Minutes of the Meeting of the
Department of Energy and National Science Foundation
Nuclear Science Advisory Committee
Doubletree Hotel and Conference Center
Rockville, Maryland
August 29, 2005

Members Participating:
Richard Casten, Chairman
Ricardo Alarcon
Cornelis de Jager
David Dean
Stuart Freedman
Alejandro Garcia
Thomas Glasmacher
Roy Lacey
Larry McLerran
Alice Mignerey
Guy Savard
Bradley Sherrill
William Zajc

Members Absent:
Ani Aprahamian
June Matthews
Kimberley Thomas

Others Participating:
Sam Aronson
Frank Avignone
Richard Boyd
Joseph Dehmer (morning only)
Eugene Henry
Dennis Kovar
Harry Miley
Eric Norman
Peter Rosen
Michael Salamon
James Symons
John Wilkerson

Presenters in Order of Appearance:
Richard Casten
Dennis Kovar
Joseph Dehmer
Eugene Beier

Minutes of the August 29, 2005, NSAC Meeting

The agenda for this meeting is attached as Appendix A.

Introduction: Richard Casten (Yale University), Chair of the Nuclear Science Advisory Committee (NSAC), called the meeting to order at 8:36 a.m. and reviewed the agenda.

Agency Presentations: Casten introduced Dennis Kovar, Associate Director for Nuclear Physics (NP) at the Department of Energy's (DOE) Office of Science (SC), to present an update on nuclear science from the perspective of DOE.

DOE's budget for FY06 is progressing through Congress. The House and Senate markups are improvements in the requested budget. There may be a continuing resolution. The FY07 budget is to be submitted to the Office of Management and Budget in mid-September. It would be back to DOE near the end of November. The Energy Bill was passed and signed. It establishes a new organizational structure with an Undersecretary for Science, which would change the nature of science in the Department. The authorization for SC is in that bill, also.

This is the last meeting of NSAC as it has been constituted until now. All advisory committees will be "expert panels" in the future. DOE's General Counsel will educate the Committee members about the change at lunchtime. Kovar turned the floor over to Joseph Dehmer, Director, Division of Physics, National Science Foundation (NSF), to give an update from the perspective of NSF.

Four significant developments have occurred:

- NSF has a new Deputy Director (the chief operating officer of the agency program), Kathie Olson.
- The NSF budget is in the same state as DOE's, except that the markups are not as generous.
- NSF has terminated the Rare Symmetry-Violating Processes (RSVP) project, although the science case is very important; the phase-out is being planned.
- The science scope of the Underground Laboratory has been revisited, and a report will be issued soon, unifying the disciplines. Out of eight candidate sites, two rose to the top. Pre-conceptual design reports will be produced for those two sites, which will be considered for funding, perhaps in 2007.

Presentation of Subcommittee Report: Casten introduced Eugene Beier to present the report of the NSAC–HEPAP (High Energy Physics Advisory Panel) Neutrino Scientific Assessment Group (NuSAG). This report addresses one of three charges to NuSAG, that concerning a U.S. program in neutrinoless double-beta decay. The membership of NuSAG (see Appendix B) has representatives from Japan and Europe for an international perspective.

Two National Research Council studies (*Quarks to the Cosmos* and *Neutrinos and Beyond*), two long-range planning exercises (HEPAP and NSAC), and a multidivisional year-long American Physical Society (APS) study have all identified compelling discovery opportunities involving neutrinos. These studies laid the scientific groundwork for the choices that must be made during the next few years. They did not identify experiments to be done. They did an excellent job of explaining the new paradigm of neutrino science, why this science is filled with important and interesting questions, and why the time is right to address these questions.

Where the timescale is long term, the United States will wait to take advantage of additional input, such as that from the National Academy Sciences study on Elementary Particle Physics (EPP2010). However, where expeditious action is appropriate, the charge letter asks NuSAG to make recommendations on the specific experiments that should form part of the broad U.S. neutrino-science program:

- **Charge 1:** NuSAG is asked to address the APS study's suggestion that the United States participate in "An expeditiously deployed multidetector reactor experiment with sensitivity to ν_e disappearance down to $\sin^2 2\theta_{13} = 0.01$, an order of magnitude below present limits."
- **Charge 2 (the topic of this report):** NuSAG is requested to address the APS study's recommendation of a phased program of sensitive searches for neutrinoless nuclear double-beta decay. In particular, a timely assessment of the scientific opportunities and resources needed should be performed of the initiatives that are presently under discussion in the research community. These include, but should not be limited to:
    - U.S. experiments [principally Majorana and EXO (the Enriched Xenon Observatory)],
    - U.S. participation in the Italian experiment Cryogenic Underground Observatory for Rare Events (CUORE), and
    - U.S. participation in the Japanese experiment Molybdenum Observatory of Neutrinos (MOON, currently an R&D project).

  NuSAG added U.S. participation in SuperNEMO [Neutrino Ettore Majorana Observatory] in France.
- **Charge 3:** NuSAG is requested to address the APS study's suggestion that the United States participate in "A timely accelerator experiment with comparable $\sin^2 2\theta_{13}$ sensitivity [to the recommended reactor experiment, i.e., $\sin^2 2\theta_{13} = 0.01$] and sensitivity to the mass hierarchy through matter effects." The discussion should include
    - U.S. participation in the Tokai-to-Kamioka (T2K) experiment in Japan;
    - Construction of a new off-axis detector to exploit the existing Neutrinos at the Main Injector (NuMI) beamline from Fermilab to Soudan, Minn., as proposed by the NuMI Off-Axis ν_e Appearance (NOvA) collaboration; and
    - As above but using a large liquid argon detector.

  There are currently two U.S. T2K efforts: B280 and 2km. The liquid argon detector project is multifaceted and is currently directed to other applications.

The charge letter asks NuSAG to look at the scientific potential of each initiative, the timeliness of its scientific output together with the likely costs to the U.S., and its place in the broad international context. For all three charges, NuSAG should then recommend a strategy of one (or perhaps more than one) experiment in that direction that, in its opinion, should be pursued as part of the U.S. program.

Existing documentation was requested from the relevant experiments on May 11. At the first meeting in June, presentations were made on all experiments. Questions were sent to all experiments for more information and/or clarification. The panel also requested input from the Germanium Detector Array (GERDA), a European experiment. The second NuSAG meeting was held July 17 to 18 and focused on double-beta decay.

Neutrinos are produced in weak-interaction eigenstates and propagate in the mass eigenstates, changing flavors (mixing or oscillating) as they propagate. Neutrinos exist in three flavors: electron neutrinos, muon neutrinos, and tau neutrinos. In the Standard Model, the three neutrinos are massless, but experiments that observe neutrino oscillations have produced evidence for neutrino mass. An experiment measuring neutrinoless double beta decay of a nucleus can determine or limit the effective mass of the neutrino, as well as investigate the fundamental question of whether the neutrino is its own antiparticle (Majorana) or not (Dirac).

Effective experiments (1) maximize the isotopic abundance and the source mass and (2) minimize the background through the use of radiopure materials, good energy resolution and topological information. However, the Standard Model-allowed two-neutrino double-beta decay produces an irreducible background. The neutrinoless double-beta decay occurs at the tail end of the two-neutrino double-beta-decay energy spectrum. The only way to distinguish between the two is through good energy resolution. Recent interpretation of one neutrinoless double-beta-decay experiment claims evidence for a peak in the decay spectrum of ^{76}Ge with a 71.7 kg-year exposure.

NuSAG studied the following experiments:

CUORE	Italy	^{130}Te
EXO	USA	^{136}Xe
Majorana	USA	^{76}Ge
GERDA	Europe	^{76}Ge
MOON	Japan	^{100}Mo
SuperNEMO	France	^{82}Se

CUORE uses 0.78 tons of TeO_2 in an array of 988 crystals. It uses neutron-transmutation-doped bolometers to measure the energy. It has the advantages of good energy resolution, high natural abundance of the isotope, approval by several organizations, and a working prototype that is identifying backgrounds. The concerns are (1) how far it can reject the background and (2) the size of the U.S. contribution to the costs.

EXO proposes an ambitious scheme that uses a large liquid-xenon detector with extraction of the daughter barium atom. Its ultimate goal is to reject the background by identifying the barium atom to tag the desired events. The EXO-200 experiment is under construction without barium tagging, 200 kg of the enriched isotope are on hand, it produces good spatial resolution for background rejection, there is a low-cost enrichment, it has the possibility of employing very large detectors, and it produces a relatively small two-neutrino double-beta background. However, it is uncertain whether barium tagging R&D will be successful.

The Majorana approach is to limit the background by segmenting the detectors, which will discriminate the backgrounds spatially and temporally to a degree. Other advantages of this experiment are that it employs a proven technique with excellent energy resolution, pulse-shape discrimination for background rejection, and it will scale well to larger sizes. The concern is the high cost of enrichment and the resulting expense of detectors.

The MOON detector concept is to use interleaved films of the molybdenum and fiber/plate scintillators and to measure position with the fibers and energy with the plate scintillators. The advantages of this experiment are that it has good spatial segmentation for background rejection; it measures (pp, ^{7}Be) solar neutrinos simultaneously; and other isotopes can be used. The concerns are its timeliness, the limited participation by the United States, the expensive isotope enrichment, and a relatively large two-neutrino double-beta background.

The SuperNEMO preliminary design calls for multiple planar track chambers submerged in a water shield to eliminate backgrounds to observe the decay of ^{82}Se. The advantages of this experiment are that it has very good spatial resolution for background rejection and its predecessor experiment is working well. The concerns are that it does not scale to 1000 kg easily (radiopurity of detector systems and the physical size are issues), isotope enrichment is expensive, and possibly the size of the two-neutrino double-beta background is too great.

Beier constructed a 3σ discovery-sensitivity matrix for the success of the six experiments in the near and mid terms that was not in the report. NuSAG chose the following criteria for deciding among the different experiments:

- How well does the experiment explore the degenerate mass region above 100 meV? (A source of approximately 100 kg is required.)
- What other prospects are there for exploring the inverted hierarchy region above 10 meV? (A source of approximately 1000 kg is required.)
- Is there any prospect for exploring the region below 20 meV? (A source of approximately 10,000 kg may be required.)

NuSAG concluded that

- Neutrinoless double-beta-decay experiments are scientifically compelling.
- All the experiments studied are likely to be successful in the 100-kg phase, although one must consider cost, timeliness, and international context at this stage.
- One cannot yet say which isotope and technology is the most promising at the scale of 1 ton.

NuSAG recommends that the highest priority for the first phase of a neutrinoless double-beta decay program is to support research in two or more neutrinoless double-beta-decay experiments to explore the region of degenerate neutrino masses. The knowledge gained in the technology developed in the first phase should then be used in a second phase to extend the exploration with a single experiment into the region of neutrino masses where the inverted and normal hierarchies may be discriminated.

NuSAG said that three experiments should be given the highest priority (in alphabetical order):

- CUORE, which has potentially good energy resolution, low background, and an inexpensive isotope;
- EXO, which may be relatively inexpensive for very large detectors if barium tagging works; and

- Majorana, which has good energy resolution and background rejection but is expensive; the experiment should start smaller than M-180 but large enough to do good science (i.e., to be able to confirm or refute the currently claimed neutrino-mass value).
- Communication should be maintained with GERDA.

A lower priority should be assigned to (also in alphabetical order):

- MOON, which is in an R&D phase until 2007 and will then issue a proposal if the R&D is successful, and
- SuperNEMO, which is doing R&D on a 100-kg detector but faces a difficult if not impossible task in developing the next phase.

In the second phase, the successful experiment needs to confirm that the neutrinoless double-beta decay signal exists, it needs to achieve a high-enough sensitivity to show a signal in the region where inverted hierarchy and normal hierarchy diverge, and it needs to have sufficient sensitivity to observe or rule out the inverted hierarchy region using neutrinoless double-beta decay and cosmology.

Clarification questions: If the nuclear matrix elements are wrong, the neutrino mass determined from double-beta decay will be incorrect. The nuclear matrix elements are probably not off by a factor of 10 but may possibly be off by a factor of 2. The latter value could increase mass sensitivity. In the end, the question is whether neutrinos are Majorana particles or Dirac particles. The important thing is the signal; this is probably the only way one will know if neutrinos are Majorana or Dirac particles.

The recommendations in the report cite "two or more" experiments because NuSAG does not know if EXO will be successful. The Majorana Experiment will work, but it is expensive. CUORE is an attractive technology. The decision depends on whether one wants to go for certainty of success or cost.

One normally goes to a larger scale to get rid of the background. But Majorana does not get better with scaling; the two numbers cited for Majorana in the report are based on different statistical assumptions. One has to decide which number to trust more. Increasing mass to limit the background can be a daunting task. NuSAG did not do a technological assessment; all of these technologies will probably work at some level. However, if the scientific community chose one experiment and it did not work, one would be left with none. NuSAG did not want to focus on just one experiment.

NuSAG suggested starting small because, if one develops one of three modules, one can get data for a baseline technical assessment early on.

Supply issues arise because some of the isotopes come from Russia; however, the collaborations have Russians on them.

Startup costs depend on the size of the experiment and start at $3.5 million.

It would have been convenient if NuSAG had picked the top two experiments. If NuSAG cannot do it, who can? The selection will have to be done by elimination. NuSAG did not have enough integrating time to get the number down to two experiments. If the process were not financially limited, the germanium experiment would probably be the most likely to be successful.

Majorana will be up and running in 7 years. By definition, that is the near term.

The numbers quoted in the report are within the band of those cited by the Heidelberg-Moscow collaboration. The goal in the near term is to get lucky and to confirm or refute the Heidelberg-Moscow results. For the long term, NuSAG recommends science priorities, not financial investments.

The CUORE experiment seems cheaper and more sensitive and is therefore very attractive. The Majorana researchers have worked with germanium for many years, but finding a cheaper isotope would be attractive.

A major question is how far the background rejection can be taken. CUORE is ongoing and is getting data on that question; EXO is also getting R&D funds to determine the answer to that question.

In the proposed experiment that meets the APS recommendations, physics data would be gathered as each module comes online, so results are expected well before 2018.

Experiments will have to be run on two or three isotopes before a best technique can be chosen. A number of factors enter in, such as

- How one knows if one is measuring neutrinoless double-beta decay?
- Two positive results (observed decay rates from two isotopes) allow one to eliminate the mass term.
- There could be other mechanisms than light-neutrino exchange.

The total cost is now $17 million, and the United States is being asked for $9 million, not counting the R&D that has been done since 1966.

Casten declared a break at 10:32 a.m. and called the meeting back into session at 11:01 a.m.

Discussion of the report: EXO's neutrino-mass reach for a 10 ton experiment running for 10 years is 25 meV.

If one knew the matrix elements exactly, one could pick an experiment now. However, those matrix elements are not known. Although the charge calls for an assessment of the resources needed, NuSAG did not do that because it did not want to jeopardize funding of experiments of lower priority. If the United States supports three experiments for the near term, the cost comes to $57 million over 7 years. One could get a handle on the costs of the three experiments to achieve a certain sensitivity if the numbers could be scaled. However, NuSAG is hesitant to do that; it does not know what the experiments are going to do in the future as they upgrade their capabilities.

The pursuit of neutrinoless double-beta decay could be a new initiative or it could come out of current funds. The charge to NuSAG does not give it a budget scenario to work toward. It is not known where the funding might come from, but it is known that there are a lot of opportunities in neutrino research, and the agencies will make it a priority. It is not impossible that new funds would be forthcoming.

The report contains nothing about resources needed, and the different experiments are at different stages of development. COURE is asking for $9 million from the United States and will be completed in 2014. EXO is funded and sponsored by HEP in DOE; that office has been resourceful in getting resources elsewhere; the first phase of the experiment will be completed in 2008 or 2009. Majorana will cost $57 million; a proposal for it is under development; a white paper was sent to DOE, but the proponents were told that DOE was awaiting guidance. A 180-kg experiment that is in line with the APS recommendations is ready to be proposed. Such an experiment has to have 100 to 120 kg to be timely and to have an impact on physics. In the proposed experiment, the first 60-kg module would be brought online and would produce data earlier than the full detector.

The costs that are being cited and for which funding is being requested are mostly for crystals but are also for electronics and installation costs. COURE will have a total cost of $17 million, and $9.3 million is being requested from the United States. Several issues affect the size of the U.S. contribution. It is difficult to set a ratio of U.S. to foreign contributions because different countries have different funding methods. For example, the Italians do not reflect personnel costs in their total costs.

All of the experiments are to be carried out at about the same depth, and the cosmic background will be handled by that shielding, although it might be that bigger experiments will need to go deeper.

The agencies have gotten guidance on scientific opportunities; they will get resources for the most promising programs. They will also look carefully at the preparedness of the experiments that are selected. There is a lot of guidance in the body of the report. This report points out advantages and concerns about the three proposed experiments. Guidance is available from other sources, as well. The available money may or may not cover all three experiments. The report gives the agencies the information they need.

Casten polled the Committee members about the acceptability of the report as amended in the course of these discussions. It was agreed that

- The summary table on 3σ discovery sensitivity should be in the report in some form.
- How the theory associated with the extraction of the matrix elements is addressed could bear some comment or recommendation.
- The phasing of Majorana should be explained.

The consensus was that NSAC should accept the report. It is well done. The recommendations are clear and the implementation ideas are sound. The importance of theory in calculating the nuclear matrix elements should be included in the report. The table listing the discovery sensitivities helps crystallize the report. The report was accepted unanimously with the improvements.

Dehmer complimented the collegiality of the NuSAG members in producing the report. Casten adjourned the meeting for lunch at 11:50 a.m. He called the meeting to order again at 1:12 p.m. and discussed scheduling.

Final NSAC Discussion of the NuSAG Report: Casten suggested the following path forward.

Friday, September 2, noon EDT	Final report submitted to NSAC
Tuesday, September 6	Final approval from NSAC
Wednesday, September 7	Report and transmittal letter sent to agencies
Saturday, September 10	NSAC membership ceases

Although the summary table has information that does not agree with what the experiment proponents say, NuSAG can refine the information included. The chairman will vet the numbers in the table with the members of NuSAG.

It was unclear whether HEPAP and NSAC were to approve the same report. The charge says that the two committees have to receive the report. It was suggested that Beier talk with Peter Meyers, his counterpart on HEPAP, to make sure that NSAC and HEPAP agree.

Public Comments: Casten called for public comment. There were no comments from the public attendees.

Composition of the Transmittal Letter: Casten showed a draft transmittal letter, and the Committee members read it. The concerns of the Committee centered on the last two paragraphs, and those paragraphs were considered sentence by sentence. Changes in wording and order of presentation were made for clarity and accuracy.

The question arose whether a common report and transmittal letter should be produced and submitted from the two advisory committees. NuSAG is not a subcommittee of either advisory committee but a joint subcommittee. A joint report can be sent to the agencies with separate transmittal letters from the two advisory committees. The original intent of the agencies was for the two advisory committees to comment on and transmit the report separately, allowing separate bodies to review the report independently. The agencies would not be bothered by separate reports, even if they varied slightly. This whole process is advisory. The agencies will have no problem responding to the recommendations. Two separate letters from the advisory committee chairs would solve the problem. Double-beta decay is the issue of interest to NSAC; the other charges to NuSAG are of interest primarily to HEPAP. A single report with two transmittal letters seemed workable. Robin Staffin (Associate Director, Office of High Energy Physics, Office of Science, Department of Energy) and Michael Turner (Assistant Director, Mathematical and Physical Sciences, National Science Foundation) were to be contacted to make sure that this process is acceptable to them. The next report from NuSAG is due in October, and the procedures for preparing that report should be determined by then.

Final Comments: Casten opened the floor to general comments. Kovar presented a plaque citing Casten's great performance as chairman of the NSAC during the previous 3 years. There was a round of applause. Casten thanked the group and thanked the NuSAG chairmen for their excellent work on the report. He also thanked Brenda May for all her help during his three years as NSAC Chair

Kovar thanked the Committee members for their hard work and their contributions to the Committee and the agencies. Richard Boyd echoed the comments on behalf of NSF.

Casten thanked the two agencies for their cooperation and support. He adjourned the meeting at 2:18 p.m.

Respectfully submitted,
Frederick M. O'Hara, Jr.
Recording Secretary
Sept. 7, 2005

Corrected,
Richard Casten, Sept. 19, 2005
Eugene Beier, Sept. 22, 2005
Eugene Henry, Oct. 3, 2005

These minutes of the Nuclear Science Advisory Committee meeting held at the Doubletree Hotel and Conference Center, Rockville, Maryland, August 29, 2005, are certified to be an accurate representation of what occurred.

Richard F. Casten
Chairman
Nuclear Science Advisory Committee
Oct. 5, 2005

Appendix A

Agenda

Monday - August 29, 2005

8:30	Welcome, Initial remarks	Casten
8:45	DOE/NSF Remarks	Kovar/Dehmer
9:15	Presentation of NuSAG Sub Committee Report	Beier
10:15	Initial Discussion	Casten/Beier
10:45	Break	
11:15	Continuing Discussion	Casten/Beier
12:00	Lunch	
1:15	Public Comment	Casten
1:45	Final Discussion of Report and Transmittal Letter	Casten/Beier
2:45	Final Comments	Casten
3:00	Adjourn	

Appendix B

NuSAG Membership

Eugene Beier (University of Pennsylvania and Co-Chair)
Peter Meyers (Princeton University and Co-Chair)
Leslie Camilleri (CERN)
Boris Kayser (Fermi National Accelerator Laboratory)
Naomi Makins (University of Illinois)
Art McDonald (Queens University)
John Hardy (Texas A&M)
Tsuyoshi Nakaya (Kyoto University)
Natalie Roe (Lawrence Berkeley National Laboratory)
Guy Savard (Argonne National Laboratory)
Heidi Schellman (Northwestern University)
Gregory Sullivan (University of Maryland)
PetrVogel (California Institute of Technology)
Bruce Vogelaar (Virginia Tech)
Glenn Young (Oak Ridge National Laboratory)
Richard Casten (Yale University) ex officio, NSAC chairman
Frederick Gilman (Carnegie-Mellon University) ex officio, HEPAP chairman