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BNL-71200-2003

Raymond Davis and the Solar Neutrinos

N. Blair Munhofen

February 2003

Chemistry Department, Bldg. 555

Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
www.bnl.gov

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Contract No. DE-AC02-98CH10886

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Prologue:

The first Chairman of the Chemistry Department, Richard W. Dodson passed away on June 13, 2002. To acknowledge his remarkable leadership of nearly twenty years, Gerhart Friedlander, along with others, planned a Memorial Symposium to honor his memory on 8 November 2002. A series of talks were to be given about significant scientific studies that occurred during his reign. Since Ray was unable to give this talk, I was asked to do so.

When Ray came here to work in 1948, he expected to be given an assignment, instead Dr. Dodson asked him what he planned to do. Since Ray was unsure, Dodson suggested he go to the library and look through the literature. A few days later, Raymond came back and announced he had selected neutrinos.

Though long expected, the announcement that Ray was going to be honored with a Nobel Prize for his Solar Neutrino discoveries, it greatly enhanced the interest in the man as well as his work.

The Experiments:

I joined the Chemistry Department in 1953 as a Department Administrator. My first encounter with Ray came when he asked to have two 55-gallon drums of carbon tetrachloride sent to the top of Mount Evans in Colorado and for their return to him after a suitable period of time. For years I thought that was the beginning of the search for neutrinos. Actually there were two preceding experiments.

Number 1 and 2: From Garman Harbottle I learned that Ray had done some "neat research" on Berylium 7 in 1951 and 1952 concerning the recoil of atoms from neutrino emission. He established that a single neutrino was emitted in each electron process. From Gerhart Friedlander I learned that there had been an experiment with a single drum of carbon tetrachloride at or in the Graphite Reactor - date uncertain.

Number 4: In 1954 we buried a 1000 gallon tank of carbon tetrachloride (20 foot of cover) in an open field east of the Biology Department. Covered wooden stairs led to one end for access to a motor driven propeller inside the tank and extraction connections. To collect and measure any Argon 37 formed required bringing a vacuum rack from Ray's laboratory for open-air processing. When finished with this facility, Ray and John Galvin (a Chemistry technician), removed all of the liquid for the next experiment. The vapors were vacuumed out. A few years

ago the safety people became concerned about the contents even though we assured them that the tank was empty. From an old photograph of the site, some trees and other structures, we were able to identify the location. The tank was removed and the only odor was that of torch-cut steel.

Number 5: In 1955 two 500 gallon vertical tanks with carbon tetrachloride were installed at the Graphite Reactor to determine whether neutrinos and antineutrinos differ in their nuclear interactions. In 1955 these tanks were moved to the Savannah River Plant where there was a much larger power level, generating more neutrinos.

Number 6: In 1957 the vertical 500 gallon tanks were replaced by six 500 gallon horizontal tanks that could be immersed in water for a fast neutron shield

Number 7: About this time Ray began thinking about an experiment in a mine. We looked at a zinc mine in New Jersey and the Retsof salt mine near Geneseo in upstate New York. The salt mine was so dry that when we came out of the mine, our skin felt shriveled. We settled on the third one, a limestone mine at Barberton, Ohio which is owned by the Pittsburg Plate Glass Company, 2300 foot deep with huge open spaces. In 1961 we had the two 500 gallon vertical tanks installed there. This time the tanks were filled with perchloroethylene. Measurements there revealed a capture rate of less than 0.5 per day. To make definitive measurements, Ray calculated he would need 100,000 gallons and a deeper mine for further reduction of cosmic rays. Thus began a search for a deeper mine and a large amount of money.

Dr. Dodson went to Washington, D.C. to persuade the funding agency (Chemical Sciences of the Atomic Energy Commission (AEC) that Ray's project was worthy of their support. They agreed and suddenly a small Department had a very large project to deal with. It is my understanding that Gerald Tape of the Director's Office was concerned about the project staying within the budget and moving along at a steady pace. I was assigned to work with Ray in addition to my regular duties.

The first thing we needed was a mine at least twice the depth of the limestone mine, stable rock to permit the excavation of a large chamber, low emissions, hoists and shafts large enough to accommodate the materials and equipment required for our project. We also needed some sort of assurance that the mine was not likely to be closed. We visited the Bureau of Mines office in Denver for their guidance and approval of the experiment from a safety point of view. Having that, I compiled a list of over 40 mines in the United States and Canada. We narrowed it down to three.

Since the headquarters of the Anaconda Copper Company were in New York, we went there before visiting their mine at Butte, Montana. They were very cordial and receptive to Ray's proposal. Later, at the mine, we were escorted to an area where Ray could set up his equipment for measuring background emissions. It was not a dry mine. It was very warm and humid. Occasional drops of water striking your skin felt like a pin-prick. When ready to attach the gas cylinder, Ray discovered we had the wrong size wrench. We tried everything we could think of and finally we had to go up top and find a hardware store - all the while losing valuable time. Mines do not have elevator service! You send a coded ring to the hoist man that tells him the cage is wanted at your level. When your turn comes he sends the cage. Now Ray is not given to profanity, but I can assure you he found the words that day.

The Homestake Gold Mine at Lead, South Dakota was next. We were given a tour of the mine and then we met the manager. He was not encouraging to say the least.

Onward to the Sunshine Silver Mine at Kellogg, Idaho. The hoists and cage were not large but they were acceptable. We had several visits there and on our last one we brought along a member of the Purchasing Department to discuss contract terms. At some point the name of the Bureau of Mines inspector came up. The mine manager, normally an affable fellow, got up from the table saying as he walked to the window, "I'm not saying I will quit," and he opens the window and spits out his tobacco and continues, "but I'm sure as hell going to think about it." This put a damper on the negotiations. On the flight back, the subject was, "now what are we going to do?" The atmosphere - dejected. Incidentally, via the grapevine we learned that a gas cylinder had dropped down the main shaft at the Sunshine mine, ricocheting back and forth taking out horizontal timbers along the way. The Sunshine Silver Mine was later the site of one of America's worst mining disasters in 1972, in which a large underground fire claimed the lives of 91 miners.

Back at BNL, lady luck smiled upon us. Somehow the President of Homestake, Donald H. McLaughlin, Ph.D., at the headquarters in San Francisco, became aware of our visit to Lead and invited us to revisit the mine. We promptly returned to South Dakota where the reception this time was very cordial.

Homestake fulfilled all of our requirements. It was founded in 1876 or shortly thereafter at the discovery of gold. They had a long history of profitable operations. Driving a shaft to the depth of 7500 foot was about to begin. At that time, mining ore with three-tenths of an ounce of gold per ton was profitable.

In December of 1964, a contract was signed with Homestake to prepare space for the Solar Neutrino Observatory. A great working relationship with Homestake had begun that lasted to the very end. Excavation began in February 1965 and was completed in May. Seven thousand tons of rock had been removed. Rock surfaces were covered with chain link fencing held in place with 1200 rock bolts, strain tested by the Bureau of Mines. Concrete floors were poured in the pump and tank rooms and in the laboratory area. A water tight bulkhead door was installed between the pump room and the tank chamber. The purpose of this was to allow a water shield around the tank and an unintended swimming pool if you were so inclined. A door was installed at the upper level entry to the tank room. Just outside the door a perchloroethylene detector and an alarm system was installed. These doors were to be kept closed at all times for safety reasons, unless we were present.

One of the things we had to confront was that just increasing the size of the tank and accessories just wouldn't fly. If anything had gone wrong in the past it could be fixed or replaced. However, with a 100,000 gallons a mile down you just couldn't do that. We had to adopt rigorous specifications and leave nothing to chance. We had to be right the first time. Fortunately, BNL had many experienced and talented employees that could and did help.

Ken Hoffman and Bob Eisler of Nuclear Engineering helped us with the specifications and design of the tank and associated equipment such as eductors in place of propellers, to sweep Helium throughout the tank. We were not sure so I had the shops make a Plexiglas ring ten feet in diameter and had it placed in the Laboratory's swimming pool. We purchased some different sizes of eductors (something like an aspirator) and an under-water camera to record the dispersions of bubbles within the ring. Before we could do the tests we and John Galvin were required to be certified for use of scuba diving equipment. The purpose of all of this was to be certain that Helium would be swept throughout the tank.

The Chicago Bridge & Iron Company of Salt Lake City won the contract to build and install the 105,000 gallon tank with the associated piping in the mine. (The extra 5000 gallons were for a helium "blanket" on top of the perchloroethylene.) When they had all of the half inch steel sheets on hand we went there and tested every sheet for compliance with the specifications related to radioactivity. When fabricated, the formed pieces were assembled in the tank chamber of the mine. All welded joints were X-rayed and later the negatives were sent to BNL for review by Art Rosenka of the welding shop. After assembly, the tank, pumps and piping were wrapped with polyethylene and helium leak tested. Bob Dryer, vacuum expert from the Accelerator

Department, and I were there to observe and verify the system was leak tight. Then the interior of the tank was shot blasted, vacuum cleaned, washed down with a solvent, and tested for any radioactive contamination. The last opening was welded shut and the exterior was painted white.

Two 650 gpm sealed Chem Pumps were used to pump the perchlorethylene through the 40 eductors.

Vulcan Industries of Wichita, Kansas won the bid to supply the perchlorethylene. We visited them to work out the delivery procedure. The Homestake railroad siding was rather small. Their delivery and removal of tank cars had to be coordinated with our schedule for three 700 gallon tank cars (one filling, one in transit, and one being emptied). At the same time we had to avoid monopolizing the cages. Of course it wasn't that easy and it took a little longer than planned. Prior to delivery, Raymond Stoenner (head of our analytical group) spent several days at Vulcan evaluating their production and analytical procedures. Every tank car of perchlorethylene was tested at the plant and again at Homestake. The transfer crew members were: Ray Davis, John Galvin, Conrad Koehler, Don Harmer and David Comstock.

***Control Room and Laboratory**. We decided to use a prefabricated building to house the control panel, electronic counting equipment, vacuum rack for mounting Argon extraction and purification systems, a lead box for counting, etc. Since we had to do the assembly at the mine, we insisted on doing it at BNL. The Union had to be persuaded that this was a valid exception. We set up the items in the building as we envisioned it would be at the mine, making a few modifications as needed. It was equipped with an air conditioner. Everything was dismantled and shipped to the mine where we and John Galvin set it up as planned.*

During all of this, Ray Davis was refining his processing equipment, updating his counting system with Lee Rogers from Instrumentation Department, improving his proportional counters with the aid of BNL glassblowers Karl Walther and Irving Meyer.

***Spring 1967**: The first data was taken and the number of captured neutrinos was found to be less than expected. It was only a third of what had been predicted by theoreticians. Astro-physicists were convinced that his data was wrong. Gertrude Goldhaber told Ray that it would be more exciting if the count remained low. She was right of course. Ray plugged on, examining every possible error. There were none and the Ray's data was proven correct, breeding*

speculations on what could be happening to the other two-thirds.

Vadin Kuzmin, Institute for Nuclear Research, Moscow, Russia, was the first to suggest the use of gallium chloride for the next generation of neutrino detection experiments. We installed a glass-lined vertical tank in the basement of the Chemistry building and filled it with 1.3 tons of this very corrosive material. The tank was placed in a plastic "spill tray" in the event of a leak. Ron Withnel installed a leak detector with an alarm in the basement and at Police Headquarters. Ray, along with Keith Rowley, began working on the chemistry for the extraction of germanium 71 and conversion efficiencies. The tank is still there.

I should point out that Ray's interests were not confined to just neutrinos. He was concerned about the technicians' exposure to chemicals. At one time, he offered to teach chemistry to them, with me as his assistant. No one was required to attend, but every one of them did. It not only was a safety benefit, it added to their capabilities and increased their opportunity for advancement. He and Raymond Stoenner worked on the Moon Rocks here and at the Johnson Space Center. He also did studies on meteorites. Tennis may not count, but we did enjoy the courts.

The Declining Years

In the early 80's, DOE was in the mood to end funding of the Solar Neutrino program because they felt there was little left to be discovered.

In July of 1984, one of the Chempumps failed and released smoke into the ventilation system. I called Chempump about the cost of repair and depending on the extent of the damage, they estimated 11 to 20 thousand dollars. A new pump would cost $85,000. Since the pump contained PCB's, the repair ran afoul of Homestake policy prohibiting the return of anything having had PCB's. Al Gillis of Homestake preferred having the pump remain in the pump room rather than in the storage yard. Considering the current status of funding, nothing was done.

The Laboratory policy on retirement at age 70 forced Ray Davis to be retired in October of 1984. Ray was given a Research Collaborator appointment that is still active. In December, Alfred P. Wolf (Department Chairman) went to Washington to seek funding for the Gallium Experiment. It did not happen. A joint Brookhaven-Los Alamos request to the MacArthur Foundation for a grant also failed. At the request of the University of Pennsylvania, discussions began on the transfer of the Brookhaven Solar Neutrino Observatory to them. Ray had allowed them to use some of our space for several years.

John Galvin and I made our last trip to Homestake in April of 1985 to make a complete inventory of the equipment and coincidently to correct a violation of our safety rules.

On May 3, 1985 at 08:55, the remaining Chempump failed, spilling 70 gallons of perchloroethylene. The ventilation system was shut down, largely confining vapors. Clean up was done wearing protective clothing and self-contained breathing equipment. Bruce Cleveland reported that 91% of the argon had been extracted, thus ending Brookhaven's eighteen years of data collection.

Carl Schmuck of Homestake, as in the 1984 failure, preferred the pumps remain in the pump room until BNL and the University of Pennsylvania decided what was to be done.

A DOE and NSF report to the Nuclear Science Advisory Committee (10 members from universities and one from Argonne National Laboratory) submitted a draft report of their extensive investigation. They strongly recommended funding of the Gallium experiment but did not support continued funding of the Argon 37 experiment at Homestake because it would not be cost effective nor would it likely add significantly to the data.

Bruce Cleveland left BNL and went to Los Alamos at the end of August. The pumps were shipped to Brookhaven for disposal. We paid off the last of our obligations. The University of Pennsylvania took over the facility and Ray was appointed a Research Professor in the Department of Physics and Astronomy of the University of Pennsylvania.