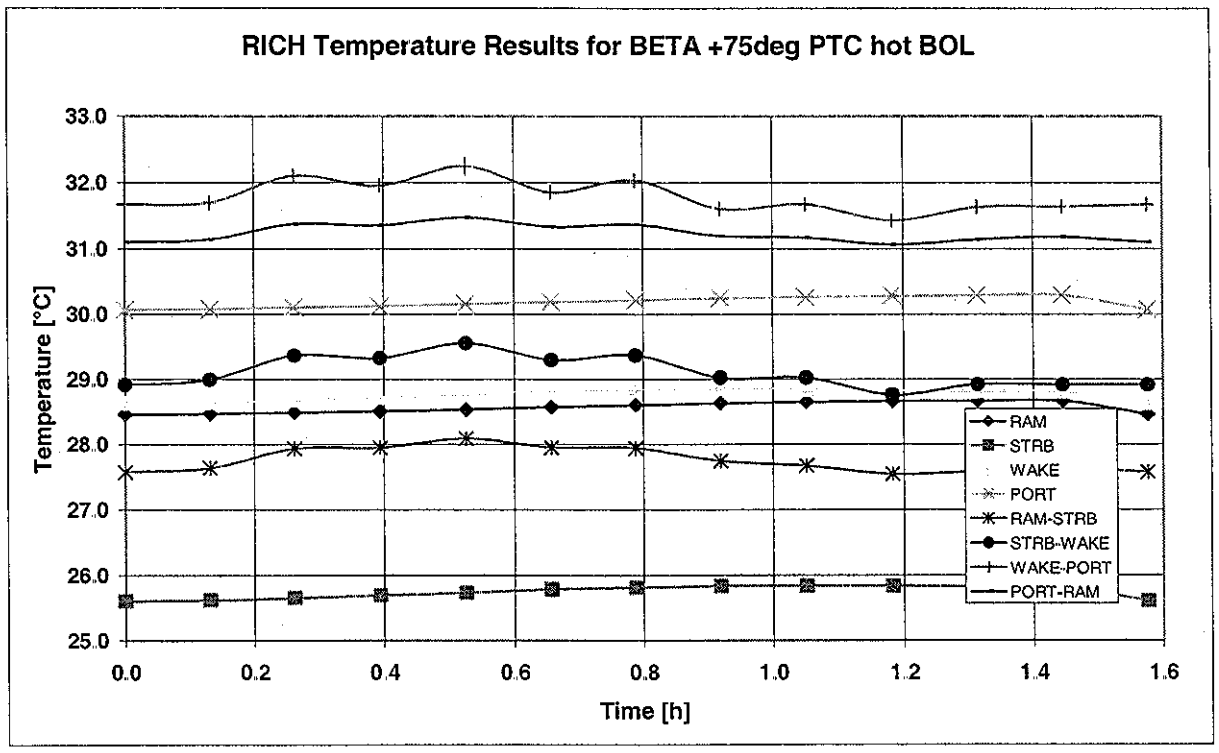

Fig. 8-3 Maximum RICH PMTs temperatures for orbit B+75 PTC hot BOL.

Maximum non operative requirements fulfilled.

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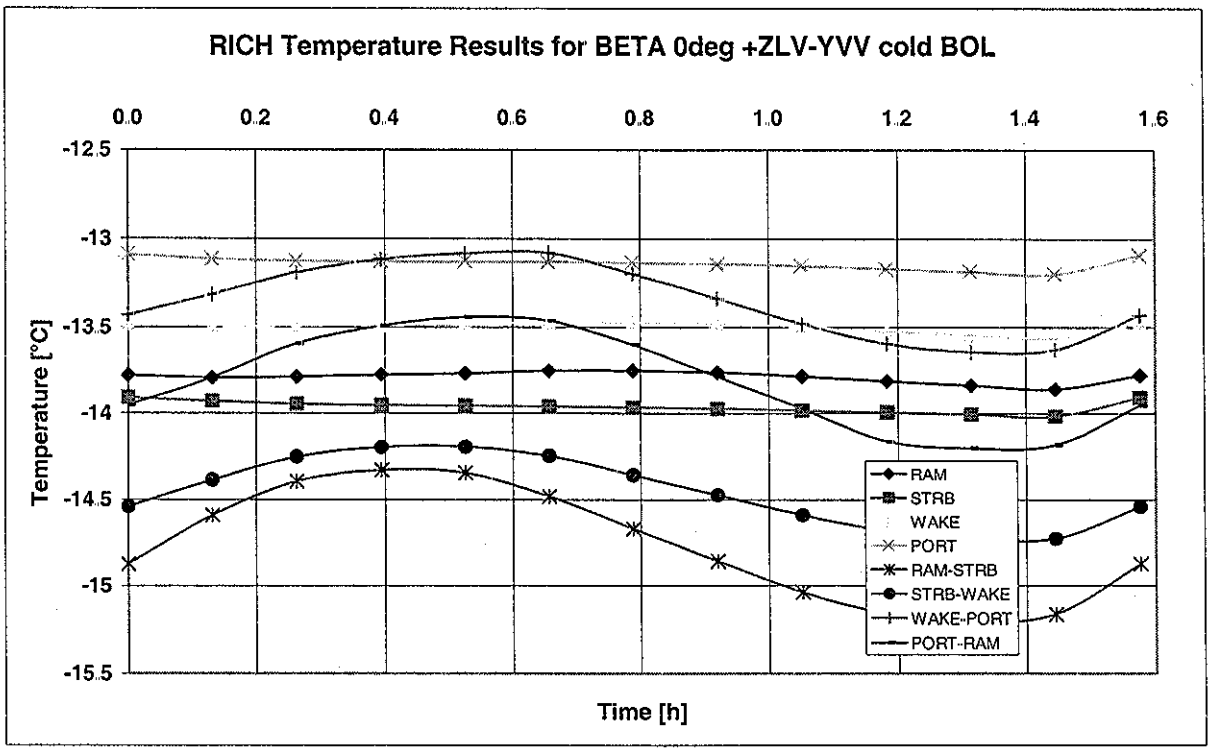

Fig. 8-4 Minimum RICH PMTs temperatures for orbit B 0 +ZLV-YVV cold BOL –

Minimum non operative requirements fulfilled without heater power

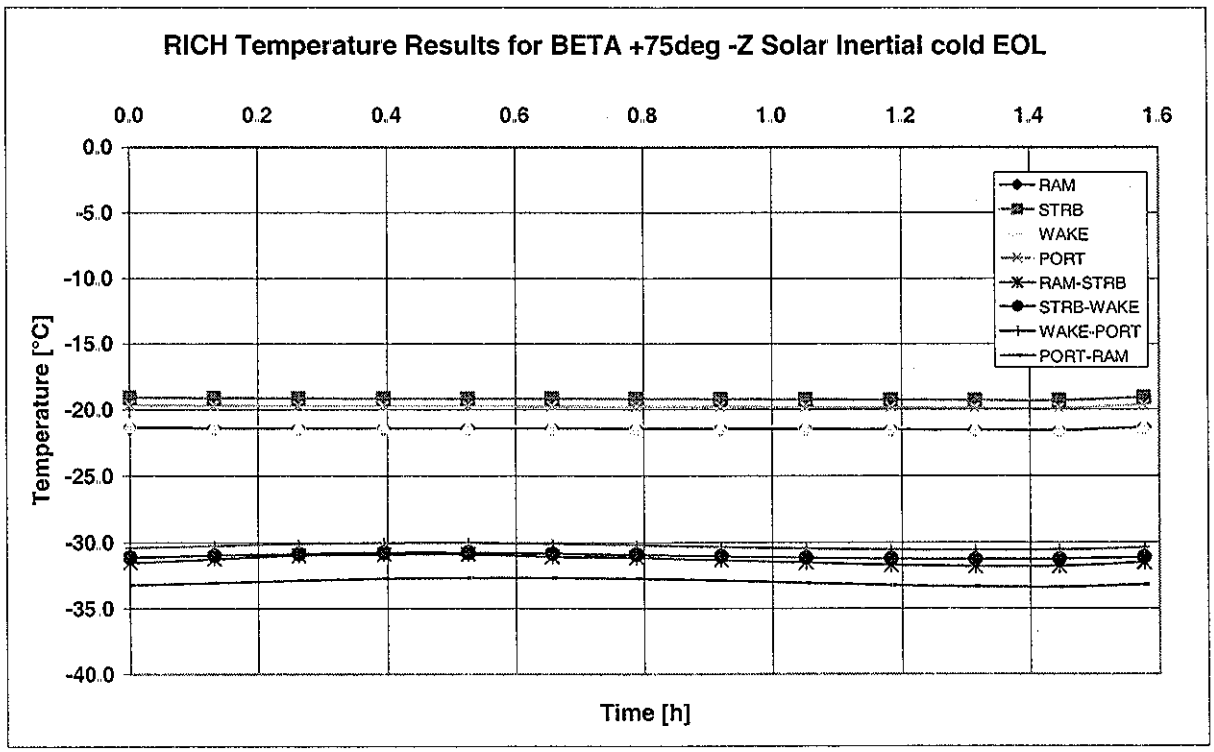

Fig. 8-5 Minimum RICH PMTs temperatures for orbit B+75 –Z Solar Inertial cold EOL –

Minimum non operative requirements fulfilled with 70W heater power

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8.1.1 CONTINGENCY CASES

Additionally, AMS-02 is required to verify the attitudes listed in Tab. 8-3.
These are extreme attitudes (hot and cold) that the shuttle could fly (in a contingency case). AMS-02 is required to determine the length of time it can remain in these extreme attitudes before a non-operating limit is violated

Attitude	Beta angle less than or equal to 60 degrees	Beta angle greater than 60 degrees
	Allowable time (to Non-Op Limit)	Allowable time (to Non-Op Limit)
+ZSI = (Bay-to-Sun Solar Inertial)	N/A	Results are presented in Fig. 8-9
+Z Space Orbrate (tail sun, Beta=0°, OR or Zero Q)	Results are presented in Fig 8-8	N/A

Tab. 8-3 STS unmated attitudes (contingency cases)

Beta angle selection has been done screening the beta range running Beta 0° , +30° , +60° and +75°

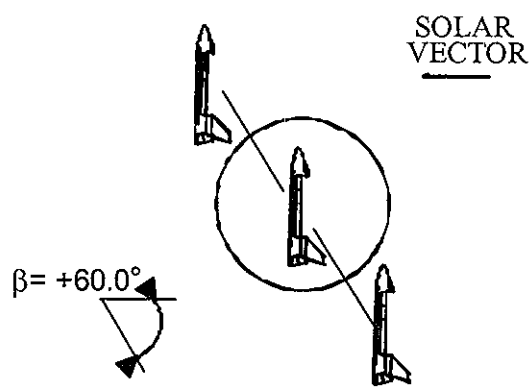

Fig. 8-6 +Z Solar Inertial STS unmated attitude

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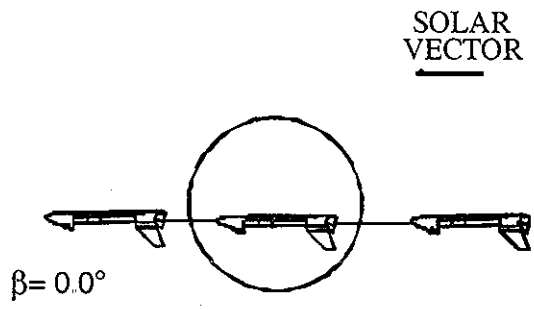

Fig. 8-7 Tto or Zero Q unmated attitude

RICH detector is required to determine the length of time it can remain in extreme attitudes described before a non-operating limit is violated.

Cold contingency case

Starting from the initial temperatures obtained in the coldest case described in Fig. 8-4, RICH PMTs temperature results are shown after having moved to +Z Space attitude: RICH detector is requested to survive for at least 90 minutes in this extreme cold phase:

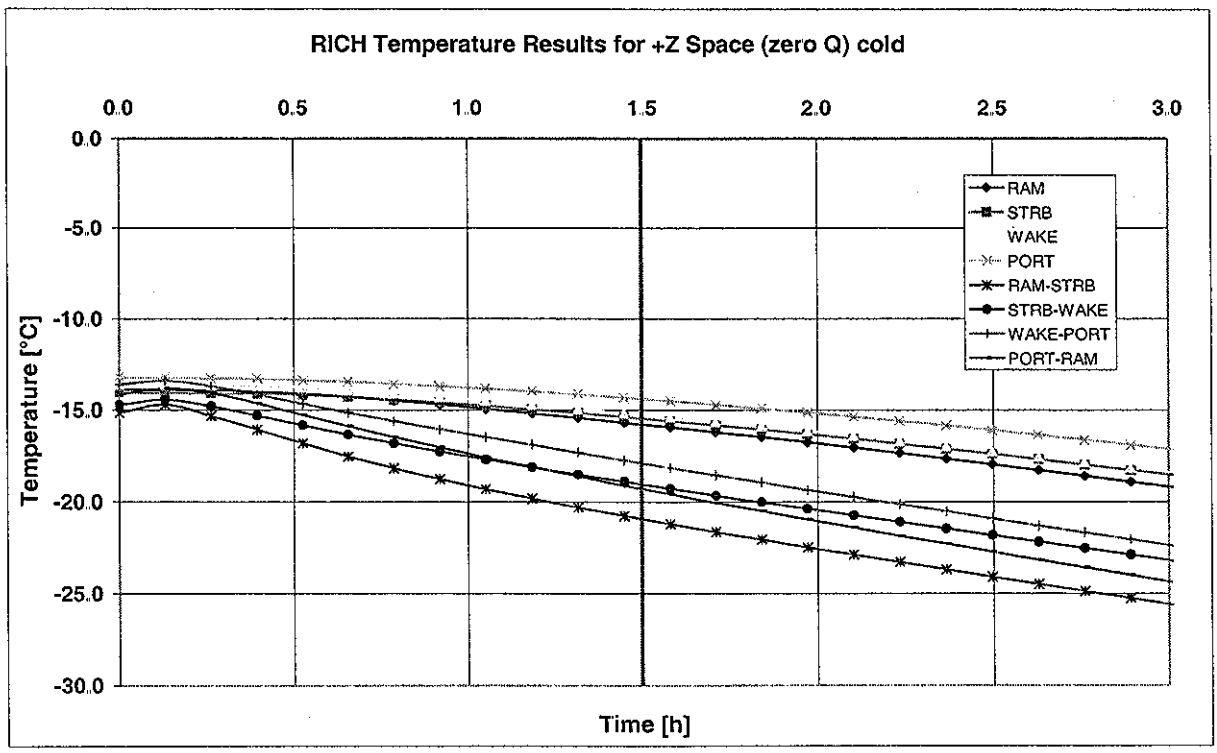

Fig. 8-8 Minimum RICH PMTs temperatures for orbit +Z Space (zero Q).

RICH PMTs can withstand even more than 90 minutes

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Hot contingency case

Starting from the initial temperatures obtained in the hottest case described in Fig. 8-3, RICH PMTs temperature results are shown after having moved to +Z Solar Inertial attitude : RICH detector is requested to survive for at least 30 minutes in this extreme hot phase:

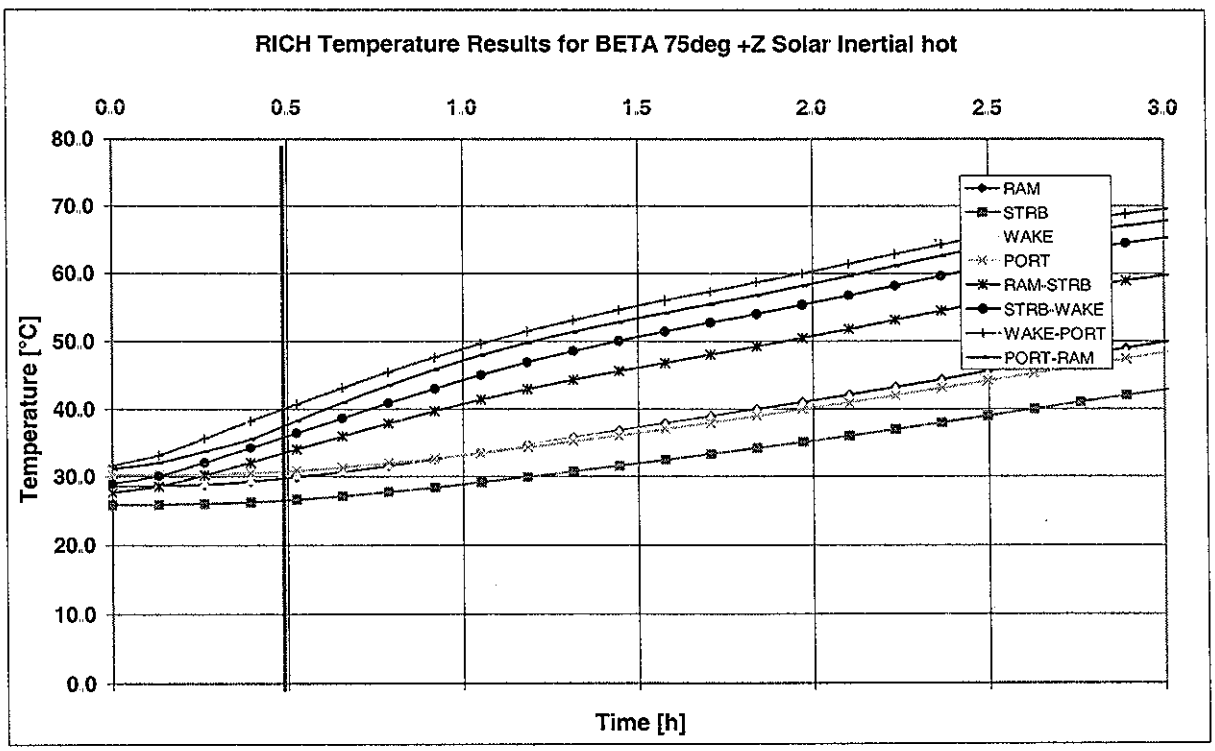

Fig. 8-9 Maximum RICH PMTs temperatures for orbit B+75+Zsolar Inertial.

RICH PMTs can withstand even more than 30 minutes

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8.2 PHASE 2: STS DOCKED TO THE ISS, AMS IN THE CARGO BAY

In this phase AMS-02 experiment is still inside STS cargo bay but this time STS has reached ISS and it has already docked. For this phase, the analysis will verify the ability of the thermal control system to maintain the TRPs in their non-operative temperature ranges for the subdetectors that are switched OFF. There are only few nominal user that need to maintain their temperatures in the operative range.
Heater power is available via APCU bus B
In order to select for each AMS experiment detector the worst hot and cold design cases the following Beta screening has been carried out:

STS ATTITUDE	ISS ATTITUDE[4]	BETA
STS docked to the ISS, AMS-02 into cargo bay; doors open	YPR= 0°,0°,0°	-60° , -30° , 0° , +30° , +60°

Tab. 8-4 STS docked to the station : beta angles/YPR Euler angles used in the determination of the worst hot/cold design cases

The design cases for RICH detector when STS is docked are as follows:

URL identifier	BETA	YPR	STS	Environment
ISS_doc_200	60	0 / 0 / 0	docked	cold

Tab. 8-5 RICH detector design case with STS docked to the ISS

The following graphs show the temperatures of the RICH PMTs (minimum) on the eight octagon sections. It is worthwhile to notice that RICH is not-operative during this phase.

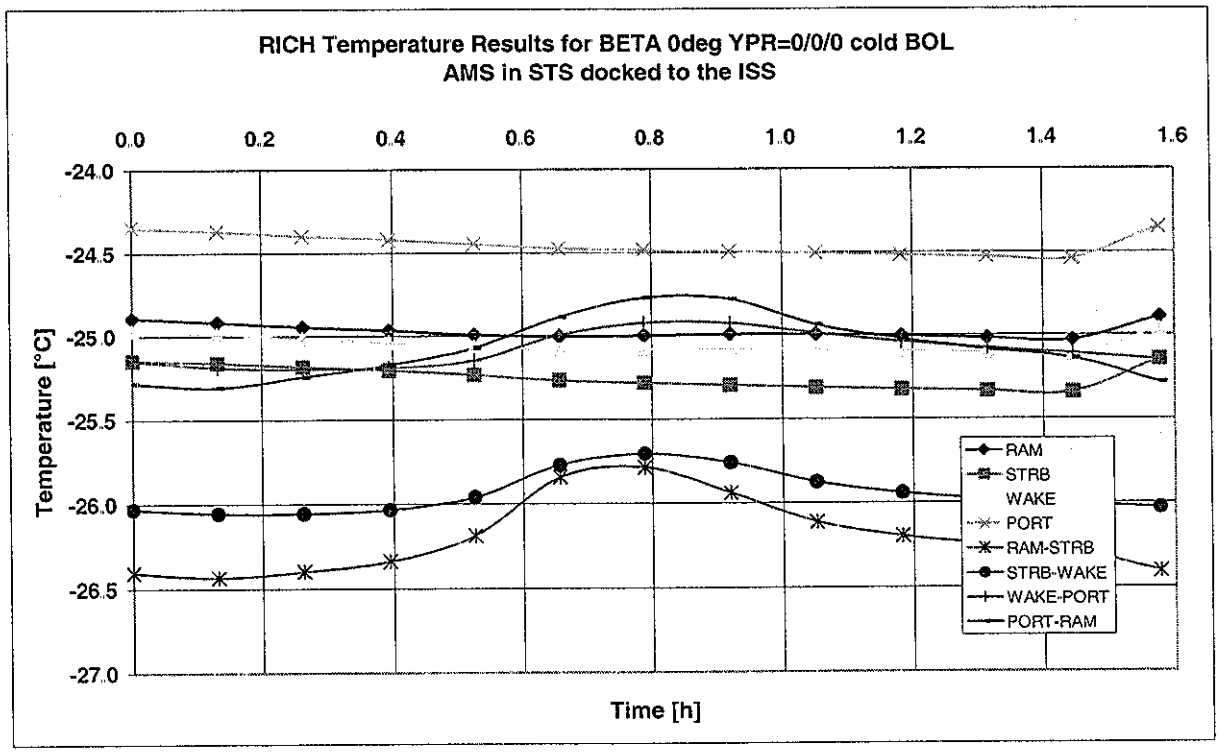

Fig. 8-10 Minimum RICH PMTs temperatures for orbit B_60_0_0_0 cold BOL

Minimum non-operative requirements are fulfilled

[4] CGS assumption in agreement with Jacobs Sverdrup

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8.3 STS DOCKED TO THE ISS, AMS02 IN HAND-OFF POSITION

AMS is removed from the Shuttle cargo bay by the SRMS (Shuttle Remote Manipulator System). No power is supplied to the AMS-02 experiment while attached to the SRMS; that means no electrical connectivity power nor data. The precise set of time-dependent positions of AMS during the transfer phase from STS to ISS is not available yet. The only available information is the intermediate position (HAND-OFF position), when both SRMS and SSRMS robotic arms are attached to AMS-02 experiment.
It has been assumed to extend this phase to a maximum of 4 hours : that should represent the maximum period during which AMS-02 experiment is grabbed by the SRMS. The initial conditions for this analysis are determined leaving AMS-02 inside the STS-docked cargo-bay indefinitely under the worst cold conditions. The analysis will verify the ability of the thermal control system to maintain the AMS-02 TRPs above the non-operative temperature ranges during the 4 hours completely unpowerd.
AMS-02 experiment must survive continuously in the HAND-OFF position when powered.

The analysis will verify the ability of the thermal control system to maintain the RICH in its non-operative temperature range.
In order to select for each AMS experiment detector the coldest design cases in HAND-OFF position the following Beta screening has been carried out:

STS ATTITUDE	ISS ATTITUDE[5]	BETA
STS docked to the ISS, AMS-02 in HAND-OFF position	YPR= 0°,0°,0°	-60° , -30° , 0° , +30° , +60°

Tab. 8-6 STS docked to the station- AMS-02 in HAND-OFF position: beta angles/YPR Euler angles used in the determination of the coldest design cases

The design cases for RICH detector when AMS is in hand-off position and STS docked to the ISS is as follows:

URL identifier	BETA	YPR	STS	Environment
ISS_doc_HO_95	0	0 / 0 / 0	Hand-off	cold

Tab. 8-7 RICH detector design case in Hand-Off position

The following graph show the RICH PMTs temperatures (minimum) after the 4 unpowered hours (red line) and then the results when the detector is heater assisted. This phase the RICH detector is not working.

[5] CGS assumption in agreement with Jacobs Sverdrup

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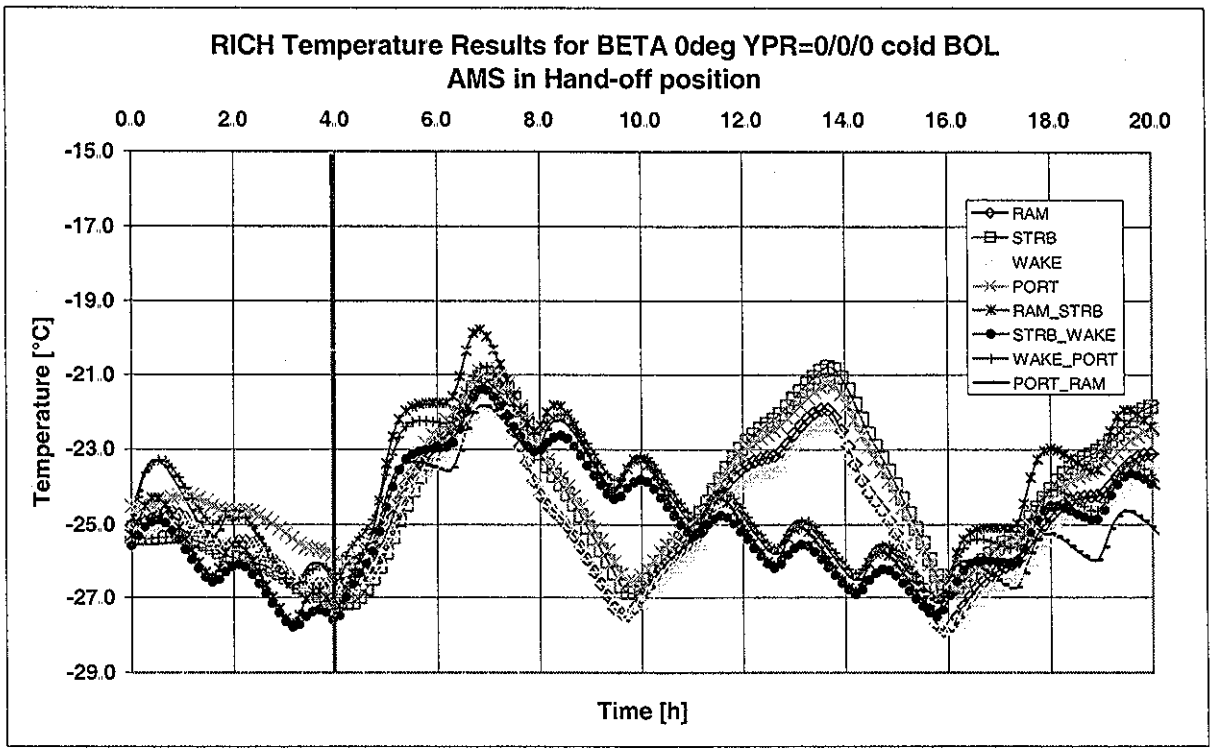

Fig. 8-11 Minimum RICH PMTs temperatures for orbit B_0_0_0_0 cold BOL (AMS in hand-off position)-

Minimum non-operative requirements fulfilled with the detector supported by heaters (70W) when power is restored.

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8.4 PHASE 4: AMS-02 ON ISS TRUSS

In this phase the AMS-02 model is moved on its final location on ISS TRUSS. For this phase, the analysis will verify the ability of the thermal control system to carry each detector up to the minimum switch on temperature and to meet all the operative/non-operative requirements.
In order to select for each AMS experiment detector the coldest and hottest design case on-orbit onboard ISS the following Beta screening has been carried out:

STS ATTITUDE	ISS ATTITUDE[6]	BETA variation range
AMS-02 on ISS	Yaw (Z) attitude angle : –15° to +15° Roll (X) attitude angle: –15° to +15° Pitch(Y) attitude angle: 0° to +25° with docked STS ; -20° to +15° with undocked STS	-75°, -50° , -25° , 0° , +25° , +50°, +75°

Tab. 8-8 AMS-02 on ISS truss - Beta angles/YPR Euler angles used in the determination of the coldest/hottest design cases

8.4.1 HOT CASE

The hottest design case for RICH detector is as follows:

URL identifier	BETA	YPR	STS	Environment
ISS_und_5	-75	-15 / 0 / 0	Undocked	HOT

Tab. 8-9 RICH detector hottest design case on ISS

RICH PMTs temperatures for this extreme orbit are presented in the following graph:

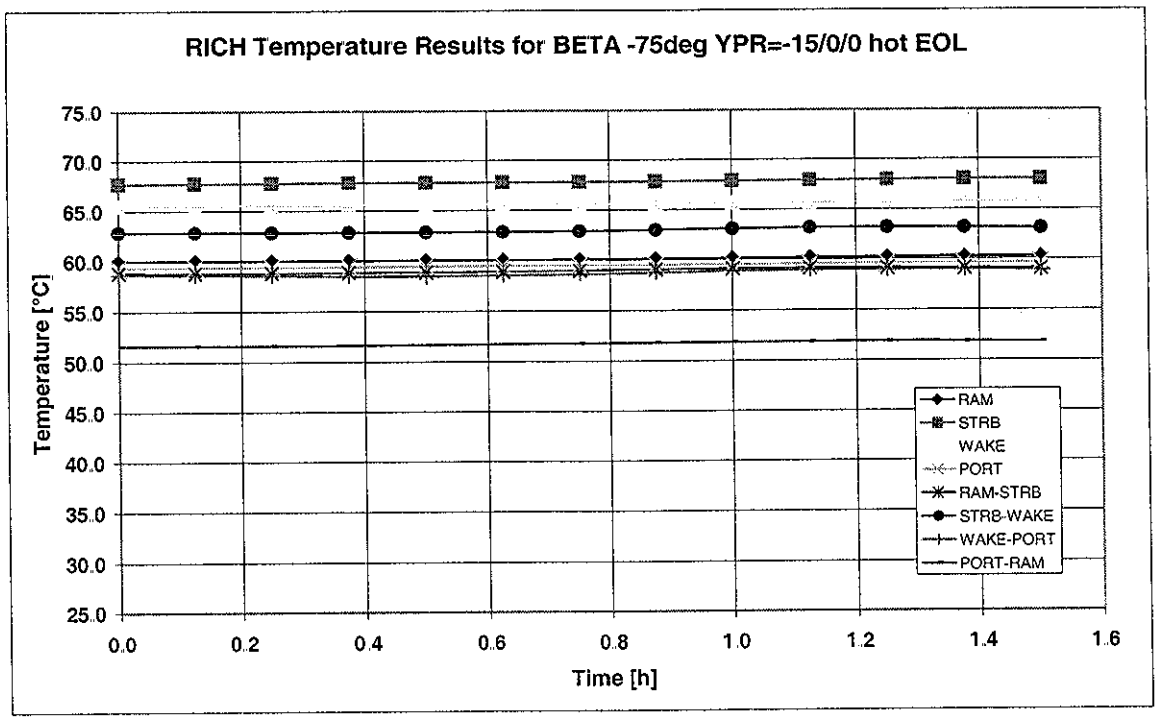

Fig. 8-12 Maximum RICH PMTs temperatures for orbit B-75-15_0_0 hot EOL

[6] CGS assumption in agreement with Jacobs Sverdrup

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RICH is operative.

Since the PMTs temperature is higher than the maximum temperature allowed, in this ISS attitude RICH has to be switched OFF. Below the PMTs results when RICH detector is OFF.

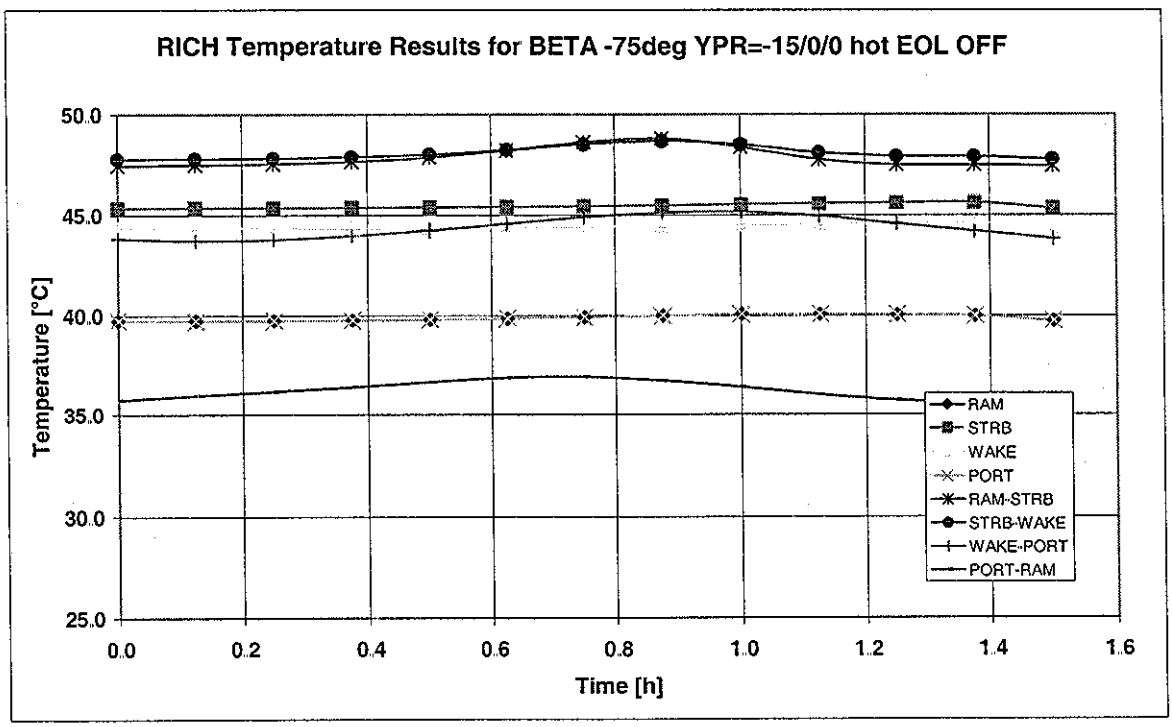

Fig. 8-13 Maximum RICH PMTs temperatures for orbit B-75-15_0_0 hot EOL.

RICH is not operative. Non operative temperature requirements are fulfilled.

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The Beta range RICH detector can work continuously is as follows:

$$-55° \leq \beta \leq +75°$$

That in terms of time means 92.7% in terms of mission time.

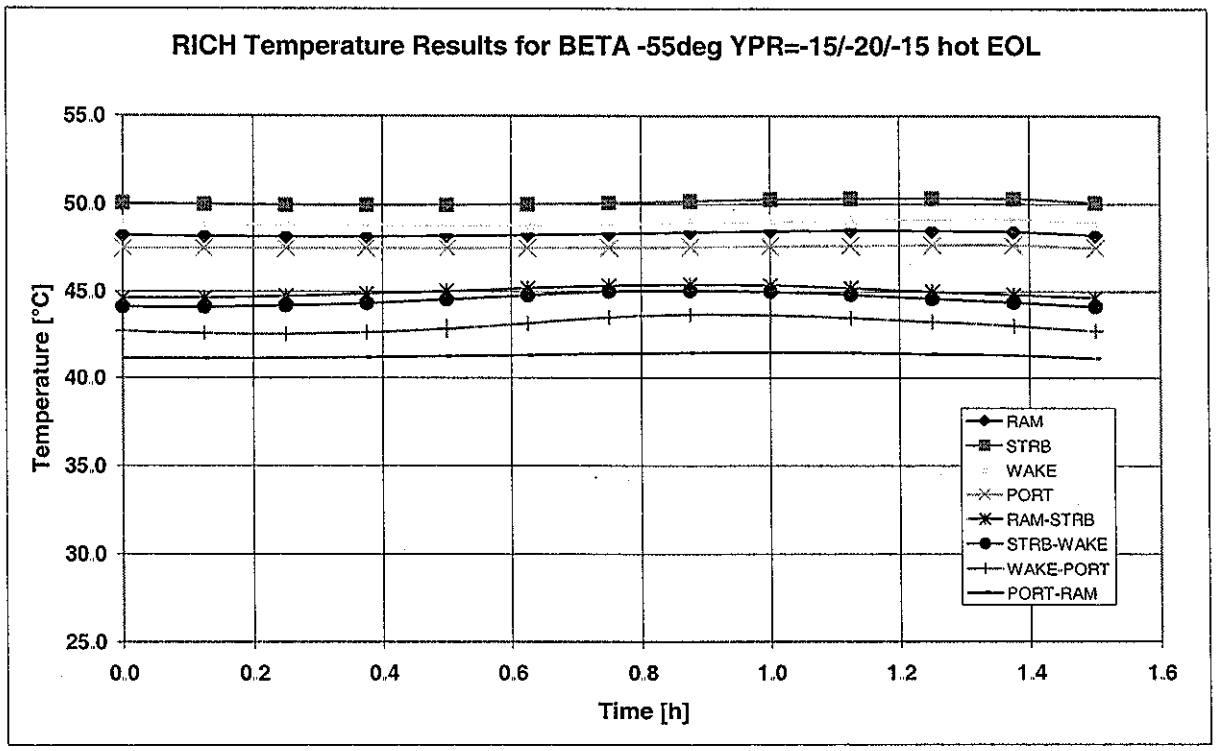

Fig. 8-14 Maximum RICH PMTs temperatures for orbit B-55-15-20-15 hot EOL.

RICH is operative.
Maximum operative temperature requirements and the maximum temperature gradient among the different PMTs are fulfilled.

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8.4.1.1 HEATERS FAILURE ON ANALYSIS

In case of heaters failure, the system must not exceed the maximum touch temperature, namely 113°C. Considering the worst hot case with RICH operative and the heaters ON at 126.5Vdc (maximum voltage), RICH PMTs temperatures are presented in the following graph

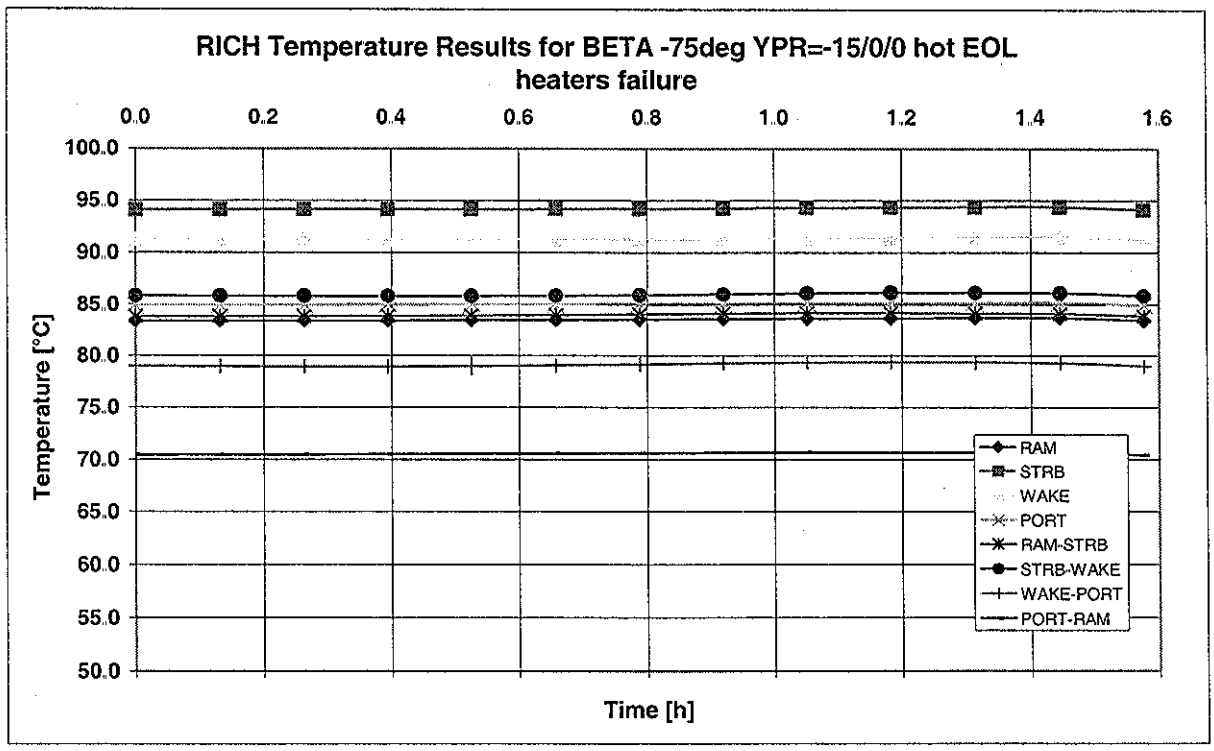

Fig. 8-15 Maximum RICH PMTs temperatures for orbit B-75-15_0_0 hot EOL.

RICH is operative. Heaters ON.

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8.4.2 COLD CASE

The coldest design case for RICH detector when AMS is on ISS is as follows:

URL identifier	BETA	YPR	STS	Environment
ISS_und_113	+25	-15 / -20 / -15	Undocked	COLD

Tab. 8-10 RICH detector coldest design case on ISS

RICH PMTs temperatures for this extreme orbit are presented in the following graph for the operative case.

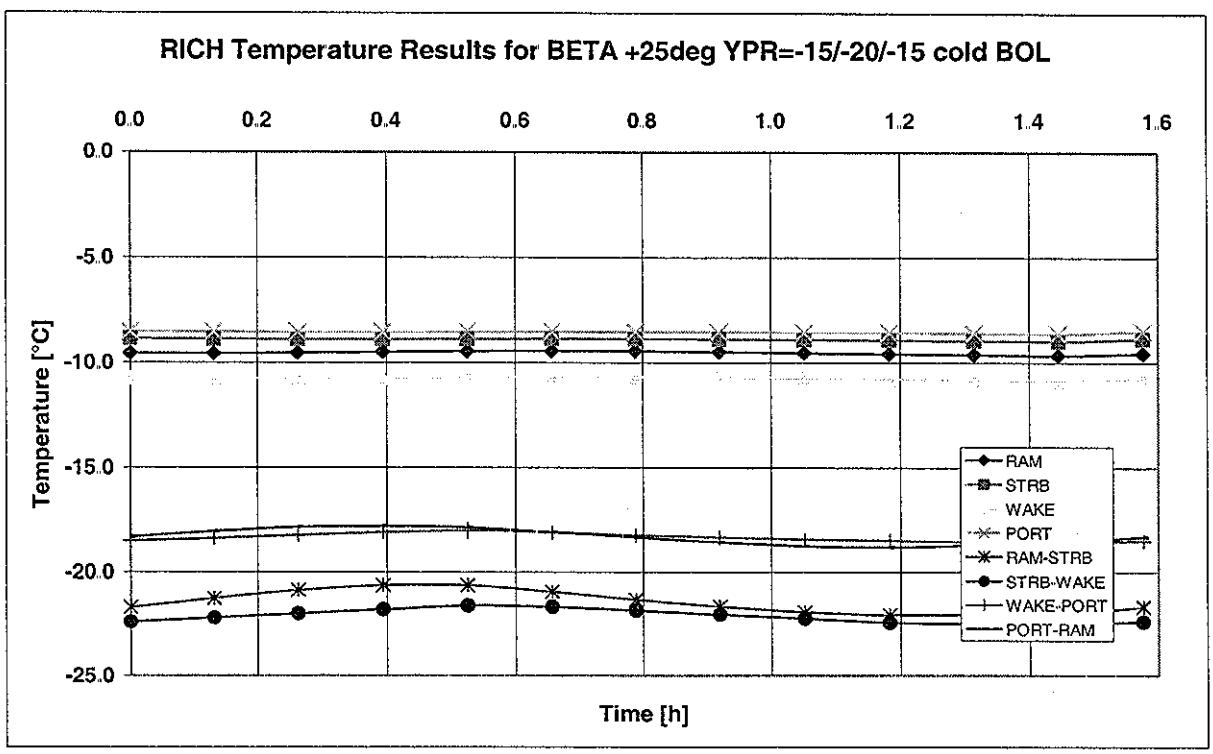

Fig. 8-16 Minimum RICH PMTs temperatures for orbit B+25-15-20-15 cold BOL.

RICH is operative.
The temperatures reached for this coldest orbit are within the operational range.

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8.4.2.1 COOLING DOWN

If a power outage occurs during coldest orbit for RICH detector, PMTs temperatures evolve as follows:

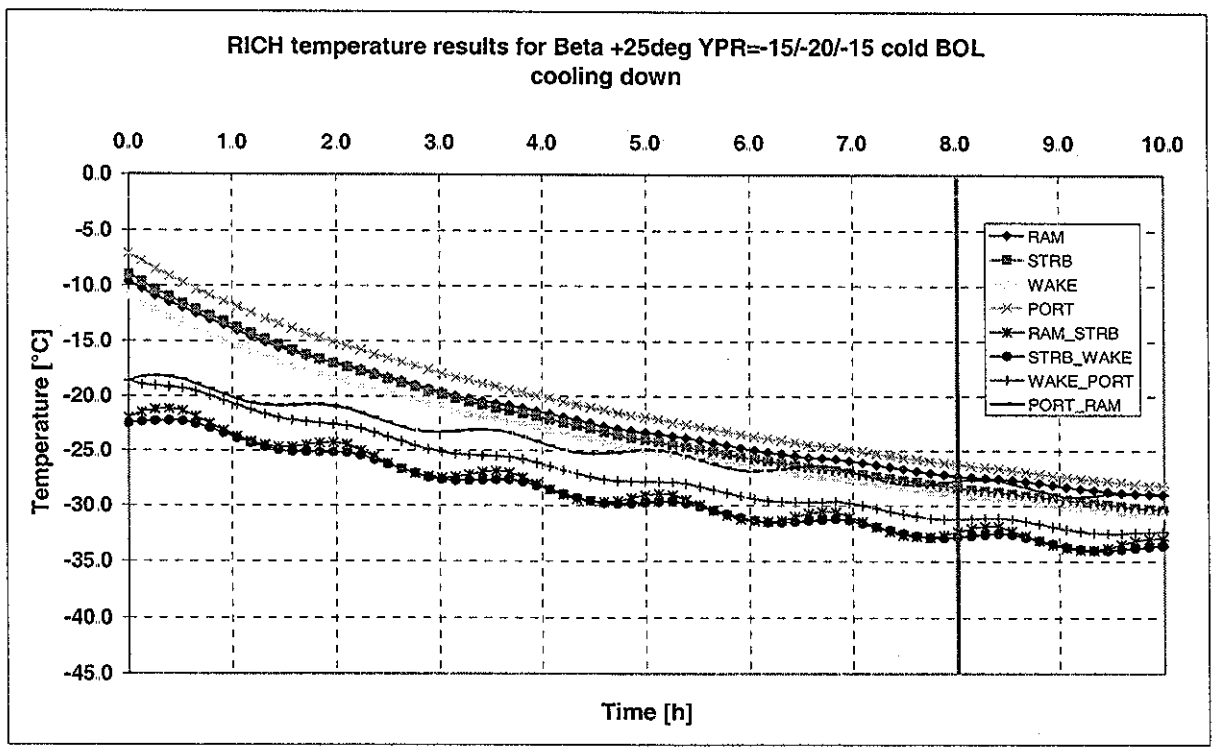

Fig. 8-17 Minimum RICH PMTs temperatures for orbit B+25-15-20-15 cold BOL after power outage

RICH PMTs can withstand even a larger period of time than 8 hours.

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8.4.2.2 SWITCH ON

Following picture illustrates the stabilization temperatures of the RICH PMTs with heaters (70W at 113Vdc) enabled. PMTs temperatures are well above the minimum switch-on temperatures.

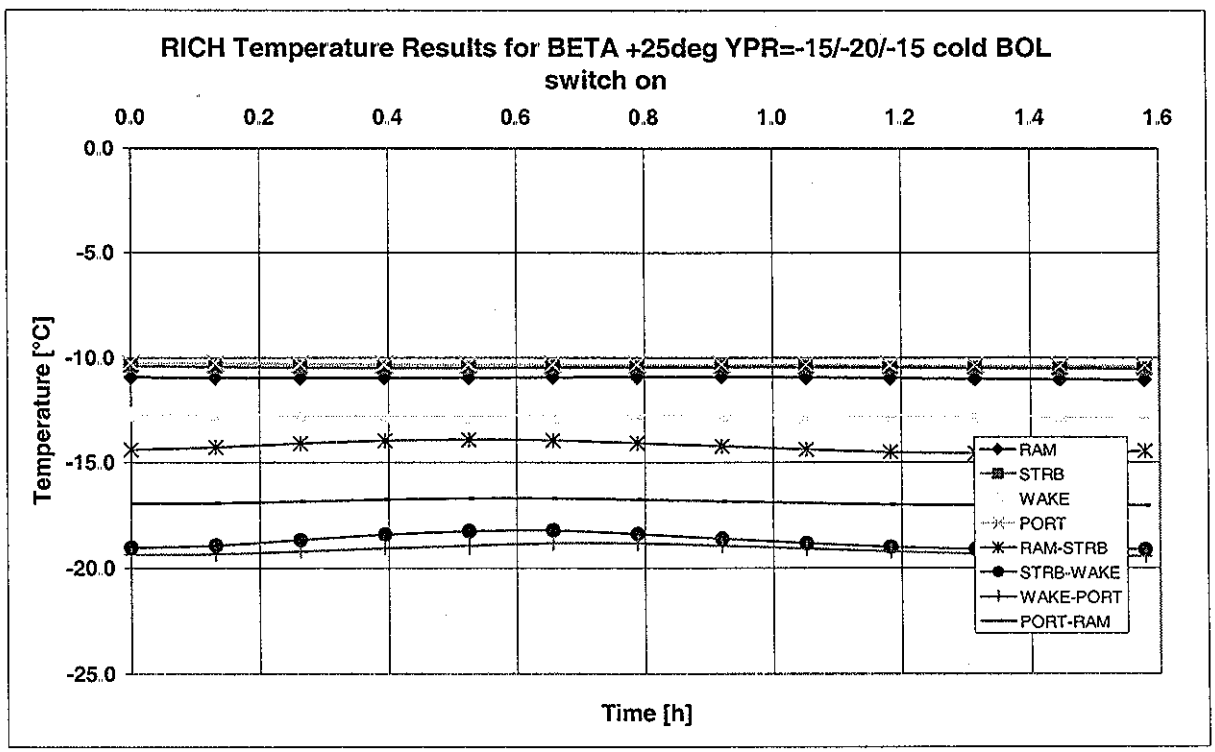

Fig. 8-18 Minimum RICH PMTs temperatures for orbit B+25-15-20-15 cold BOL.

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9. CONCLUSIONS

The Thermal Mathematical models of RICH have been described.
All the temperature predictions for the 4 phases of the LTA sequence have been presented.
There are violations of the temperature requirements only in the hot case when AMS-02 is on the ISS truss.
RICH can't be operative for all the mission, but 92.7% in terms of mission time.
Cold cases are not a critical at all if 70W heaters (@113Vdc) are available for the detector.

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