Minimizing Energy Consumption of
Accelerators and Storage Ring Facilities *

MASTER

A Panel Discussion

Moderator: M.Q. Barton, BNL

Members: H. Gerke, DESY

G.A. Loew, SLAC

R.A. Lundy, FNAL

W. Schnell, CERN

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Summary by the moderator.

The discussion of energy usage falls naturally into three parts. The first is a review of what the problem is, the second is a description of steps that can be taken to conserve energy at existing facilities, and the third is a review of the implications of energy consumption on future facilities.

Lundy started the discussion with a summary of the power usage and costs for the three major U.S. Labs. These results are shown in Figure 1. The three laboratories each face a different energy problem. At Brookhaven, the electrical energy is generated by the local utility, Long Island Lighting Company, using imported oil. This fuel is the most expensive for electric power generation and has shown extremely sharp costs increases in the last few years. An additional problem is that oil is also used for space heating and cooling which adds another \$750,000 to the cost of the high energy physics program. Fermilab buys its electric power from the Commonwealth Edison Co.; this power is generated by nuclear power and coal. The rate is much lower than Brookhaven's and the rate increases have been less marked. Even so, the costs have been going up and budgets are so tight that reductions have been necessary in the laboratory's program. SLAC gets a major fraction of its power from the Western Area Power Administration (WAPA), a federal agency who distributes at cost the power from federally funded hydro-electric power stations. This power is much cheaper than the commercial rates. The additional usage due to the operation of PEP has, however, pushed the power requirement beyond that available from WAPA and the incremental power is purchased from the Pacific Gas and Electric Company at rates comparable to those paid by Brookhaven.

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H. Gerke followed with a description of the power situation for the European laboratories. In the first part of Figure 2 we see the installed power

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for the various machines and, as we all know, the increasing scope of these facilities has been accompanied by increases in power requirements. The second part of this figure shows the particular cases of $e^+ e^-$ rings and the required power is broken down into portions used by the magnet, the rf, and that radiated by the beam. We see that for the newer and larger machines the power is largely channeled through the rf to beam radiation while for the older and smaller machines the magnet represented a more significant portion of the power. The third part of the figure shows the electricity costs at DESY over the last decade. We see that rates have steadily climbed as in the U.S. and, with the addition of DORIS and PETRA, the total electricity costs have gone up by a factor of five. The rate structure shown is representative of the general situation in Western Europe. With labor and other costs also rising, the power costs are exerting serious pressures on budgets as in the U.S. The last part of the graph shows how operating schedules can affect energy costs. The first curve gives the costs for constant usage. The second curve shows some savings by reducing usage during winter months when power costs are higher. The third curve shows the penalty resulting from strongly peaking the power usage. It is interesting to note that at DESY and CERN, power costs more in the winter while at the U.S. laboratories, the summer rates are higher.

At this point in the discussion the moderator described various steps that can be taken at existing laboratories to reduce energy costs. The first step is motivation of the staff. Electrical energy is a precious resource in diminishing supply and we have a moral obligation to use it responsibly. Beyond that, we saw in the first part of the discussion that the power costs represent so much pressure on budgets that operations are limited. Our staffs must realize that power saved can result in additional hours of running. The next step is to gain information. By metering, equipment evaluation, examination of operating schedules, etc., many candidates for energy saving can be quickly identified. An immediate result of these examinations can be simple load management. For example, several years ago at Brookhaven we found that we could get more physics per megawatt hour by running the neutrino program sequentially with the counter spark chamber program rather than trying to run both programs simultaneously. Similarly, SLAC has worked out load management

plans with WAPA to optimize use of their low cost power. Gerke mentioned earlier the cost implications of matching schedules with seasonal fluctuations in rate structures. There are other operating procedures that are effective for reducing energy usage. At Brookhaven a program called "Save A Watt", has been initiated. Any time the physics program is shut down, a list of equipment is turned off or to a reduced power state. The list depends on the anticipated length of the shutdown. Some of these procedures are automated and some are manual. A sizeable amount of energy can be saved by this simple technique. Similar plans have been instituted in most laboratories. During prolonged shutdowns such as for maintenance periods, significant amounts of power can be saved by searching for pumps, compressors, air conditioning equipment, etc., that can be switched off. Another savings can result by running the accelerator at the lowest energy consistent with the physics requirements. The ultimate step to save energy is the modification of equipment. Several laboratories now have superconducting magnets in various beam lines. These surely save energy although it is not so clear that they save money. Lundy pointed out that the cost of a technician is comparable to the cost of a megawatt hour. Thus the labor cost of operating a cryogenic system can challenge the savings in power. Energy can also be saved by pulsing the magnets in beam lines. CERN has successfully employed this technique at the SPS. As G. Brianti of CERN pointed out in the discussion, all beam lines around the SPS will be operated in a pulsed mode in the near future and the power savings are about 50%. The cost of laminated magnets is now actually cheaper than solid yoke magnets so there is really nothing standing in the way of using this saving. Of course these arguments are not so compelling at machines like the AGS or PS where the duty cycle is less favorable and where the magnets would have to be retrofitted. Another interesting development at CERN has been the replacement of the rectifiers in the PS power supply by more efficient units with a significant savings in power. There are many older power supplies at various laboratories that are candidates for replacement by more efficient units.

A constructive suggestion that could be made in this discussion would be that each laboratory could distribute to the energy "czars" of other laboratories the minutes of meetings or other information containing suggestions for energy savings.

Lundy continued the discussion with a description of the energy implications of the energy-saver-doubler project at Fermilab. According to the design report for that project, each magnet is allowed a static heat load of seven watts and a dynamic load, when the machine is ramped on a 35 second cycle, of thirteen watts for dipoles and eleven watts for quadrupoles. For the entire machine, the load becomes 7.68 kw + 2000 liters/hour for the static load and 20.12 kw + 3500 liters/hours when the machine is ramped. The liquid requirements are those required to vapor cool the current leads. When one goes through the usual arguments about refrigeration cycles and efficiencies, it turns out that these loads correspond to about 11.3 Mw of compressor power. This is clearly a small amount of power for such a high energy facility. Note the complementarity between the superconducting magnet and normal magnets. For normal magnets it is the high current flat top that requires power. For superconducting magnets the static load is virtually independent of the operating current and it is the ramping that causes additional power requirements. This power is generated in hysteretic losses in the superconductor and various eddy current losses. Much of the equipment referred to in this analysis has been tested and confirms the design report. The individual magnet loads have been verified and the central liquifier operates at design capacity with the design sized motors and transformers. An unknown is the performance of the string of 24 satellite refrigerators. It will thus be a few years before the overall economy of such a cryogenic system is completely understood.

The moderator then made some similar remarks about the ISABELLE project. A few years ago when the ISABELLE project was designed to have 200 GeV in each ring, a conceptual design study was done of a similar project using room temperature magnets under a constraint of comparable capital cost. This project had lower performance although with slightly more money a booster injector ring

could be added to bring the performance to the same level. It was found in that study that the power cost four to five times that required for the superconducting design. A similar study was not done for the 400 GeV version but some insight comes from the following table:

Power Requirements for ISABELLE

Injection, RF	10 MW
Magnet	6.5
Cryogenics	20
Exp. Areas	11
Miscellaneous	1
	<u>48.5</u> MW Installed

During most of the operating time, the rf, injection lines, and most of the magnet input power will be off so that the expected operating load should be less than 25 MW. This could be compared with the expected 120 MW from the LSR design at CERN which was a study of a machine of comparable performance.

During the discussion, R. Palmer of Brookhaven raised several interesting points about these comparisons. In the first place he notes that if the conductor areas were doubled in the warm ISABELLE design, the cost would have risen only 26% and we are seeing increased superconducting costs such that the total costs would remain comparable and the power would be comparable as well. Since the projects will not always operate at full field, there is additional savings. These are numerous short shutdowns, as well, so that the cryogenic plant has to run for a higher percentage of the time than the machine itself. Thus the total equivalent mean power may actually be less for the warm version. His conclusion was that power savings have not been demonstrated for superconducting rings.

The moderator's response was that Palmer's arguments are perhaps valid for the 200 GeV case under his pessimistic assumptions about the amount of down time. There are some performance questions. The higher field available in superconducting magnets keeps the circumference down and, inherent to their

design, permits a larger vertical aperture at essentially no additional cost. These parameters are both important towards controlling instabilities and these arguments favoring superconducting magnets gain strengths as the energy increases. Thus we must push for the superconducting solution. J. Patterson of SLAC also raised the question about the loss of load management possibilities with superconducting magnets. The large refrigerators can, presumably, not be switched off and on in seconds like other loads. In answer, the moderator pointed out that when the machine shuts off, the current lead load is removed and the power required is decreased. Furthermore, the refrigerator cooling can be switched off and the magnets warm slowly enough that they can be quickly restarted. Lundy also pointed out that storing liquid helium is easier than storing electricity.

W. Schnell presented a discussion of energy considerations involved in the design of LEP. This facility, its layout, and parameters were described at this conference in a review paper by A. Hutton. The energy consumption of LEP must be judged at a European if not global scale, but even so it is a matter of serious concern and keeping it down must be, and is, one of the fundamental design criteria.

Physics research will start at 50 GeV per beam in a so-called phase one, when only a fraction of the space set aside for the RF system is filled with room-temperature copper cavities. A change to superconducting cavities may be made thereafter, but about 90 GeV per beam can be reached with copper cavities if necessary. Above that and up to the maximum possible energy of 130 GeV superconducting cavities are a necessity. The parameters for various stages of operation are shown in the table on the following page.

ENERGY STAGES

	Phase 1					
STAGE	1/6 ¹⁾	1/3	1 ²⁾	4/3	2	
DESIGN ENERGY	49.4	62.3	86.11	92.86	130	GeV
LUMINOSITY	0.385	0.616	1.07	1.15	1.04 x 10 ³²	cm ⁻² s ⁻¹
CURRENT	5.71	7.20	9.15	9.15	6.16	mA
RF POWER	16	32	96	128	96	MW
LENGTH OF RF CAVITIES	272	543	1629	2172	1629	m

1) now increased to 51.8 GeV

2) now increased to 88.8 GeV by higher tune

MAIN RF SYSTEM PARAMETERS, STAGE 1

DESIGN ENERGY	E	86.1 ^{*)}	GeV
DESIGN LUMINOSITY	L	1.07 x 10 ³²	cm ⁻² s ⁻¹
SYNCHROTRON ENERGY LOSS/TURN	U _o	1370	MeV
PARASITIC ENERGY LOSS/TURN	U _{hm}	110	MeV
PEAK RF VOLTAGE/TURN	V _{rf}	1949	MV
STABLE PHASE ANGLE (FROM ZERO CROSSING)	φ _s	130.6	Degrees
FREQUENCY	F _{rf}	353.4	MHz
NUMBER OF SYNCHROTRON OSCILLATIONS/TURN	Q _s	0.158	
LENGTH OF ACTIVE RF STRUCTURE	L _c	1628.8	M
SHUNT IMPEDANCE/UNIT LENGTH	Z	40.0	MΩ/m
FUNDAMENTAL MODE CAVITY DISSIPATION AND REFLECTION	P _d	61.7	MW
SYNCHROTRON POWER (TWO BEAMS) 2I _b U _o	P _b	25.1	MW
WAVEGUIDE LOSSES		7.2	MW
PARASITIC MODE LOSSES (TWO BEAMS)	P _{hm}	2.0	MW
TOTAL RF GENERATOR POWER	P _g	96.0	MW
NUMBER OF RF STATIONS		16	
TOTAL NUMBER OF KLYSTRONS		96	
TOTAL NUMBER OF FIVE-CELL CAVITIES (EACH ONE COUPLED TO A STORAGE CAVITY)		768	

*) Now 88.8 GeV

The synchrotron radiation power - simply the product of average beam current and energy loss in electron-volts per particle revolution - may appear as the most unavoidable sink of power in this machine. Some thought has been given to recovering part of this power, chemically or thermally, but nothing tangible has resulted so far. This is not surprising, given the nature of the radiated power - incoherent X-rays spread over 20 km of circumference. However, by designing the machine for the lowest possible beam current, the synchrotron radiation power can be kept reasonable - 25 MW at 88 GeV.

With a room temperature RF system the power loss in the cavities is the largest single sink of power, due to the very high voltage per turn required - almost 2 GV in LEP at 88 GeV. The predominant contribution to this voltage is again the radiation loss - about 1.4 GeV per turn. But losses associated with transient beam loading (sawtooth of the cavity voltage) at the fundamental RF and with higher mode losses make a non negligible contribution. These, again, must be minimized by designing for the lowest possible beam current. Overvoltage is required for a good quantum lifetime. This tends to be a seemingly modest factor, of the order of 2 or so, but it must nevertheless be minimized by choosing the strongest focusing possible. The choice of frequency also enters and tends to come out lower than what one likes for the size and cost of the RF structures. The reason is that the shunt impedance per unit length does not increase indefinitely with frequency for a given beam aperture, while the overvoltage factor and the higher-mode losses continue to increase.

As the next step the shunt impedance of the RF structure must be made as large as possible. For LEP the plan is to add a device to the accelerating structure that saves a factor 1.5 in power dissipation by modulation. The method consists of coupling a low-loss, H-mode, storage resonator to the accelerating cavity and exciting the coupled system, with CW power sources, at both its resonant frequencies. This makes the stored energy oscillate between the two resonators spending, on average, half the time in the low-loss environment. The coupling is adjusted to make peaks of the accelerating field coincide with the passage of a pair of $e^+ e^-$ bunches.

Having done all this one finds the total RF generator power for about 2 km structure length and at 88 GeV to be a still very impressive 96 MW.

Obviously the conversion efficiency, from dc input to Rf output of the RF power generators is another vital parameter. According to a series of detailed design studies made for us by industry 75% overall conversion efficiency can be expected for klystrons or tetrodes. Models for both kind of power sources are now being developed by industry for us. An efficiency of 70% has in fact been demonstrated with one of the PETRA klystrons (made by Valvo). With 75% efficiency we find 128 MW dc input into the main RF system, at 88 GeV.

Superconducting cavities would substantially reduce the power dissipation. The development work with such cavities is still concerned with basic problems but the progress is encouraging. Single-cell 500 MHz test cavities have been made at Karlsruhe Kernforschungszentrum and at CERN respectively, in which accelerating fields of several MV/m at Q-factors above 10^9 were achieved. However even with superconducting cavities the power dissipation does not become negligible because of the refrigerator power required to cover heat losses and residual dissipation at liquid helium temperature. According to estimates, a fully superconducting cavity system in LEP at 88 GeV still needs about 40 MW of input, beam power included.

Figure 3 then shows the dc input of the LEP main RF system as a function of beam energy, for room temperature cavities. It drops rapidly with decreasing energy, but not as rapidly as it could in principle because of the decreasing efficiency of the RF power sources not used at their maximum output. Improvement is desired here, for instance by variable coupling to the klystron outputs.

At 89 GeV superconducting RF cavities would save 90 MW input.

Unfortunately the remaining power loss is by no means negligible - 45 MW at 50 GeV and 113 MW at 88 GeV. This is lost in the inefficiencies of rectifiers and mains power distribution, an auxiliary third-harmonic RF system, the LEP magnet system, the experiments and experimental areas, cooling and miscellaneous

other consumers (not counting the injector). Thus, even in an electron machine like LEP, much depends on general measures of economy not related to RF technology such as: choosing large conductor cross-sections for normal magnets, making magnets superconducting whenever economically feasible (e.g., the experimental magnets) or scheduling top-energy runs outside the hottest season.

As in every other machine the possibilities of recovering waste heat are severely limited by the low temperature of the heat output. Running normal cavities or magnets at increased temperature does not pay as the dissipation due to increased conductor resistivity wins over the increase in thermodynamic efficiency. In LEP we intend to run the cooling of the RF power sources (i.e., the klystron collectors or tube anodes) at about 90°C so the output can be used for heating, an inconspicuous but substantial advance over the present situation. It is hoped that other waste heat can be used for green gardening, a very promising possibility for which the Geneva area is well suited. Obvious non-technical problems to overcome are the questions of who benefits, who pays, and who assures continued input during periods of shutdown.

G. Loew followed with a discussion of energy consideration for single pass colliders. As described in Lundy's presentation, SLAC used about 40 MW of power or 200 GWH per year in fiscal year 1979 and expects, with PEP now operating, to be up to 65 MW and 300 GWH per year in 1981. Because of the peculiar rate structure involving the WAPA power and the local utility power, the cost goes from \$1.4 M to \$7.4 M. The single pass collider which SLAC has proposed for FY 85-86 operation is expected to require 25 MW of incremental power or a total of 100 GWH per year. At an incremental cost of 5¢ per kwh, this is an incremental cost of \$5M but that occurs at a time when most of the fixed target program may be shut down so perhaps the overall incremental cost is not so bad.

For the more distant future, Loew pointed out that linear colliders would like to have very long and very high gradient accelerator structures. Now a traveling wave structure of n cells of length l , filling time t_f , powered with a source of power P provides an accelerating voltage

$$V = n [Pt_F (1 - \tau) \frac{R\omega}{Q} \ell.]$$

and energy required is $Pt_F = \frac{\eta P_{AC}}{r_{pps}}$

It is clear that to achieve high fields at low power we want a low attenuation parameter $\tau = \omega t_f / 20$ which implies a low t_f and a high group velocity. Furthermore the efficiency η of power conversion of a.c. power P_{AC} to rf power P should be high. A high impedance $R\omega/Q$ implies a high ω . For energies of hundreds of GeV, even when these parameters are pushed, the power requirements become quite high and some tricks may be necessary. One such trick would be to place a storage cavity between the klystron and the accelerating structure. A fast switch now dumps the stored energy of the cavity into the accelerating structure so that the storage cavity output appears to be the "gigawatt source" that is required. Even then, the power required is impressive. For 200 GeV on 200 GeV $e^+ e^-$ collisions using two 2km structures with 650 klystrons operating at r_{pps} of 180 Hz and with an efficiency $\eta = 0.2$, we find $P_{AC} = 200$ MW. One way to reduce the power might be to use a superconducting storage cavity and a feedback system which returns the accelerator structure energy to the storage cavity after the pulse. The cavity powers are now small but the refrigeration power is of the order of 40 MW.

Of course maybe one should fold these high power numbers into an overall system and Loew presented a slide, Figure 4, which shows how all the water heated by klystron anodes and the excess microwave power can be utilized.

During the week before this conference there was a "Workshop on RF-superconductivity" at Karlsruhe. H. Gerke reported on the main aspects related to this discussion. RF-superconductive resonators for use as low-loss accelerating structures are under study in many laboratories. Studies are done on different shaped cavities and structures and at various resonant frequencies. Procedures of surface treatments were compared to realize maximum field strength and low loss factors. The present state of the attained maximum accelerating field strength is shown in Figure 5. There is a strong dependence of maximum field strength on resonance frequency. At low frequencies only Helix-circuits

were tested, and in the frequency range up to S-band, only single cells. Maximum accelerating field strengths of more than 20 MV/m were observed in single cells with frequencies higher than 4 GHz.

Various effects were observed which limit the attainable accelerating field strength, and cures were proposed and tested to overcome these. Single-side or two-side multipactoring, mostly seen in low frequency resonators, can probably be avoided by special shapes of the resonators (spherical cells at Geneva and Wuppertal, etc). Also multipactor grooves, as used in former times in klystron gaps to avoid multipactoring, were proposed and tested (Cornell). To reduce electron loading (by field emission electrons), a surface coating was proposed to prevent oxidation (KFK). Also RF-processing and special surface treatments were proposed and tested. Magnetic break-down can probably be prevented by a careful surface treatment, by RF-processing (at least at high frequencies), and by avoidance of surface disturbances at regions of high field strength (welds, couplers, etc.). Tests of superconductive cavities and intense electron bunches may answer questions of the influence of synchrotron radiation and parasitic modes on the superconductivity. An S-band "Muffin Tin" structure was already successfully operated in the Cornell synchrotron, and a 500 MHz-single-cell cavity is under preparation to be tested in the DORIS storage ring in a collaboration of KFK, CERN and DESY. In order to increase the transition temperature, superconducting alloys should receive further study, probably including also alloys other than niobium-tin. For large scale production of superconducting structures it may be necessary to develop techniques to produce superconducting layers on normal conducting materials. This technique may be advantageous also for improved heat conductivity. The choice of the resonant frequency is critical. At high frequencies higher field strengths are obtained and production may become cheaper. At lower frequencies the stored energy becomes larger. Why the field strength in superconductor cavities increases with frequency is an open question. The number of impurity spots decreases proportional to f^2 and the energy of field emission electrons decreases with frequency. The stored energy in a cavity, which may be dissipated in one region (or spot) when it transitions to the normal state, decreases like f^3 . This behavior probably contributes to a reduction of field strength at lower frequencies.

A next step should be the design of multicell-structures, keeping in mind the synchrotron radiation shielding, the field configuration in the end cells, and the parasitic mode-impedance. Whether or not parasitic modes have to be attenuated is still an open question. Also high power couplers should be designed and developed. A normal conducting coupler, acting through the beam port and used also as a radiation shield, is a possibility. If the described problems are solved and one can produce reliable superconducting RF-structures in large quantities, what energy saving can be expected? Some people seem to think that the electricity consumption will be reduced to nearly zero. But a practical example, LEP at the stage of 93 GeV particle energy, shows that due to the radiation loss and power to the refrigerators, at least 1/3 of the electricity consumption required for the normal conducting RF-system will still be needed. The following table shows the comparison.

	nc-cavities	sc-cavities
Energy [GeV]	93	93
Energy loss/turn [MeV]	1860	1860
Peak RF-voltage [MV]	2600	2600
Active RF-cavity length [m]	2172	1086
Shunt impedance [$M \cdot m^{-1}$]	40	550×10^3
Quality factor Q		1×10^4
Accelerating field [$MV \cdot m^{-1}$]	1.2	2.4
Radiation loss [MW]	34	34
Parasitic mode loss [MW]	2.5	2.5
Cavity dissipation [MW]	82	0.012
Waveguide loss [MW]	9.5	2.8
Total RF-power [MW]	128	39.3
Refrigerator-power [MW] ($n_{ref} = 2 \cdot 10^{-3}$)	-	6
Total mains input [MW] power for RF-system ($n_{RF} = 0.621$)	207	66

At the end of the presentations there was a lively discussion between the panel and the audience. Some of this discussion was included above in the body of this summary because of the close connections to the presentations. Some other questions and responses were:

- J. Humphrey, (BNL) Would the panel or someone in the audience comment on any studies done on cryoresistive operation, i.e., systems which do not go superconducting but are refrigerated to achieve lower resistance.
- G. Loew (SLAC) For rf cavities operated at 70 K liquid nitrogen temperature one always loses because the resistivity only goes down a factor of three and that does not make up the cost of the refrigeration. There have been reports of some super pure aluminum which may have a gain of 10 but I do not know of anyone who has worked on that.
- M. Barton (BNL) For magnets, very pure aluminum can have such high conductivity at cryogenic temperatures that it should offset the refrigeration cost but the magneto-resistance prevents the practical application of this technique.

- E. Keil (CERN) So far the whole discussion has been devoted to the energetic aspects of the operation of those facilities. I wonder whether any member of the panel would care to comment on the energetic aspects of the production of those facilities.
- G. Loew (SLAC) I only know a very big number which I read about a few years ago that anything one makes has a 10% energy content in cost. But of course if you are talking about that furnace required to bake a kilometer and a half of superconducting cavities at 2000 degrees then maybe things will begin to change a little bit.
- W. Schnell (CERN) I am afraid we take it for granted that we have to do without that or else we just would not make it. In all other cases that I can now think of, I can not identify things that would be more economic in running but would cost more power in producing. I cannot think of any such dilemma at this moment.

- M. Barton (BNL) Superconducting materials are probably energy intensive in production because of the refining processes, etc.
- R. Lundy (FNAL) We should not forget that helium is not necessarily infinite in supply. It is not clear what energy price one attaches to this but conservation programs should probably be resumed in the U.S. and possibly in other parts of the world as well.
- G. Loew (SLAC) Niobium is also getting more expensive. It has gone up by a factor of 3 in the last few years and it is likely to double again.
- A. Maschke (BNL) There is a problem with designing a facility to minimize operating costs. When we build a facility we get a certain amount of money from the government and we try to get as much facility as possible in terms of performance for that money rather than trying to optimize the performance against the total cost including the cost of operation for its life. Such an optimization would be done, for example, by an industry building a factory. The funding agencies need a better understanding of this total cost so that they can best attain their long-range interests.
- W. Schnell (CERN) We do take into account ten years power costs at the present price of electricity in optimizing components of LEP.
- M. Barton (BNL) This argument is more obvious for LEP than for any accelerator up until now because of the enormously steep function of synchrotron radiation versus energy.
- B. Montague (CERN) I think it is not just confined to LEP. It has been the practice in CERN for 25 years to try and optimize machines with respect to both capital and running costs over a ten year period. It may not be the practice in the USA but I think it is the practice in Europe.
- R. Bell (SLAC) I'd like to point out that it is a practice in the U.S. The magnet system was optimized for power consumption over a ten year period.

W. Schnell (CERN) Coming back to Maschke's comment, it has been a tradition here to optimize machines including something like ten years of power costs and it has been done for LEP. The surprising result is that the 90 GeV version of LEP is the room temperature version. This reflects the fact that power is still cheap compared to many other costs. If during operation power costs increase or there is a shortage, one might have to do things like running LEP at reduced energy which would mean that the machine would not then appear to be optimized.

J. Galayda (BNL) The cost estimate that one assumes for power over the next ten years has a tremendous effect on the conclusions which one draws from such optimizations. Does anyone care to comment on the accuracy of forecasts on the cost of energy for the next ten years? Many of these cost estimates, had they been done five years ago would have much different outcomes than if they were done today.

M. Barton (BNL) My projection is that it is not going to get better.

W. Schnell (CERN) So far in Europe, electricity has not increased much more than general inflation. Extrapolating from that, one cannot afford to put in capital costs for saving power. It may go up steeper or there may simply be a shortage.

M. Barton (BNL) We have at BNL an anomalous example because all electricity in the Long Island area is generated using imported oil and this cost has increased faster than inflation.

J.B. Adams (CERN) I would like to ask the panel when you do the cost optimization you take present costs, equipment costs, and present power costs, and optimize over a certain period of time for the power. When you start the project you spend your money on material equipment, when you finish the project you spend your money on power. At that time the power has gone up. Now at what point of time should you do the cost optimizing? If you could get the same answer you could do it anytime, but I think usually you have made your commitment very early in the project, i.e., tunnel sizes, magnet apertures, etc. I do not think you can defer that question.

M. Barton (BNL) If power costs were simply scaled like other costs or had the same inflation rates as other items, then one would get the same answer anytime but we are all guessing at what future energy costs will be so there is no correct time to do the cost optimizing. One is forced, as you say, to do it very early and then recognize that it may be inaccurate.

The moderator has prepared these summary notes without benefit of proofreading or editing by members of the panel and apologizes for any errors of omission or commission that have resulted. He wishes to thank members of the panel for their thoughtful presentations and, to the audience as well as the panel, for their participation in the discussion.

MQB:pmb

FIGURE CAPTIONS

Figure 1. These graphs show the use and costs of electric power at the three major U.S. high energy physics laboratories.

Figure 2. These graphs show the power required for some major European high energy facilities, a more detailed breakdown for $e^+ e^-$ laboratories, the costs at DESY as a representative case, and the effects on DESY power costs of varying the load during the year.

Figure 3. This graph shows the rf input power in LEP as a function of electron energy for various configurations of klystrons and cavities.

Figure 4. SLAC's complete single pass collider power system is shown in this picture.

Figure 5. The performance of superconducting rf cavities is summarized in this graph.

Figure 1

Figure 2

FIGURE 3

Figure 4

Present State of Superconducting RF-Accelerating Cavities
Maximum Accelerating Field strength vs. Frequency

Figure 5