Department of Energy/
National Science Foundation
Review Committee Report

for the

Technical, Cost, Schedule, and
Management Review

of the

DARK ENERGY SURVEY (DES) PROJECT

May 2007

EXECUTIVE SUMMARY

A Department of Energy (DOE) Office of Science (SC) and National Science Foundation (NSF) review of the proposed Dark Energy Survey (DES) project was conducted on May 1-3, 2007 at Fermi National Accelerator Laboratory. The review was conducted at the request of Dr. Robin Staffin, Associate Director for High Energy Physics, DOE/SC, and Dr. Wayne Van Citters, Director, Division of Astronomical Sciences, NSF, and was chaired by Mr. Stephen Tkaczyk, Office of Project Assessment, DOE/SC. The purpose of the review was to assess the scientific goals and conceptual design of the entire project. The validation of the conceptual design and the cost range of the proposed DOE parts of DES were requested in support of DOE Critical Decision (CD) 1, Approve Alternative Selection and Cost Range.

The Committee endorsed DOE pursuing CD-1 for the Dark Energy Camera (DECam) project (within the DES project). The DECam project manager has established a basis for a well-controlled, well-managed project and has shown a cognizance of areas needing improvement. The DES Project Director has done a remarkable job in assembling an enthusiastic collaboration, bringing a diverse set of complementary capabilities with significant in-kind contributions. In all, there were 58 recommendations from the committee.

The DES collaboration has submitted a proposal to both DOE and NSF to construct and operate an experiment to study the nature of dark energy. The recent Dark Energy Task Force (DETF) described the optimum intermediate- and long-term programs for dark energy investigations. The DETF report, released in July 2006, recommended that one or more mid-term experiments with a combination of techniques be done and that, in combination, they should achieve at least a factor of three gain in the DETF figure of merit over current projects. DES is a candidate to become selected as the DOE preferred alternative for a mid-term ground-based dark energy experiment. The DES experiment proposes to utilize the existing Blanco Telescope at the Cerro-Tololo Inter American Observatory (CTIO) in Chile. The construction project includes a new camera (DECam) optimized for the study of dark energy, the CTIO facilities improvement project (CFIP) upgrades and a data management system (DESDM). The DES is requesting funding for the DECam from DOE and funding for the DESDM and CFIP from NSF. Funding for CFIP would be provided through the National Optical Astronomy Observatory (NOAO), CTIO's parent organization. In addition, funds are being requested from other U.S. and foreign institutions.

The Committee found that the science case, as written, passes the requirement for CD-1. There were ten recommendations concerning science.

The Committee reviewed all of the technical areas of the project, such as optics, focal plane detectors, readout electronics, data management, telescope and facilities upgrade, integration and installation. There were 35 recommendations in these areas. The DECam project design has progressed sufficiently to support a CD-1.

The DES project is divided into three parts, the camera, data management and facility improvements at the telescope. The projected costs, including contingency by funding source, are shown below.

DES Project Construction Costs ($M then year)

	NSF	DOE		NOAO	Other	Total
		OPC	MIE			
Camera		$5.17	$19.81		$8.00	$32.98
Data Management	$2.39				$2.46	$4.85
Facility Improvements				$0.65		$0.65
					Total	$38.48

In addition to the three agencies, the project has arranged for $10.46 million in in-kind contributions. The proposed DOE Total Project Cost (TPC) is $24.98 million. The DECam project presented a price range of $24.1 to $26.7 million. The cost estimate for DECam is consistent with the planned deliverables. There is adequate contingency proposed for this project.

CD-2 (Approve Performance Baseline) and CD-3 (Approve Start of Construction) for the DECam project are scheduled for early FY 2008. CD-4 is projected for the first quarter of FY 2012. There are approximately 23 weeks of schedule contingency to that date, which appears to be adequate. Currently, CD-2 and CD-3 are planned to occur at the same time. The design will not be at the CD-3 level by the time of the CD-2 review. CD-3 will have to be broken into segments (CD-3a, CD-3b, etc.) or delayed until after CD-2. The schedule will have to be modified accordingly.

Environmental, Safety and Health aspects of the project are properly addressed given the project's current stage of development.

There were no specific Action Items resulting from the review.

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1. INTRODUCTION

The discovery that the expansion of the universe is accelerating was first announced in 1998. Studying the nature of the "dark energy" causing this has become one of the most important science objectives in physics and astronomy. This mysterious dark energy comprises about 70 percent of the matter-energy contents of the universe. Not much is known about it other than that it exists.

The Dark Energy Survey (DES) experiment proposes to utilize the existing Blanco Telescope at the Cerro-Tololo Inter American Observatory (CTIO) in Chile to study dark energy. The DES collaboration submitted a proposal for the full experiment to both the Department of Energy (DOE) and the National Science Foundation (NSF) in January 2007. The construction project would include: a new camera (DECam) optimized for the study of dark energy; the CTIO facilities improvement project (CFIP) upgrades and a data management system (DESDM); and 30 percent (over 5 years) of the Blanco Telescope observing time.

The DES is requesting funding for the DECam from DOE and funding for the DESDM and CFIP from the NSF. Funding for CFIP would be provided through the National Optical Astronomical Observatory (NOAO), CTIO's parent organization. In addition, funds are being requested from other U.S. and foreign institutions.

The purpose of this review was to assess the scientific goals and conceptual design of the entire project. The validation of the conceptual design and the cost range of the proposed DECam, which would be the DOE-funded part of DES, is needed for DOE Critical Decision (CD) 1, Approve Alternative Selection and Cost Range.

The joint High Energy Physics Advisory Panel (HEPAP) and Astronomy and Astrophysics Advisory Committee (AAAC) Dark Energy Task Force (DETF) subpanel report was released in July 2006. The current review considered whether the scientific goals were justified, compelling and attainable by DES, in the context of recommendations by the DETF report. The DES will utilize all four methods recommended by the DETF to study dark energy: supernovae, galaxy clusters, baryon acoustic oscillations, and weak lensing. The main method is the use of galaxy clusters. They plan to combine their data with other telescope experiments such as the South Pole Telescope to enhance their results.

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2. SCIENCE

2.1 Findings

The context of the science case for the DES is presented in the report "Dark Energy Task Force" (DETF, 20061996, astro-ph0609051) commissioned by DOE, NSF, and National Aeronautics and Space Administration (NASA). The DETF defined four stages of dark energy study:

1. Stage I represents what is now known about dark energy
2. Stage II represents the anticipated state of knowledge upon the completion of ongoing projects that are relevant to dark-energy.
3. Stage III comprises near-term, medium cost, currently proposed projects
4. Stage IV comprises a Large Survey Telescope (LST) and /or the Square Kilometer Array (SKA), and/or a Joint Dark Energy (Space) Mission (JDEM).

In particular, the DETF recommended:

"II. We recommend that the dark energy program have multiple techniques at every stage, at least one of which is a probe sensitive to the growth of cosmological structure in the form of galaxies and clusters of galaxies."

"III. We recommend that the dark energy program include a combination of techniques from one or more Stage III projects designed to achieve, in combination, at least a factor of three gain over Stage II in the DETF figure of merit, based on critical appraisals of likely statistical and systematic uncertainties."

"Smaller, faster programs (Stage III) are needed to provide the experience on which the long-term projects can build. These projects can reduce systematic uncertainties that could otherwise impede the larger projects, and at the same time make important advances in our knowledge of dark energy."

"13. Six types of Stage-III projects have been considered. They include:

a. A BAO survey on a 4-m class telescope using photo-z's.
b. A BAO survey on an 8-m class telescope employing spectroscopy
c. A CL survey on a 4-m class telescope obtaining optical photo-z's for clusters detected in ground-based SZ surveys.
d. A SN survey on a 4-m class telescope using photo-z's.
e. A SN survey on a 4-m class telescope employing spectroscopy from an 8-m class telescope
f. A WL survey on a 4-m class telescope using photo-z's.

These projects are typically projected by proponents to cost in the range of tens of millions of dollars. (Cost projections were not independently checked by the DETF."

The DES will survey 5,000 sq-deg in the filters *griZY* and a repeated pointing of 9 deg-sq in *riz* for supernovae to a depth of *i=24*. The 9 sq-deg field will be visited five times per lunation. To do these surveys, the DES will build DECam, which is a 3 deg-sq camera using fully-depleted Charge-Coupled Devices (CCD). The survey will use 30 percent of the available observing time on the NOAO Blanco four-meter telescope at CTIO over a five-year period, concentrated during the period from September to March each year. For the remaining time, DECam will be made available to the NOAO user community through the usual telescope time allocation process at NOAO. The DECam is scheduled to be ready for installation on the telescope in October 2010 with the first science images in February 2011.

The DETF report, released in July 2006, recommended that one or more mid-term experiments with a combination of techniques be done and that, in combination, they should achieve at least a factor of three gain in the DETF figure of merit over current projects. DES is a candidate to become selected as the DOE preferred alternative for a mid-term, ground-based dark energy experiment.

DES will measure properties of dark energy using the DETF-recommended four probes of dark energy: supernovae, galaxy clusters, baryon acoustic oscillations, and weak lensing. The 10-sigma limiting magnitudes along with a two percent photometric error will measure photometric redshifts for individual galaxies to a precision of 0.1 in z, and to 0.02 for galaxy clusters. The DES will select clusters and estimate their mass using weak lensing, Sunyaev-Zel'dovich (SZ) detection from the South Polar Telescope (SPT), and optical galaxy cluster identification. The DES will cover the full SPT field. Using an equation of state formulation of $w(z) = w_0 + w_a(1-a)$, the estimated increase in the figure of merit from the expected Stage II experiments will be 4.6, consistent with the findings of the DETF for Stage III experiments.

The four techniques for measuring dark energy measure two independent aspects of dark energy—the relative size change of the Universe (the "geometric" measurements) and the growth of structure. The supernova and Baryon Acoustic Oscillations (BAO) projects use purely geometrical measures and are sensitive to dark energy in different redshift ranges. The weak lensing and the cluster evolution measure both geometry and growth of structure.

The DECam can reach to higher redshifts because the fully-depleted CCDs have high quantum efficiency past 1 micron, and produce no fringe patterns. The DES will collaborate with the European Southern Observatory Visible and Infrared Survey Telescope (VISTA) and its VISTA Hemisphere Survey (VHS) that will provide JHK_s photometry of the DES survey region using the VISTA 4m telescope in Chile. The DES field is chosen to overlap with the SPT field of 4000 sq-deg. The SPT will produce a catalog of flux deviations over this field from the SZ effect. These flux deviations show the presence of the total mass of galaxy clusters, but do not provide any information about the redshift of the clusters.

The photometric redshifts are important for the four tests. Presently, the supernova project will obtain large numbers of spectra from ground-based telescopes, but the majority of the redshifts for the other projects will come from photometric redshift fits. Because the DES goes only to a shallow depth of $i=24$, the atlases of spectra needed to train the photometric redshift technique available at the time of the start of the DES will provide roughly 400,000 spectra in the magnitude range covered by the DES.

2.2 Comments

The DES is an ambitious project that will provide significant scientific results on all four of the science projects recommended by the DETF: supernovae, clusters of galaxies, baryon acoustic oscillations, and weak lensing. The science proposed clearly fits in the Stage III project envisioned by the DETF, both in terms of science goals and exploring systematic errors that will affect the Stage IV experiments. DES demonstrated that it meets the minimum factor of three recommended by the DETF.

The DES was conservative in developing science requirements in order to match technical constraints, including matching the science to the telescope deliverables. In other words, there are no large looming technical requirements that could compromise the science goals. Careful attention was paid to understanding the systematic errors in the data, and designing the experiment to make these effects either irrelevant or controllable by the experimental technique. However, there are significant details that were only partially explored in data reduction, calibration, and science analysis. With immediate attention, none of these details will seriously affect the project's success.

DES is unique, as it will work on all four science projects with one telescope. The project has the ability to combine all the heterogeneous data into a single cosmological fit. To date, the dark energy tests have combined separate experimental results in a Fisher matrix style analysis. However, DES can fit all of its data simultaneously to fit the dark energy parameters. Other unique aspects of DES include:

- collaboration and access to the VISTA VHS data
- simultaneous fits to dark energy parameters across all four experiments
- cost effectiveness by using a single telescope both in instrumentation costs and manpower needed to reduce the data

- access to the southern sky surveyed by SPT
- public access to data (as compared to Pan-STARRS)
- wide-field survey covering the full SPT field
- a redshift range where the photometric redshifts can be calibrated with existing spectral atlases
- a public precursor experiment to the Stage IV LST whose data can be used to explore systematics and provide raw data for tuning the LST pipelines
- multiple ways of measuring similar quantities which will allow systematic errors to be measurable
- access to massive computing facilities through the DOE
- access to DOE management for large instrumentation projects (not typical in astronomical projects)

Perhaps the biggest competitor to DES is Pan-STARRS (other competitors include BAO—BOSS/HETDEX/WiggleZ; SN— Pan-STARRS /SNLS; WL—CFHT; Clusters—PISCO). This project is very secretive and was funded largely by congressional earmarks. It has not been peer reviewed. Some of the science will overlap between these two projects, and it is likely that Pan-STARRS may be better at the supernova science. The DES is unique in that it surveys the *southern* sky where the SPT and VISTA will provide data. This uniqueness with respect to Pan-STARRS is a critical reason why the DES should go forward.

The supernova survey science goals were not as well developed as the other science goals. A uniqueness of the supernova project is that a deep and wide survey in the southern hemisphere will complement the Pan-STARRS survey allowing all sky studies of the variation in w over large scales. Since this is a relative measurement, most of the systematic errors will be minimized.

DES should actively review the other projects to continually re-evaluate the DES goals and timetables to those goals. The DES maintains a healthy advantage in getting the science done, provided that the funding does not slip.

Access to the U.S. community is very important. However, that opens up the problem of parallel science projects. There is presently no resolution to how the project will protect itself (if it can) from similar science projects from the community using the same camera.

There were a few problems regarding linkage between the science goals and the calibrations. There is no clear roadmap on how the science will be divided among the groups.

A goal of two percent (rms) relative photometry will seriously affect the supernova science. An optimistic goal of one percent (rms) relative photometry should be a best effort goal with two percent as the minimum accuracy.

The DETF recommended that Stage III experiments also should provide a figure of merit increase of at least a factor of three and improved understanding of systematic errors for Stage IV experiments. The science case was well stated and consistent with Stage III, but the quantitative goals for the improvement of specific systematic errors were in most cases lacking. The project should develop a parallel science case to discuss goals for improving systematic errors.

The Committee found that the science case, as written, passes the requirement for CD-1. The recommendations should be resolved for the CD-2 review.

2.3 Recommendations

1. Explore a program to improve Blanco telescope image quality from 0.9” to 0.7” Evaluate such a program in terms of incremental cost to the project, incremental science gains, and the possibility of real improvement in the image quality.

2. Convene an NSF, NOAO, and DOE common users advisory group to recommend the U.S. user’s community needs for the use of DECam.

3. Resolve science overlap between DES science goals and user community science goals in the case where the user community proposes for time on DECam to do the DES science.

4. Actively review progress of competitors to maintain timeline towards scientific goals.

5. Determine the uniqueness of the science beyond achieving the factor of three goal of Stage III experiments.

6. Consider making the goal of one percent relative photometry as best effort goal with two percent minimum goal.

7. Review and expand the goals of the supernova science component. Consider varying the cadence of data in the wide field survey to maximize sensitivity to SN science.

8. Organize a coordinated theory group across all the science projects.

9. Create a plan for the DES if the SPT telescope for some reason does not deliver the SZ clusters.

10. Produce quantitative goals for the improvement of systematic errors for the Stage IV experiments, as outlined in the DETF.

3. TECHNICAL

3.1 Optics, Optical Corrector, Mechanical Systems

3.1.1 Findings

A conceptual design for the optomechanical assembly and subsystems for DECam was completed and reviewed. The design includes the corrector and barrel assembly, filter changer and shutter mechanisms, cryostat assembly, camera, cooling system, hexapod positioning system, cage assembly, and interface to the vanes on the CTIO Blanco telescope.

The team was assembled for developing the DECam optics and optomechanical components. The work is being distributed over a number of collaborating institutions:

- Fermi National Accelerator Laboratory (Fermilab)—prime focus imager, barrel assembly, C5 cell, hexapod positioning actuator, cage assembly, telescope simulator, process systems, cooling and auxiliary systems
- U. Chicago—prototype cryostat assembly and rotation fixtures
- U. Michigan—filter procurement oversight/testing, filter changer, shutter, light baffles.
- U. College London (UCL)—lens cells, lens optical fabrication, management of lens procurement and assembly of the corrector
- NOAO/CTIO—telescope upgrades, DECam installation/commissioning/operations.
- Argonne National Laboratory (ANL)—FEA and control system

A work breakdown structure (WBS) and a budget that includes the DECam assembly was developed with capital costs and resource loading.

A preliminary FEA analysis of the corrector barrel was done and a complete DECam and telescope FEA model is being developed.

Blanks for the corrector lenses are available from two vendors. Only Corning can produce the largest (C1) blank, using a slumping technique. Quotes were obtained.

Multiple potential fabricators are available for polishing the corrector optics and ROM quotes were obtained. Multiple potential vendors exist for filters and coatings.

The shutter is available from Bonn University, which built similar albeit smaller mechanisms (Pan-STARRS). The filter changer mechanism will be designed and built by University of Michigan and will be similar to the design developed for Pan-STARRS.

The final assembly of DECam (by the DECam team) will take place in a clean room at the Blanco Telescope. CTIO will have lead responsibility for installing DECam on the telescope and commissioning. The DECam team will provide support through commissioning.

3.1.2 Comments

Scientific and engineering resources are available for the DECam optomechanical work. The highly distributed organization of this effort will require good managerial and systems engineering controls. These need to be in place well before CD-2 if the schedule to CD-2 is to be maintained. Additional resources were being added to the DECam team to address this issue. The broader issue of management of the DES is addressed in Section 7.

Early prototyping and the adaptation of existing designs give confidence that the engineering solutions being developed will work in the production camera. Examples are the camera focal plane assembly, barrel assembly, and shutter and filter mechanisms (Pan-STARRS).

The planned telescope simulator, while costly, will allow mechanical testing of the optomechanical assembly prior to shipment to Chile including the cage and vane interface to the telescope structure. This will help the project meet its tight schedule for assembly, integration, and testing on-site.

Costs and schedules were deemed credible particularly where backed up by vendor ROMS and prototype experience with the caveat that the amount of additional systems engineering recommended to reach CD-2 will push the schedule.

A Finite Element analysis of DECam mounted at the top end of the Blanco telescope is required in order to assess the performance of combined structure at various assumed telescope orientations and to validate the design. The planned analysis should look at stresses, deflections, and modal performance. A dynamic response analysis would also provide information about wind induced image blur. The vanes and hexapod should receive special attention. This analysis is needed well before CD-2 in order to allow further optimization of the design, in particular the cage assembly and vanes, if necessary to achieve acceptable static and dynamic performance.

The optical design of the corrector satisfies project scientific and technical requirements. No Atmopheric Dispersion Corrector (ADC) is required for the DES but non-DES programs with wide-band coverage in the blue could be affected by dispersion. However, the addition of an ADC would significantly complicate the DECam design and be costly. The Committee did not recommend changes.

The design of the corrector barrel is judged to be viable pending the final results of FEA analysis. The stainless steel barrel is robust compared with the rest of the top assembly and further optimization of these structures is advised. Using carbon steel for the barrel assembly may be preferable to SS for thermal reasons. Corrosion at the mating surfaces of steel mounting flanges is an issue that was confronted by other telescope/instrument builders. The project may benefit from consulting these builders. It was stated that an external light shield will be installed around the barrel assembly. The need for this is unclear and the shield will inhibit passive cooling of the barrel and service access. The Committee noted that a full stray light analysis is planned.

DES received quotes for polishing the corrector lenses from two optical fabricators: Sagem and SESO. SAGEM included in its quote testing of the lenses in transmission while SESO would only measure surface figure. The requirements for testing involve a trade off between risk and cost taking into account the expected index uniformity of the fused Si blanks. The project should decide whether it requires a measurement of the transmitted wavefront for acceptance of the lenses and, if so, include wavefront phase error specifications in the requests for proposal to polishers.

The corrector lens alignment procedure proposed by UCL appears to be adequate at this stage of the project. Flexure and run-out in the rotary and x-y stages will have to be minimized for this procedure to succeed. UCL has adopted a belt-and-suspenders approach to alignment that combines very tight mechanical tolerances on the lens and barrel assemblies backed-up by run-out measurements of the mounted lenses in the barrel and optical tests using a laser to check the complete assembly. Further analysis of expected error sources may show whether the testing could be simplified.

The 620 mm DES filters are 30 percent larger than the largest-ever SDSS filters produced for Pan-STARRS. This is a challenging item to make and filter vendors are notorious for delivering filters that do not meet specifications. An independent means of verification is essential for qualifying the delivered filters and for periodically determining that the filters maintain their properties over the duration of the project and beyond. DES's plan to build equipment (at the University of Michigan) to measure filter throughput and spectral properties is a key part of the filter quality assurance that addresses this issue.

Great care will be required in handling filters given their cost, critical importance to the science of the project, and the fact that spares are not provided. An insertion/extraction fixture is provided for the filter changer but there also need to be containers and procedures for storing and moving filters around at the observatory and for shipping them. These can be developed after CD-2.

The filter changer and shutter mechanisms are scaled-up versions of similar devices produced for Pan-STARRS. The DES units are 20-25 percent larger. During the survey, they will be cycled many times throughout a night and must operate with a high level of reliability. The mechanisms and controls should be procured with sufficient time to allow thorough testing at various orientations on the DES simulator to check for failure modes and wear. No design for the motorized lens cover assembly was presented. The cost will be modest but should be included in the CD-2 baseline.

The detector cooling system will probably work as presented but a design using commercial components (e.g., Cryo-Tigers) may be simpler and significantly less expensive. Space constraints for mounting cooling heads on the cryostat are a recognized factor that led to the decision to adopt the current design. A further discussion of this issue is presented in Section 3.2.

The hexapod support was not demonstrated to meet the current positioning specifications with the specified combination of speed, resolution, stroke, and load capacity. Relaxation of DES specifications and/or further discussions with potential vendors may resolve this issue. On the other hand, an alternative slide type mechanism may provide the required three degree-of-freedom (DOF) motion with adequate resolution and speed, less complexity, and lower cost.

One problem with the hexapod is that it couples all six DOFs for every move. The complete or even partial failure of any one actuator will render the system inoperative. Except for focus, the operating range of motion for the remaining DOFs (tilt or translation) is quite small and could be accomplished with fairly simple mechanisms. The project should consult other groups (that have used hexapods with varying success) to learn from their experience.

Corning was the only vendor identified that could supply the largest of the fused Si corrector blanks. The project should stay in touch with Corning to ensure timely availability when an order is ready to be placed.

Very tight tolerances on the barrel mounting surfaces for the optics drive its cost and could be relaxed for radial displacements since the optics will be aligned optically at UCL. The difficulty of manufacturing to such tight tolerances may be indicated by the fact that only one of five venders asked to quote on the fabrication submitted a bid. On the other hand, the cost of the barrel ($80K) is small relative to the Total Project Cost.

Weights presented for the top-end assembly parts omitted the counterweight. This was compared to the PF cage weight limit, which was calculated by subtracting the weight of all fixed components at the top end, including the f8, from the upper surrurier truss load capacity.

The balance neglected the (~500 kg) counterweight. All components need to be included in the FEA analysis and in calculating the balance of the telescope.

The plan for turning DECam over to CTIO prior to installation and check-out on the telescope raises questions of responsibility when problems inevitably arise. Acceptance and handoff of DECam is discussed and recommendations are presented in Section 7.

3.1.3 Recommendations

1. Augment the systems engineering effort within the DECam group.

2. Complete the FEA for the DECam structure and combined instrument/telescope assembly for CD-2. Revise the design of the cage assembly and vanes if necessary.

3. Perform a cost-benefit trade study of lens fabrication methodology (surface figure only versus transmission testing) for CD-2. Revise lens specifications if necessary.

4. Maintain contact with Corning regarding lens blank availability.

5. Complete a stray light analysis.

6. Re-examine the need for a light baffle enclosing the barrel assembly and delete if superfluous.

7. Resolve hexapod performance issues and consider alternative designs.

8. Include the f/8 assembly and counterweight in the weight and balance tabulations.

9. Complete the lens cover conceptual design.

3.2 Focal Plane Detectors and CCD Camera

3.2.1 Findings

CCDs that exhibit performance meeting all DECam requirements were manufactured, indicating that there are no fundamental technological obstacles.

The package design is approaching maturity. The assembly procedure must be altered to avoid minor non-flatness and QE artifacts caused by the adhesive tape. A concept for this was suggested, but not yet developed. Several alternatives were proposed to address the fragility of the Nanonics connector: either the connector will be eliminated by directly attaching a pig-tail flex circuit, or features will be added to the invar foot to resist torque on the connector, which can cause damage to the solder joints.

The readout electronics for the test system is fairly well developed, except that noise (digital interference) and/or grounding are not yet allowing detector-limited performance.

The test system is capable of performing comprehensive tests of all relevant CCD parameters, using appropriate algorithms. One exception is the linearity, which is reporting worse than normal CCD linearity (gain should vary by only a few tenths of a percent from zero signal to the blooming threshold). Tests were sufficiently automated.

Sufficient experience was gained with the test system to predict the throughput for automated testing. Plans were developed to make five copies of the test system to support the testing at the projected CCD production rate (five per week).

A database to store, collate, and present test data was said to exist, though presentation materials did not reflect its existence. (Presentation materials appeared to be spreadsheets constructed by hand, rather than the result of data base inquiries. Plots or histograms of parameter distributions were not shown.)

A detailed cost and schedule shows an appropriate range of yield scenarios (see Table 3-1).

Table 3-1. Cost and Schedule Scenarios

Yield	Schedule Slack at end of CCD tests	Incremental cost
25%	30 wks	$-1.8M
20%	10 wks	$-0.9M
15%	Some CCDs retrofitted at CTIO	Reference Cost

Overall yield (product of the yields for each manufacturing step) was estimated to be between 19-29 percent, based on recent devices produced after remedying the latest round of problems. Some defects originate at DALSA. Modest losses occur during backside processing and frontside metallization at Lawrence Berkeley National Laboratory (LBNL). Devices are selected for packaging based on wafer probing at -45C by LBNL after the wafers are finished. A small number of devices can be damaged during subsequent packaging and some could fail flatness tests. A significant number of devices were rejected due to performance deficits discovered after packaging since it is only then that the devices are operable at -100C. Cosmetic defects are the principal cause of yield loss due to performance.

The cooling system was mentioned for further study at a previous review. The project reported that the original continuous flow LN2 system with remote reservoir and liquefaction system off-telescope was still recommended. This closed-cycle, continuous-flow cryostat is fed by long evacuated counter flow LN2 lines from a 1000L reservoir off-telescope where return gas is liquefied by a 300W Gifford McMahon cooler dissipating 8kW. The thermal load of the 1000L reservoir was stated to be 40W. The thermal load of the CCD Imager was stated to be a total of 100 Watts: 40 Watts for the focal plane, 40 Watts for the trim heaters, 10W for the electronics and 10 Watts for the heat exchanger. This breakdown was not clearly itemized in the presentations. At various times this was said to be the radiative load on the CCDs or the entire load in the dewar (the former would appear to be more likely). The project stated that 30W was lost in the LN2 transfer system and 30W in the remote liquefaction and storage dewar, which is much larger than the CCD dewar but is presumably well radiation shielded. Another 100W is allowed as safety margin. The total heat load of the cooling system is 300 watts and has an estimated cost of $386K (WBS 1.5.2.2). Cooling & Purge Systems (WBS 1.5.2) is costed at $595K for FY 2008-FY 2010 with additional expenditures during the R&D phase

A full prototype is to be constructed. The components of the prototype do not appear to be reused in the final installation nor to be shipped as spares.

Alternatives considered (but not presented in any detail) were various closed cycle coolers that were dismissed due to “Issues with Vibration, Capacity, and Space”. A LN2 reservoir within the CCD cryostat was excluded due to lack of space. No data was presented in the face-to-face meetings to support any of these claims, in spite of the previous criticisms of the continuous flow system’s complexity and expense. The clearance from the focal plane to the f8 mirror assembly is 27”. The dewar is 22” in diameter with an 18”rear-access clearance. The current dewar design does not include a radiation shield.

3.2.2 Comments

There is every indication that the DECam CCDs will meet or exceed all specifications, and that the project has the competency and an appropriate plan to procure, test, and integrate sufficient CCDs into the focal plane.

Since each cosmic ray typically affects more pixels than in a conventional CCD due to the increased thickness of these CCDs, the Committee noted the importance of monitoring the event rate in the after packaging changes and when new materials are introduced into the dewar(s) in case any prove to be radioactive. It would be prudent to test a sample of the glass to be used in making the window (final lens of corrector) unless this material is known not to contain radioactive elements.

The project's single greatest concern is the *uncertainty* in yield and the consequent budget and schedule uncertainty. Latest yield estimates, while promising, are based on too few devices to be considered a reliable predictor of future yield.

The project felt that the "cosmetic yield", a significant component of the yield loss, may be artificially depressed by the simple way in which the flow-down from scientific requirements has been performed. Examples of how cosmetic specifications may be relaxed include:

- "Carbon trading"—specify cosmetic defects as an average across the entire focal plane rather than across a single detector. Allow higher bad pixel/column counts on some CCDs if others are better than the requirement.

- Determine how much of the image area is deemed to be lost due to a single bad pixel or columns versus a contiguous cluster. Does a single bad column count as (say) four columns lost due to the width of the PSF? Do two contiguous bad columns then count as five lost?

- Alternatively, treat bad columns like gaps between CCDs, which are somewhat mitigated by observing each field with three offset pointings.

Some of the detector performance requirements are quite loose compared to expected CCD performance, notably noise and non-linearity. The Committee judged that it is desirable to aim for detector limited performance in the test system even when this is more stringent than DECam performance requirements. Relevant examples include:

- If the electronics show shorted input noise of 7e- then the CCD noise must deliver 7e- to meet the 10e- total noise specification.

- If the lamp intensity drifts systematically during the linearity test by 0.8 percent, then a CCD with 0.3 percent non-linearity variation of the same sign will be erroneously rejected. Clearly better lamp stability and/or a test designed to measure and subtract lamp drift will result in higher perceived yield.

Therefore, it seems prudent to hold the test system and electronics to higher standards than what is acceptable for the science, leaving maximum margin for CCD performance variation, which is less easily controlled. Furthermore, the ability to detect abnormal performance (albeit still acceptable) in the electronics or the CCDs will potentially flag a deeper problem, which may require attention.

LBNL is attempting to account for the increased incidence of backside defects that cause localized high dark current. While efforts to reduce these defects are applauded, it is important to monitor the amplitude distribution since this may affect cooling system requirements. A trade must be made between operating at lower temperature in order to suppress dark current on the CCDs exhibiting backside defects and the shorter red cutoff wavelength resulting from operating all CCDs colder.

The presentations of the cooling system left the Committee wondering whether the complexity and expense were really required. The minimal discussion of the cheaper/simpler alternatives without quantification of the basis for their rejection left the impression that these options have not received the serious consideration they merit given the potential cost savings.

It was not clear during the review why the components used to build the prototype are not reused in the final system. From informal conversations, it became apparent that there was no plan to ship these components to Tololo to serve as spares.

The DECam team has assembled a detailed thermal budget for heat flows into the cooling system, which of course drives the technical options and cost. Although radiative transfer from the window to the CCDs was correctly reported as the dominant source, no radiation shield is provided to block radiative transfer from dewar walls to the rear of the mount. It is true that smaller CCD dewars are often built with polished internal surfaces and no shield but it was shown that such a shield can improve performance by an amount that may make the difference in what cooling options are available to DECam. [Thermal load measured in the Multi CCD Test Vessel is thus likely to be higher than what could be achieved and not be a sound basis for cooling system requirements except to establish a worst case.] The lack of discussion of this topic suggests it was omitted in error.

Notwithstanding the obvious effort invested in CAD drawings and finite element analysis of temperature profiles and consequent focal plate distortion, a number of design choices are at odds with known working solutions in mosaics at CFHT, MMT, and ESO, which are within a factor 2 of DECam area, including:

- Closed-cycle coolers were rejected due to mechanical vibration, when CFHT has an operations closed-cycle cooler (MMT and ESO used LN2).

- It was unclear that a pair of Cryotigers (Polycold Compact Coolers) could not be used. This is a common solution for cooling astronomical CCDs though not yet used at CTIO, and is offered as an example to show that cryocoolers are plausible. These have no moving parts and thus low vibration and each sinks a maximum of 32W. Care would be needed to pin down the actual thermal load (~60W) and a liquid Nitrogen pre-cool loop would be desirable to speed cool down time.

- Lack of space was another argument presented for rejecting these coolers but with 27" clearance behind the focal surface this would appear to be more an unwillingness to arrange other components to accommodate the space required for cooling.

- The sides of the dewar are taken up by electronics boxes. Is this space allocation non- negotiable given the knock on effect on cost if this is what drives the selection of the continuous flow solution?

- Lack of space on the back surface for a cryocooler is caused by the large footprint of the four-inch gate valve and Ionization Pump. The more conventional alternatives are cheaper and possibly better.

The very large valve opening is sized to improve pumping speed of water outgassing from Kapton cables. The large (expensive) valve is no use unless it is backed by a comparably dimensioned hose, turbo pump, and turbo pump valve. Have the other mosaic cameras really had this problem with their many Kapton cables and been forced to go to such expense? A more common (and cheaper) solution is to include a replaceable getter cartridge containing zeolite, which pumps water vapor even at room temperature. A companion activated carbon sieve was found to be a good substitute for the ionization pump since it sheds contaminants (water) at room temperature and thus is in top condition every thermal cycle. This allows a smaller valve to be used, and eliminates the need for the ionization pump (a common source of electrical noise). Vacuum hoses and down stream turbo pump can then be smaller since the as volume is not huge.

Water vapor does outgas from Kapton and Aluminum (oxide), but is rapidly frozen upon cooling. The radiation shield serves as a significant obstacle to water vapor since most outgassing and the zeolite getter are inside the shield, whereas the CCDs are outward looking. When replacing the zeolite getter through a small access hatch water absorption can be minimized by backfilling with dry air and simply minimizing the time the access hatch is open.

Techniques exist for speeding the water pumping without using very large diameter plumbing. A cold trap right at the dewar valve eliminates the impedance of the vacuum lines. The dewar internals and case can be warmed a few tens of degrees (well within safe limits for the

CCDs and epoxies) to speed outgassing and diffusion. It was reported that a slow dry Nitrogen (or air) bleed through a separate small valve works very well to speed desorption and transport of water and organics, better in fact than large pumping lines and apertures that do nothing to increase outgassing speed.

Given that radiative transfer to the CCDs is what drives the cost of the cooling system, there is some incentive to measure the (product of) emissivities of the window and CCDs rather than assume unity. The range of uncertainty appears to be about 10-15 percent per surface and thus 19-28 percent in the dominant radiative load. This could be the difference between adequate margin or not. The test can be made in a test dewar by replacing a CCD with a gold mirror, though the best test is to cover the opening in a fully-shielded CCD dewar with a cap and various size apertures. The test will capture both the effect of CCD emissivity and edge effects, so that scaling to a large focal plane will be most accurate. Of course, this test will become unnecessary if other considerations drive the project to a solution, which has enough margin to support unit emissivity.

The LN2 transfer lines must flex as they pass though RA and DEC cable wraps. This is said to be a solved problem, but the method for traversing the top end ring pivot point is more problematic and was not discussed. Compressed gas lines for the cryocooler options are somewhat less problematic since they are designed to be decoupled and mated again, but they still present some risk of contamination if this is not executed correctly.

The question arises then as to whether a simple internal LN2 tank would not fit. Assuming 90 percent emissivity for window and CCDs and a radiation shield cooled by boil-off gas, for maximum ambient temperature 22C, radiative load on the CCDs will be ~36W and for 10W heater power likely total load would be 61W. Note that a 10C increase in ambient temperature (which would ruin the image quality) would cause the heater power to drop from 10W to 4W but cause loss of thermal control. If the dewar hold time was 16 hours and tank diameter 19”, then tank depth (assuming only half the volume is used) would be 7.9” out of the total 27” distance from focal surface to rear obstruction. This includes allowances for all of the minor heat loads, but no allowance for greater than 50 percent tank utilization.

This preliminary estimate was forwarded to the project team for consideration. It illustrates that a much cheaper and simpler solution is *plausible*, particularly if two fills per day (the traditional cadence on Tololo) are allowed.

The cumulative cost of the liquid Nitrogen ($1.25/l) was noted to be significant compared to the capital cost of the closed system, but was not compared to electricity (8kW) or maintenance cost to run the Nitrogen liquefaction system.

3.2.3 Recommendations

1. Fully test a sufficient number of packaged CCDs in time to provide a more accurate yield projection by CD-2, and enable the project to carry a smaller range of budget and schedule scenarios. Determine the dependence of yield on operating temperature (due to freeze-out of back side defects).

2. Pursue a testing strategy for lot 2 CCDs, which includes several 2k x 4k CCDs in advance of CD-2, not just 2k x 2k devices, to address the concern that the 2k x 4k devices might present yield or performance issues not seen in the 2k x 2k devices.

3. By CD-2 develop detailed plans and cost estimates for all yield scenarios under consideration.

4. Cost, schedule, and impact on science need to be quantified for the fall back scenario in which some CCDs are replaced with better ones in Chile.

5. In both DOE funding scenarios (1 and 2), maintain a steady pace in the manufacture, packaging and testing of CCDs to avoid yield losses due to process startup. Ramp-up to a pace that will fully engage the various participants ASAP and avoid interruptions to maximize yield.

6. Work with the science team to develop a more sophisticated measure of performance yield. A formal process should be initiated to update the flow-down of science requirements, which should be under change control.

7. Obtain empirical data on radiative transfer from window to CCDs and the effectiveness of aggressive radiation shielding, so major expense is not incurred simply to allow margin for large uncertainties in thermal load projections.

8. Conduct an external review prior to CD-2 to evaluate the cryogenic and vacuum options considering development cost, operating cost, maintenance cost, and reliability. The review should address the vacuum system design issues and options raised in the comments section of this report. This mini-review should also examine the (dis)assembly method that is intimately coupled to the vacuum and cooling system.

3.3 Readout Electronics, SISPI

3.3.1 Findings

The collaboration plans to use a modified Monsoon platform augmented by several small signal conditioning front-end boards. Prototypes of most of the boards were fabricated and are being tested. In general two more iterations of each board are planned.

Following recommendations from the director's review last year the CCD signals were buffered with JFET (junction gate field-effect transistor) devices located near the CCD. A preamplifier board was added between the JFET and the Monsoon system. A prototype of the preamplifier board exists and will probably be located inside the dewar. Differential and single-ended outputs are being considered.

Monsoon Crate-Based Modules

- The acquisition board was modified from 8 to 12 channels, a prototype exists and performance with a single CCD seems to meet specification in tests conducted to date. Board evaluation with multiple CCDs in the final system configuration are planned this summer.

- The clock distribution board was redesigned to support more CCDs and the bias section was removed (i.e., moved to the acquisition board). A prototype (provided by the Madrid collaborators) exists and is partially tested.

- The transition module: a prototype exists and seems to perform as expected. It may provide differential-to-single-ended video signal conversion if required.

- The master control board (Barcelona). Main modification is conversion from Systran to S-link interface to the PAN computers. May require a new layout or possibly just manual modification. A board including the manual modifications implemented is in test.

Several options are pursued for the power-supply system (linear versus switching, synchronized or not). Experiments are under way to determine the best configuration. The prime-focus package is conceptually designed and includes the power-supplies, liquid cooling, and the Monsoon crate. It is designed to be thermally neutral to avoid disturbance of the telescope optics.

The Survey Image System Process Integration (SISPI) subsystem covers the camera control and monitoring (exposure sequencing), user interaction (commands and displays), data acquisition and delivery (reformat raw CCD data and move to data-transport system), and the coordination with the telescope (guiding).

The entire SISPI system, with the exception of the focal plane emulator, is constructed with off-the-shelf commercial hardware. Six PAN PCs are planned for the reformatting/sorting of CCD raw data (one PC for each Monsoon section), and a farm with several PCs for the building of the complete images and FITS formatting.

An approximate 20-FTE-year software development effort is being estimated. The majority is provided by in-kind contributions from collaborating institutions.

Database and communication protocol options are actively being evaluated and a down-select is planned for this summer. Most of the remaining design is at the conceptual level. The emulator design has been completed, a prototype has been fabricated and operates satisfactorily.

3.3.2 Comments

The project has made good progress on Readout Electronics since the director's review. The personnel working on the project are experienced and have chosen low-risk approaches in most cases. A good deal of prototyping has already taken place, providing valuable preliminary data on electronics performance. In general, the Committee did not foresee any serious issues or risks as long as sufficient attention is put on understanding (measuring and analyzing) system performance.

There are still decisions to be made on some system implementation options. The Committee strongly supported the planned system test with the multi-CCD test vessel including all prototype electronics modules to check performance (cross-talk, noise, etc.).

There is a question whether a preamp is really required (or e.g., if paralleling JFET's to increase the drive would suffice). Analysis with subsequent tests might be an option. If the preamp board is to be located in the dewar, then thermal issues and outgassing have to be assessed. Noise limitations and sources and requirements on settling time of JFET signals should be analyzed. As a general comment, the Committee judged that decisions about alternative configurations should be taken based on analytic considerations, which should be validated by subsequent measurements. Any discrepancies should be fully understood before proceeding. The approach to date seems to have been more empirical. In addition, the focus on rms noise as a single figure of merit has the potential risk of overlooking negative impacts on other performance such as crosstalk and linearity.

A controller board in crate for power-sequencing, etc. still needs to be designed. The complexity of the board is expected to be small but it still needs to be designed and explicitly budgeted.

The electronics team was commended for preparing comprehensive diagrams of the grounding system. Some details are still being investigated and still need to be understood. Support services, like the liquid cooling lines, should be electrically isolated to avoid ground-loops.

The allocation of the noise budget between the CCDs and the electronics was not presented. The noise allocation to the electronics should provide a margin to allow for considerable variation in CCD performance, as the CCD yield may otherwise be adversely affected.

A few subsections within the SISPI still have not been staffed and that needs to be addressed. A decision is expected this summer about where to run the focus algorithm and how this will impact the cabling. Whether the thermal control system needs to be synchronized with data-taking to avoid EMI interference is to be evaluated.

The guider is read-out at a 1-Hz rate only while the CCDs are integrating. Therefore, guiding information first becomes available about one second after the shutter is opened. One needs to analyze whether image quality is degraded unacceptably by the pointing errors induced by any guiding errors at the start of exposure when a small step change in track rate results from the initiation of guiding. This can be tested by looking at pointing errors when an existing guider is turned on and off.

The guide CCDs are fabricated in the same technology as the science array. For the science sensors, an “erase” cycle is necessary after every exposure to remove persistent charge left over from bright stars imaged in the previous exposure. The erase cycle takes several hundred milliseconds to complete. The proposed mode for the guide CCDs is to operate at 1Hz frame rate, window mode, without the erase cycle between readout. The impact of whether persistence effects influence the centroid finding should be evaluated.

Plans on how to interface to the CCDs in order to minimize damage due to ESD should be formalized. A plan to verify the interface to the CCDs should be documented and each signal should be measured during all possible modes (including power-on/off and software initialization) to assure that the CCDs are not degraded or damaged.

Some labor estimates for the Acquisition Board (WBS 1.3.7) appear high considering the present status. The project should consider allocating some of the labor to a separate WBS for the testing of the electronics system performance.

3.3.3 Recommendations

1. Down-select, before CD-2, the configurations of electronics modules with justification for each option chosen. Experimental results should be compared with theoretical expectations:

    - JFET on or off AlN substrate
    - Paralleling JFET's versus having a preamplifier board
    - Preamplifier in or out of dewar (if applicable)
    - Single-ended or differential signal transmission
    - Kapton versus micro-coax cable
    - Mechanical design choices of connector attachment to CCD package
    - Power supply configuration choices
    - Multi-crate synchronization choices

2. Consider, as an option, calling an external review of the video signal chain prior to CD-2.

3. Analyze scenarios that could put CCDs at risk and evaluate mitigation strategies, if applicable (e.g., power-on or off, or software initialization transients exceeding safe voltage limits).

4. List and review all material properties for vacuum compatibility (e.g., outgassing).

5. Ensure that a failure in one CCD string does not impact the operation of other CCDs.

6. Evaluate tracking errors caused by the unavailability of guiding information immediately prior to the exposure and resulting from persistence effects in the guide CCDs.

3.4 Data Management an DECam Simulations

3.4.1 Findings

The DES Data Analysis program spans the interval from the bits coming off the camera to the publication of scientific results. As such it is critical both for the specific science of the

DES, and for the general science performed with the DECam during the 75 percent of observing time spent on projects. This is no more the first data processing system for this type of data than DECam is the first mosaic camera, but, despite this prior knowledge, both aspects of the project are difficult, pushing the state of the art. The overall DES Data Management (DES DM) task comprises three distinct but interrelated parts:

1. The community DECam pipeline, to be delivered to NOAO as part of a Memorandum of Understanding (MOU) granting the DES collaboration c. 500 nights of Blanco time;

2. The DES simulations, data reduction (algorithms and implementations), and management (data flow and job control). The first of these components was presented by Fermilab, while the latter two appear to be the responsibility of the National Center for Supercomputing Applications (NCSA) group; and

3. The DES science post-processing, to be delivered by DES collaboration scientists.

The community pipeline will provide instrument-specific tools for the basic reduction of all data taken by the DECam. While its specific details have yet to be determined, it is an integral part of making the DECam useful to the wider community, and is required for the acceptance of the instrument and allocation of telescope time by NOAO/CTIO.

The DESDM program (part 2) encompasses both the data flow (from instrument to archive to/from local disk to/from memory) and the data reduction (algorithms, implementations, job submission and control). It is the most mature of the three parts, with significant FTE contributions having already been made, particularly at NCSA and Fermilab. It can be summarized as involving a distributed data archive managed by a central server and a collection of grid-enabled analysis job-sets, each of which involves calls to standard tools and/or project-specific implementations of standard methods. It will ultimately produce (and allow others to reproduce) science-ready data products from the DECam DES data. Given its critical role in the DES project it is essential that the DESDM be validated and verified, both to demonstrate its capability for the task and to quantify its contribution to the end-to-end error budget; this is the role of the data simulation project.

The scientific post-processing will derive the dark energy (and other) science from the resulting catalogues and processed images. In accordance with the DETF recommendations, DES projects a reduction in the uncertainty on the two fiducial dark energy parameters (measured by the area of their joint error ellipse) by a factor of three or more. This work is expected to be supported by the participating institutions themselves, supplemented by specific scientific enquiry grant applications.

3.4.2 Comments

The outputs of the community pipeline and the inputs to the scientific post-processing are both poorly specified. In both cases working groups are currently being established to remedy this. In part, as a consequence of this, robust science-driven requirements on the reduction and simulation components are not yet developed.

The Committee was concerned that the proposed scope of the community pipeline was restricted to not much more than removing the individual CCDs instrumental signatures, despite the much more ambitious processing being accomplished at NCSA for the DES team.

The DESDM is characterized by: 1) data that flows at a steady rate during the observing season (and not at all outside of it) and represents a fairly significant volume today but only a moderate volume when the survey completes, and 2) analysis algorithms that appear modest in their computational complexity, primarily consisting of moderate numbers of embarrassingly parallel serial tasks that are farmed through a small to intermediate number of cores. However, it should be noted that the DESDM team does not yet have detailed complexity analyses—including scalings, pre-factors, efficiencies, and memory footprints—of their algorithms. This caveat, as currently scoped does not appear to be a particularly computationally challenging project.

The DESDM program is building a framework of a distributed data archive and grid tools for: 1) distributed data management, and 2) local job control at a number of grid-enabled high-performance computing centers including amongst others NCSA (on the Teragrid), Fermilab (on the Open Science Grid), and the Barcelona Supercomputing Centre. While this is a viable approach it is by no means the only one, and the case could certainly be made for either a dedicated project cluster or a concentration of efforts at a single high performance computing (HPC) center; all three approaches have advantages and disadvantages. While it is not clear which would be *scientifically* optimal for the DES project, the DESDM team argues that the grid-based approach best addresses the socio-political requirements of a distributed international collaboration.

It is not clear that the DESDM team has seriously considered the actual or potential disadvantages of their framework, or made efforts to mitigate them. Amongst other things this would include the exclusion of non-grid computing resources, the dependence on annual HPC allocations, and the uncertainty about the evolution of HPC hardware in the next decade (e.g., significantly reduced memory per core as with the current IBM Blue Gene systems, production computing environments on very large systems that may only support a subset of the current range of operations and languages, and/or the advent of multi- and many-core systems and the associated drive to implicit parallelism), all magnified by the possibility of divergent directions taken by the multiple HPC centers being served.

The DESDM aim is to provide both the raw and processed data to any DES collaborator, together with the tools necessary to reproduce and/or augment the reduction themselves, and a computational framework that makes this as simple as possible. While this is a laudable goal, only limited attention was paid to issues of data validation across such a system—certainly the current expectation of bitwise identical data products is optimistic in the extreme!

The requirements on the hardware are much better developed than those for the software. In order to correctly assign tasks to their correct part, and to ensure that all required tasks were identified, the project needs to develop robust science-driven requirements on the data simulation, reduction, and management components. Furthermore, these requirements should be used to associate an error budget with the DESDM components.

The DESDM team has chosen to employ external software, particularly the SExtractor/ SWarp/SCamp suite from Emmanuel Bertin and the French Terapix group, for critical aspects of the image processing. These packages are widely used in astronomy, but the committee questioned whether they were up to the task of reducing the DES data. The DESDM group recognize this, and are expecting that Bertin will make appropriate changes (The Committee noted the letter to this effect from Bertin). However, the Committee was concerned that such an important aspect of the entire DES project relies on a best-effort agreement with someone who is not more directly involved with the survey. The Committee had similar concerns with the point spread functions (PSF) and shape extraction pipelines, and judged that the NCSA group had sufficient experience with astronomical image processing to be able to provide core components of the data processing should it prove necessary.

Some core data reduction steps (e.g., the detection of transients needed for SNe) are omitted from the data reduction and were not even presented at the review. As another example, while Jain, Jarvis, and Bernstein are world leaders in this field, the DESDM plan as presented moves their contributions to part 3, the "science post-processing" rather than placing it under the control of the DESDM lead.

Some of the necessary algorithms (image subtraction; galaxy photometry) probably require research into appropriate algorithms, not just coding. The Committee felt that this should be explored and discussed explicitly, as it results in some small risk to the success of the DES project.

The simulations are currently mostly useful for demonstrating throughput and interfaces; they will need more accurately to replicate data as it will arrive from the DECam to be useful for scientific validation. In particular, at present the simulations make some assumptions for convenience (e.g., shapelet expansions of galaxies and the PSF) that are also made in the currently proposed shape analysis pipelines.

3.4.3 Recommendations

1. Define the scope of, and requirements on, the science-ready data products.

2. Use these to prepare a requirements document for the simulations, data reduction, and data management.

3. Include all parts of the pipeline needed to generate science-ready DES data products in the data processing WBS (and requirements).

4. Strengthen the astronomy/image processing group responsible for the core data reduction.

5. Include the data reduction in the end-to-end error budget.

6. Develop a characterization of the computational complexity of each of the data reduction tasks (including its scaling, prefactor, efficiency on base architecture(s) and memory footprint).

7. Identify potential consequences of the chosen framework, and develop plans to minimize possible negative impacts.

8. Define the specification of the community pipeline. The Committee urged NOAO to work with the DES team to define an appropriate level of functionality for this pipeline to maximize the scientific return to the entire astronomical community of the DECam on the Blanco telescope.

3.5 Telescope and Facilities Upgrade, Integration and Installation of DECam, SISPI, and CTIO Operations

3.5.1 Findings

Success of the DES depends on successful integration of the camera onto the Blanco telescope. This involves coordination between the CFIP and the DECam project.

CFIP is implementing upgrades to the Blanco telescope that are necessary to accommodate the mechanical and electronic requirements of DECam and the scientific requirements of the DES. These projects include repairs to the mirror support cell, a new Telescope Control System (TCS), replacement of the telescope drive encoders, and the transformation of the Coude feed room into a clean room facility for use by DECam (and other planned facility instruments like NEWFIRM). The telescope improvement project is already underway using funds in the CTIO base budget. These are proceeding apace; the only concern is the TCS system that is traditionally time-consuming and expensive.

NOAO is also responsible for the data transfer system that will transfer the DECam data from the telescope to the archive/processing center at NCSA. The data transfer system is on track to provide ample bandwidth for the job, when projected to 2010. However, the amount of preprocessing that is needed at the mountain (for real-time data verification) is still undefined, as is the role of the DES in the community pipeline.

The camera integration project has two major components. First, there is the integration of the camera with a full model of the Blanco top end that will be performed at Fermilab, followed by a test of the data acquisition and mechanical and electronic systems on the Blanco clean room floor in Chile. This project is part of the DECam project. Second, there is the preparation by CTIO of the Blanco telescope to receive DECam as a facility instrument on the telescope, including acceptance testing of the camera on the telescope and science validation.

The camera integration by the DECam project can be broken down into the telescope simulator project and its connected projects of SISPI integration and readout electronics integration. The team has set up a very good process to generate and test the telescope simulator. It is particularly encouraging that the development of the simulator by the DECam team is strongly coordinated with the CTIO staff. The telescope simulator is a critical element in the DECam project because it allows for time savings in the integration and testing at CTIO once the optics are delivered.

SISPI integration likewise has a reasonable plan for progress, although this part of the project will not be testable until the boards being prepared by the Spanish DES collaborations are available for integration at Fermilab. The current budget defers some of SISPI testing to FY 2010.

Electronics integration has a well-defined plan that is quite tight, because of the time of camera deployment. The plan is for six weeks of integration testing with the camera on the simulator, then six weeks at CTIO before the acceptance testing. There is some concern that the team be attentive to issues of noise and crosstalk during integration.

This is particularly important because the readout goals are quite conservative, and there are potential issues that may hurt DECam's performance as a facility instrument, or even DES if the optics and calibration are better than expected.

CTIO staff presented a plan for camera-telescope integration, with a schedule that includes three weeks of physical integration, followed by two separate testing periods with a shakedown period off-telescope in between. Although the skeleton of the plan was in place, there were some problems identified with this plan (see comments section).

3.5.2 Comments

The schedule and budget plans for CFIP seem reasonable. The TCS system appears to be the item requiring the longest lead time. However, the DES's requirement on TCS performance is not so aggressive. This part of the operations looks fine. It is worth noting that there are steps in the improvement project (for example the design of the heat extraction system for the PF cage) that are still in the early design phase, and should be restudied in the next year.

Construction of the Blanco top-end model at Fermilab (and the whole telescope simulator project) is essential to reducing the actual integration times once the camera is in Chile and mitigating the risk of catastrophic inconsistencies given the aggressive schedule for the final phases of integration.

The project has a very good process to generate and test the telescope simulator. It is particularly encouraging that the development of the simulator by the DECam team is strongly coordinated with the CTIO staff. The telescope simulator is a critical element in the DECam project because it allows for time savings in the integration and testing at CTIO once the optics were delivered.

Integration of SISPI and the electronics likewise has a plan. There is some concern both on the part of the DECam team and from the reviewers about the potential lack of time to test the full focal plane camera with the telescope simulator. In the schedule, six weeks are allotted, which might not be enough if problems are found at this stage. If SISPI integration becomes a possible bottleneck, resources should be allocated to it.

There is some concern that because the readout requirements are not very challenging the integration will not place enough emphasis on minimization of effects like crosstalk that may become limiting to the survey if the telescope/optics work better than expected.

Overall, the plans for integration with the telescope simulator appear to be well-defined and on track.

Integration into the telescope is sensitive to the CCD procurement schedule, and also to the delivery of the optics barrel by UCL. There is a need to verify that at all stages the test barrel at Fermilab and the barrel being constructed at UCL stay consistent.

There are two potential problems with the camera-telescope integration. The CTIO plan for installation, commissioning, and integration is still not completely settled, but the plan seems too aggressive, in that the last step (science validation) is very quick (two weeks) (although the rest of the on-sky validation timescales are reasonably good). On the other hand, the schedule presented did not have DES starting until the end of January 2011, which really sets the survey "real observations" start in September 2011.

The CTIO and DECam teams have been doing a very good job of coordinating on DECam documentation, but this effort has to be continued and budgeted for explicitly, since the documentation will be a deliverable of the camera. This points to a more general uncertainty in where the boundaries between the DES subprojects lie during the final phase of the project. There is a strong need for accurate and very explicit wording in the MOU to control the handoff procedures during telescope integration. This document must contain deliverables and a precise statement of the responsibilities in case there are problems when the camera is put on the telescope.

There is an urgent need for NOAO to specify exactly what they view as requirements of a facility instrument. This is especially important in that the documents contain wording of an unspecified "community pipeline", but also because it affects issues of documentation, access to the camera and maintenance that will be critical for the success of the DES. Without seeing an actual signed MOU, the Committee could not determine whether the DES was at risk.

There is concern that the expertise needs to be built at CTIO for at least a portion of the DECam maintenance by the time of handoff. This is also important for the DES portion of the use of DECam.

3.5.3 Recommendations

1. Develop an explicit plan to integrate the camera at Fermilab with engineering-grade CCDs if necessary in order to test the full camera backplane as early as possible.

2. The DES project has to plan either for a revised science case for a start of real science in 2011 or for a revised project schedule that has commissioning on the telescope starting before September 2010. A description of the science costs of missing the earlier date needs to be specified.

3. A signed MOU is desperately needed. It should contain explicit details about responsibilities and contingencies during the commissioning phase at CTIO (both on the floor and on the telescope). In particular, plans need to be in place for ameliorating problems that arise.

4. NOAO should implement its process for determining its expectations for deliverables (community pipeline, documentation, quick-look tools). Ideally, this should be done with community representation, and be completed well before the next DOE review.

4. ENVIRONMENT, SAFETY and HEALTH

4.1 Findings

Environment, Safety and Health (ES&H) at CTIO will be governed by Chilean law or the Occupational Safety and Health Administration (OSHA), whichever is more strict.

ES&H on the DECam project was found to be in order for this stage of the project. A Preliminary Hazard Analysis was prepared and included in a director's review. Impacts to the environment are anticipated to be minimal. National Environmental Policy Act (NEPA) for the project is covered by Categorical Exclusion. Work to be conducted at the Fermilab site will be covered under Fermilab's existing Integrated Safety Management Program. A Safety Assessment Document specific to DES will be produced prior to sustained operations. Fermilab's Particle Physics Division ES&H will review each Level 2 system and will conduct Operational Readiness Reviews of major systems.

4.2 Comments

The types of processes and materials used by the project at Fermilab are not new and are covered by existing documentation and practices.

4.3 Recommendations

None.

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5. COST, SCHEDULE, and FUNDING

5.1 Findings

The DES project is divided into three parts, the camera, data management, and facility improvements at the telescope. The project is requesting funding from NSF, DOE, and NOAO (NSF) for these three parts. The projected costs including contingency are shown in Table 5-1.

Table 5-1. DES Project Construction Costs ($M then year)

	NSF	DOE		NOAO	Other	Total
		OPC	MIE			
Camera		$5.17	$19.81		$8.00	$32.98
Data Management	$2.39				$2.46	$4.85
Facility Improvements				$0.65		$0.65
					Total	$38.48

In addition to these three agencies, the project has arranged for $10.46 million in in-kind contributions. The total cost is approximately $38.48 million. The DOE Total Project Cost (TPC) is $24.98 million. The DECam project presented a price range of $24.1 to $26.7 million.

The camera project (DECam) costs were presented in detail. The DECam project has a detailed WBS with costs and basis of estimate for each line item. In many cases, the basis of estimate contained a copy of the manufacturers quote or a pointer to a document in the project database that had the rationale for that basis of estimate. The MIE is carrying a 40 percent contingency. The contingency was determined by assessing the risk on each line item and assigning a factor based on that risk.

The $3.6 million in MIE funds for FY 2008 is included in the budget request. The requested funding profile is shown in Table 5-2.

Table 5-2. Requested Funding Profile (DECam Construction Phase)

	FY07-Q4	FY08	FY09	FY10	FY11	Total
R&D	0.99	2.97	1.20	0.00	0.00	5.17
MIE-base	0.00	2.69	6.15	4.47	0.75	14.05
MIE-Cont.	0	0.91	1.35	2.2	1.3	5.76
MIE-Total	0.00	3.60	7.50	6.67	2.05	19.81
Total (R&D+MIE)	0.99	6.57	8.70	6.67	2.05	24.98

The cost of the CCD arrays for the camera is still in question. There is an issue with the number of CCDs already in hand that will be used in the final article. In addition, the yield estimates are based on a small sample. The cost presented is based on a 15 percent yield.

The earned value system for the project is in place and is being used on the R&D phase of the project. The project presented milestones at a high level with underlying milestones for the subsystems.

CD-4 for the DECam project is projected for the first quarter of FY 2012. There is approximately 23 weeks of schedule contingency to that date. The critical path goes through the lenses. The first step is the purchase of the blanks with university money. That is waiting on a favorable review indicating that the government is going to fund the project as planned. The blanks go to Europe for polishing and, possibly, coating on (UK) funds. Those funds are available pending indication that the U.S. government is going forward with the project.

5.2 Comments

The cost estimate for DECam is consistent with the planned deliverables. There is adequate contingency proposed for this project. While there are questions about the cost of the silicon, the project's assumptions are adequately conservative to support the cost estimate. The cost, schedule, and funding are documented at a level that the project is ready for approval CD-1.

The basis of estimate is well developed for this stage of the project. There are items where the basis just restates the cost number without the underlying rationale. These need to be completed by CD-2. In addition, the project should present a table with the percentage of the Total Estimated Cost (TEC) that fall in each bin (guess to firm quote) at the CD-2 review. This would help the reviewers evaluate the state of the estimate.

While the earned value system can be useful for quantifying the overall progress of a project, it often lags too far behind events to be useful in tactical decisions in the project. An earlier indicator is erosion of schedule contingency to milestones. A useful tool is a table of schedule contingency to milestones coming in the next six months. A new column is generated each reporting period so the management can see those activities that are eating into the schedule contingency and take corrective action before that activity is on the critical path. In addition, this requires milestones with adequate density at each level.

Currently, CD-2 and CD-3 are planned to occur at the same time. Since the design will not be at the CD-3 level by the time of the CD-2 review, CD-3 will have to be phased (CD-3a, CD-3b, etc.) or delayed until after C-2. The schedule will have to be modified accordingly.

5.3 Recommendations

1. Re-plan CD-3 to be consistent with the planned state of the design.

2. Monitor the foreign contributions from UK and Spain closely. Delays in funding could be a risk to the overall project.

3. Form a resource management board with director level persons from the primary institutions.

4. Add Level 2 milestones with a density of about one per month.

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6. PROJECT MANAGEMENT

6.1 Findings

The DES project is made up three major subprojects: the DECam project, the DESDM project, and the CFIP project. A project director oversees the DES Collaboration and project that currently consists of 17 institutions and 110 individual collaborators. The Office of High Energy Physics within DOE/SC funds the majority of the DECam project. Fermilab is the lead institution for DECam. The NCSA at the University of Illinois at Urbana-Champaign (UIUC) leads the DESDM project with NSF funding. The NOAO leads the CFIP project with funding from the NSF as well. In-kind contributions and no-cost resources and deliverables form substantial and critical contributions in all three projects. In addition to the American collaborating institutions, there are three foreign consortia – UK-DES, Spain-DES, and Brazil-DES – each with specific in-kind deliverables. Additionally Spain-DES and the UCL have successfully applied for and received explicit funding from their respective funding agencies to participate in the DES project subject to USA funding agency approval of the project. In several instances, the in-kind or no cost contributions from collaborators include subcontracts to other institutions (for example University of Michigan subcontracts to Bonn University for the shutter) or vendors (UCL procures the optics from potential multiple suppliers).

A DES Council representing Fermilab, NCSA, and NOAO provides director level oversight of the project. H. Montgomery (Fermilab), T. Dunning (NCSA), and T. Boroson (NOAO) presently serve as its members. A draft MOU was developed concerning the DES Council and its working relationship between the three principal institutions in 2005. At the time, there were aspects of the MOU that were considered undesirable by the funding agencies (NSF and DOE) and further development of this overarching MOU was placed in abeyance until DOE CD-1, Approve Alternative Selection and Cost Range for the DECam project.

Each of the DES collaborating institutions has a letter of application outlining its commitments and in-kind contributions to the DES project. The DES project anticipates transforming these letters of application into MOUs, but currently (May 2007) an MOU with LBNL, the supplier of the CCD arrays, appears to be the only active MOU.

There is a DES Management Committee chaired by the DES Project Director (J. Peoples) with members elected from the collaborating institutions and consortia with the DECam Project Manager (B. Flaugher), the DESDM Project Leader (J. Mohr), and CTIO Director (A. Walker) participating as ex-officio members. The management committee addresses collaboration management and overall DES project coordination.

The DES project has a Science Committee that is tasked with providing the survey science requirements to the DES project as a whole. They have captured these requirements in the document *The Dark Energy Survey Science Requirements and Technical Specifications* (Version 6.5 Draft at the time of this review). This document contains both basic scientific requirements and derived technical specifications.

A Community Needs Working Group has been established to review and integrate community needs into the three projects. It will be the forum for the integration of the community pipeline into the NOAO/DPP E2E system and the DECam use of the NOAO DTS.

In addition to the project manager and two deputies, the DECam project has seven Level-2 managers (one of which, the Level-2 manager of integration is also a deputy project manager). The project manager indicated the need to add a project systems engineer to DECam.

The DECam project presented a Microsoft Project schedule loaded with cost estimates and contingency analysis. An explanation of the basis of estimate along with other details of the specific item have been captured in the work breakdown structure (WBS) dictionary. The project has defined change control procedures and thresholds. Monthly project meetings include the Federal Project Director and other members of the Federal Integrated Project Team as needed.

The schedule presented to the Committee indicated simultaneous CD-2 (Baseline Project) and CD-3 (Construction Start) occurring in March 2008. The DECam project indicated that they were asked to consider two different funding profiles one with $1 million being moved from FY 2008 to FY 2011.

6.2 Comments

The Committee endorsed DOE pursuing CD-1 for the DECam project (within DES).

As a result of the various design and R&D issues, it is unlikely that the DECam project will be ready for CD-3 to occur simultaneously with CD-2. Specifically, too many design trades and aspects have not yet been resolved. It is advisable that the DECam project split CD-2 and CD-3, and perhaps seek a CD-3a to permit the use of MIE funds for long-lead procurements and well advanced parts of the project.

The documentation of the DECam project is thorough and particularly advanced for a project at the end of the conceptual design phase (CD-1). The DES project did not present detailed documentation for the CFIP and DESDM projects (both NSF funded) and therefore the Committee could not comment on its adequacy for a project at this stage of development. The CFIP appears somewhat less advanced in its development with respect to DECam and DESDM appears to be somewhat behind that.

The DES Council (Director Level) has been meeting regularly and helps the project even without a formal working MOU in place. Likewise, all of the collaborators in the DES project with in-kind contributions appear committed to meeting their deliverables in a timely manner. However, many are waiting for CD-1 approval by the DOE before formally proceeding. The establishment of the governance and control delineation of the DES project is now entering a critical phase in its development. It must be clearly defined and implemented prior to establishing the baseline of the project. For example, the mechanism for providing oversight of the project at the agency level needs to be documented (e.g., through the Joint Oversight Group).

The DECam project and the entire DES project consists of complex multiple collaborators, funding sources and in-kind contributions. Consequently, before the DES project as a whole, and DECam in particular, can be baselined a complete set of MOUs with annually revised statements of work need to be executed. These MOUs are at several levels. At the highest level, they are between the three principal institutions (Fermilab, NOAO, and NCSA) responsible for the projects that comprise the DES project (DECam, CFIP, and DES Data Management). At the lowest levels, these MOUs, within each of the individual subprojects, must carefully delineate the deliverables, work products, and milestones needed from either explicitly funded work or in-kind contributions.

There is uncertainty within the DES project concerning operational spares, and in particular spares associated with the various subsystems of the DECam (cooling for instance). It would beneficial for the DES project to have an analysis and understanding of needed operational spares from a reliability and availability standpoint completed prior to the baseline review (CD-2). As well as identifying needed spares, the DES project should address how to provide and pay for the required spares.

The present *Dark Energy Survey Science Requirements and Technical Specifications,* (Version 6.5 Draft) combines fundamental scientific requirements with derived technical specifications. This can lead to derived technical requirements being rigidly held when they should be carefully examined and developed through tradeoffs as part of the design progression. This present document should be divided into at least two separate document sets. One document would be only the fundamental scientific requirements. The DES project should immediately place this document under revision and release control. The DES project has already established an appropriate management and control approach in its *Principles for the Organization and Management of DES Science Projects* (April 10, 2007). The DES project should collect the derived technical specifications into a series of documents (one for each of the projects within the DES project for example). Likewise, the DES project should put these derived technical specifications under revision and release control as soon as possible.

The DECam project is already using an earned value management system (EVMS). EVMS provides good feedback on the progress of a project, but often its timeliness can be a challenge. EVMS becomes even more problematic when significant *in-kind,* or *no-cost* resources are present, such as in the DES project. Sometimes in order to accommodate such in-kind contributions the equivalent value is included in the resource-loaded schedule. This, however greatly complicates formal contractual EVM reporting. Another approach is to supplement the EVMS with aggressive milestone monitoring and control. This is achieved by developing a sufficiently dense set of milestones (one would expect approximately one Level-2 milestone/month and each successively lower level should increase in number of milestones by a factor of 5-10), as well as a complete list of the schedule contingency associated with each of these milestones. In the course of weekly meetings, reports are given as to progress against these milestones, as well as any consumption of schedule contingency on the individual milestones. This quickly highlights areas within the project where issues exist that need addressing. DECam, DESDM, and CFIP could also benefit from the use of this approach.

Systems engineering and integration is an area that requires significant attention at this stage for all three projects comprising the DES project. The DECam project indicated that a project engineer is needed. This person's roles and responsibilities need to be carefully reviewed as (s)he needs to have overall integration and configuration control of the DECam project in order to ensure that all subsystems properly function together.

Additionally, strong integrating and system resource support is needed at the overall DES project level in order to ensure that interfaces, requirements, deliverables, and work products from each of the projects (DECam, DESDM, and CFIP) satisfy overall project needs. This extends to assigning and carefully monitoring overall error budgets for all three projects (cf. Section 3.4). This integrating and systems management support at the highest level of the DECam project is very important given the highly distributed project and the complex interfaces and interactions that are necessary for project success. The tradeoff between CCD acceptance levels and electronics noise; handoffs and responsibilities associated with the transfer of the camera from Fermilab and its acceptance by CTIO; and error budgets that encompass data management aspects are just three examples that illustrate how such integrating systems support can greatly benefit the DES projects.

The DES Project Director has done a remarkable job in assembling an enthusiastic collaboration and bringing a diverse set of complementary capabilities with significant in-kind contributions together. A strong and appropriate set of principles for the organization and management of the conduct of the DES Science Projects was developed that provides the necessary focus on scientific objectives without clouding the facility and infrastructure project deliverables.

The DECam project manager has established a basis for a well-controlled and managed project and has shown a cognizance of areas of management needing improvement including the MOUs and statements of work. All three projects within the DES project require strong project management.

6.3 Recommendations

1. Determine whether it is feasible and justified to seek a simultaneous CD-2 and CD-3 review or revise the project plan to reflect staggered CD-2/CD-3 and potentially the use of phased CDs (e.g. CD-2a/b; CD-3a/b) and solicit DOE concurrence.

2. Develop and finalize a complete set of MOUs with annually revised appendices describing scope of work and management details at all necessary levels of the DES project before the DES project review for CD-2. These MOUs must include the principal laboratory directors MOU (Fermilab/NOAO/NCSA) and all additional collaborating institutions with in-kind contributions.

3. Provide additional systems management resources at the highest level of the DES project to ensure complete and proper delineation and integration of the three projects (DECam, DES Data Management, CFIP) before the next DOE/NSF review.

4. Separate into two separately controlled sets of documents the fundamental scientific requirements and derived technical specifications before August 1, 2007.

5. Develop and implement a project monitoring and control approach that may include low-level milestone tracking, for DES Data Management and CFIP that will ensure the timeliness of progress of explicitly funded and in-kind contributions that make up the balance of these two projects prior to the next DOE/NSF review.

6. Consider developing and implementing active milestone monitoring of the DECam project and in particular in-kind contributions that includes frequent explicit monitoring of individual milestone schedule contingency consumption prior to the DECam CD-2 review.

7. Consider the development of a DES Project Resources Board and coordinate its scope and direction with DOE and NSF with respect to any Joint Oversight Group that might be formed prior to the next DOE/NSF review

8. Fill the systems/project engineering position within the DECam project as soon as possible.

9. Develop explicit criteria and definitions for the end of the DECam project and its corresponding CD-4 before the CD-2 review. Specifically, address issues of number of acceptable and installed CCDs on the focal plane and *gatepoint* criteria needed to determine when to transfer the instrument to CTIO.

APPENDIX A

CHARGE TO THE COMMITTEE

U.S. Department of Energy

and the

National Science Foundation

March 13, 2007

To: Mr. Daniel Lehman, Director, DOE Office of Project Assessment, SC-1.3

Subject: Request to Review the Proposed Dark Energy Survey project

The Dark Energy Survey (DES) collaboration has submitted a proposal to both the Department of Energy (DOE) and the National Science Foundation (NSF) to construct and operate an experiment to study the nature of dark energy. In 1998, it was discovered that the expansion of the universe is accelerating due to a previously unknown "dark energy". Understanding the nature of dark energy has become one of the most pressing questions in physics and astronomy. Determining its nature is a high priority science objective for the agencies. The recent Dark Energy Task Force (DETF) described the optimum intermediate- and long-term programs for dark energy investigations. The DETF report, released in July 2006, recommended that one or more mid-term experiments with a combination of techniques be done and that, in combination, they should achieve at least a factor of three gain in the DETF figure of merit over current projects. DES is a candidate to become selected as the DOE preferred alternative for a mid-term ground-based dark energy experiment.

This letter is a request that you review DES on May 1 - 3, 2007 at Fermi National Accelerator Laboratory. The purpose of this review is to assess the scientific goals and conceptual design of the entire project. The validation of the conceptual design and the cost range of the proposed DOE parts of DES are needed for DOE Critical Decision 1 (CD-1) Approval of Alternative Selection and Cost Range.

The DES experiment proposes to utilize the existing Blanco Telescope at the Cerro-Tololo Inter American Observatory (CTIO) in Chile. The construction project includes a new camera (DECam) optimized for the study of dark energy, the CTIO facilities improvement project (CFIP) upgrades and a data management system (DESDM). The DES is requesting funding for the DECam from DOE and funding for the DESDM and CFIP from NSF. Funding for CFIP would be provided through the NOAO, CTIO's parent organization. In addition, funds are being requested from other U.S. and foreign institutions.

In performance of the general assessment of the science goals, project status and identification of potential issues, the committee should address the following specific items for all parts of the project:

1. Science: Are the scientific goals justified and compelling? Are the goals attainable by the planned experiment?

2. Technical: Do the conceptual design and associated implementation approach for each part of the experiment satisfy the performance specifications required to meet the scientific goals?
3. Cost: Is the cost estimate consistent for the project deliverables with the stated technical performance? Are the estimated costs adequately justified and supported by documentation?
4. Schedule: Is the proposed schedule reasonable and appropriate in view of the technical tasks and projected funding profiles? Are the estimated schedules adequately justified and supported by documentation?
5. Management: Are the proposed project teams identified and ready to start the next phase of the project? Do they have adequate management experience, design skills and institutional support needed?
6. Are the environmental, safety and health (ES&H) aspects being properly addressed and are the future plans sufficient given the project's current stage of development?
7. Is the DECam documentation required by DOE O 413.3A in order and ready for Approval of CD-1?

Kathleen Turner is the DOE program manager for the Dark Energy Survey and will serve as the Office of High Energy Physics contact for the review. Nigel Sharp of the NSF Division of Astronomical Sciences will serve as the NSF contact for the review.

We appreciate your assistance in this matter. As you know, these reviews play an important role in our programs. Both agencies look forward to receiving the Committee's report, within 60 days of the review.

/signed/	/signed/
________________________	________________________
Wayne Van Citters	Robin Staffin
Director	Associate Director
Division of Astronomical Sciences	Office of High Energy Physics
National Science Foundation	Department of Energy

APPENDIX B

REVIEW PARTICIPANTS

Department of Energy/National Science Foundation Review of the Dark Energy Survey (DES) Project

REVIEW COMMITTEE PARTICIPANTS

Department of Energy

Stephen Tkaczyk, DOE/SC, Chair

Review Committee

Andy Albrecht, UC Davis
Julian Borrill, NERSC
Ian Dell'antonio, Brown U.
Gunther Haller, SLAC
Matt Johns, Carnegie Inst.
Steve Kahn, SLAC
Lowell Klaisner, SLAC
Robert Lupton, Princeton U.
Paul O'Connor, BNL
Kem Robinson, LBNL
Rober Smith, CalTech
Nick Suntzeff, TAMU

Observers

Glen Crawford, DOE/SC
Randy Johnson, DOE/SC
Mike Procario, DOE/SC
Kathy Turner, DOE/SC
Paul Philp, DOE/CH
Nigel Sharp, NSF

APPENDIX C

REVIEW
AGENDA

Department of Energy/National Science Foundation Review of the
Dark Energy Survey (DES) Project

AGENDA

Tuesday, May 1, 2007—Wilson Hall, 7th Floor Crossover/"Racetrack"

8:30 am	DOE Executive Session	Steve Tkaczyk
9:30 am	Introductions	Pier Oddone/Hugh Montgomery
9:45 am	Overview of the DES Science Program	Josh Frieman
10:25 am	Break	
10:40 am	DES Project History	John Peoples
11:20 am	DES Data Management Project	Joe Mohr
12:00 pm	Lunch WH2XO	
1:00 pm	DECam Project	Brenna Flaugher
1:40 pm	CTIO Facilities Improvement Project and Integration	Tim Abbott
2:20 pm	Break	
2:30 pm	Subcommittee Breakout Sessions	
	Group 1: Science, Survey Strategy and Science Req. (topic 1)	Josh Frieman*
	Group 2: DECam (and CFIP) Management (topic 6)	Brenna Flaugher*
	Group 3: DECam Focal Plane and CCDs (topic 3a)	Juan Estrada*
5:00 pm	DOE Executive Session - Racetrack, WH7XO	
6:30 pm	Adjourn	

Wednesday, May 2, 2007

8:30 am	DOE Executive Session - Racetrack, WH7XO	
9:30 am	Subcommittee Breakout Sessions	
	Group 1: Science, Survey Strategy and Science Req. (topic 1)	Huan Lin*
	Group 3: Opto-mechanical Systems (topic 2)	Andy Stefanik*
	Group 4: Readout Electronics and SISPI (topic 3b)	for 1st half Terri Shaw*
	and Cont CCDs if necessary	for 2nd half Jon Thaler*
10:30 am	Group 2: Data Mgmt and DECam Simulations (topic 4)	Joe Mohr*
	Snake Pit, WH2NE	
12:00 pm	Lunch WH2XO	
1:00 pm	Subcommittee Breakout Sessions (continued)	
	Group 1: Data Mgmt and DECam Simulations (topic 4)	Joe Mohr*
	Group 2: CFIP/DECam Integration (topic 5) within DECam and with CTIO	Tim Abbott*
	Group 3: Mgmt with three Directors (topic 6)	Hugh Montgomery?*
3:30 pm	DOE Executive Session - Racetrack, WH7XO	

Thursday, May 3, 2007—Racetrack, WH7XO

8:30 am	Subcommittee Working Sessions
10:30 am	Closeout Dry Run
1:30 am	Closeout Presentation
2:30 pm	Adjourn

APPENDIX D

COST, SCHEDULE
and
FUNDING TABLES

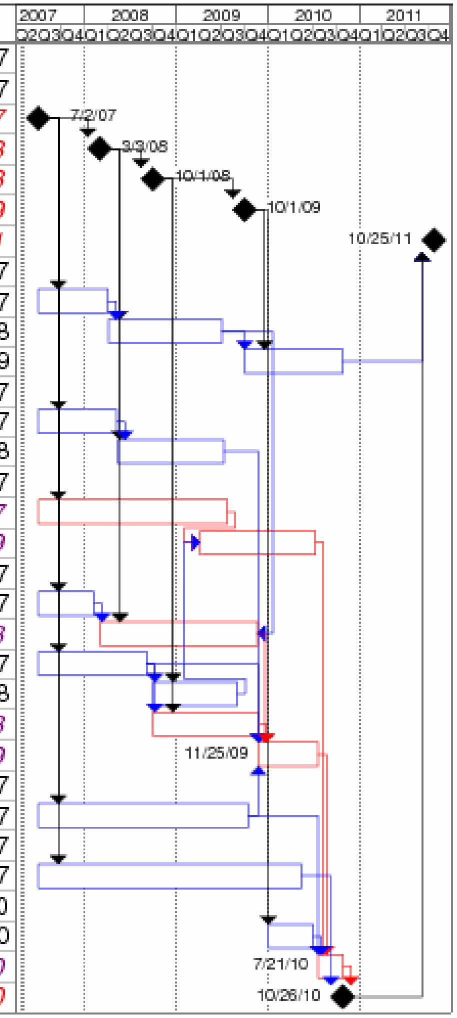
Cost and Schedule Range

- The NSF/DOE proposal (Dec. 2006) contains cost and schedule estimates updated in response to the Directors review of July 25, ‘06.
- The cost and schedule presented at this review has been further updated to reflect funding guidance from DOE.
- The cost and schedule range cover the difference between our understanding of the cost and schedule now compared to what we will know at the baseline review ~ Nov. 2007
  - A better yield estimate for the CCDs.
  - Low noise readout of multiple CCDs in the Multi CCD test vessel.
  - Contracts in place for procurement of the optical elements.
  - A better understanding of the funding profile.

Total Project Cost Range: $24.1M – $26.7M
Schedule Range: April 2011-April 2012

DECam Schedule Summary

Task Name	Start
DECam Project	7/2/07
Management (WBS 1.1)	7/2/07
CD-1 approval	*7/2/07*
CD2/3 approval	*3/3/08*
FY09 funding available	*10/1/08*
FY10 funding available	*10/1/09*
CD-4	*10/25/11*
Focal Plane Detectors (WBS 1.2)	7/2/07
CCD R&D	7/2/07
Procure Package and test Lot 2 CCDs	4/7/08
Procure Package and test Lot 3A and 3B CCDs	10/1/09
Readout Electronics (WBS 1.3)	7/2/07
Prototype and testing	7/2/07
Production of RO electronics	5/12/08
Optics (WBS 1.4)	7/2/07
Procure polished coated lenses	*7/2/07*
Put Lenses in cells and barrel and ship to CTIO	*4/6/09*
Opto-Mechanics (WBS 1.5)	7/2/07
Test prototype imager and cooling system	7/2/07
Design, build and test Prime Focus Imager, Cooling, controls	*3/3/08*
Design, build and test prototype Barrel	7/2/07
Design, build, test and ship final barrel to UCL	10/1/08
Design, Build Test Cage, Telescope simulator, Hexapod	*10/1/08*
Tests of all equipment on Telescope Simulator, Ship to CTIO	*11/25/09*
Survey Image System Process Integration (WBS 1.6)	7/2/07
Prototype and Final SISPI software and hardware	7/2/07
Survey Planning (WBS 1.7)	7/2/07
Simulations and Observing Plan	7/2/07
CTIO integration (WBS 1.8)	1/4/10
Finalize Integration, installation and operations plans	1/4/10
Reassemble and test DECam	*7/21/10*
Acceptance Testing Complete	*10/26/10*



Profiles and Dates

- DECam is in the FY08 Presidents Budget Request for a construction start and $3.6 M in equipment funds.
- We were asked to investigate the following funding profiles, with the knowledge that FY-08 and 09 are ~ fixed and there is flexibility in the FY10-11 numbers.

MIE	FY08	FY09	FY10	FY11
Guidance 1	3.6	7.5	5.4	2.3
Guidance 2	3.6	6.5	5.4	3.3

DECam Funding Need Profile

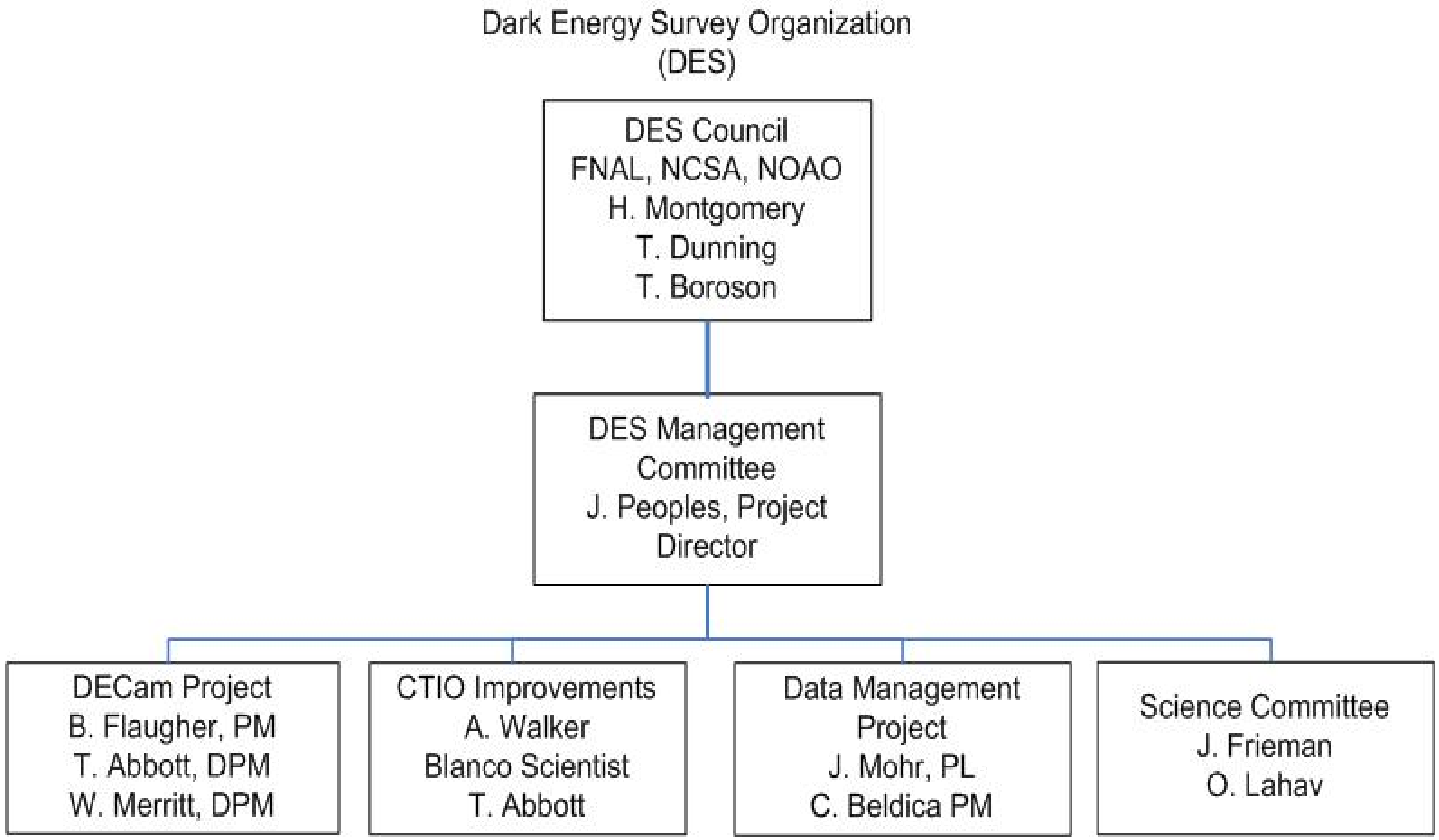
	FY07-Q4	FY08	FY09	FY10	FY11	Total
R&D	0.99	2.97	1.20	0.00	0.00	5.17
MIE-base	0.00	2.69	6.15	4.47	0.75	14.05
MIE-Cont.	0	0.91	1.35	2.2	1.3	5.76
MIE-Total	0.00	3.60	7.50	6.67	2.05	19.81
Total (R&D+MIE)	0.99	6.57	8.70	6.67	2.05	24.98

- Contingency on the MIE is heavily distributed in FY10 and FY11 because this is when extra CCD lots would be processed, packaged and tested.
- DES Collaborators are contributing in-kind labor, cash and equipment with a total value of ~ $8M. These commitments include contingency.
- Base Schedule: delivery to CTIO in July 2010, testing complete Oct. 2010
  - No explicit schedule contingency included
  - These dates are used to coordinate with the other DES projects.
- DECam project complete milestone is Oct. 2011. This includes 12 months schedule contingency (~ 31%).
- The slower funding profile (Guidance 2) shifts the end date by ~5 months.

APPENDIX E

MANAGEMENT CHART

DES Organization—A Collaboration Perspective



DECam Project Level 2 Managers