

The SOFIA Science Instrument Program: Lessons Learned

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ABSTRACT

We present an overview of the science instrument program for the Stratospheric Observatory for Infrared Astronomy (SOFIA). Funded for an initial suite of facility and PI instruments, the SOFIA instrument development program includes imagers and spectrometers from both U.S. and German development teams. With an emphasis on lessons learned, we review the development of the facility instrument suite. We conclude with the anticipated role for SOFIA as a new technology test bed for the latest far-infrared detectors.

Keywords: SOFIA, far-infrared, detectors, instruments, lessons learned

1. INTRODUCTION

1. The Observatory Program

SOFIA is the world's premier airborne observatory. Under development as collaborations between the U.S. and Germany, the program is managed through a memorandum of understanding between NASA and the DLR. The observatory consists of a 747SP 'the Pan Am Clipper Lindbergh' modified to accommodate a 2.7-meter optical quality telescope. Under NASA, the contract for development and operation of SOFIA was awarded in 1996 to the Universities Space Research Association (USRA)[1].

Operating at an altitude of 41,000 feet and above, the observatory's core wavelength range for observations is between 30 and 300 microns. University, Government, and Industrial laboratories experienced in airborne astronomy are developing instruments designed for this wavelength range. A list of the U.S. and German instruments now under development and their respective principal investigators is presented in Table 1.

1.1. Instrument Classes

The SOFIA science instruments fall into one of three distinct classes – special purpose instruments, principal investigator instruments, and facility instruments. Special purpose class instruments are designed with specific functionalities and narrowly focused science objectives. The principal investigator or PI class instruments are developed and operated in a fashion similar to programs aboard NASA's previous airborne observatory – the Kuiper Airborne Observatory (KAO). Facility instruments are developed by teams under principal investigators and are delivered to the observatory for operation by the USRA staff.

1.1.1. Special Purpose and PI Instruments

Special purpose and PI instruments are available on a shared risk basis. When using these instruments, general investigators work closely with the instrument team in proposing their observations, planning the data acquisition, reducing and analyzing the data, and publishing their final results. PI instruments are expected to use the latest technologies and to quickly make enhanced capabilities available to the general investigator community.

1.1.2. Facility Instruments

Facility science instruments (FSI) are generally designed for broader community use, incorporate more established technologies, and are capable of supporting a greater number of missions per year. General investigators seeking to obtain data from SOFIA's facility instrument program work with the observatory personnel in preparing proposals,

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planning observations, and reducing data. Observatory personnel are assisted in supporting general investigators through the SOFIA data cycle system (DCS) software infrastructure.

Table 1. SOFIA's funded suite of first light instruments

Instrument	PI	Institute	Type of Instrument	Instrument Class	Cost (\$M)
HIPO	T. Dunham	Lowell Observatory	High-speed Imaging Photometer for Occultations 0.3 – 1.1 microns	Specialty Instrument (Test Instrument)	2.0
FLITECAM	I. McLean	UCLA	Near-infrared test camera 1 – 5 microns	Facility Instrument (Test Instrument)	2.0
EXES	J. Lacy	Univ.of Texas	Echelon Spectrometer 5 – 28 microns R=10 ⁵ , 10 ⁴ , 3000	PI Instrument	1.9
FORCAST	T. Herter	Cornell Univ.	Mid-infrared camera 5 – 40 microns	Facility Instrument	4.3
GREAT	R. Guesten	MPIfR KOSMA DLR-WS	Heterodyne Spectrometer 60 – 200 microns	PI Instrument	NA
CASIMIR	J. Zmuidzinas	Caltech	Heterodyne Spectrometer 250 – 600 microns	PI Instrument	3.4
FIFI-ls	A. Poglitsch	MPE, Garching	Imaging Grating Spectrometer 42 – 210 microns	PI Instrument	NA
HAWC	D. A. Harper	Univ.of Chicago	Far-infrared bolometer camera 50 – 240 microns	Facility Instrument	8.8
SAFIRE	H. Moseley	NASA-GSFC	Imaging Fabry-Perot Bolometer array spectrometer 145 – 655 microns R = 1000 to 2000	PI Instrument	>2.2

1.2. The USRA Call for Instrument Proposals

In response to the U.S. call for instrument proposals issued on April 8, 1997, USRA received nineteen (19) proposals by the July 15, 1997 deadline covering a wide range of wavelengths and functionalities [2]. All proposals were reviewed by a panel of scientific peers at the Lunar and Planetary Institute in Houston, Texas, on September 4 – 5, 1997.

Recommendations for selection were made to Dr. Eric Becklin, the USRA Chief Scientist and Observatory Director. NASA management approved the final selection of U.S. first-light instruments for the SOFIA program and for USRA to begin funding instrument teams in October of 1997. Because of limited science instrument funding, the call for proposals strongly encouraged ‘cost and science effectiveness’ in all proposals (e.g. cost sharing with the proposer’s institution or extensive use of past space, ground-based, or KAO experience or equipment).

1.3. The Current Suite of Instruments

The 1997 U.S. instrument selection includes three facility-class instruments (FORCAST, HAWC, and AIRES), two PI-class instruments (CASIMIR and EXES), and one specialty-class instrument (HIPO). One U.S. instrument (FLITECAM) was originally proposed by USRA to NASA for characterization of the observatory. Two German led instruments (FIFI-ls and GREAT) are also of the PI-class and received sufficient internal funding from their respective research institutions to be approved by DLR as first light SOFIA instruments. In 1998, an additional U.S. instrument (SAFIRE) was added to the first light instrument suite with leveraged funding from NASA ARC, NASA GSFC, and NASA HQ.

Each SOFIA instrument operates close to the diffraction-limited performance of the observatory ($\theta[\text{arc-seconds}] = 0.1 \times \text{wavelength} [\mu\text{m}]$) [3]. All SOFIA instruments incorporate state-of-the-art technologies. Most of the detectors used by SOFIA instrument leverage several funded space-based initiatives.

2. FACILITY INSTRUMENT DEVELOPMENT

2. The FSI program

The SOFIA facility instrument program is a key aspect of USRA’s plan for a broad-based engagement of the astronomical community. To deliver the instrument performance promised to both NASA and the community, USRA required each facility instrument to undergo a series of reviews. These are a preliminary design review (PDR), a critical design review (CDR), and a final acceptance review. Upon successful completion of the facility instrument acceptance review, the observatory director will award the principal investigator 50 successful flight hours together with a research grant for data analysis and publications costs of the data collected under the flight hours awarded.

2.1. Review boards and reports

The observatory director convenes all reviews, formulates a review board and appoints a chairman to lead the review. During the review, the board is instructed to provide constructive comments and avoids extensive problem solving discussions. Request for action forms (RFAs) provided by the observatory capture the recommendations of the review.

The review board is responsible for making judgments and recommendations concerning the review content. The board chairman is to supervise the review, mediate discussions, meet the review objectives, and maximize the value-added contributions of the review board. Following the review, the board meets to discuss finding, review and assign RFAs, and prepare a draft report. The chairman prepares a final report of concerns and recommendations. The board rejects or adopts either in part or in full all submitted RFAs from the review. Major concerns of the board following the review are made available to both the PI and the observatory director.

Table 2. Two week incremental timeline for review completion

1. All review material submitted to the committee
 - a. All review material available on an internal web site
2. Committee chair submits review report to the observatory director
3. Observatory director reviews report with PI and USRA team
 - a. Instrument team submits response to report
4. Observatory director issues instructions to the PI for continued development

The principal investigator for the facility instrument is responsible for a detailed meeting agenda, presenting the material, tending to review logistics, and assembling a hard copy package of the material to be presented at the review. The deliverables expected for each review are summarized in Table 2 and is expected at two weeks intervals from the time of the actual review.

2.1.1. Review Board Lessons Learned

The boards consisted of USRA management along with scientists and engineers from inside and outside the SOFIA community. Instrument teams typically provided their briefing material days before the actual review although draft versions were available for internal review by the science support staff in the weeks before.

The peer-to-peer nature of the reviews made for a good exchange of ideas and comments. Although, many of the review comments focused on management issues, stronger and more vocal management participation would have provided additional emphasis on these issues. System level management concerns provide a strong framework the development. Misplaced management concerns can also over-load a development with a burdensome infrastructure. A judicious selection of management practices is needed for the sub-orbital instrument programs.

Following successive reviews, board participation and final report completion needed continued attention. In future reviews, a member of the science support staff should draft an initial version of the report for review by the committee. The board chairman circulates the draft report for comments and final editing. As the board moves from PDR, delta-PDR, CDR, delta-CDR, etc. it may be advisable to shift the review responsibilities to the observatory staff. Reviews can be accomplished with smaller incremental reviews by the observatory staff while rolling-up the results into a final external peer review effort.

The pass-fail nature of reviews tends to apply considerable pressure to the instrument team. The review chairman should remind all participants of their fiduciary responsibilities. Reviews fail to achieve their intended goals when being candid and fourth coming is not the highest priority of the review.

2.2. Project Implementation Plans

The basis for all the SOFIA reviews is the development and completion of a project implementation plan (PIP). The PIP is expected to evolve over the life of the project and describes the instrument's form and function to all concerned. Prior to the preliminary design review for each instrument, the SOFIA science support staff is expected to contribute to the formulation and review of the PIP and provide concurrence of the following issues:

- a. Statement of preliminary instrument requirements
- b. Feasible design concepts with a viable approach
- c. Suitable rationale for trade studies
- d. Listed problem areas and risk mitigations
- e. Stated adequacy of schedules, resources, and planning

The PIP document should replace the original science proposals. The suggested table of contents for the PIP is listed in Table 3. Under the USRA program, only facility instruments were required to complete project implementation plans [4].

2.2.1. Project Implementation Plan Lessons Learned

Each of the facility instruments developed an implementation plan for their programs. Drafts of the PIP were prepared for the PDRs with final versions completed by CDR. These same documents serve as the basis for the commissioning plans needed for the FSI pre-ship and acceptance reviews.

The actual PIP documents for FLITECAM, FORCAST, and HAWC differed from the suggested outline as needed for each development. The FSI PIP documents were often more detailed with specific system and subsystem level

instrument requirements and was very helpful in getting the instrument teams through the various review stages. A preliminary version of the PIP should be developed from the earliest stages of the instrument.

Aside from deliverables, an important aspect of the PIP is risk identification and mitigation. As the instrument develops, the mitigation stage may result in decision to temporary defer scope in some aspect of the instrument so as to meet the required development schedule. As a sub-orbital program, not all deferred scope items need be permanent.

Table 3. Suggested contents for Project Implementation Plans

1. Specifications and Verification of Instrument Design
 - 1.1. Final design-to-specifications (level 1)
 - 1.1.1. System design guidelines
 - 1.1.2. System performance parameters
 - 1.1.3. Operational constraints
 - 1.2. Design implementation (work break down structure)
 - 1.3. Derived design dependent requirement (level 2) and verification plans
 - 1.3.1. Hardware
 - 1.3.2. Software
 - 1.3.3. Operational concepts
 - 1.4. Facility instrument verification and acceptance plans
2. Required interface control documents
 - 2.1. External documents and verification plans
 - 2.2. Internal documents and verification plans
3. Airworthiness
 - 3.1. Cryostat
 - 3.2. Instrument mount
 - 3.3. Instrument electronics
 - 3.4. Instrument installation
4. Project management
 - 4.1. Integrated product teams
 - 4.2. Instrument schedule
 - 4.3. Instrument budget
 - 4.4. Deliverables
5. Project deliverables
 - 5.1. Hardware
 - 5.2. Software
 - 5.3. Manuals and documentation
6. Risk identification, mitigation, and de-scope

2.3. Preliminary Design Review

The first formal review required by USRA was the preliminary design review (PDR). The primary purpose of the PDR is to verify that the technological implementation satisfied the operational requirements proposed by the instrument teams. The review board verified that design and fabrication could proceed within allocated costs, schedule, manpower, and facilities. The PDR should be completed prior to the start of major detailed design activities. The policy for SOFIA facility instrument reviews required a broad range of topics to be covered during each review. The preliminary design review board was instructed to review the following areas:

- ◆ Statement of operational requirements
- ◆ Verification plans for compliance requirements
- ◆ Identify inherited designs and commercial products
- ◆ Major system design parameters
 - Performance
 - Volume
 - Layout
 - Power
 - Interfaces
- ◆ Results of major design trade-offs
 - Justification of chosen implementations
- ◆ Discussion of key design details
 - Preliminary drawings, schematics, and planning
- ◆ Outlined of planned development tests
- ◆ Major support equipment requirements
- ◆ Preliminary operations planning
- ◆ Schedule, budgets, and task status
- ◆ Major concerns, risks, and de-scope options
- ◆ Open items and resolution plans

2.3.1. PDR Lessons Learned

All facility instrument PDRs were scheduled for completion prior to the USRA-SOFIA PDR in November 1998. Whereas the FLITECAM and FORCAST development passed their PDRs, the review committees for HAWC and AIRES requested delta-reviews to address unresolved issues. It may have been advisable for USRA to request a System Definition Review (SDR) shortly after the selection of instrument proposals in 1997. Many of issues uncovered during the instrument PDRs could have been addressed by an earlier stage review. Holding the SDR so soon after proposal selection may have proved troublesome. The USRA-SOFIA SDR was held approximately 9 months after NASA's contract award. For the facility instruments, USRA could have awarded a portion of the requested funding at proposal selection with further allotments based upon successful completion of review milestones [5].

2.4. Delta PDR

In the case of both HAWC and AIRES, separate incremental reviews were required to make up the following items [6]:

1. Complete requirement flow-down to all subsystem.
2. Agreed upon of roles and responsibilities between the upper most levels of management.
3. Complete work breakdowns, schedules, and budgets.
4. Designs consistent with all known envelopes (size, mass, cost, and schedule).

For HAWC, clearly defined requirements along with inter-agency agreements and a complete management plan were required for the delta-review. For AIRES, the delta-review required a complete management plan along with a design that fit within SOFIA's established instrument envelopes. The complexity of both instruments meant that each team needed to spend more time in the formal requirements definition and management planning stage to satisfy their respective review committees. With the award of funding in October 1997, all instrument teams were eager to plunge directly into the hardware development phase and somewhat reluctant to completely map out the requirements and management needs of the instrument. The review committees requested clearly defined sub-system requirement based upon proposed instrument performance levels.

2.4.1. Delta-PDR Lessons Learned

Both the HAWC and AIRES team responded to all of the points raised by their review committees. For both developments, the assignment of management leads with suitable levels of authority above those of the principal investigator and knowledgeable about the development has proven to be a challenge.

2.5. Critical Design Review

The primary purpose of the CDR is to verify that the detailed design is complete and ready for manufacturing, and that fabrication and testing can proceed within allocated cost, schedule, manpower, and facilities. The review should be

scheduled after completion of the design and prior to the fabrication and purchasing. The critical design review board was instructed to review the instrument according the following:

- ◆ Operational requirements and verification compliance
- ◆ Summary of major derived design specifications and constraints
- ◆ Major changes since PDR
- ◆ Interface details and status of agreements
- ◆ Selected design details
- ◆ Critical component status
- ◆ Selected manufacturing details and plans
- ◆ Configuration control plans for hardware and software
- ◆ Maintenance plans for hardware and software
- ◆ Documentations status
- ◆ Breadboard and prototype test status and results
- ◆ Test plans for the deliverable units
- ◆ Operational features and constraints
- ◆ Spare provisions
- ◆ Support equipment requirements, provisions, and plans
- ◆ Schedule, budget, and flow plan status
- ◆ Major concerns, open items, and plans for resolution

Note that long lead items may be purchased prior to the review.

2.5.1. Critical Design Review Lessons Learned

Three of the four funded facility instruments passed their critical design reviews. In several cases, the critical design review dates shifts by a year or more from their initial estimates at PDR. This can be attributed to the optimism of SI developers but also the work needed to complete the preliminary airworthiness review process.

It is very important for the critical design review to be as complete as possible as this review sets the stage for successful completion of the instrument. All aspects of the development plan (PIP) need to be completed. Reviewing all the required documentation requires considerable effort of the science support staff and will require needed staffing resources at the observatory level. A key aspect of this review is the need for testing plans for completed sub-systems. For a challenging development, the verification of performance is what makes for successful delivery of sub-systems and their integrated components.

The successful acceptance of the PIP and the completion of the CDR can result in the award of a fixed price contract for the development of the instrument. The fixed price contract tied to the requirements and deliverables of the PIP would represent the final agreement between the observatory and University management. Currently, all SOFIA instruments are developed as research grants to the PI's home institutions. Prior to the CDR, the inherent risk of instrument development may preclude the formal commitment to fixed price contracts with agreed upon deliverables.

2.6. Assessment and Cancellation Review

It is a very unfortunate situation for the observatory director to call an assessment or cancellation review. By carefully following the review process above, the director should have a clear indication if such a review is required. Albeit difficult, continuity of the review board members and the documented results of previous reviews will make this effort objective.

2.6.1. Assessment and Cancellation Review Lessons Learned

In the case of the AIRES review, the projected cost and schedule growth of the instruments resulted in the observatory director requesting an instrument assessment review following a requests by USRA and NASA management to 'stop work' on the instrument. Held in June 2001, the review committee recommended cancellation of the instrument. The cancellation of AIRES was a serious blow to the morale of the entire SOFIA science team.

2.7. Quarterly Reports and Trimester Reviews

From the start of the October 1997 funding, all the SOFIA instruments were required to submit quarterly reports to the USRA business office in Waco, Texas. With the limited number of reports submitted in non-standard formats, a standard format was circulated in January 2000 with a request for quarterly updates.

At the request of NASA management, the formal submission of quarterly reports was replaced in October 2001 with stand-up reviews for all the science instruments. Called the Science Instrument Trimester Reviews (SITRs), the presentations provide all of USRA and NASA management a venue for questioning and monitoring the development of both facility and principal investigator instrumentation.

2.7.1. Quarterly Reports and Trimester Review Lessons Learned

With a development program the size of SOFIA (\$60M/year), there management groups that need visibility into the development of science instruments. This status is best communicated through stand-up reviews that should occur a 12-month to 6-month to 3-month intervals [7]. An instrument manager is required to organize these reviews. Each instrument should report status in a standard format detailing technical and financial status. For SOFIA, each trimester review was preceded with a telecon reminding all the teams about status and preparation details followed by a written report detailing the events of the meeting. Meeting preparation and completion of the report were somewhat time consuming for the science support staff. The report, however, provides a paper trail that all management can use in tracking the development of each instrument.

2.8. Acceptance Reviews

The purpose of the acceptance review is to give final approval of the instrument developed and delivered to the USRA science and missions operations center. The following items are requested in presenting the acceptance review:

- ◆ Delivery of agreed upon systems
 - Hardware
 - Software
 - Supporting components
- ◆ Verification of expected instrument performance
- ◆ Straight forward data acquisition, reduction, and calibration
- ◆ Acceptable data archival tools and summary data

2.8.1. Acceptance Review Lessons Learned

Since SOFIA has yet to achieve first light and the acceptance review is based upon the instrument's in-flight performance, we have yet to accept any instruments. A key aspect of the acceptance review is delivery of needed instrument documentation. All facility instruments are required to support specific astronomical observing templates (AOTs) that partner instrument capabilities with working data reduction pipelines. The USRA program has invested in a software infrastructure called the data cycle system (DCS) that allows observatory personnel to manage the flow of general investigator observing requests and the delivery of final data products. All facility instruments need to be fully integrated with the DCS and supporting a minimum number of AOTs to pass their acceptance review.

3. OVERVIEW OF THE FSI DEVELOPMENT

3. Facility Instrument Reviews

Reviews for all of SOFIA facility instrument efforts were held on the dates indicated in the table 4. The conceptual design reviews held were not as a formal review of the instrument development and served as an introduction to the designated engineering representatives of the FAA who help shape SOFIA's current science instrument airworthiness certification program.

Table 4. Facility instrument review dates

<u>FSI</u>	<u>Conceptual</u>	<u>Preliminary</u>	<u>Delta</u>	<u>Critical</u>	<u>Pre-ship</u>
FLITECAM	Apr. '98	Jul. '99	N.A.	Aug. '00	Nov. '04
FORCAST	Apr. '98	Aug. '98	N.A.	Mar. '00	Apr. '05
HAWC	Apr. '98	Oct. '98	Dec. '99	Feb. '01	Apr. '06
AIRES	Apr. '98	Oct. '98	Feb. '00	Jun. '01*	N.A.
DCS	Jun. '99	Mar. '00	N.A.	Mar. '01	

Both HAWC and AIRES instrument were required delta-PDRs to address topics not covered at their first formal design review.

3.1. Facility Instrument Development Challenges

The HAWC and the AIRES development had several management challenges. However, one of the principle challenges for both instruments was the need for detectors operating at far-infrared wavelengths of 60 to 200 microns. For this wavelength regime, commercial detectors do not exist. A summary of the detector array technology for SOFIA instrumentation is presented in Table 5.

For HAWC, a key challenge was the distributed nature of the development team needed for the pop-up bolometer detector (PUD) development. For AIRES, the challenge would lie in the incorporation of three differing detector technologies and a development program for stressed and unstressed arrays of doped Germanium detectors. The other SOFIA detectors leverage development efforts outside the SOFIA program.

3.2. Far-Infrared Detector Development Challenges

Both bolometers and far-infrared semiconductors lie outside of defense and commercial industry interests. In addition, the far-infrared detector sensitivities necessitate low temperature cryogenic solutions. Although the temperatures required are still consistent with pump He-3 operating points (0.3 K), the overall instrument design is more complicated than detectors running at elevated liquid helium temperatures of 8 K (Si:Sb) or 30 K (InSb). The challenge of the far-infrared detector technology only adds to the growing cost of the instrument. Among all SOFIA instruments, the ability to leverage the detector development within larger space flight programs helps to mitigate the risk of novel technologies. The HAWC and AIRES developments were funded outside of NASA's current far-infrared missions SIRTf and Herschel. The HAWC PUD development was assisted with considerable in-house support from NASA GSFC and through the development of a proto-type array for Caltech's SHARC II instrument. For the AIRES instrument, a similar deep pocket partner did not exist. The lack of additional detector development support within the AIRES development only added to an already challenging program.

Table 5. A summary of instrument detector technologies and developers.

<u>Instrument</u>	<u>Detector</u>	<u>Size</u>	<u>Wavelengths</u>	<u>Developer</u>
HIPO	CCD	1024 x 1024	0.3 – 1.1	COTS
FLITECAM	InSb	1024 x 1024	1.0 – 5.0	NOAO
EXES	Si:As	1024 x 1024	5 – 24	JWST/ARC
FORCAST	Si:As/Sb	256 x 256	5 – 40	SIRTF/Cornell
GREAT	HEB	1 x 1	60 – 200	Bonn
CASIMIR	SIS(NbTiN)	1 x 1	200 – 600	Herschel/JPL
FIFI-Is	Ge:Ga	16 x 25	60 – 110	Herschel/Garching
	Ge:Ga*	16 x 25	110 – 220	
AIRES	Ge:Sb	16 x 24	60 – 120	SOFIA
	Ge:Ga*	8 x 12	110 – 220	
HAWC	P:B PUD	12 x 32	60 – 200	SOFIA/GSFC
SAFIRE	TES:PUD	16 x 32	200 – 600	SOFIA/NASA

4. SUMMARY

SOFIA's instrument program represents the international participation of university, government, and industrial partners. Special- and PI-class instruments are operated by PI instrument teams and are available to general investigators on a shared risk basis. Facility-class instruments are developed by PI instrument teams and delivered to the observatory for operation by the USRA staff. The development of facility-class instruments are subject to a series of reviews – preliminary design reviews, critical design reviews, and a final acceptance review. All of SOFIA's facility instrument have completed their preliminary and critical design reviews and are working toward instrument commissioning aboard the observatory. The acceptance review for the facility instrument program will require a demonstrated level of instrument performance, completion of all agreed upon deliverables, and integration with the observatory's data cycle system.

All of SOFIA's science instruments are working to satisfy the observatory's airworthiness requirements. The task of meeting the airworthiness requirements of the Federal Aviation Administration and NASA will be the topic of subsequent papers on SOFIA's science instrument development.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. S. C. Casey, "The SOFIA Program: Astronomers Return to the Stratosphere", COSPAR E1.5-0011-02, 2002, and references therein.
2. SOFIA Call for Proposals, USRA ID #CFP97-001.
3. Details on all SOFIA science instrument are available from <http://www.sofia.arc.nasa.gov>
4. Project implementation plans (PIPs) are available for FLITECAM, FORCAST, and HAWC.
5. The "Systems Engineering Handbook (SP-610S)" is an informative NASA guideline for instrument developers.
6. The HAWC PDR report Oct. 1 – 2, 1998; AIREP PDR report Oct. 7 – 8, 1998.
7. Reviews are a means of mitigating the risks of development. The higher the risk (based upon both staffing and technologies), the more frequent the reviews. T. Herter once said to his instrument team – "the reason we have quarterly reviews is so we don't have to have monthly reviews!" Annual reviews should be a minimum for all developments. The need for monthly reviews verges on micro-management.