SLAC BEAM LINE

"The problem was so difficult that it was hard even to get a wrong idea about it."

-A. Pais in Radioactivity's Two Early Puzzles

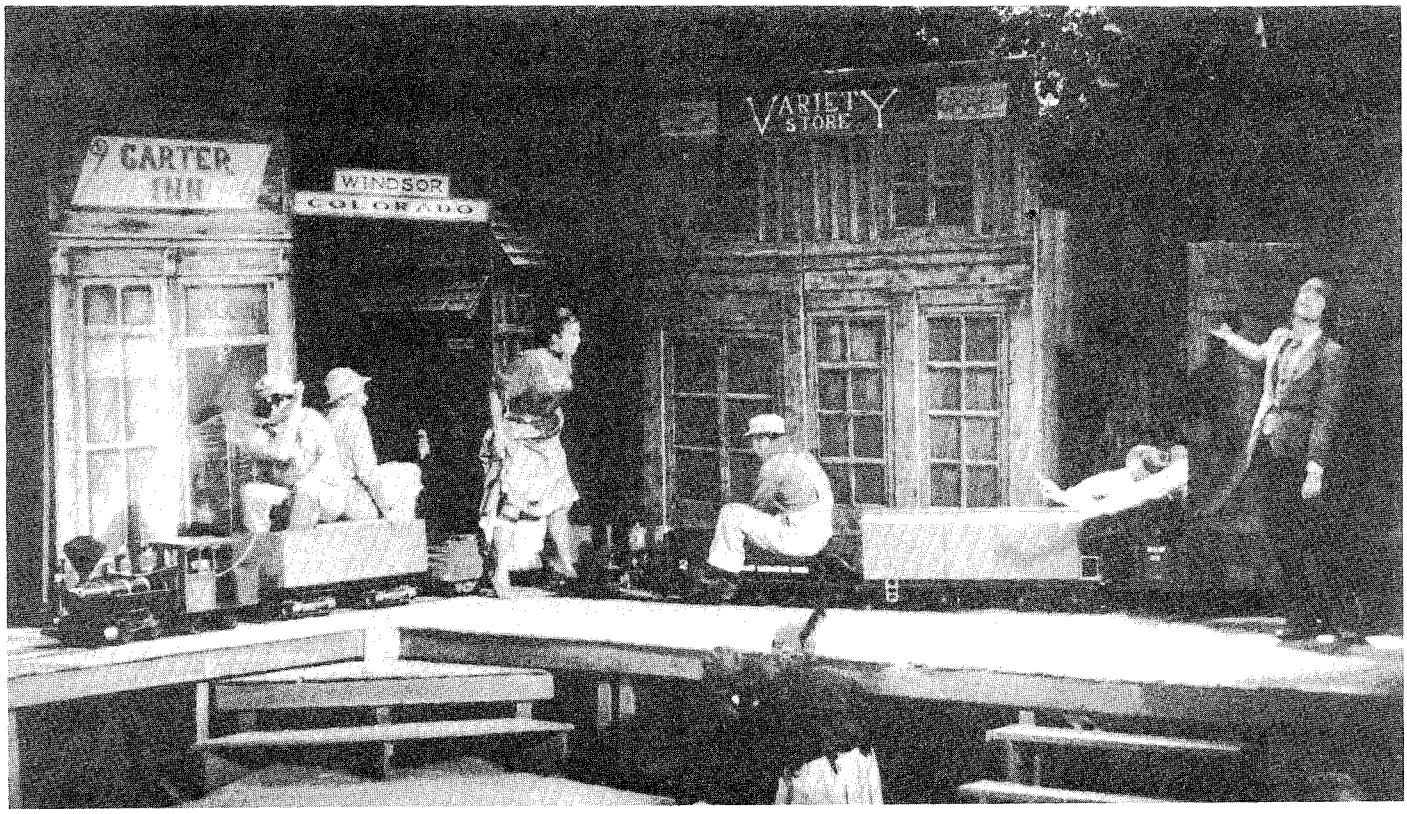
Volume 13, Number 5 *May 1982*

WHY IS THIS PLANE SMILING? The grin on this C5A puts PSA's smile to shame, as the giant plane prepares to take on the truck carrying the Crystal Ball. The Air Force flew the fragile experiment to Frankfurt, Germany, on April 17. After four productive years at SPEAR, the detector has been installed at the German storage ring, DORIS, which runs at an energy between that of SPEAR and PEP.

SLAC Beam Line, Bin 80
Stanford Linear Accelerator Center

Editorial Staff: Bill Ash, Jan Adamson, Dorothy Edminster, Bob Gex, Herb Weidner
Photography: Joe Faust, Walter Zawojski
Graphics: Technical Publications Department

In This Issue



LIVE STEAM AND SHAKESPEARE

Last summer the Theater Works, a semi-professional theater group in Palo Alto, came to the West Valley Live Steamers with an unusual request. Could we help them mount a western version of Shakespeare's "Merry Wives of Windsor" including scale model trains to carry the actors on and off the outdoor stage?

At first the idea seemed ridiculous, but it grew on us and finally it seemed almost sensible. First came the track which had to be built into the set at the beginning. The company agreed to pay half the cost for the construction of the portable track which would later belong to the club. Next came the cars and engines. Justin Escalera, myself and other club members provided them.

The cast was quite excited about sharing their stage with our trains and rehearsals began with great enthusiasm. Although we didn't have lines to remember, the practice was essential to develop our timing. In the opening scene the engine circled through the audience and then onto the stage bearing Falstaff and whistling away. Even though the timing was only ±5 seconds here, it required very careful planning to get the steamer to perform on cue.

Other difficulties showed up during the rehersals. There was no noise allowed backstage during a production--not the ideal place to fire up a locomotive and run an engine to work out the condensation. And no safety valve noise allowed, of course. We had to convert the consolidation to propane since coal proved too messy and it would have been impossible to control the firing finely enough to keep the safety from popping. All these problems were solved, and I even had time to train the set crew to operate the equipment including the firing of the consolidation with propane for the opening scene. To be on the safe side, though, I operated the engine for the first few shows.

How did it go? Well, when an actor delivers a superior performance he receives applause, and that only after the play is over. The consolidation and its engineer, however, got their applause as soon as they came on stage at the opening of the play. Through several rehearsal and thirteen performances all of the equipment worked very well: no broken wires in the electric controllers, no parts falling off the steam engines, and only one or two minor derailments. The play's the thing.

-John Grant

JACK HOLLENBECK RETIRES

Jack Hollenbeck decided that, after 48 years of gainful employment, it was time to retire and enjoy the fruits of his labor. The last 18 years of that stretch were spent at SLAC, 15 as a utilities electrician. For the last three years he was responsible for the care and feeding of the SLAC Fire Alarm and Fire Suppression systems. His dedication to this assignment bordered on reverence except, of course, on those occasions when he had to respond to trouble calls in the middle of the night or on weekends. It was probably on one of those occasions that Jack first entertained thoughts of retiring.

Jack grew up in the Fresno area and graduated from Fresno Technical High School in 1935. The two subjects that interested him the most were Principles of Electricity and Radio. In fact, Jack later pursued these interests, not only as a vocation, but as an avocation as well. He earned his Ham Radio Operator's license fifty years ago and has been an ardent operator ever since. It shouldn't surprise you to learn that Jack was a charter member of the SLAC Radio Club and an officer in the club for a number of years.

Another hobby that held Jack's interest for many years was a large-scale model railroad that he and his sons built. When his last son left the roost, Jack dismantled it, which is just as well, because it then allowed him to devote more time to his other hobby--raising Basenjis, an African breed of small, curly-tailed dogs that don't bark. There hasn't been a great demand for them as watch dogs, but Jack has been successful in breeding champion show dogs.

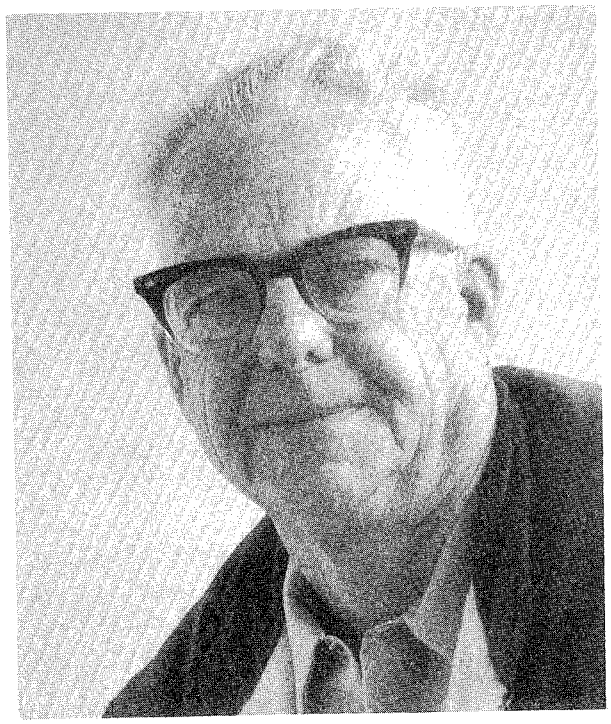
Shortly after graduating from high school, Jack entered the U.S. Navy Reserve, served six years and advanced to Radioman First Class before finishing his second hitch in 1941. Jack then worked on the Oakland Bay Bridge as an electrician for the Key System Transit Co. until the electric trains were removed in 1949 to make room for progress.

Jack then worked a 10-year stretch at S.R.I. and another four at Varian before joining SLAC in 1964. You can see that Jack hasn't ventured too far from the mid-Peninsula for a number of years. It's also unlikely that he and Gerry, his wife (who obviously has taken good care of him for 43 years) will venture too far from their three daughters and three sons and a dozen or more grandchildren living in this general area. Of course, this doesn't mean that Jack and Gerry won't take off in their van for a little fishing now and then.

Jack will be remembered by those who worked closely with him the last few years for his dedication to the Fire Alarm Systems and his determination in analysing and correcting malfunctions.

Jack will be missed. We all owe him a vote of thanks for his devotion to the job and wish him an enjoyable and bountiful retirement.

-Joe Fish



FOUND KEYS

A variety of car and other personal keys that have been found at SLAC over the past two years are now collecting dust in the Plant Office, Room 232, A&E Building. If you have lost keys you are invited to stop by and paw through the collection.

-G. Ratliff

POSTSCRIPTS--VIOLA BELTON

We have received a thank you card from Viola. She asked that we pass along to "all my friends at SLAC" her appreciation for the delightful farewell lunch at Rick's Swiss Chalet and the lovely gifts.

Waiting to greet Viola upon her arrival at Lake Shore Pines was a 2'x4' greeting card signed by her many SLAC friends. Dave Downing, who was on a lengthy vacation tour with his family, stopped there in a driving rainstorm to post our goodwill message.

-Dorothy Edminster

NEWS & EVENTS...

SLAC BOWLING LEAGUE

Outstanding performance: Tony Grieco bowled a 279 game on April 14.

Bowling Banquet - Friday, May 21, 8:00 p.m.

VERY SOFT BALL

The 21st annual softball game between the Experimentalists and the Theorists is scheduled for Saturday, May 22, at 1:00 p.m. on the SLAC grass. It could be interesting this year, the Theorists have designed new baskets lined with gluon. The Experimentalists just sit and wait and sharpen their spikes.

SERA

The costs of relief have been inflating too. The SERA Board encourages SLAC people to join SERA or to increase their contribution. The current average contribution is $1.38 per month. Payroll deduction is available.

If you don't already know, SERA (SLAC Emergency Relief Association) is an employee financed and managed deductible charity for helping SLAC people who are in emergency financial trouble.

Payroll deduction forms are available at the SLAC Information Office in the A&E Lobby.

CULTURE AT STANFORD

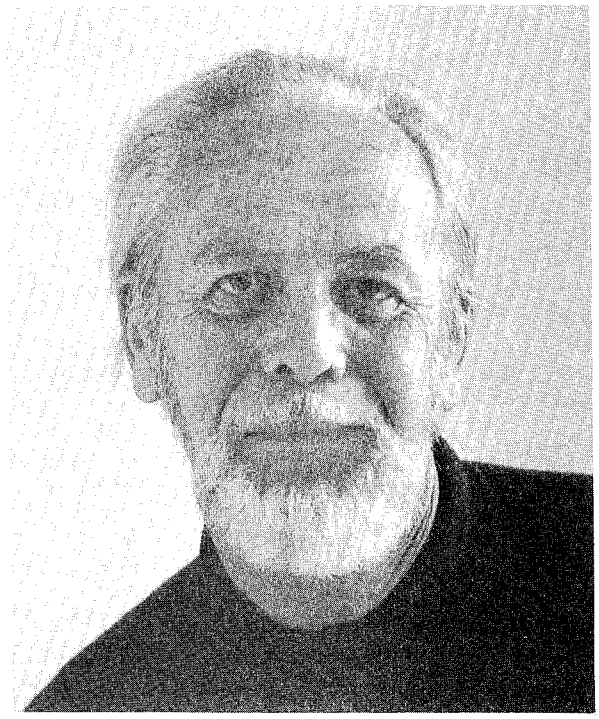
Carmina Burana (an oratorio by modern composer, Carl Orff) will be performed by the Stanford Symphony Orchestra and Chorus (with soloists):

Friday, May 21 - 8:00 p.m.
Sunday, May 23 - 2:30 p.m.
at Dinkelspiel Auditorium.

Tickets: $4.00 ($2.00 for students)

STOP SMOKING!

Stanford University is again offering its STOP SMOKING program at SLAC. The eight-session series will start on Monday, June 14th in the Blue Room at 3:30 pm. There is a $30 fee. Contact Marian Bono (x3345) or Joan Gardner (x2282) to register or if you have any questions.



ERNIE FREI RETIRES

Typical to the European tradition, Ernie Frei hosted his own retirement party last month. His many friends and co-workers joined him to celebrate the nineteen years that Ernie had been employed at SLAC.

A native of Switzerland, Ernie came to SLAC in 1963 as a mechanical fabricator in the SLAC Accelerator Structures Group. His work with the Mechanical Engineering and Klystron Departments, his technical expertise and conscientious drive for excellence earned him the respect of all his associates. We wish Ernie and his wife, Lucy, a happy retirement. His dedication and and uncompromising devotion to SLAC will long be remembered.

BEAM LINE CHANGES - HELP WANTED

We are changing the Beam Line into a regular monthly with current information and articles about SLAC people. (The traditional technical side of the Beam Line will be carried on in special supplements.) We can type, we can rewrite, and we can get pictures taken. What we can't do is gather all the news that you would find useful. So, get it to us in any form and we'll do the rest. Please send your comments, questions, leads, notes, and classified ads to Jan Adamson at mail bin 12 or extension 2451.

SLAC BEAM LINE

Special Issue, Number 1 *May 1982*

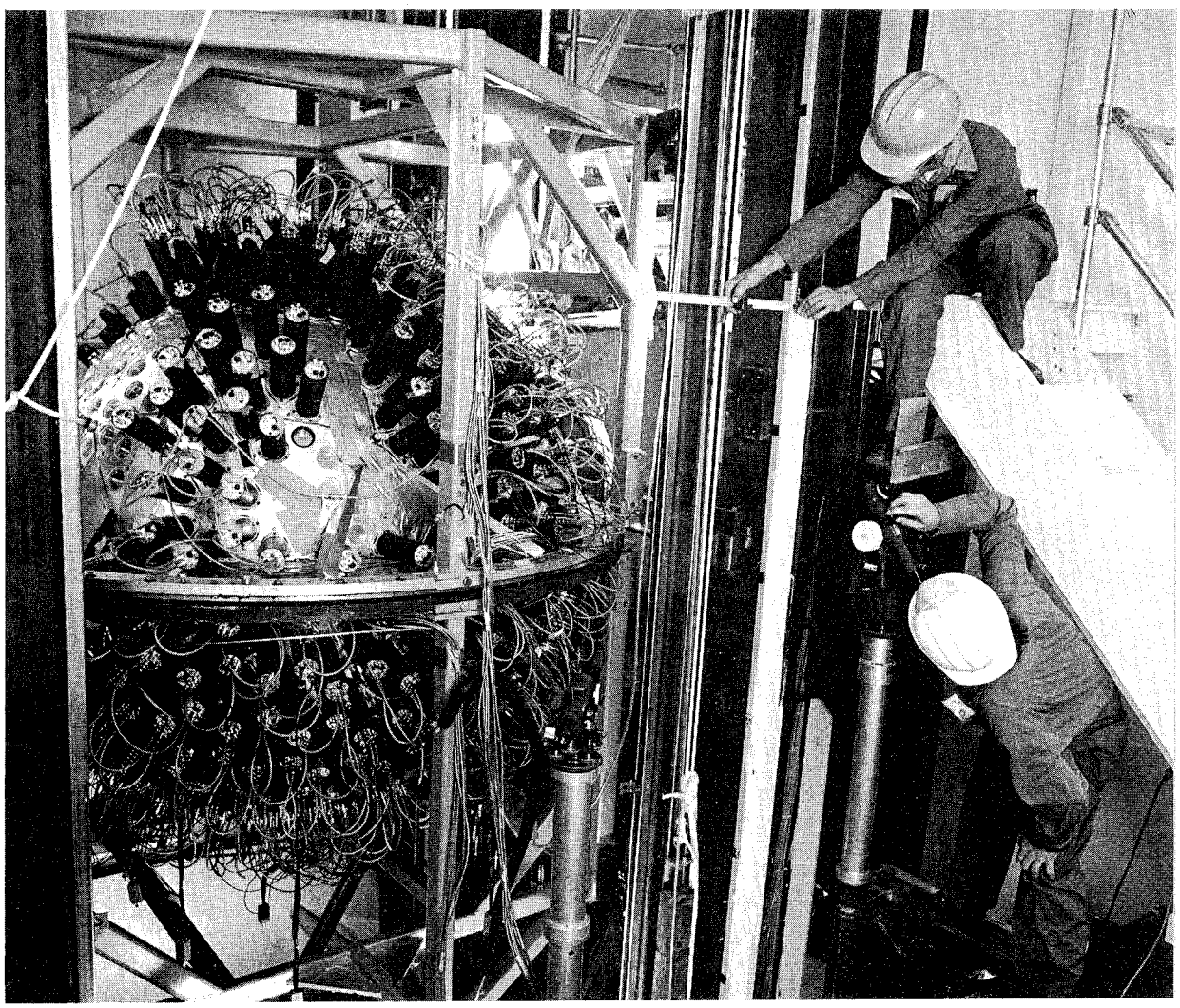


Photo--Joe Faust

The Crystal Ball, shown above during its assembly, has recently completed a very successful run of several years at SPEAR. A collaboration of physicists from SLAC and Germany is now beginning to use this unique detector at the intermediate energy storage ring in Hamburg. This special issue of the *Beam Line* surveys the physics accomplishments and the history of this instrument, as well as the impressive task of moving it--by air--to Germany.

Special Issue
Number 1

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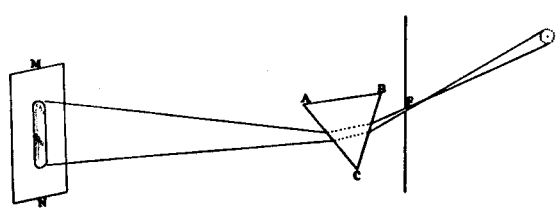
CRYSTAL BALL PHYSICS

THE RAINBOW OF CHARM

If we imagine that the collision of a positive and negative electron produces a brilliant burst of white light, then the Crystal Ball detector is a prism which shows up all the colors in that flash. The analogy is not as far fetched as it might seem; much of the physics and the language used to describe what can be seen with a simple prism applies to the studies of high energy physics.

About 400 years ago Isaac Newton performed an experiment which is shown below in an illustration from his book, *Opticks*. The sun's light passed through the hole in the screen, spread out in the prism, and produced the band of light with the colors of the rainbow on the wall (blue at the top, red at the bottom).



Newton called the display a spectrum, and this name is still used to describe the measurement of anything in terms of simpler parts, such as white light in terms of its component colors. The usual names for the colors of the rainbow (red, orange, yellow, green, blue, indigo, and violet) can be used to describe a spectrum, but they fall short of an objective measurement. "Reddish-orange" is fine for a sunset, but it doesn't tell a Kodak chemist if a new dye will work better than an old one.

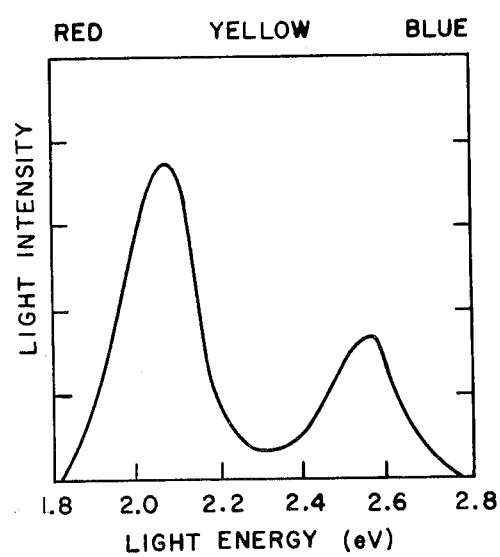
The color of light can be measured in terms of the frequency of the light waves or according to the energy in the packets of light. Then a precise description of a spectrum can be made by measuring the intensity of the light at each color. The result is a graph like the one shown at the right, a spectrum. This particular spectrum correponds to a mixture of orange and green, a little heavy on the orange.

We haven't said what kind of machine would make this measurement, but we have a name for it--a spectrometer. A simple spectrometer would be a photographer's light meter moving up the wall where a prism had spread out the light, taking readings every tenth inch or so. These readings can then be plotted against the distance to give a spectrum for the light.

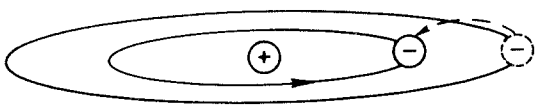
Light meters weren't available to Newton, of course, nor to another physicist in this study who followed him by about 100 years. Joseph von Fraunhofer studied the sun's spectrum with a more refined prism spectrometer which included slits and lenses. What he saw didn't require a precise measurement of the light intensity at each point, but only that light be very well split up into its colors.

At certain places in the sun's spectrum Fraunhofer saw dark lines, as if the light of that color were being absorbed. These lines would show up in a plotted spectrum as valleys. The spectrum below, for example, could have been made by passing white light through a piece of yellow glass before it got to the prism. Fraunhofer's lines, however, didn't look anything like what you get with colored glass and dyes. Something new was responsible for the absorption of this very narrow range of color.

The effect showed up in a simpler way closer to home. When a prism spectrometer was aimed at the light made by an electrical spark in a simple gas like hydrogen or neon, the spectrum consisted of several bright lines. Here all the light was produced in a few, very sharp colors. Why?



The search for an explanation of these lines led to quantum theory about 70 years ago. In the quantum picture of the hydrogen atom, for example, an electron can revolve about the positive nucleus only in certain special orbits. When it jumps from one orbit to another which is closer to the nucleus (as in the schematic below), it has to get rid of some energy. This extra energy is given off as a packet of light with just the right color (or energy) to make up the difference. The units used for energy in these problems are electron volts, or eV, and the official name for a packet of light is a photon. A jump to an orbit which is at a lower energy by about 3 eV results in a 3 eV photon--blue light; a jump of about 2 eV gives red light.



Hydrogen Atom

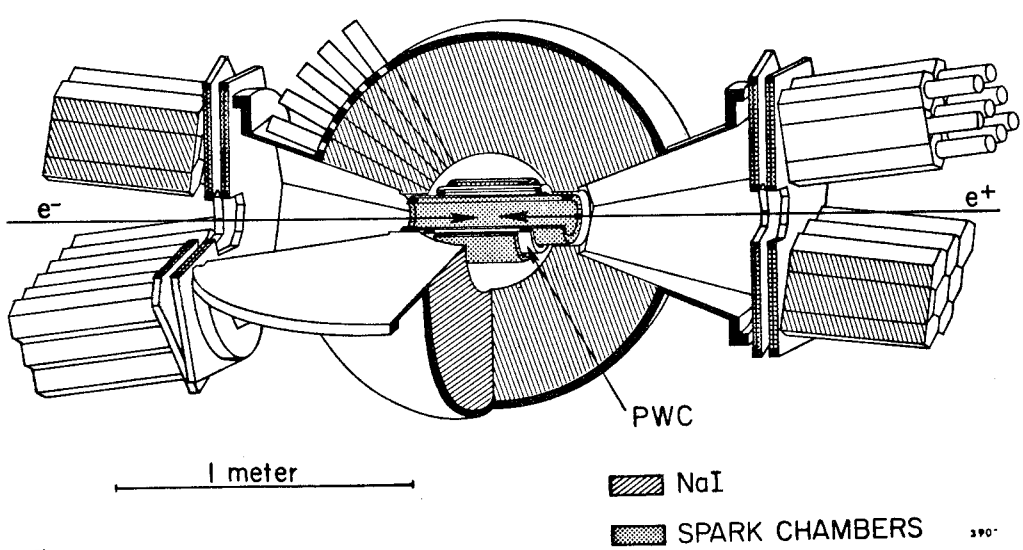
Looking very carefully at the color of light tells you something about how atoms rearrange themselves. The same idea applies to the much smaller particles, quarks, which make up the insides of the proton (which served as the center of the hydrogen atom in the above example). The energies involved are much different, however. A basic principle of physics states that the smaller the particles, the larger the energy needed to keep them together. The photons which appear when quarks rearrange have energies of a hundred million electron volts, compared to the one or two eV for visible light. If we had a prism that could spread out the whole spectrum on the wall and the visible portion were one inch wide, then the 'colors' associated with the quarks would be about one thousand miles past the blue. Some prism.

Photons of such high energy are not in the realm of optics. They behave in many ways like high energy particles, and they are detected and measured with the tools of high energy physics. The Crystal Ball is one such detector.

The Crystal Ball is shown during its assembly in the cover photograph and in a schematic at the bottom of the page. The heart of this detector is the arrangement of about 700 tapered crystals which pack together to form a hollow ball surrounding the collision point of two beams. When a high energy photon hits one of these dense crystals, the photon breaks up into a pair of oppositely charged electrons. These interact in the crystal to make more photons of lower energy. These photons make more electrons in turn and the process continues leaving a 'shower' of hundreds of low energy charged particles in the place of the original photon.

This shower process is common to high energy photons in any material and is the basis for all detectors of high energy photons. The crystals of sodium iodide which make up the Ball, however, have the special property of making small flashes of visible and near-visible light when these left-over charged particles pass through. The original high energy photon ends up as 'ordinary' light which is converted into electrical signals by the photomultiplier tubes at the ends of the crystals for measurement and recording. We have a spectrometer which can measure the spectrum of light at the very high energies of quark physics.

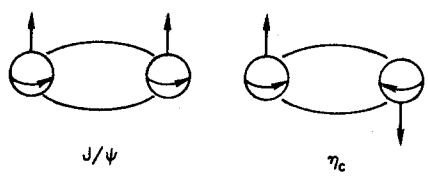
The light which this spectrometer looked at was produced by the collisions of electrons and positrons at the storage ring SPEAR. Most of the time the positrons and electrons in a storage ring miss each other, or deflect each other slightly. When they really do collide, the original particles disappear in a single flash



7-80

of energy. Most of the time this energy shows up as another electron-positron pair, or a swarm of other charged particles. Sometimes, though, very simple combinations of quarks are produced and these in turn give off light of a distinctive energy or color.

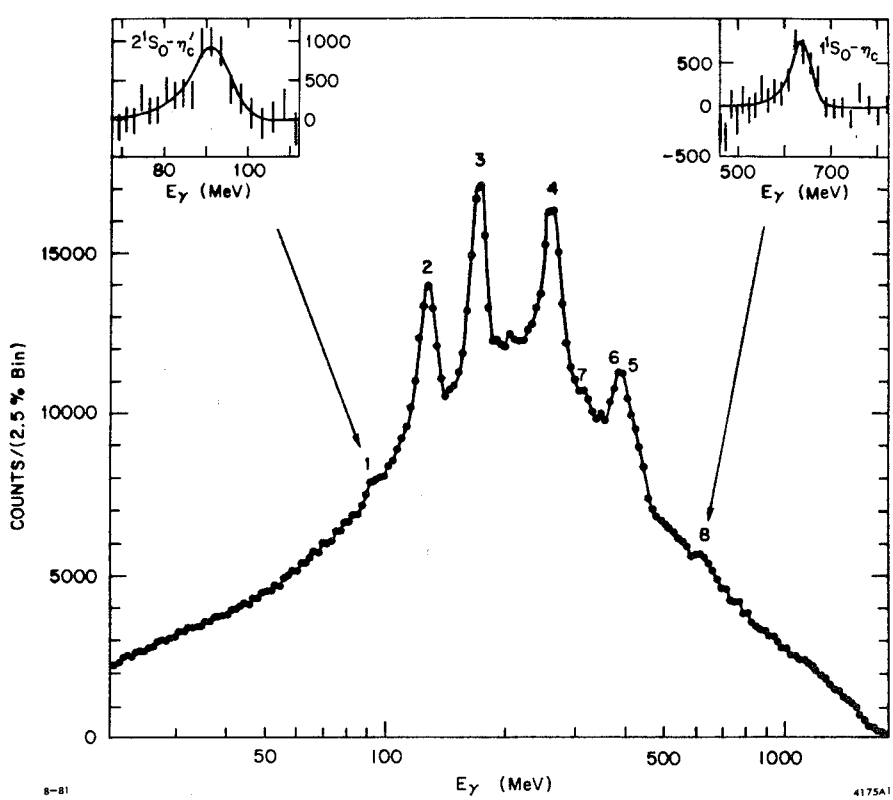
One of these special combinations is shown below. When the SPEAR beams are tuned to the right energy, the combination of a c-quark (for charm) and an anti-c-quark is produced. This is much like the picture of the hydrogen atom used earlier. In hydrogen an electron moves about the much heavier proton; here the two move about a common center since they have the same mass. In hydrogen the two are attracted by electrical charge; here it is a new force which is being studied.



There is a new feature here which we could ignore in hydrogen. The quarks have a property like that of a spinning top. This has been shown above by the arrows along the equators, and by arrows pointing up or down depending on the direction of the spin. This spin makes a difference in how the two attract each other. The combination of the two with the spins in the same direction is produced directly in SPEAR collisions and is called the J/ψ. Its discovery in 1976 brought the Nobel prize to Burton Richter at SLAC and to Samuel Ting at Brookhaven. The search then began for new combinations of this quark with itself. There was also the hunt for combinations of the c-quark with the three previously known quarks, called u(up), d(down) and s(strange). Storage rings were ideal for this study and the discoveries came quickly, with names like ψ' and χ , D and D*. Not all that was looked for showed up right away, however.

The combination of c-quarks shown at the right in the sketch was one of the first things to be sought and one of the last to be found. It should have an energy lower than that of the J/ψ and should be produced when the J/ψ combination flips one spin and gives off a photon with the energy difference. Light with just the right 'color' would prove the existence of this combination called η_c (eta sub c).

This was clearly a job for the Crystal Ball. Although other detectors could find photons of distinct energy, only the Crystal Ball could measure the energy well enough to see these sharp lines in the presence of photons with a broad range of energies from other processes. This is best shown below in the



actual spectrum measured by the Crystal Ball and published as part of their discovery of the η_c in 1980.

Their spectrum has a general curve to it and is punctuated by many sharp spikes which correspond to special rearrangements of the c-quark system. The right hand side corresponds to 'blue' and the left to 'red' in this plot. The smooth part of the curve is produced by other processes which can give photons of any energy. This is like a background of white light which makes the special colors more difficult to pick out. The color signaling the η_c is almost invisible but shows up as a little bump at the right, labeled 8. An expanded view is given in the right hand corner. It takes a detector which can measure photon energies very well to separate out these subtle details. This is the Ball at its best, sorting out the lines that other devices just cannot see.

Actually, this spectrum is not the one which illustrates the quark rearrangement set up in the sketch in which the spin simply flips. The spectrum shown here is of a slightly more complicated system in which the two c-quarks are in the next orbit farther out (like the second orbit in the hydrogen atom example). This state, called ψ', was picked up by the Mark I detector at SPEAR soon after its discovery of the J/ψ.

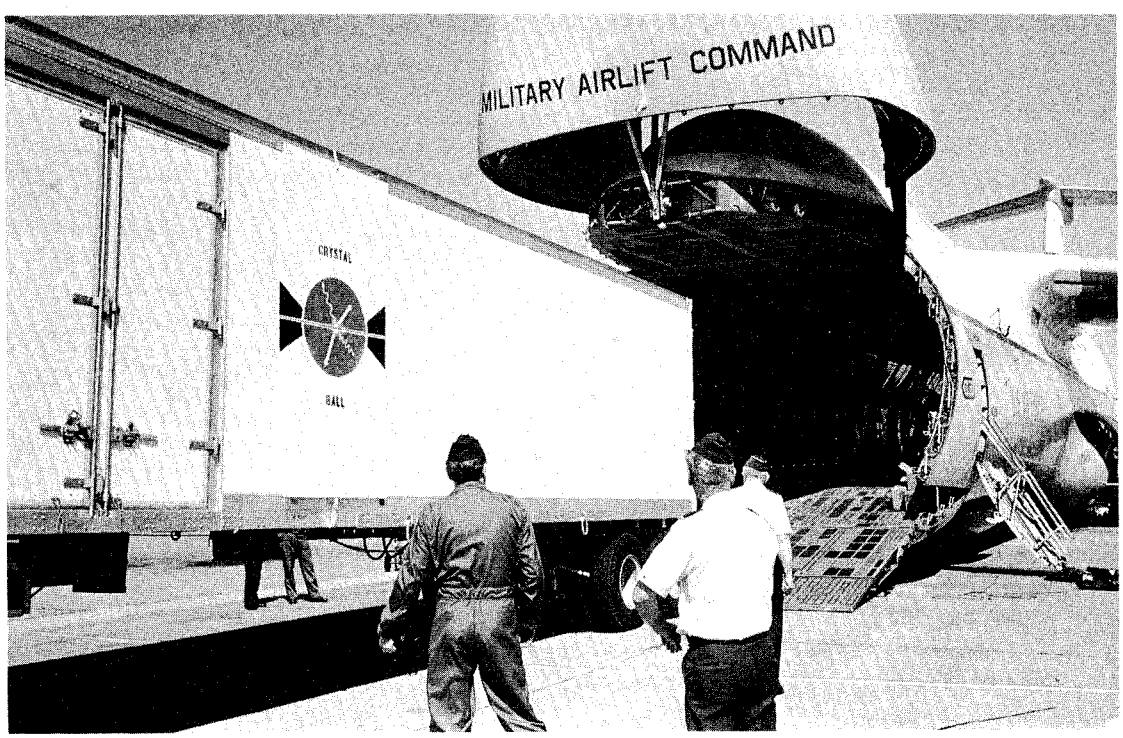
The η_c is produced from the ψ' when the quarks both jump to the lower orbit and flip spins. The bonus here is that if the spin flip happens alone, a new state, called η_c', is formed. This shows up as the bump in the red end of the spectrum. The more prominant bumps in between correspond to rearrangements of the quark pair in which the shape of the orbit changes. These are called χ-states and have been seen in several detectors.

When the c-quark was found in the J/ψ, there also began a hunt for additional new quarks. Theory predicts that there might be three new ones, just as there were three old. The second one (called b for bottom) has been uncovered in an experiment at Fermilab. The third (called t for top) has been sought at the large storage rings, PEP and PETRA, but so far has not been seen.

Clearly the next step is to study the b-quark in the same way as done with the c-quark. It takes more energy to produce a pair of the b-quarks, however, and SPEAR does not have enough. PEP could, in principle, run its beams at the right energy for producing the b-system, but it was designed to run at a higher energy and would not be efficient.

The German laboratory in Hamburg (DESY) had been planning to rebuild its low energy ring DORIS to run in the b-quark region and had room for the Crystal Ball. After much discussion physicists at SLAC and DESY agreed to move the Ball to DORIS, and the event photographed below resulted. The Crystal Ball, having painted a rainbow of charm at SPEAR, is off to another pot of gold. Color it successful.

--Bill Ash



A BRIEF HISTORY OF THE CRYSTAL BALL

Particle detectors for use in high-energy physics research have a peculiar life cycle. The gestation period (building) is usually 2-3 years, followed by an adolescence (running-in) of about a year. Maturity (data-taking) lasts a few years, with a rapid onset of senility and demise (equipment obsoleted) a few years later.

The Crystal Ball Detector's life cycle has lasted almost 8 years and by usual standards it should be headed for the dustbin or the Smithsonian. Instead, it is experiencing a second childhood; the instrument and an every-growing circle of admirers* have embarked on a new research thrust to be centered at the DESY high-energy facility in Hamburg. Last April 17, as the Ball left SLAC for Germany, accompanied by a bevy of young and expectant students, the script read like Horace Greely, in reverse.

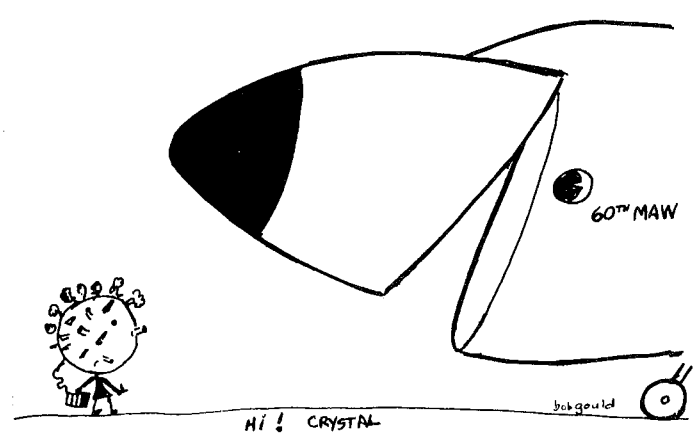
To understand this migration, we need to go back to the reasons for which the Crystal Ball was fabricated, and its subsequent use. The idea was born to a small group of physicists from HEPL and SLAC (both Stanford) at the 1974 summer study for the PEP storage ring; soon after they were joined by Caltech and Harvard groups in a proposal to build the detector. This collaboration guessed that a particle detector specially sensitive to electromagnetic radiations (such as photons and electrons) could measure important and fundamental phenomena at the storage rings which annihilate matter and antimatter. Such a specialty had been neglected because it was hard to get this feature simultaneously with other desirable, conventional goals.

The design was made for a very large, ambitious (and expensive) detector using a great number of crystals of sodium iodide. This material emits visible light when traversed by particles which interact electrically--a fact first discovered by Robert Hofstadter (Stanford) in Princeton, New Jersey in 1948. The group called their brainchild a "Crystal Palace", clearly an impolitic name amidst the funding crises of those years. The design, submitted for approval to run at the SPEAR storage ring at SLAC, was applauded but rejected on monetary grounds. Asked to reconsider the design, the Crystal Palace shrank and became the Crystal Ball, in which one could hope to see the future of particle physics (or at least some of it). Ably shepherded by Elliott Bloom of SLAC, the project was approved and design studies were begun.

Many reputable physicists believed it would not work--the radically different nature and precision required looked very scary. The project received a big boost in 1975 when some of the physicists joined a pre-existing group from Princeton, Maryland, Pavia and San Diego and produced (in six weeks) a very ragtag version of a Crystal Ball, using parts borrowed or stol--appropriated from other groups. In a very short, desultory try, this group showed that the postulated match of technique to physics really was there, ripe for plucking if one had a really decent detector of this type. Subsequently, Princeton was added to the list of Crystal Ball collaborators.

The Crystal Ball was completed in the spring of 1978, with heroic efforts of many collaborators. While waiting for entry into SPEAR, it was "tuned up" to a degree unusual for such experiments. As a result, within a few months after installation, it began to take significant data that corrected previous misconceptions about particle physics.

Other reviews of the physics discoveries are more thorough than what follows (a Scientific American article has appeared in the May issue). In short, the Crystal Ball enabled precise comparisons of theory and experiment to be made concerning charmonium, the atom-like arrangement of a charmed quark with an anti-charmed quark. Missing states (named η_c and η_c') corresponding to the famous ψ and ψ' were found. In addition, using the Ball to look for decays of ψ into a



*The physicists now outweigh the detector!

Cartoon--Bob Gould

photon, plus something else, at least two candidates for a very weird state of matter having no quarks were found. The stream of papers from 1979 to the present has entertained, bewildered and even sometimes aided the theoretical community.

So why in the midst of such satisfying research has the group suddenly picked up its marble and gone away? The answer is multifold. So much data had been accumulated at SPEAR that diminishing returns had set in--another ten years of running would have been required to make a big impact on the results (this is an exaggeration--some projects could be done in less if one knew ahead of time what they were!). A move to another energy regime beyond SPEAR was clearly dictated. The Crystal Ball had been approved for PEP, but that energy regime looked too high for a study of the b-quark (analogous to the c-quark and the c-$\bar{c}$ "atom") and too low for anything new that would match the capabilities of the Ball. Machines at Cornell (CESR) and at DESY (DORIS) offered the right energy regime. The choice was very hard: the relative proximity and intimacy of the Cornell Lab versus the extensive support and priority promised at DESY. Both locations promised miserable winters. In the end, the physics considerations won and the Ball headed toward the place where it could become competitive earliest--DORIS. The DoE, NSF and the individual Universities were most helpful, showing that basic research is truly an international enterprise.

The logistics of getting the Ball to Germany were complicated and drawn-out. Assistance came from a host of new collaborators; Carnegie Mellon University, DESY, University of Hamburg, University of Erlangen, University of Florence, University of Nijmegen, University of Krakow, University of Wurzberg. Routes by truck/boat/plane, via Panama/New York/direct etc, were considered. Eventually (with some prodding from people in high places) what emerged was shipment of non-delicate parts via Panama, semi-delicate parts via New York and the North Atlantic, and the very delicate Ball itself, by the super cargo plane, the C5A, from Travis AFB to Frankfurt. The crystals are delicate because of susceptibility to shock and to moisture. The multimillion dollar Ball can be damaged beyond use by a 30 second exposure to a typically (not this winter!) dry California atmosphere. It must be sealed and buffered against the world, like the old safety tires of the forties. A womb for its highway travel was constructed from a 45' air-ride trailer, with life support systems aboard. A number of special flight protocols and dispensations were put into effect, such as the option to hold at various altitudes on the flight path for pressure equalization within the Ball. A midair refueling was performed in order to avoid touchdowns for the sensitive cargo.

The Air Force mission was performed flawlessly by the 22nd A.F. (out of Travis Air Force Base) The transfer of the Ball from Frankfurt to DESY proceeded via truck and autobahn, but hardly without incident. Near the birthplace of quantum mechanics, Göttingen, a valve in the truck decided to tunnel through a piston and we spent the night at the Göttingen motel. But the problems were quickly overcome and the Ball arrived apparently unscathed at DESY lab amid much celebration. The cooperation of all concerned on the international scale started this venture on a good footing.

Thus the Crystal Ball has left its home at SLAC for the hostile environment (physics-wise) of the b-quarked atom where discoveries (if any) will come more slowly, and SLAC's first "user" experiment will commence. We, of the old collaboration, thank SLAC and its management and support groups for the nuturing we enjoyed there and hope to reflect well on our parent institutions and on US physics with our Desy adventure. Wiedersehen!

-Don Coyne

THE PEOPLE BEHIND THE MOVE

The Crystal Ball collaborators wish to extend their thanks to all those people at SLAC who contributed to its success and to those who helped in the preparations for the big move. Chief technical consultant for the move was Ian Kirkbride (HEPL).

Our main contacts with the Air Force were through Larry Womack. The flight crew (besides the Air Force, Col. Grable piloting) consisted of physicists and engineers, technicians, administrators and diplomats; a list contains names familiar to many at SLAC and elsewhere: Blumberg, Coyne, Edwards, Fazzino, Gelphman, Hawley, Nolan, Parks. The receiving crew at Frankfurt was led by Bloom, Bienlien, Koch, Krech, Lenzen, Sinram, Strobusch and Trost.

So many people made significant contributions to the preparations for the move that space does not permit us to do more than offer our heartfelt thanks.

Special mention must be made, though, of the contribution of Aaron Baumgarten who died in December of 1981. Aaron prepared the preliminary plans and was in the midst of the intricate negotiations when he was stricken.

THE DAY OF THE MOVE---FLYING HIGH

The sentry at the gate was helpful and all business: white-laced combat boots, black beret, blue silk scarf and pearl-handled pistol. She gave us our directions with a smile and we drove off with a high appreciation for the looks of the new Air Force. Joe Faust and I were at Travis Air Force Base to take pictures and make notes about the loading of the Crystal Ball detector from SLAC onto the world's largest aircraft. The "Ball" was going to Germany for a long experiment at the intermediate energy storage ring, DORIS.

Travis is a big flat spot about 40 miles northeast of San Francisco with several long and strong runways and gusty winds that first attracted the Navy to it 40 years ago because it was like the deck of an aircraft carrier. Now it is the home of the 60th Military Airlift Wing of the Twenty Second Air Force, one of the two arms of the Military Airlift Command. MAC provides air transportation for the Department of Defense and other government agencies. Travis has about 10 percent of the personnel and half the big planes in MAC; when you have a big lifting problem, you go to Travis and the 60th.

The loading was scheduled for mid-afternoon, so we had time to look around the base, guided by Captain Mike Cox, the base information officer. The base has a population of around 20,000 including dependents. It's a small city with its own weekly newspaper, gas station, church, store, hospital, and jail; the only difference is that the signs are factual instead of commercial. The town has a safety campaign going now; if you're caught driving without a seatbelt, you get three points in a system that can lead to suspension of driving privileges on the base.

We had heard that Travis had a flight simulator for training pilots of the big planes. Capt. Cox made two phone calls and we drove over to the building that has the "sims." My last ride in a simulator was in a Link trainer at a demonstration in the eighth grade. It was comparable to the quarter-a-ride ponies outside today's supermarkets. Times have changed. This machine is controlled by a big computer in several anonymous blue cabinets and by Captain Gary Lohse in a worn jumpsuit and continuous grin. The simulator is a large box, about half the size of a camping trailer, sitting on a motor-controlled platform. When you enter the box and close the door, you're in the cockpit of a C5A, the big plane.

It takes a minute to adjust to the lighting, since this simulator is for night flying and only the glowing instruments are visible. Since Faust flies small planes, he was pilot. Lohse was co-pilot, and Cox and I stood back by the Flight Engineer and Navigator stations. What makes this simulator seem so real is what you see when you look up: the runway--not a schematic of the runway, not an artist's rendition of the runway, but the Travis runway with lights on the side, painted stripe and cracks in the concrete. The computer can provide the base at Rhein-Main, Germany, or any of about 20 others the C5A is likely to land at.

We started rolling down field. There was a slight crosswind so we drifted over but eventually lifted off. The display is so good, that you feel no illusion. Instead you feel drifts and ups and downs; only by closing your eyes does the feeling of motion go away. While Faust looked for the basic gauges for airspeed and altitude among the hundreds of dials and lights, our co-pilot pulled back and brought us up to 10,000 feet for a good view of Napa. Then, he put the plane into a loop and barrel roll and the stars were down and the ground lights were up. "You wouldn't want to try this in the real plane." We came in for a touch-and-go landing a little too fast; the General Proximity Warning System cut in, a klaxon went off, and a computer voice advised "Pull up. Pull up. Pull up."

We pulled up and went around for a second pass. Gary switched off the cloud cover to give a better view this time. On the second approach, he switched on the auto-pilot and we landed without a hitch. Lohse apologized that the motion system hadn't been on, and noted that the commercial airlines have systems that are more sophisticated and include daytime flying. Maybe, but this was already no shabby operation. We blinked our way down the ladder to firm ground.

Now it was time to see the real airplane. Noting that I probably didn't have 125 million bucks in my pocket to pay for new plane if I made a wrong turn, Capt. Cox drove our car out to the edge of the field. We stopped for the guard, young but armed with a very business-like M16 automatic rifle. He quickly checked the pass, saluted Cox smartly, and said, "Have a nice day, Sir." We were still in California.

We drove past a few very large hangers to a gathering of about 10 C5A's which covered the corner of the field, parked by one of the planes and got out. There was still about one hour before the loading began and we were free to move around the general area, which was completely dominated by 'our' plane. This plane is big; this plane is huge. But anything that can fly must have some grace, and this plane, in spite of its size, is still pretty. How big? Cox had given us a fact sheet about the C5A.

It has a cargo compartment which is 19 feet wide and 13½ feet high. The plane is about 250 feet long, most of it in cargo space. We walked up the ladder into the cargo area. It was set up for hauling with skid pads and rollers built into the deck and rigging gear stowed away in the sides. There's no inside skin or Pan Am plastic; all the struts and rivets are there. Along the top the space between beams is filled with electrical wires, hydraulic lines and metal cable. Walking along and looking up at the hard, sharp metal detail is like the opening scene of Star Wars as the battle cruiser skims overhead. A ladder runs up from the cargo area to the flight deck. This wasn't as much a surprise now because it looked just like the simulator. Capt. Cox led us down a corridor toward the back past several doors: "Sleeps three--sleeps three--head--seats six--galley--seats nine. Your guys will be back here." There is another cabin section by the tail which carries 70 more.

The C5A has a payload of a quarter of a million pounds, a takeoff weight about three times that and 4 jet engines with 40,000 pounds of thrust each. Lockheed made around 70 of these beginning in 1965, developing wide-body technology which was later used in commercial aircraft. There has been talk of a new, big carrier for the Air Force, and the best plan may well turn out to be the reopening of the assembly line for the C5. It is a good plane.

Back outside the first part of the loading operation begins. The plane kneels. The nose of the plane opens up, the front landing gear slowly retracts and the plane settles down on the runway like a nesting bird. The internal ramp folds out and the plane is ready for traffic. This the the Waldo tunnel with wings.

The cargo we're interested in has been off to the side. A Fruehauf semi was guided up earlier in the morning by Jim Nolan, who worried through the rigging operations at SLAC. The idea was to make a completely self-contained package that would protect the Crystal Ball. The trailer has a gasoline powered engine with battery backup to run the air conditioning and electronics. A small console inside the trailer monitors conditions inside the detector. At the rear of the trailer is another box, about six feet on a side, which contains the Ball itself.

This detector is not like the usual equipment of high-energy physics--which is already fairly delicate. The Crystal Ball is named for the Sodium Iodide crystals which were carefully grown, cut to shape and packed into two hemispheres. The two pieces are put together around the collision point in an electron-positron

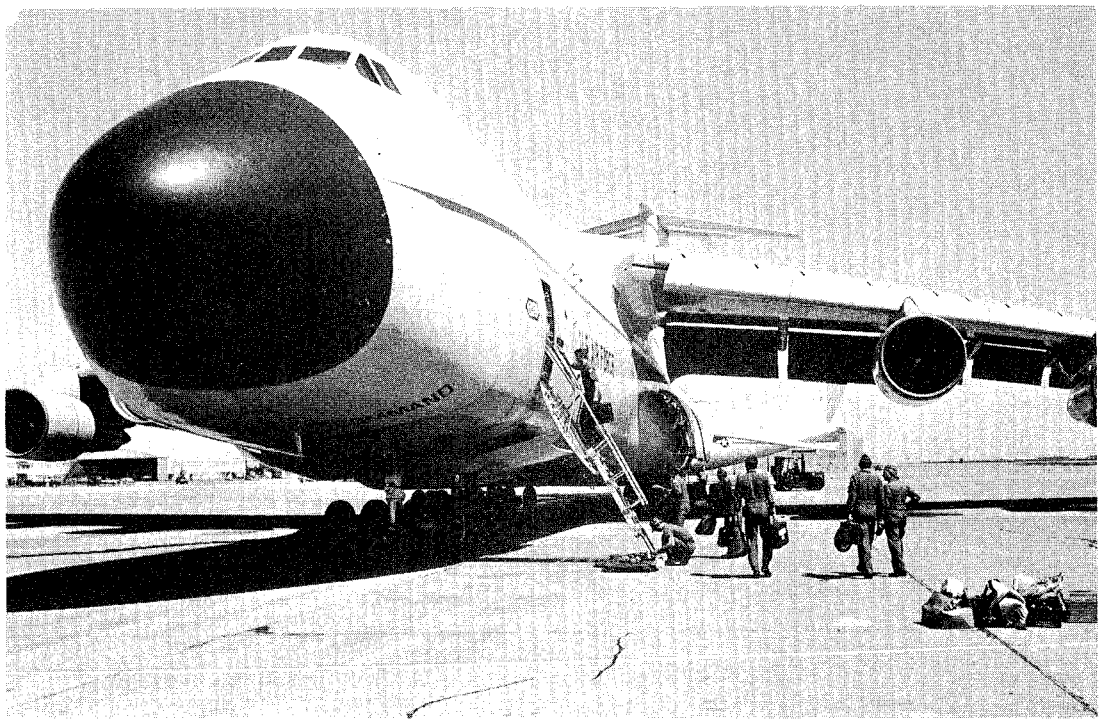


Photo--Joe Faust

storage ring. The crystals are individually connected to photomultiplier tubes which convert the light produced in the Ball into electrical signals for recording and analysis. The Crystal Ball is like a large, inside-out eye looking at its center.

The special problem, apart from the crystal's being fragile, is with water vapor. Sodium Iodide, when exposed to even the water vapor in the air, quickly clouds over and becomes useless. This device had to be assembled in a special room under surgical conditions and forever sealed against the atmosphere. The stuff is expensive and the Ball is pretty much irreplaceable now.

So, why move it in the first place? This is where the physics comes in. Our picture of nature now is that the smallest pieces of the world, protons and neutrons, are made up of still smaller particles, called quarks. We also have the fairly well behaved electron which seems to do no more than carry electrical charge. When two high-energy electrons (one positive and one negative) collide in a machine called a storage ring, they disappear in a flash of energy, out of which comes lots of other particles, such as the protons and neutrons. The quarks have a lot to do with how this happens and this is a good way to study them. Sometimes the quarks emit light in all this turmoil. The special talent of the Ball is looking at and measuring this light.

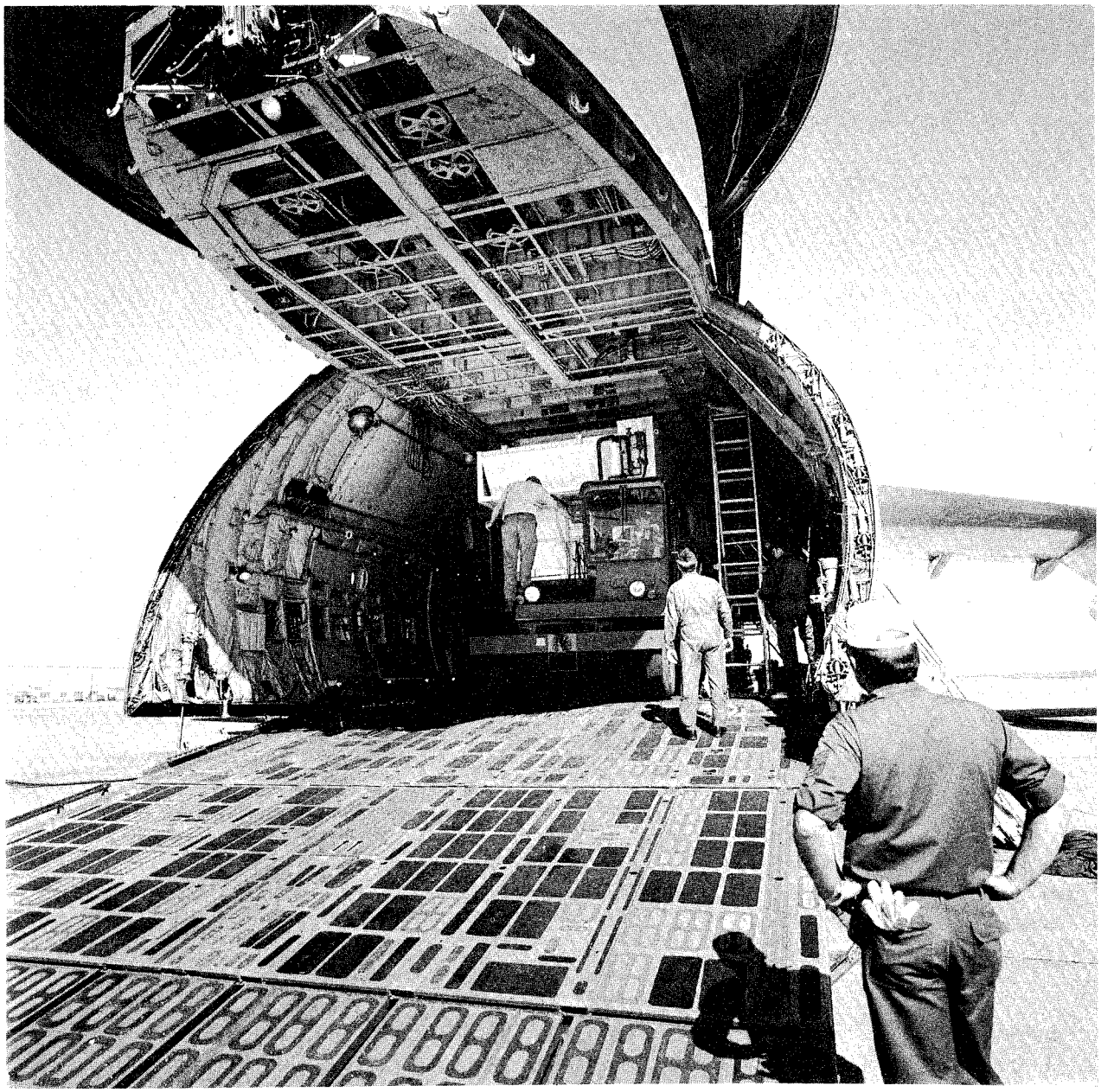


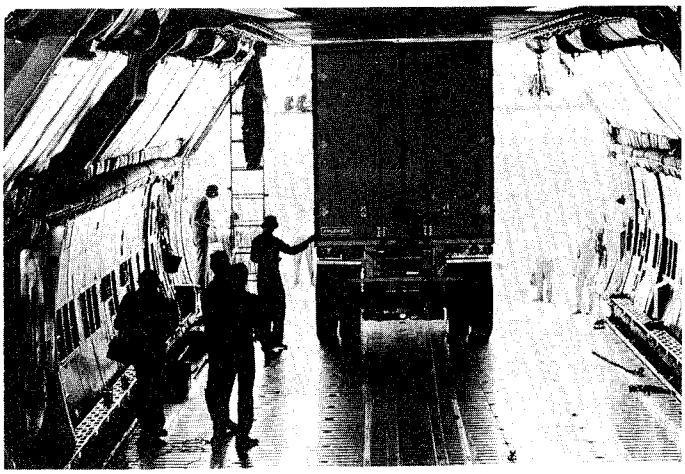
Photo--Joe Faust

Five years ago, there was evidence for only three quarks, named u(up), d(down) and s (strange). Then, a fourth was found in the low energy ring at SLAC, SPEAR. Theory predicted that this new quark, called c(charm) should be associated with two more, and the search was on. SLAC and the German lab, DESY, built new rings of higher energy, about 3 times bigger than SPEAR to look. They are still looking for the sixth, but the fifth has been found in a different kind of experiment at Fermilab near Chicago. The Germans have improved a smaller ring so that it can study this fifth quark at an energy about one and one-half times that of SPEAR. The Crystal Ball had done a superb job in its study of the c quark at SLAC, and is now off to study the fifth, called b(bottom or beauty), in Germany.

Having left the dark trailer and the talk of the world's smallest things, we are back in the bright sunshine among some of the world's largest things. Larry Womack, from SLAC, is standing next to the trailer. He has been handling the negotiations for most of this business and has a book 18 inches thick to show for it. All that paper is now reduced to a small shipping label on the side of the trailer: "piece number 1, total pieces 1, weight 35,000."

While waiting, there have been several take-offs of the big planes; Cox said that there are usually two in the pattern, mainly for training. A C5A moved down the runway, not fast, not slow, and certainly not lumbering. It moved at its own speed and simply took off as if it were still rolling on a solid track which no longer followed the ground. Even at 100 miles per hour, it takes a C5A two seconds to go its own length and this tricks the eye.

Now the trailer was backing into the front section of the plane. There was plenty of room to the sides, but the top was going to be close and two techs were up on ladders checking the clearance. There was one inch to spare. This move required the use of the load levelers on the trailer, and the question now came up as to whether the tractor at the other end of the line would have the same hardware for control. Ian Kirkbride, one of the physicists with the Ball, talked about it with Col. Robert Grable, the aircraft commander. They had been working closely on all the questions of the flight: what to do in case of loss of pressure; what kinds of shock will there be in landing; how to smooth out the pressure changes in takeoff. They will refuel over Montana so the flight can be nonstop and avoid an extra landing and takeoff. They will fly a polar route to avoid many changes in altitude required in flying crowded space. Grable knows all the details and cares; this man, who is going to fly the plane, is now talking about the equipment they will have on the Mercedes trucks which will unload the trailer in Germany.



This kind of attention was typical of the Air Force here. The commander of the Twenty Second, General Donald Bennett, was out here for the loading and checked out the inside of the trailer. The maintenance crew had been efficiently scurrying around the plane all this time. Cox noted, "They're very young and very good." There is no way the 60th is going to let any harm come to anything in their charge.

Jet engine noise covers the conversation now as two planes face each other on the taxiway waiting for control tower directions. The nearer one is the smaller (but not much) C141. This particular plane is in full camouflage, a giant eel. But it is also a bit sinister. We had been talking about science and flying all afternoon, but this plane had the paint of war and raised the questions you'd like to forget. Earlier, four men had wandered over and one said to the general group: "We're from Lockheed and we wanted to watch how this load went on. We're gonna be shipping out our D5 missile soon and it's about twice as long as this thing." The April 16 issue of *Science* carried a series of three pictures taken in 1974 showing a study of the concept of an air-launched ICBM: a Minuteman was dropped from a plane on a parachute and ignited at 8000 feet. The plane was a C5A and could have been the one we were now standing beside.

That's the kind of thing you have an Air Force for, and that's the kind of world it seems to be. Yet, we were walking around pretty freely, having identified ourselves with a handshake to these men in the uniforms who were very excited and interested in moving a delicate scientific experiment. The world was better for an afternoon.

-Bill Ash

THE AIR FORCE AND THE CRYSTAL BALL

This description of the Crystal Ball Mission is excerpted from an article written by Captain Michael Cox for the Travis Air Force Base weekly newspaper, The Tailwind.

After examining several means of surface and commercial air transportation, Dr. Kirkbride decided to talk to the Military Airlift Command to see if they could handle the job. That brought him to Travis where eventually he met with CMSgt. Hoover T. Robbins and SMSgt. Danny J. Brittain, both from 22nd Air Force Standardization and Evaluation. Their conversation centered on the meshing of the requirements for the safe transportation of the Ball and the capabilities of the C-5 to do the job.

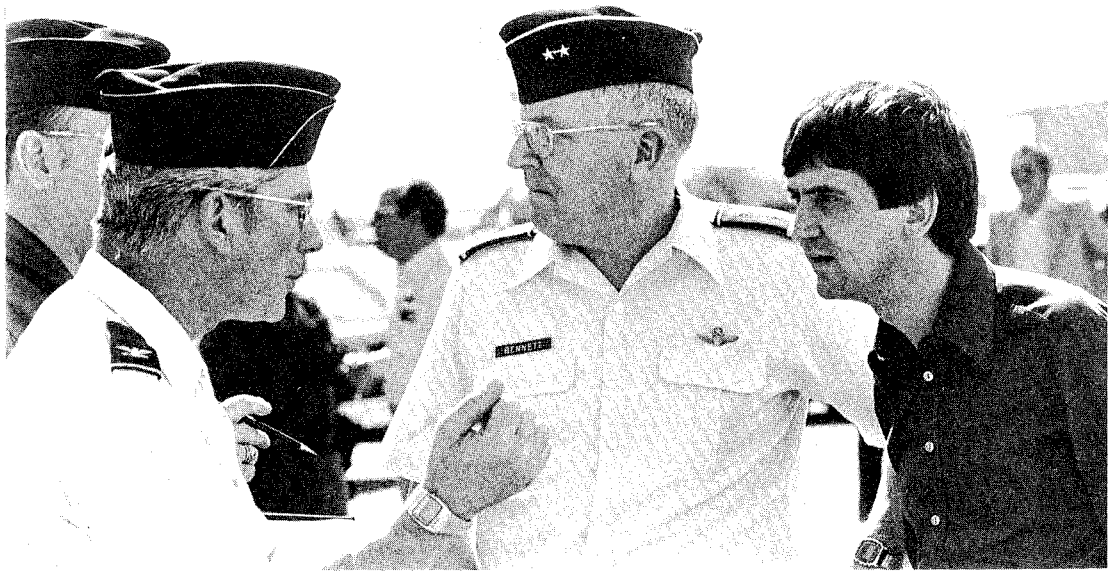
. . . . . .

Chief Robbins had researched the history of rapid decompressions in the C-5. There has been one in the past 10 years. He outlined three systems he could draw upon to maintain the proper temperature levels in the aircraft. Col. Grable and the Chief had a well developed and coordinated cabin altitude pressure plan that allowed a steady climb and descent with the Chief able to slowly raise the cabin to 5,500 feet and keep it there without causing an unusually high flow of nitrogen to keep the crystals dry. Care was taken to avoid weather to cut down on turbulence, and then there was the matter of landing. Colonel Grable was in charge of that, he wasn't concerned.

Dr. Kirkbride would have instruments that gave continuous readouts on the temperature, humidity, and G-forces and pressure differential. This would give the crew some early warning if problems were developing. The concern here was, if there were a power loss, the instruments would be useless, and air conditioning and nitrogen flow control would be lost. Sergeant Brittain was prepared with several back-up means of power to the trailer. He was also ready to take necessary actions in the event that venting nitrogen from the trailer reached excessive levels thus endangering the people in the aircraft.

The twelve hour flight from Travis to Rhein-Main AB was anti-climatic in that it was uneventful. The 75th MAS crew kept a close watch on the trailer and the instruments monitoring the internal atmosphere of the Ball. Preparation had been so complete that everyone was prepared to deal with any emergency that might occur. After about three hours of flight, the C-5 eased up to a tanker for an aerial refueling and the Crystal Ball mission continued on its way.

Pilots use the term "grease job" for a smooth landing. The arrival at Rhein-Main was the essence of eau de grease. One veteran crew member was heard to comment as the aircraft taxied in, "Have we landed yet, or are we just flying low?" Needless to say, a sudden shock on landing was no longer a concern.



CRYSTAL BALL MISSION Ian Kirkbride discusses the loading of the Crystal Ball with Major General Donald Bennett (center) and Colonel Richard Glogowski.