Report of the Subpanel on High Energy Physics Manpower of the High Energy Physics Advisory Panel

To the U.S. Department of Energy

U.S. Department of Energy
Directorate of Energy Research
Division of High Energy Physics

June 1978

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	Microfiche:	\$ 3.00

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March 13, 1978

Dr. John Deutch, Director
Office of Energy Research
Department of Energy
Old Executive Office Building
Washington, D. C. 20545

Dear John:

I am happy to transmit to you the report of the HEPAP sub-panel on High Energy Physics Manpower as endorsed by your High Energy Physics Advisory Panel.

I hope the key recommendations of this report, prepared under the leadership of Dr. Jeremiah D. Sullivan, will be implemented and that the report itself will be widely circulated. It is important not only for its conclusions and recommendations but as a valuable presentation of data on the current and near term job prospects for young scientists in the field of high energy physics.

With best personal regards,

Sidney D. Drell
Chairman, HEPAP

SDD:br

Enclosure

Report of the
SUBPANEL ON HIGH ENERGY PHYSICS MANPOWER
of the
High Energy Physics Advisory Panel

(Accepted February 1978)

Members: Jeremiah D. Sullivan (Chairman), University of
Illinois (Urbana/Champaign)
Thomas L. Neff, Massachusetts Institute of Technology
Melvyn J. Shochet, University of Chicago
Walter D. Wales, University of Pennsylvania

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Summary

In the past few years high energy physics has enjoyed spectacular and profound advances in its study of the fundamental interactions of nature. New states of matter and new types of forces have been discovered at accelerators at the same time that an elegant and unified theoretical picture of the basic interactions of matter has emerged. These complementary experimental and theoretical achievements, culminating a decade and more of steady and solid progress, point to a future of even greater opportunity and understanding for the field.

The promises of the future will not be met, however, unless high energy physics continues to experience a steady flow of highly trained and highly creative new researchers into its ranks at the universities and national laboratories. This is not at all guaranteed in an era which promises, at best, a very limited growth at these centers.

The following is the report of a Subpanel which was appointed by the High Energy Physics Advisory Panel (HEPAP) to examine the production in recent years of new researchers in high energy physics and the rate at which they have moved into short term and permanent positions in the field. The Subpanel made use of the 1973 and 1975 ERDA Census data, statistics collected by others, as well as a number of surveys conducted by the Subpanel itself. Even though many uncertainties and gaps exist in the available data, several important points clearly emerge.

- 1) New Ph.D. production in high energy physics has decreased in recent years even more rapidly than in physics as a whole. From a high in 1971 of 278 new Ph.D.'s in high energy physics (16 percent of all physics), production in 1976 was 137 (10 percent of all physics). Near term projections indicate new Ph.D. production at slightly less than this level for the next few years.
- 2) New Ph.D.'s in experimental and theoretical high energy physics have been produced for many years in roughly equal numbers in spite of the fact that employment in the field at all levels shows a ratio of experiment-to-theory approaching two-to-one.
- 3) A very large fraction of the approximately 1700 Ph.D.'s in high energy physics (employed at 78 universities and 5 national laboratories) hold tenured positions (383 theorists and 640 experimentalists). The next largest group are those at the Research Associate level (154 theorists and 350 experimentalists). The remainder hold Assistant Professor or Laboratory equivalent appointments, (72 theory and 117 experimentalists).

- 4) The age distribution of those in the tenured ranks reveals that the number of retirements will be extremely small during the next decade but will then start to have a significant impact on the opportunities for those who are seeking careers in the field.
- 5) Promotions to tenure at the universities during the 4 year interval AY72/73-AY76/77 have averaged about 10 per year in experiment and 10 per year in theory. The national laboratories have promoted or appointed to equivalent positions approximately 5-6 experimentalists per year and 1-2 theorists per year during the same period.
- 6) The biggest uncertainty in our present knowledge is the rate at which those in the Research Associate ranks have moved into Assistant Professor and laboratory equivalent positions since the 1975 ERDA census. The ongoing 1978 DOE census of high energy physics will provide this vital information.

Our key recommendations are:

- 1) High energy physics should support a small but continuous effort to monitor manpower changes and developments in the field. The results should be made generally available to workers in the field and to new graduate students who are selecting a research specialty.

It is particularly important that the latter group be given a fair and balanced presentation which shows that career opportunities do exist in the field, but that the keen competition requires high talent and achievement.

- 2) In view of the fact that the coming decade appears to be a critical one, a nationally organized program should be created to retain additional young experimentalists and theorists in semi-permanent positions. The program should be a temporary one to bridge the gap between the present situation of limited opportunity and the situation of greater opportunity which should occur in roughly a decade. The program need not be a large one to have a real impact on the opportunities available to those who are now seeking positions in the field above the Research Associate level. It can be begun with resources within the field; small amounts of new support would enhance its success.
- 3) In addition to making known the opportunities for exciting and creative careers that do exist in high energy physics and making sure that an adequate number of appropriate positions for new workers will be available in the future, greater attention should be paid to those who are trained in high energy physics at the universities and national laboratories but who go on to pursue careers in alternative fields. It is not necessary nor appropriate that all who receive Ph.D.'s in the field go on to find permanent employment within its confines. The introduction of high energy physics techniques and talents into other fields has been valuable in the past and will continue to be so in the future. Mechanisms should be encouraged which would smooth the transition from employment in high energy physics to employment in other fields. A set of summer institutes devoted to one or more topics in applied physics is one useful mechanism. A broadening of the graduate curriculum is another.

Background

In June 1976 a High Energy Physics Manpower Subpanel was appointed by the Chairman of the High Energy Physics Advisory Panel (HEPAP), Sidney Drell, to review the production of new Ph.D.'s in high energy physics, to examine the progression of these new researchers into temporary and permanent positions in the field, and to make recommendations as appropriate. The following is a report of this Subpanel. Members are: Jeremiah D. Sullivan (Univ. of Ill.), Chairman, Thomas L. Neff (MIT), Melvyn J. Shochet (Univ. of Chicago), and Walter D. Wales (Univ. of Penn.).

The rapid growth of high energy physics beginning in the 1950's, continuing up to the late 1960's, followed then by an abrupt halt in growth is a well known story. Essentially all other subfields of physics, as well as science in general, experienced the same pattern of rapid growth terminated by a sudden leveling of resources and decline in opportunity. Certainly high energy physics was as ill-prepared as any other subfield of physics for the adjustments which had to be made. The impact of these adjustments fell overwhelmingly on the young researchers in the field who were coming out of graduate schools in record numbers. Although the intense trauma of this period is mostly behind us, the character of the field and the makeup of its practitioners strongly reflects this recent history. There remain many highly productive researchers who have not found appropriate positions in the field 6 or more years after the Ph.D.

It is not yet clear that high energy physics has entered a new era of stability. As we shall see below, available data indicate that young researchers are being absorbed into the field in non-zero but small numbers. Available data are subject to considerable uncertainties, however, making extrapolations into the future difficult. Nonetheless, it is our opinion that the rate of absorption of new researchers into career positions in high energy physics is not yet sufficient to sustain the health and vitality of the field over the long run. With a modest amount of new resources and, even in the absence of this, by redirecting existing support within the field for a limited number of years (roughly a decade) high energy physics can bring about a substantial improvement in the opportunities now available for its younger members and in so doing strengthen its own future.

There have already been a number of studies of the manpower situation in physics; several are ongoing. For years Beverly Porter and Susanne Ellis of the American Institute of Physics (AIP) have gathered and published valuable statistics on enrollments, degrees and employment in physics. The National Research Council has done similar work for engineering and science as a whole including, on occasion, data for

physics broken down by subfield. The NSF and DOE/ERDA/AEC have conducted surveys on physics, including high energy physics, from time to time. Lee Grodzins, since 1971, has followed with great detail the evolution of physics faculties.

In the early days of the "job crisis" Ron Aarons and colleagues at Northeastern University organized the High Energy Physics Job Information Pool in an attempt to bring some order to the chaos of those times. The management of the Information Pool was later taken over by the AIP, extended to all subfields of physics and operated from AY72/73 through AY74/75. In 1973 A. Rosenfeld, R. Peierls, M. Einhorn and D. Levy at Berkeley^{1/}, using the 1970 AEC Census made a survey of high energy physics and made a number of suggestions similar to the ones in this report. The Forum Division and the Committee on Education of the American Physical Society (APS) along with the American Association of Physics Teachers (AAPT) sponsored a novel conference on physics graduate education at Penn State during the summer of 1974. A second was held in the summer of 1977.

A committee of the APS under the Chairmanship of Milan Fiske, in collaboration with the AIP, is currently carrying out three separate surveys. The first by L. Grodzins, a pilot survey examining the careers of those who left the academic rosters of 13 major universities from 1962-74, is reported to be close to publication and should provide valuable insights into an often forgotten group.

The above are only some of the many efforts to study the present and past in hopes of unlocking the secrets of the future. In the field of manpower, however, prophesy is always hazardous and seldom correct. We hope that our modest efforts reported herein will be of some use and have some validity for the near future. At the very least they point the way to what could and ought to be done to better monitor the crucially important advancement of new researchers into our field.

^{1/}

A Suggestion to Particle Physicists from the Economic Concerns Committee, UCID - 3595, 1973.

Demography

High energy physics (HEP) is a discipline with rather well defined boundaries except for its intersection with medium energy nuclear physics. (One recognizes, of course, that many of the tools and techniques of high energy physics, both theoretical and experimental, have impact and applications in many other areas of physics and science in general.) Research in HEP is carried on in the United States in a limited number of universities and now at six national laboratories. Except for a few special purpose projects, research in the field is supported by two federal agencies, the National Science Foundation (NSF) and the Department of Energy (DOE--formerly the Energy Research and Development Administration--ERDA). We first look briefly at the institutions involved in high energy physics research and then look at detailed profiles of the researchers in the field using the ERDA 1975 census data. (These data represent the situation as of January 1975 and will hereinafter be referred to as ERDA/75.) We also utilize the ERDA 1973 census^{1/}, as well as other surveys, to measure manpower changes in the field.

A. HEP Institutions

ERDA/75 lists a total of 78 universities and 5 national laboratories engaged in high energy physics research with support from NSF and/or ERDA. The distribution by size of the programs in the 78 HEP university departments is shown in Fig. 1. Size is measured by the total number of Ph.D.'s (theory plus experiment) at all levels. Research Associate - Professor, engaged in HEP. As mentioned above some of those included should probably be counted as full or part-time nuclear physicists. One sees that roughly one-third of the university groups have less than 10 members (Category I), one-third have 10-14 members (Category II), and one-third have large 15-45 member groups (Category III).

^{1/}

The 1973 Census was published under the Atomic Energy Commission but herein is referred to as the ERDA 1973 Census.

In Table I we list the individual institutions in each of the Categories. The group of large HEP institutions has been further broken down into two Subcategories IIIa (15-24) and IIIb (25-45).

Table I -- HEP Institutions According to Ph.D. Workers - All Ranks, theory plus experiment (Source ERDA/75)

Category I (1-9 HEP Ph.D.'s) (#25)

Bartol Institute	U. of Pittsburgh
U. of Cincinnati	St. Louis University
U. of Colorado	Southeastern Massachusetts U.
Duke University	Stevens Institute of Technology
U. of Houston	SUNY (Buffalo)
Illinois Inst. of Tech.	U. of Tennessee
U. of Kansas	Texas A&M
U. of Massachusetts (Boston)	U. of California (Davis)
U. of New Mexico	U. of California (Riverside)
U. of North Carolina	U. of California (Santa Cruz)
U. of Oregon	U. of Utah
Pennsylvania State U.	Wayne State U.
	U. of Wisconsin (Milwaukee)

Category II (10-14 HEP Ph.D.'s) (#23)

U. of Arizona	U. of Miami
Brandeis University	U. of Minnesota
Brown University	U. of Notre Dame
Case Western U.	Northwestern University
Florida State U.	New York University
U. of Hawaii	Ohio State University
U. of Illinois (Chicago)	U. of Texas
Inst. for Advanced Study	Tufts University
Iowa State U.	U. of California (Irvine)
Johns Hopkins U.	U. of California (Santa Barbara)
Louisiana State U.	Vanderbilt University
	Virginia Polytechnic Institute

Category IIIa (15-24 HEP Ph.D.'s) (#15)

City College of CUNY	U. of Rochester
Carnegie Mellon U.	Rockefeller U.
Indiana University	Rutgers University
U. of Maryland	Stanford U. (SLAC excluded)
U. of Massachusetts (Amherst)	Syracuse University
Michigan State U.	U. of California (San Diego)
Northeastern U.	U. of Washington
	Yale University

Table I (con't)

<u>Category IIIb</u> (25-45 HEP Ph.D.'s) (#15)	
Cal. Inst. of Tech.	Massachusetts Inst. of Tech.
U. of Chicago	U. of Pennsylvania
Columbia University	Princeton University
Cornell University	Purdue University
Harvard University	SUNY (Stony Brook)
U. of Illinois (Urbana/Champaign)	U. of California (Berkeley)
U. of Michigan	U. of California (Los Angeles)
U. of Wisconsin (Madison)	

B. HEP Population

Table II displays the total HEP Ph.D. population at universities and five laboratory centers: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Fermi National Accelerator Laboratory (Fermilab), Lawrence Berkeley Laboratory (LBL), and Stanford Linear Accelerator Center (SLAC). (No high energy physics at Los Alamos Scientific Laboratory (LASL) is indicated in the 75 census.) One sees that about 25 percent of the HEP manpower is employed at the laboratory centers, and that for the field as a whole approximately one-third of the researchers are theorists and two-thirds experimentalists.

Table II -- Ph.D.'s in High Energy Physics* with NSF or ERDA Support (Source ERDA/75)

	<u>Theory</u>	<u>Experiment</u>	<u>Total</u>
78 Universities**	523	714	1,237
5 Laboratories†	73	369	442
TOTAL	596	1,080	1,679

* All ranks: Res. Assoc. - Professor

** Including Inst. for Advanced Study

† ANL, BNL, Fermilab, LBL, SLAC. No LASL data for HEP in ERDA/75.

Figure 2 shows the HEP population for eight fiscal years beginning 1969. The laboratory count includes Princeton-Pennsylvania Accelerator (PPA) and Cambridge Electron Accelerator during the years these accelerator facilities were in existence. The constancy with time is remarkable. Also shown is the manpower count for university based high energy physics. The numbers represent only those Ph.D.'s (theory plus experiment) supported by ERDA/AEC. Corresponding numbers for the NSF-supported programs are not available at this time.

Let us next examine the rank and age distribution of the HEP community in the United States. Table III shows the breakdown by rank separately for theory and experiment according to ERDA/75. The numbers in parentheses are the corresponding values from ERDA/73. Laboratory physicists are included in both sets of figures and are assigned to that academic rank which most closely describes their appointment status.

Table III -- Ph.D.'s in HEP by Rank at Universities and Laboratories as of January 1975 (Jan. 1973); (Source ERDA/75 (ERDA/73))

	<u>Theory</u>	<u>Experiment</u>	<u>Unclassified</u>	<u>Total</u>
Full Prof	237 (205)	326 (301)	4 (5)	567 (511)
Assoc Prof	146 (159)	314 (331)	3 (5)	463 (495)
Asst Prof	72 (79)	117 (114)	1 (2)	190 (195)
Inst/Res Assoc	154 (144)	350 (326)	8 (10)	512 (480)
TOTAL	609 (587)	1107 (1072)	16 (22)	1732 (1681)

In the 2-year interval between 1973 and 1975 the field of high energy physics experienced a very modest 3 percent growth in manpower at all levels. One sees, too, that the rough rule of 1:2 for theorists to experimentalists applies to each of the three general categories: tenured faculty (Full and Assoc. Prof. and Lab. equiv.), non-tenured faculty (Asst. Prof. and Lab. equiv.), and Research Associate. These categories represent in turn, 60 percent, 10 percent, and 30 percent of the manpower in high energy physics. The high fraction of tenured to nontenured faculty is well known and typical of almost all disciplines represented at universities. The high number of workers in the field at the Research Associate level is unique to high energy physics as is shown in Fig. 3; only biophysics comes close in percentage of post doctoral workers. (Note that the total number of Ph.D.'s in Elementary Particles reported in this figure differs considerably from the ERDA census numbers given in Table III. Part of this difference may be due to individuals counted as Theoretical Physics or Nuclear Physics.)

The future health of high energy physics and the opportunity for new Ph.D.'s to find career positions in the field is affected greatly by the age distribution of those currently holding appointments in HEP. In Figs. 4 and 5 we show this information for theory and experiment respectively, for Jr. Faculty (Res. Assoc. and Asst. Prof.) and Sr. Faculty (Assoc. Prof. and Full Prof.).

As in Table III both university and laboratory equivalent appointments are included. The top line of these two figures gives the year of retirement^{1/} based on an age 65 norm. It is clear that retirements will not generate a significant number of new positions in theory until a decade from the present. The situation is similar but not quite as severe in experiment. In about 7 years the number of retirements will begin to exceed 10 per year and then start to climb rapidly. Fifteen years from the present (roughly the time at which a freshman major in physics in AY77/78 might be completing a second post doctoral appointment) the effect of retirements will be dramatic.

The very uneven age distribution shown in Figs. 4 and 5 is similar to that for university faculties as a whole and reflects the period of rapid expansion of universities, and high energy physics in particular, which began in the late 1950's and peaked in the late 1960's. In Figs. 6 and 7 we show two curves of the evolution of physics faculties (all subfields) for the period 1963-1977^{2/}.

Reliable extrapolations into the future would be very useful but are extremely difficult to make. In Fig. 8 we show the projections of Cartter^{3/} for junior faculty openings (all fields and institutions) up to 1990. The precipitous drop beginning in 1980 and the negative dip in 1985 are driven by an anticipated 25 percent decline in the size of the college-age population. The fact that the minimum in Cartter's curve coincides with the time (approximately one decade hence) at which retirements in HEP begin to become significant is sobering.

^{1/} We are aware of Federal and state legislative initiatives to eliminate or postpone mandatory retirement. Such actions if successful and if applicable to university faculties could have a disastrous effect on job opportunity for new workers.

^{2/} L. Grodzins, Presented at the Penn. State Conference on Changing Career Opportunities for Physicists, Aug. 1977, AIP Conference Proceedings No. 39 (American Institute of Physics, New York, 1978).

^{3/} A. M. Cartter, Ph.D.'s and the Academic Labor Market, Carnegie Commission on Higher Education Series (McGraw-Hill, New York, 1976).

While the drop in overall college-age population will undoubtedly have an effect on faculty hiring in high energy physics, we believe that the effect will not be anywhere near as severe as the projections for junior faculty openings as a whole. The only institutions involved in high energy physics are the major Ph.D. granting universities and these will probably be able to hold their own at the expense of the smaller universities and 4-year colleges. If so, faculty retirements at the major universities will generate new openings. If HEP remains an exciting and viable field there is no reason why the majority of these replacements cannot be kept within the field. Real growth, on the other hand, seems unlikely.

C. Ph.D. Production

Let us next consider the flow of new talent into the ranks of high energy physics beginning with the production of new Ph.D.'s. In Fig. 9 we show the production of Ph.D.'s--all physics and separately high energy physics beginning in 1958. Also indicated in the lower half of Fig. 9 is the percentage of the physics Ph.D.'s which were awarded in HEP. (These data for HEP from the NRC Doctoral Record File represent theory plus experiment. Unfortunately no breakdown into the two categories is available from NRC.) Since the peak in 1971, high energy physics has been a decreasing percentage of a decreasing total. This dramatic decrease by a factor of approximately 2.2 in 5 year's time is undoubtedly the single most important reason that the employment situation in HEP for new Ph.D.'s has improved considerably from the dismal 1970-73 era.

In order to examine the breakdown of new HEP Ph.D.'s into theory and experiment and to learn which institutions are training new workers in the field, we conducted a survey of the 48 largest HEP university departments. The results for Ph.D. production during four consecutive academic years are shown in Table IV.

Table IV -- HEP Ph.D. Production^{*}
(Source: Author's Survey of 48 Largest HEP Universities)

	<u>AY72/73</u>	<u>AY73/74</u>	<u>AY74/75</u>	<u>AY75/76</u>	<u>AVG</u>
Theory	80	70	57	66	68
Experiment	99	63	73	71	77
TOTAL	179	133	130'	137	145

* No attempt has been made to adjust for unsurveyed universities.

The same information is further broken down by institutional sizes in Table V.

Table V -- HEP Ph.D. Production - By Institutional Size*
 (Source: Author's Survey of 48 Largest HEP Universities)

Category IIIb (all 15 surveyed)

	<u>AY72/73</u>	<u>AY73/74</u>	<u>AY74/75</u>	<u>AY75/76</u>	<u>AVG</u>
Theory	46	36	33	34	37.2
Exp.	60	36	45	41	45.5

Category IIIa (all 15 surveyed)

	<u>AY72/73</u>	<u>AY73/74</u>	<u>AY74/75</u>	<u>AY75/76</u>	<u>AVG</u>
Theory	20	19	17	21	19.2
Exp.	31	20	21	20	23.0

Category II (12 of 22 surveyed)

	<u>AY72/73</u>	<u>AY73/74</u>	<u>AY74/75</u>	<u>AY75/76</u>	<u>AVG</u>
Theory	12	10	7	9	9.5
Exp.	8	6	9	5	7.0

Category I (5 of 25 surveyed)

	<u>AY72/73</u>	<u>AY73/74</u>	<u>AY74/75</u>	<u>AY75/76</u>	<u>AVG</u>
Theory	2	4	0	2	2.0
Exp.	0	1	2	1	2.0

* No attempt has been made to adjust for unsurveyed universities.

The figures from our survey for HEP Ph.D. production for AY74/75 and AY75/76 agree well with the NRC values shown in Fig. 9. Our values for the preceeding 2 years are somewhat lower for reasons unknown at this time. Perhaps in the earlier but not in later years HEP degrees were being produced at smaller institutions not surveyed by us.

There are two critical parameters of interest for the future. The first is the rate at which Ph.D.'s will continue to be earned in HEP. Projections of the AIP^{1/} for total physics Ph.D. production over the 5-year interval AY76/77 - AY80/81 indicate a constant rate of 1000 new Ph.D.'s per year. If the fraction of these which are in HEP remains at the 10-12 percent level of the last 2 years, we can anticipate slightly over 100 HEP degrees per year in the U.S. in the near term. Obviously the fraction of new Ph.D.'s which are in HEP can change in the future and upset these predictions.

The second critical parameter is the ratio of theoretical-to-experimental HEP degrees. Although the ratio fluctuates some from year to year, it is close to 1:1 and dramatically different from the approximately 1:2 ratio of workers in the field at all levels (recall Table III). Others have told us that earlier surveys have indicated the same 1:1 ratio for new HEP degrees. Clearly the chance that a new high energy theorist will find a career position in the field is significantly less than for an experimentalist.

D. Research Associates

The receipt of a Ph.D. in high energy physics is but the first step in a lengthy process of obtaining a permanent position in the field. The next step in the ladder is a Research Associate appointment at one of the national laboratories or HEP universities. Typically the first appointment is for a 2-year term although some institutions do grant 3-year terms to new Ph.D.'s. This latter practice is somewhat more common in the experimental sector. The first post doctoral appointment, once the only term of apprenticeship, is now typically followed by one or more 2-3 year research appointments during which the aspirant must establish a solid research reputation if he/she hopes to move up to the Assistant Professor (or laboratory equivalent) level. The final barrier which must be crossed is promotion to tenure. (In this study we adopted the conventional assignment of tenure level to be Associate, Full Professor, and laboratory equivalents. We are aware of the small but growing trend at some institutions to make selected promotions to Associate Professor without tenure. We know of no way to correct for this in the available data. We believe, however, the effect is not significant considering the many other uncertainties in our work.)

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S. D. Ellis, Enrollments and Degrees, AIP Pub. No. R-151.44, June 1977.

At each step of the above progression, physicists trained in the field are lost to high energy physics. We do not have sufficient reliable information to study in detail the attrition at each step. Nevertheless a number of facts are known from which a crude picture emerges; we present them now.

In Table VI we show the number of applicants, by year of Ph.D., who applied for a Research Associateship in Theory for fall 1977 at one or more of the following institutions: SLAC, Fermilab, Inst. for Advanced Study, and U. of Illinois. Matched lists were employed in order to eliminate double counting.

Table VI -- Number of Applicants, by year of Ph.D., for a Research Associate Appointment in Theory beginning Fall 1977
(Source: Combined, matched lists from SLAC, Fermilab, IAS, U. of Illinois)

Year of Ph.D.	<u>1977</u>	<u>1976</u>	<u>1975</u>	<u>1974</u>	<u>1973</u>	<u>1972</u>	<u>1971</u>	<u>1970</u>
Ph.D. (U.S. Inst.)	45	15	18	10	4	8	10	3
Ph.D. (Foreign Inst.)	11	6	9	4	3	1	3	3

It is reasonable to regard the above numbers as good approximations to the total number of theory applicants since the four institutions represent the full spectrum of research interests in HEP as well as geography. It is common in theory for applicants to file multiple applications, 10-30 is not unusual. If we accept the above hypothesis then we see that 45 new Ph.D.'s in HEP theory were awarded in the U.S. during AY76/77. This is slightly lower than the trend indicated by the numbers of previous years given in Table IV but is roughly consistent with the above estimate of slightly over 100 HEP Ph.D. degrees in AY76/77 divided equally between theory and experiment.

Moreover, we see a total 68 applicants from Ph.D. years 1970-76 who are seeking post doctoral employment. This represents 44 percent of the theoretical post doctoral pool shown in Table III. Again, such a percentage seems consistent since this pool consists of a majority of theorists on 2-year appointments with the remainder on 3-year appointments. (Only a few hold greater than 3-year appointments.)

The large number (15) of applicants in Table VI with Ph.D. year 1976 is difficult to interpret. Some of these may be individuals who were kept on at their institution of graduate study for an additional year to complete an ongoing research project, or were kept on purely as a strategic move in hope that they would fare better 1 year later in the

post doctoral competition. Others may be de facto 1975 Ph.D.'s whose degrees were not officially awarded until 1976 for one reason or another. The former should be associated with those seeking their first post doctoral appointment; the latter should be assigned to the group who are seeking their second such appointment.

In any case one sees a very large drop in the number of theorists who are still in the field 2 or more years after earning the Ph.D. For example, Table IV shows that 57 Ph.D. theorists in HEP were graduated in 1975. It is reasonable to believe that at least two-thirds (~38) found post doctoral positions in HEP. Two years later only 18 (47 percent of 38) are seeking second positions. Since very few can be attributed to 3-year appointments and essentially none to the Assistant Professor level, it follows that the remainder (53 percent) are leaving the field for one reason or another. Comparing to the initial group of 57 Ph.D.'s we see only one-third seeking a second post doctoral appointment. (We have no way of knowing how many of the applicants shown in Table VI are actually successful in locating employment in HEP for AY77/78.) One also notices in Table VI the long tail of the experience distribution. The pool contains many who have completed two or more post doctoral appointments.

Corresponding information for experimental HEP Ph.D.'s would be equally interesting. Unfortunately, however, there is no simple way to assemble such data. At present, experimental post doctoral positions for new Ph.D.'s are adequate and may perhaps even exceed the supply. Consequently, multiple applications are not common. Therefore, one cannot survey a small set of institutions and thereby build up a complete picture of the post doctoral situation in experimental HEP. It is reasonable to anticipate, however, that there are many similarities to the theoretical HEP after the first appointment. Future census data will fill this gap.

E. Faculty Positions

Consider next the Assistant Professor level. According to the census data (ERDA/73 and ERDA/75) shown in Table III, the number of Assistant Professors in HEP theory decreased by seven from AY72/73 to AY74/75. Experiment showed an increase of three during this interval. This may be compared to the 10 percent decrease per year in the number of Assistant Professors observed by Grodzins for physics faculties as a whole (see Fig. 6).

One thing is clear, however. The Assistant Professor (plus laboratory equivalent) pool is not a stagnant one. Comparing ERDA/73 and ERDA/75 one finds separately for theory and experiment that there was a 50 percent

turnover in the Assistant Professor pool in this 2-year interval. A breakdown of these changes is shown in the first two columns of Fig. 10 for theorists and Fig. 11 for experimentalists. In order to measure changes in the original 1973 Assistant Professor pool since ERDA/75, we have taken all those who are still at the Assistant Professor level in AY74/75 (according to ERDA/75) and established their academic rank in AY76/77 by consulting the AIP Directory of Physics and Astronomy Staff Members. The changes which took place in this latter 2-year interval are shown by the second and third columns of Figs. 10 and 11.

In addition we have looked at the entire HEP Assistant Professor pool indicated in the 1975 ERDA census and again used the AIP Directory to establish changes in the 2-year interval AY74/75 to AY76/77. The results are quite similar to the patterns shown in Figs. 10 and 11. Namely, for the 72 HEP theoretical Assistant Professors shown in ERDA/75, one finds after 2 years that 23 (32 percent) were promoted, 16 (22 percent) were unknown, 31 (43 percent) remained at the Assistant Professor level and 2 (3 percent) moved to a national laboratory (rank unknown). For the 117 HEP experimental Assistant Professors listed in ERDA/75, we find that after 2 years 26 (22 percent) were promoted, 19 (16 percent) were unknown, 65 (56 percent) remained at the Assistant Professor level, 4 (3 percent) remained at a national laboratory (rank unknown) and 3 (3 percent) moved to a national laboratory (rank unknown).

Note that the above study of the 1975 Assistant Professor pool has a considerable overlap with the information shown in Figs. 10 and 11 since approximately half of the total ERDA/75 Assistant Professor pool is accounted for in the middle column of Figs. 10 and 11. Since the AIP Directory does not list research subfields, it cannot be used to determine how the total HEP Assistant Professor pool has developed since ERDA/75.

To monitor changes at all levels of the HEP population, we have made a name-by-name comparison of the ERDA/73 and ERDA/75 census. The results are shown in Figs. 12-21. Fig. 12 shows the changes which occurred in theoretical graduate students as a function of the year of birth of the students. The upper histogram shows the distribution of birthdates of the 160 students added to the published census between 1973 and 1975. The lower histograms show the 196 older students who left the graduate student ranks in this same period, either by advancing to a higher rank in the field (shaded) or by leaving the field (or the country).

Fig. 13 shows the changes which occurred in the "Junior" ranks (Research Associate plus Assistant Professor) of theorists at both the universities and laboratories. The upper histograms

show the additions due to "promotions" of graduate students (the shaded curve which is, to the first approximation, a reflection of the negative shaded histogram of Fig. 12) and to additions to ERDA/75 itself. This latter category includes physicists returning from abroad, physicists new to this field, and physicists who were missed in ERDA/73. The negative histograms show deletions from the "Junior" ranks, either due to promotion (shaded) or removal from the census. This latter category probably includes many postdoctoral physicists who left the field. The centroid of the negative histograms occurs approximately 4 years earlier than the centroid of the positive histograms, indicating a "dwell" time of about that length.

Figure 14 shows the changes which occurred in the "Senior" ranks (Associate plus Full Professor) of theoretical physicists at both the universities and laboratories. The positive histograms show promotions (shaded) and additions. As expected, the promotions were primarily of relatively young theorists. It is interesting to note that many of the deletions were also of relatively young theorists. This is in part a reflection of the fact that the average age of "Senior" theorists is relatively low. Since the Senior ranks contain the bulk of the population we have broken it down into the laboratory and university components and displayed the changes in each in Figs. 15 and 16.

Figs. 17-21 show the corresponding information for experimentalists. A comparison of Fig. 17 with Fig. 12 shows that a larger fraction of experimental graduate students went on to the "Junior" ranks than did theoretical students. This is almost certainly a reflection of the fact that new Ph.D.'s are produced in comparable numbers in theory and experiment but must find places in a profession which has substantially more experimental than theoretical positions. Figure 18, like Figure 13, indicates a relatively large attrition in the "Junior" ranks. The "dwell" time for experimentalists does not appear to be significantly different from that for theorists. Figures 14 and 19 both indicate that much of the attrition in the "Senior" ranks is among individualists well below retirement age. The age distributions which were shown earlier in Figs. 4b and 5b suggest that retirements are not likely to play a significant role in the next decade.

We have also made a number of informal surveys. Table VII contains the results of a three question survey of experiment at 40 HEP universities.

Table VII - Long Term Appointments in Experiment at HEP Departments
(May 77) (Source: Author's informal survey)

Q1) No. of HEP Experimentalists hired in last 3 years
(AY73/74, 74/75, 75/76) on appointments in excess of 3 years?

Answer = 63 → 21/yr

Q2) No. of HEP Experimentalists who now hold long-term, non-academic positions?

Answer = 54

Q3) Plan to offer long-term, non-academic position(s) in near future or have mechanism for doing so?

Yes = 25

No = 15

The large number (54) of experimentalists who occupy long-term, non-academic positions at these universities is notable. This trend seems to be a growing one and has started to appear in theory as well. At the present time at least eight theorists are on long-term, non-academic appointments at universities in the U.S., and the number appears to be growing.

In Table VIII we show the number of tenure appointments or promotions in HEP experiment made at the universities and at the national laboratories for the 2 years AY75/76 and 76/77.

Table VIII - Tenure Promotions and Appointments-HEP Experiment
AY75/76 & AY76/77 (Source: Author's informal survey)

<u>Place</u>	<u>Number</u>	<u>Rate</u>
Universities	11	6/yr
Laboratories*	Fermilab 9	9/yr
	SLAC 6	
	BNL 2	
	ANL 2	

* Mostly part-time research/part-time accelerator physics-administration.
Division depends strongly on laboratory.

The average rate of promotions to tenure at universities per year indicated by Table VIII is to be compared with the rate of 10 per year indicated in Fig. 11 for the same 2-year interval. Since the numbers in Table VIII come from the author's survey of only the 40 largest HEP universities whereas the data in Fig. 11 are based on the census data for all 78 HEP universities, this difference is understandable.

The information given earlier in Fig. 11 does not enable one to draw any conclusions about promotions to tenure at laboratories. The rate of nine per year given in Table VIII should, however, reflect the situation well since all of the major HEP national laboratories were surveyed. It should be kept in mind that not all of these latter positions, although tenured, are the equivalents in research time and opportunity of university faculty appointments. Moreover, close to half of these laboratory appointments (for AY75/76 and 76/77) were at the newest accelerator center, Fermilab. The pattern and numbers in future years may be very different.

For theoretical high energy physics our informal surveys indicate tenure promotions for AY75/76 and 76/77 at the major HEP universities at a rate of 5-6 per year consistent with the rate of 10 per year at all 78 HEP universities shown by Fig. 10. Adding the national Laboratories increases this rate very little--by 1-2 per year.

Firm numbers for the rate of new appointments to Assistant Professor and laboratory equivalent in both theory and experiment for AY75/76 and 76/77 will have to wait until the DOE/78 census. Our current guesses, based on informal surveys of universities and laboratories, are: 6-10 hires per year in theory and 8-12 per year in experiment.

Steady State Model

High energy physics will continue to be a viable and productive research field provided: (1) deep and fundamental issues continue to develop and demand investigation; (2) adequate funding is available for accelerator facilities and experimental equipment; and (3) if there is an adequate and orderly flow of new and talented researchers into the field. There is, of course, no way of predicting future discoveries or developments in fundamental research. It is our faith, however, that the past record of high energy physics, especially the many exciting developments of recent years, is indicative of a future with many opportunities for profound discoveries. It is our faith, too, that our nation will continue to support basic scientific research, including high energy physics, at a level of effort at least equal to that of the present. We are all aware of the many worthwhile opportunities which could be exploited at a higher level of support. It is not, however, our purpose to address this topic here. Rather we wish to focus on the third requirement--the necessity that an adequate number of new, high-quality researchers enter into permanent career positions in high energy physics.

Of the three requirements listed above, it is this third which involves the most complex issues, the answers to which cannot be found by simple rules. The judgment of what influx of manpower is adequate and what level of scientific creativity constitutes high quality will always be partly subjective. We present here some simple models which we have used to focus our thinking and to provide a framework for our recommendations in the next section. The reader need not accept our models to accept our recommendations.

As we have seen in Table III of the preceeding section, there are about 1220 Ph.D.'s (460 theoretical, 760 experimental) working in HEP at the level of Assistant Professor or higher. (Throughout this section all numbers for faculty ranks include laboratory equivalents.) An ideal model might be one in which the age distribution for the population is a uniform one beginning with new Assistant Professors of age 30-33 and extending to senior researchers at the retirement age of 65-68. Such a model would provide, through retirements and other mechanisms, the same number of new openings each year. Ideally, these would be filled by the most promising members of the post doctoral pool. Admittedly, selection processes are less than perfect and judgements of quality are colored by many other variables; but nevertheless, each new class of researchers would have roughly the same opportunity as those before and after. This is more desirable than the situation of the recent past of inflated opportunity in the 1960's and deflated opportunities in the 1970's. This cyclic pattern will tend to replicate itself if nothing is done.

We take 30 years as the average career time in the field after the post doctoral period. This allows for some attrition, transfers into university administration, etc. In the ideal model there would be, therefore, 15 openings per year in theoretical and 25 per year in experimental high energy physics. The uptake has been below this in recent years.

A more detailed model might be one which treats separately the non-tenured and tenured faculty and laboratory ranks and allows for an acceptable level of attrition at the transition. It is perhaps reasonable to assume 4 years as the average dwell time at the Assistant Professor level, a promotion probability to tenure of 67 percent (recall we are selecting Assistant Professors after 3-5 years of demonstrated post doctoral research), and 28 years as the "dwell" time in the tenure category. The results for a population of 460 theorists with uniform age distributions in each of the two tenure categories are: 80 Assistant Professors, 380 Tenured Professors, 20 new hirings at the Assistant Professor level, and 14 promotions to tenure each year. For a population of 760 experimentalists the same assumptions lead to: 134 Assistant Professors, 626 Tenured Professors, 34 new hirings at the Assistant Professor level and 22 promotions to tenure each year. Figs. 10 and 11 indicate that the annual promotion rate to tenure has been below these values.

Instead of the above models, one might use instead the simple rule of thumb that any ongoing organization must introduce new manpower at a rate of 3 percent per year (33-year turnover) in order to stay healthy over the long run. This rule is essentially identical to the first model sketched above and thus gives the same results.

All of the above models are obviously naive and will never be achieved. Nevertheless they give by comparison some indication of where HEP now stands and what kinds of adjustments are desirable. We emphasize that the above numbers are extremely conservative and allow for no net growth.

Recommendations

- 1) Better and more accurate statistics are needed on the composition and changes with time of the Post Doctoral and Assistant Professor pools as well as the rate at which people leave the Senior Faculty pool for reasons other than retirement.

We recommend, therefore, that a small but continuous effort be maintained in order to develop and record these data. A central component is the ongoing DOE/78 census of high energy physics which will bring up to date the valuable information in the ERDA/73 and ERDA/75 surveys.

We feel, too, that good use might be made of the detailed demographic information which is already provided to NSF and DOE in contract proposals and progress reports. Perhaps a standard format could be devised to make this information easily exploitable.

- 2) Predictions of future employment possibilities are extremely difficult and subject to large errors due to unforeseen events. Nevertheless:

We recommend that available data be widely distributed to workers in the field and to graduate students who are in the process of selecting their research specialty.

It is important for prospective students to know that there are genuine opportunities for careers in high energy physics. It is important for them to also know that the selection process is highly competitive and only the best and most talented can expect to endure.

Since other subfields of physics have not yet developed corresponding manpower data, it might be argued that our field will put itself at an artificial disadvantage by such publicity. We feel, however, that it is best to state as clearly and openly as possible the opportunity for careers in high energy physics. We believe that the serious student will use the information in a balanced way. Hopefully high energy physics can serve as a model and stimulus to other subfields of physics to develop and provide similar information.

- 3) High energy physics, like most of the other subfields of physics represented in academic departments, trains more workers than it can absorb. It is not necessary or desirable that everyone who gets a degree in HEP be assured of a lifetime position in the field. However, better recognition should be given the fact that many highly trained and highly talented HEP graduates will ultimately be pursuing alternative careers. In addition to ensuring that students receive broad training in graduate school more should be done.

In particular we recommend that a modest set of summer institutes, analogous to the many now organized around particular research topics, be organized with NSF/DOE support and focus on topics in newly developing areas of physics and applied physics which offer industrial and national laboratory (non-HEP) employment possibilities.

Such institutes should be pitched at the level of Ph.D.'s who have the research maturity of 2-4 years of Post Doctoral experience. These would give such physicists an excellent change to get started in a new field of research in advance of actually locating a new job. Several of the large multipurpose national laboratories (e.g., LASL, ORNL, ANL, etc.) would seem ideal hosts.

- 4) In spite of the fact that high energy theorists and experimentalists have found their way into the system in recent years, the numbers of new people are small. We believe the present numbers are inadequate to sustain the long-term health of the field.

Consequently, we recommend that a temporary program be created to retain a small additional number of experimentalists and theorists in semi-permanent positions. This will help bridge the gap until retirements become significant in 1985-1990 and thus help to reestablish a relatively uniform age profile within the field. It is important that a majority of these people are kept within the university physics departments in order that they have the maximum chance of obtaining appointments when such openings occur and that the expertise and enthusiasm of these relatively young people will help the very best of the next generation of graduate students.

A variety of methods of setting up and managing such programs can be envisaged. First and foremost, however, must be a commitment to adopt such a program. Given that, the detailed mechanisms can be worked out and adjusted as time and experience dictate. Close cooperation and participation from the funding agencies is clearly required but is likely given the concern of these agencies for the health of U.S. science.

This Subpanel suggests two methods of setting up semi-permanent positions in HEP. First, the funding agencies should encourage the large contract groups to transfer some of their post doctoral money to long-term positions or provide a small amount of money earmarked for such positions. This would retain experienced physicists who are necessary to the success of complex experiments. A number of universities have already begun such a program because of the severe reduction in available Assistant Professorships. However, it is not clear that these positions have achieved the status and prestige that the holders need and deserve.

When done under group auspices, the appointments should be made through the physics departments so that the appointee's qualifications are known to the entire faculty. To further integrate these people into the department, they should carry some department responsibility, including the teaching of up to one course per year. This, coupled with either a rolling tenure or a 5-year renewal term of appointment, would foster the view of these people as semi-permanent, integral additions to their departments. These people would then, hopefully, be considered for regular faculty positions when openings occur. Salary support of appointees, in proportion to their teaching load, should be borne by departmental instructional funds, not by research contract funds.

The second method we propose is a program of 5-year national fellowships, administered by the funding agencies. A fellowship should have a prerequisite of 4 years of Post Doctoral experience and the possibility of renewal for one additional 5-year term. The award would be made through an institution of the fellow's choice. This would allow the applicant to negotiate with several departments and choose one suited to his or her research interests and offering the prospect of a permanent position at the end of the fellowship. As with the first program, involvement in physics departmental affairs would be encouraged. The national selection carries with it an element of prestige not as evident as in the departmental selection, possibly compensating for the reduced long-term commitment made by the department.

It is anticipated that this second method will prove most beneficial in the case of theorists. Hopefully, both NSF and DOE together would utilize both methods, thus incorporating a degree of pluralism in the selection process. It should be noted that selection after 4 or more years of research experience will make the process of selection more reliable. However, considerable care should be taken in applying both methods in order that the most promising few are selected.

The actual number of semi-permanent positions to be created at the beginning of the program can be set once the DOE/78 census information is available. This census, together with the earlier ones, will provide a clear and complete record of the manpower changes in HEP over a span of 5 years. Similarly, the size and scale of the program in future years should be determined by watching the uptake of high energy physicists into university and national laboratory career positions. The program is a low risk one and can be scaled up or down as required. We anticipate that the program would be largest in the first year

or two in order to pick out of the senior members of the post doctoral pool the best and most productive researchers who completed graduate study when Ph.D. production in HEP was substantially higher than at present. The number of new positions created each year would then decrease with time. It is not possible to say precisely at this time how long the program should function, but, as remarked earlier, the time scale is roughly a decade. The program is conceived as, and should remain, a temporary one. We emphasize that one cannot state with certainty that recipients of long-term appointments as described above will ultimately find permanent positions in HEP. Careful selection of the people will tend to maximize the possibility; other aspects of the program should have this goal in mind as well.

- 5) Recommendation 4 is not highly original, in fact one or another version has been suggested by many others from time-to-time. And, as we have found, parts of such a program are developing spontaneously. What is needed is a clear endorsement from the field itself after adequate discussion. Some central planning is also needed in order that the program not grow too large or too rapidly and thereby create a new set of problems. It is important, however, to get on with the task.

We recommend that the merits and detailed mechanisms of the program outlined in Recommendation 4 be settled as soon as possible in order to initiate the program for AY78/79.

Acknowledgments

The Subpanel members thank Dr. Robert Woods of the DOE Division of High Energy Physics for his valuable assistance with the ERDA census information, Beverly F. Porter of the AIP for generously providing manpower data gathered by her office, and the many other individuals who assisted our work by answering endless phone calls and survey forms.

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FIGURES

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Fig.I No. Ph.D's in HEP

Fig.2 ERDA/AEC HEP Manpower;
Ph.D Count at end of each
fiscal year.

Fig.3 Post-Doctoral Representation in Physics and Astronomy Subfields

Fig. 4A Year of Birth

Fig. 5A Year of Birth

Fig.5B Year of Birth

Growth of Faculty Ranks in Departments Granting the Ph.D in Physics or Astronomy

Size of Faculty Rank - normalized to unity in 1962-63

Fig.6 Academic Year

Number of Physics Faculty Members
Total counts in Physics Directory
(Astronomy Depts. excluded)
Source-AIP, Physics Manpower, 1973

Fig. 7

Comparison of junior faculty openings with earned doctorates awarded, actual 1948-1973, projected 1974-1990. (Source: A. Cartter)

Fig. 9 Ph.D. Production

Theoretical Assistant Professors Listed in 1973 HEP Census

1973 HEP Census

1975 HEP Census

1976-77

Status of 79 Assistant Prof.

Experimental Assistant Professors Listed in
1973 HEP Census

Fig. II

Fig.12

Fig.13

Fig.14

Fig.15

Fig.16

Fig.17

Fig. 18

Fig.19

Fig.20

Fig. 21