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June 8, 1989

Dr. David L. Hendrie
Director, Division of Nuclear Physics
Office of Energy Research
Department of Energy
Washington, DC 20545

Dear David:

Enclosed are the recommendations by NSAC on three detector proposals, the Large Cherenkov Detector at LAMPF, Gammasphere and the Sudbury Neutrino Observatory. This document is in response to the charge issued by you and Dr. D. Hendrie (Dr. Karl Erb) from DOE/NSF to our committee at the NSAC meeting of March 5/6, 1989. We are pleased to note that one of the recommendations, namely that a siting process be initiated for Gammasphere, has already been implemented.

Sincerely,

Peter Paul

Peter Paul
Chairman, Nuclear Science
Advisory Committee

PP:fs
Encl.

xc: Dr. Karl Erb
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NSAC Members

Recommendations on Three Large Detector Proposals

Nuclear Science Advisory Committee

June 1, 1989

1. Introduction.

At its meeting on January 27, 1989, the Nuclear Science Advisory Committee was asked by NSF/DOE to provide advice on the scientific merits of three major detector proposals. Specifically the charge states that:

> Proposals to construct three large detector projects have reached advanced stages of review and are being considered for funding. Any of these. if undertaken, would have a significant impact on the funding balance and distribution of effort within the field of nuclear physics. NSAC is therefore asked to advise DOE and NSF on the scientific benefits associated with the construction of these detectors. The committee should include in its consideration the results of existing technical and scientific reviews. The agencies will also provide the Committee with an understanding of the financial implication of a decision to fund such proposals, and asks NSAC to take this into consideration as well (full charge given in the appendix).

These proposals had already undergone complete reviews by scientific panels for their individual scientific merits, and by technical panels for their technical and cost integrity. Thus the important aspects of the charge to NSAC were how the detectors fit into the scientific program of Nuclear Physics, broadly defined, and how they impact on the equipment funds available to the nuclear physics program for major instrumentation in all areas of need.

Listed in alphabetical order, the three proposals are:

- **a. Gammasphere** proposed by a consortium of nuclear physicists from Universities and National laboratories with F. Stephens from LBL as presenter,

- **b. The Large Cerenkov Detector (LCD)** proposed by Los Alamos in conjunction with a large group of university collaborators, with Hywell White from Los Alamos as presenter, and
- **c. The Sudbury Solar Neutrino Detector (SNO)**, a proposal advanced by a consortium of US physicists from several Universities and from Los Alamos, with E. W. Beier from the University of Pennsylvania as presenter, to participate in an International Solar Neutrino Project, to be sited in Sudbury, Ontario, Canada.

NSAC discussed these proposals and the context of other foreseeable needs of major projects at its meeting of March 5/6, 1989 in Chicago. Additional discussion took place in the scheduled NSAC meeting on April 30/31, 1989 in Baltimore. The agendas of both meetings are given in the appendix.

The NSAC recommendations are given in this report.

As background for the NSAC deliberations the scenario for funding of ongoing equipment needs was presented to the committee by Dr. David Hendrie from DOE. Pending approval all of these projects were to be considered candidates for funding from DOE resources. In 1989 DOE funding for non-line item equipment came to \$18.5M of which \$12M was needed to cover basic needs and \$6.5M was available for new needs in ongoing projects.

2. The Projects:

a. Gammasphere: This project proposes to build a highly segmented (110 elements) detector array of high-resolution Ge detectors with 480 BGO Compton suppressor elements, which will detect low energy γ rays with high resolution, over the full sphere around the target. By covering 50% of the full solid angle with large volume Ge detectors (20% "real" full-energy efficiency) the array permits the recording of 5-fold γ coincidences at a rate higher than that of the 3-fold ones of the current, smaller instruments. A number of elements can be replaced by BaF_2 detectors for the measurement of high energy γ rays in coincidence with low energy transitions. The detector will improve the sensitivity of γ ray studies of nuclear structure at high spin by about a factor of 100. The detector will impact the research programs of an estimated 200 scientists from at least 20 institutions who are working on nuclear structure problems at low-energy accelerators. Its main scientific focus will be the properties of nuclei at very high angular momentum and at finite temperatures, such as the evolution of shell structure as a function of deformation, and the evolution of nuclear shapes and other properties as a function of spin and temperature. In addition, the 4π coverage, the high segmentation and the excellent γ energy resolution will provide new opportunities for a large number of additional topics, such as the study of basic symmetries in nuclei, of exotic nuclei and of nuclear reactions near the nuclear barrier.

The detector has a 3 year construction schedule and its cost was estimated in the proposal at $15.7M for the main detector. A crucial aspect which was not resolved at the time of these discussions, is the choice of accelerator siting. Since it is projected that the detector will need about 2500 hrs/year of beam time dedicated to its program, about 60% of the useful yearly beam time of a low energy heavy ion accelerator, it will have a major impact on the program of the host facility. At the same time this sophisticated detector will change the landscape of low energy nuclear physics research in the US by introducing many more spectroscopy groups to the mode of user's operation.

The proposal has undergone a scientific mail review. The reviewers emphasize the importance of this detector for the advance of high-spin nuclear structure research in particular and for the vitality of nuclear structure physics as a whole. The design of the detector elements is judged a safe extension of a proven technology. Some questions were raised about the design of the anticompton elements.These points were satisfactorily addressed by Dr. Stephens in his presentation to NSAC. A second committee reviewed the technical and financial aspects of the proposal. It commends the design, in particular the chosen segmentation geometry, as an optimum between cost and performance. The review committee computes the total project cost at $19.3M, including a 30% contingency, which could be reduced to $17.5M if some software support and assembly manpower were provided by the host laboratory.

NSAC agrees that Gammasphere represents a very major and timely advance for frontier research over a broad stretch of nuclear structure physics. This instrument will make it possible for US laboratories to maintain a leading position in the exciting area of high spin physics vis-a-vis Europe where an instrument of similar capability (Euroball) is being considered. Although some technical and systems details need to be completed in the design stage the detector is largely ready to move to construction. Because of its complexity this large detector would be moved between sites only with great difficulty and would, in all likelihood, be placed permanently at a chosen facility. Thus some of the technical resources at the host site should be made available to the construction of the detector.

b. LCD: This is a large neutrino detector which would be sited at the extracted beam of the Proton Storage Ring (PSR) at LAMPF. The dominant purpose of this detector, and the one which drives the design, is a significant test of the standard model of the electro-weak interaction which would be unique because it is done at low momentum transfer. Specifically, the proposal is to measure the Weinberg angle, or the quantity $sin^2\theta_W$, to an accuracy of about 1%, which is about a factor of ten better than the present error. LCD will improve on the accuracy of the only other ongoing experiment by about a factor of 3 to 5. It will complement other high energy experiments which measure properties of the Vector bosons directly, by measuring the Weinberg angle at low momentum transfer. Because it involves only leptons, the interpretation of the result will be free of the ambiguities of semi-leptonic measurements. The detector makes excellent use of the unique properties of the LAMPF and PSR facility, especially its pulsed beam characteristics. In addition to the fundamental test, LCD will be able to make measurements on neutrino oscillations caused by the mixing of ν_μ and ν_e , and on the neutrino magnetic moment.

The detector consists of a large volume (7500 tons) of pure water in which Cerenkov light is detected by about 10,000 photomultipliers. Neutrinos are produced at the target in the heavily shielded (total shielding weight 64,000 tons) center of the detector by beam bursts from the PSR. The proposal estimates a 3 year construction period.

A scientific review committee, chaired by Professor Barry Barish, found the scientific goal of the proposal of high merit and judged the accuracy claimed for the experiment as realistically attainable. It expressed concern about long running time of the experiment needed to achieve the required statistics (6 years at the time of the review), about the quality of the beam injected into the PSR, about the possible level of beam related background, and about uncertainties about the performance and price of the photomultipliers which are a crucial part of the detector. A later technical review found the updated total cost estimate of $28M a realistic estimate for the detector, and estimated the total cost of the project at $40M when necessary operating funds and a 30% contingency are included. It also raised questions about the efficacy of the shielding of neutrons stemming from beam losses, and about the supply of the photomultipliers. It judged a 3 year construction schedule as realistic.

In his presentation to NSAC Dr. White addressed these concerns and presented some specific solutions. A prototype of a 10 in phototube has been produced by Burle Inc. and has substantially exceeded all specifications. It is estimated that 9400 of these tubes will provide adequate (16%) areal coverage at the initially estimated cost (about $7M). EMI Thorne has been identified as an alternate supplier of a 10" p.m.tube. Advances have also been made in the injection of the proton beams from the LAMPF linac into the PSR by correcting some inadequacies. Finally, the estimated running time for the experiment has been shortened to about 2.5 years (assuming 3000 hrs of beam time per year) by increasing the frequency of injection into PSR five fold and the rate of protons/sec two-fold. This is made possible by a mode of operation in which the linac accelerates simultaneously H^- and H^+ ions at maximal intensity.

In their discussion, NSAC members emphasized the fundamental nature of the proposed Weinberg angle measurement and felt reassured by the developments on the photomultipliers and the improved beam injection. But several concerns remained: Because of the long lead time for the final result, with an estimated construction time of 3 years and a data taking cycle of 3 years, the measurement, although significant in the first year of running, will not have reached its final statistics until 1996. Secondly, the question about the actual neutron background from slow beam loss will not be resolved experimentally until about 1991 when the PSR upgrading program is scheduled for completion, although it seems plausible that the earlier problems have been understood. There was the general feeling that additional R&D remained to be done before this massive and complex detector could move to construction.

In view of the direct connection between the motivation for LCD and several high energy physics detectors, one could expect a high interest in the proposed experiment by the high energy physics community. This interest did not manifest itself in the recent report by HEPAP on the High Energy Physics Priorities for the next ten years.

c. **SNO:** The Sudbury Neutrino Observatory will consist of an underground detector which can measure the solar ν_e neutrinos with energies above 7 MeV, and the flux of all neutrino types with energies above about 2 MeV. The detector is a unique one, consisting of a Cerenkov detector containing 1000 tons of D_2O, surrounded by an active shield of 5000 tons of regular water. It will be installed in the Sudbury mine in Ontario, Canada. The detector is made possible by the loan of the 1kT of heavy water from the Canadian reactor reserve. Although a firm commitment for the availability of the D_2O has been made only through 1998, this time limit might well be extended. Because of the use of deuterium, the SNO detector can measure the shape of the incident ^8B neutrino spectrum and thus directly observe the effect of a possible neutrino mixing from the MSW effect in the solar medium. With its large fiducial volume it produces about 10 events from solar neutrinos per day allowing the observation of time varying cycles in the neutrino flux such as are now suggested by the ^{37}Cl detector results. A flux corresponding to the standard solar model will produce about 6500 events per year. Again, because of the use of D_2O, the detector is able to measure neutrinos of any flavor via neutral current processes. If the mixing of neutrino flavors is responsible for the solar neutrino problem, about 2800 neutral current events will be observed per year. Since the detector can separately determine the ν_e flux reaching the earth and the total flux of all neutrinos, it can directly observe neutrino oscillations without recourse to solar model.The detector will also be a very sensitive detector of neutrinos from supernova events.

The proposal has been reviewed by a joint Canadian-US scientific and technical review committee which enthusiastically supports the detector for its scientific potential, judges it ready for construction, and recommends funding. The US participants in this Canadian-US-UK collaboration are a distinguished group from several Universities and from Los Alamos, and have extensive background in neutrino studies. Professor E. W. Beier from the University of Pennsylvania presented the proposal to NSAC. The capital cost of construction is US $32.5M of which the US collaboration is asked to contribute $8M over 4 years. The first year request from the US would be about $1M. The all important heavy water has a value estimated at $200M. Construction time is estimated to be 4.5 years after start of funding. NSAC heard several presentations from representatives of the Canadian Scientific Councils who testified that Canada has already given this project its highest priority, that the councils are redirecting resources toward the project and that a commitment for $20M already exists. It was estimated that after construction the incremental operating costs for the US collaborators would be about $500K per year.

NSAC was greatly impressed by the many outstanding scientific opportunities offered by this unique detector and by its great cost effectiveness for the US partners of the collaboration. This project appears ready to go, and the US groups are already directing part of their experimental effort to SNO.

3. Recommendations.

A. Gammasphere: This detector represents a huge step forward in the refinement of experimental study of nuclear structure at high angular momentum, finite temperature and large deformation. The proposal has captured the imagination of a large and enthusiastic group of nuclear physicists in the US. It will provide the major focus for nuclear structure research for many years, literally redefining one frontier of that field. The timely availability of this well conceived detector, with the participation of some of the best physicists in the field, will assure a lively activity in this important area of nuclear physics in the US for many years.

NSAC recognizes the high scientific merit of Gammasphere and recommends that the project be funded.

In the committee's judgment the proposal is ready for substantial funds for prototyping and R& D in FY'90,and for full construction in FY'91. It is also recommended that a site selection process start as soon as possible so that the framework of the detector operation can be defined.

With an estimated annual funding requirement of about $5M, this project would exhaust most flexible equipment funds available under the scenario outlined to NSAC by DOE. NSAC is reluctant to see this happen. Possibly, this detector could be funded from a mixture of some ongoing equipment funds, some new equipment money, and with existing resources of the host facility.

B. LCD: This detector represents an elegant use of the unique accelerator capabilities available at LAMPF to make a fundamental test of the standard model with a precision which improves significally on present knowledge. Although other experiments will undoubtedly improve their results over the long time span needed for the LCD experiment, the fact that it is a low q^2 measurement will make it unique and complementary to the high energy results. The collaborators who propose LCD are a distinguished group of experts in neutrino measurements. Although several technical problems have been resolved in a satisfactory way, NSAC feels that the project needs some additional R&D time. It could be ready for FY91 construction funding.

The detector costs about $40M, including engineering and technical support, but exclusive of scientific manpower. This makes it a very costly proposal by nuclear physics standards and emphasizes the fact that this proposal is at the intersection between nuclear physics and high energy physics. Its funding would represent a very major perturbation on the long range plans of Nuclear Physics and would make it impossible to fulfill the substantial needs of the core programs at existant and new facilities, planned or under construction, which are the center of nuclear physics research.

Therefore, despite the substantial scientific merit of LCD, because of its large price tag and the long-term nature of this program and thus its major and lasting impact on funding for nuclear physics, NSAC can not recommend funding of LCD from the ongoing Nuclear Physics program.

C. The SNO Proposal: This proposal represents an exceptional opportunity to create and work at a unique world class facility. It has a very high potential for fundamental discoveries in solar physics and in the properties of neutrinos. The use of 1 kT of D_20 for the detection of neutrinos is a unique chance to measure not only the flux but also the spectrum of solar neutrinos in real time , as well as the total flux of all neutrino flavors and their mixing. The facility will be an excellent detector for neutrinos from supernovas.

The US participation in this project is especially cost-effective both in terms of construction costs and, eventually, operating costs. The detector will provide an experimental capability for a well mixed and highly experienced group of US scientists from universities and a national laboratory. The project already has the strong endorsement of the Canadian Research Councils and has a commitment of Canadian funds for construction.

NSAC enthusiastically recommends that the US participation in the project be funded immediately.

The first year request of $800k fits well into the available flexible equipment funds as described to NSAC.

NSAC MEETINGS REGARDING THREE DETECTOR PROPOSALS

Agenda of NSAC Meeting, March 5-6, 1989 at Chicago O'Hare Holiday Inn

Sunday, March 5	Afternoon and evening
3:00 pm-5:30 pm	Discussion of SNO, LCD and Gammasphere Proposals
7:30 pm-10:00pm	Discussion of Long Range Planning Procedures
Monday, March 6	All Day
8:30 am-12:30 am	Discussion of charge on KAON initiative and interim report on KAON subcommittee, discussion of interim report of Subcommittee on Instrumentation, response to charge concerning the three detector proposals
1:30 pm-4:00 pm	Final formulation of Long Range Plan procedures
4:00 pm-5:00 pm	New business
5:00 pm	Adjourn

Agenda of NSAC Meeting, April 29-30, 1989, at Baltimore, Hayatt Regency Hotel

Saturday, April 29	Afternoon
1:00 pm-3:30 pm	Reports on DNP Town Meetings
3:30 pm-5:30 pm	Selection of working groups for Long Range Plan
5:30 pm-6:30 pm	Preparation of LRP Meeting at Indiana University
Sunday, April 30	All Day
9:30 am-10:00 am	Response to charge on Instrumentation report
10:00 am-11:00 am	Final discussion and report on Detector Proposals
11:00 am-12:30 am	Response to charge on KAON Report
12:30 am-1:00 pm	Report on Nuclear data activities
1:30 am-3:30 pm	Preparation of charge to working groups for LRP and of LRP Workshop at Boulder
3:30 pm-4:00 pm	Other business
4:00 pm	Adjourn

CHARGE TO NSAC

Proposals to construct three large detector projects -- the Large Cherenkov Detector (LCD) at LAMPF, the Gammasphere, the Sudbury Neutrino Observatory (SNO) -- have reached advanced stages of review and are being considered for funding. Any of these, if undertaken, would have a significant impact on the funding balance and distribution of effort within the field of nuclear physics.

NSAC is therefore asked to advise the DOE and NSF, by May 1, 1989 on the scientific benefits associated with the construction of LCD, SNO, and Gammasphere. The Committee should include in its considerations the results of existing technical and scientific reviews, which will be made available. The funding agencies will also provide the Committee with an understanding of the financial implications of a decision to fund such proposals, and asks NSAC to take this into consideration, as well.

Karl A. Erb
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David L. Hendrie
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