Demographics of Investigators Involved in OSSA-Funded Research

01 February 1991

A Report in Partial Fulfillment of Grant NAGW-1415

to

The Center for Space and Geosciences Policy

University of Colorado

S. Alan Stern[1]

Ronald Konkel[2]

Jay Habegger[1]

and

Radford Byerly, Jr.[1]

28 Manuscript Pages

39 Figures, 7 Tables

[1] Center for Space and Geosciences Policy, University of Colorado, Boulder, CO 80309-0361.

[2] Retired/NASA Headquarters, Office of Space Science and Applications, Washington, D.C., 20546.

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I. Executive Summary

The purpose of this study was to describe the characteristics of the NASA Office of Space Science and Applications (OSSA) Principal Investigator/Co-Investigator (PI/Co-I) population and to determine the degree to which the OSSA space science investigator population faces a "retirement wave." PIs represent the "leadership" of the OSSA scientific population; Co-Is represent an important facet of the PI "replacement" population.

To conduct the study, we investigated the demographics of the present PI (Principal Investigator) and Co-I (Co-Investigator) populations contained in a data base formed from OSSA's Announcement of Opportunity (AO) mailing list. Using the demographic data, we then modelled the future PI population for the years 1991 through 2010 under various NASA and PI growth scenarios. These PI population projections and demand scenarios were then compared to determine the conditions under which a shortfall might be expected to occur.

We chose eight parameters to use in our examination of the aging and general demographic characteristics of the U.S. space sciences research population. These are: gender, year of birth, country of birth, level of highest degree, year of highest degree, primary research field, type of employer (e.g., academe, NASA, other government), and state of residence. To obtain this information for members of the AO Data Base, we searched for each PI in a variety of biographic sources (e.g., American Men and Women of Science). Individuals not identified through these sources were contacted by telephone or located through the Membership Records of the American Astronomical Society and NASA internal data bases. Of the 3517 PIs in the NASA AO Data Base, 259 names were discarded because they consisted of either duplicate records or nonpersons with generic titles such as "Department Chairman", "University Vice President", or "Librarian." Thus, 3258 records were retained. We ultimately located and found age and other data on 2874 individuals. After excluding discarded names, our final search success rate on OSSA PIs was 88%. The information gathered was entered into a computerized data base for analysis.

The primary finding of this initial study was that over 27% of OSSA PIs are over 55 years of age, and thus within 10 years or less of "standard" retirement; 65% are over 45 years old and hence within about 20 years of retirement. A typical OSSA PI is a male, 50 years old, employed in academe, who received his PhD at age 29. The mean age of OSSA PIs was found to be approximately independent of employment sector and scientific discipline.

We also documented the demographic state of the OSSA Co-I population which subscribes to OSSA AOs. Unfortunately, however, we were not able to determine the fraction of the total OSSA Co-I population which are contained in the AO mailing list; therefore we could not determine how representative a sample the AO data base contains. For several reasons (e.g., the much smaller number of Co-Is than PIs in the mailing list), we strongly suspect that the population we studied is not representative of the whole Co-I population.

We also forecast the future population of OSSA PIs using a PI population model based on data derived from our study and a set of varying demand scenarios. *We found that if OSSA grows significantly, current rates of PI attrition and replacement imply a serious shortfall of PIs by the late 1990s. Other factors, such as the inflow of investigators from fields outside space science, may naturally satisfy even the most ambitious OSSA growth scenarios if funding is available to attract "outside" investigators. However, even more serious than the potential shortfall of PIs will be the loss of so many highly-experienced investigators who were exposed to high flight rate opportunitites of the 1960s and 1970s. Therefore, beyond making up any future quantitative shortfall in its PI population, OSSA must also address the serious potential for a qualitative decrease in experience level and quality of the aggregate PI population.*

Finally, we make several recommendations based on our prediction of a potential shortfall if OSSA PI requirements grow dramatically. These include: (i) a recommendation for additional studies to better document historical trends in the PI and Co-I populations (the AO data base only allows a current-day "snapshot" to be studied); (ii) a recommendation for enhanced early-career stability for space science researchers in order to reduce early-career attrition rates from the field; and (iii) a recommendation to increase the effectivness of PIs by creating a para-professional career track for Masters-level researchers who would assist PIs, thereby decreasing the need for growth in the number of PhD-trained PIs.

II. Introduction

The birth of the U.S. civil space program and the subsequent, dramatic growth in the ranks of the space science research population occurred in the 1950s and 1960s[1]. The large, post-Sputnik/Apollo buildup in space program manpower is now approximately one career-lifetime in the past. It is therefore natural to anticipate that a large fraction of the space program engineers, scientists, and managers who pioneered the early exploration of space are approaching retirement. Such a "retirement wave" bodes both a loss of manpower and, more fundamentally, a loss of experience from the civil-space manpower base. Such losses could play a critical role constraining in NASA's ability to expand or maintain its technical capabilities. If this indeed applies to the NASA space science research population, then the potential for problems is exacerbated by the anticipated growth in flight rates, data volume, and data-set diversity which will accompany the planned expansion in the OSSA science effort during the 1990s and 2000s.

The purpose of this study was to describe the OSSA PI/Co-I population and to determine the degree to which the OSSA space science investigator population faces a retirement wave, and to estimate the future population of PIs in the 1990-2010 era.

To conduct such a study, we investigated the present demographics of the PI and Co-I population contained in the NASA/OSSA Announcement of Opportunity (AO) mailing list. PIs represent the "leadership" class of the OSSA scientific researcher population, and Co-Is represent one important, oncoming component of the "replacement" generation. Using the PI population data, we then make projection estimates of the future PI population from 1991 through 2010, under various NASA growth/PI demand scenarios.

III. Scope

In accordance with the statement of work outlining the grant renewal for NAGW-1415, the University of Colorado's Center for Space and Geosciences Policy has expanded its initial, in-house study of the demographics of the OSSA science investigator population by conducting three additional study tasks and producing a comprehensive report to NASA's Office of Space Science and Applications. This document constitutes that report.

We expect the results of the study reported here to be a useful planning tool for OSSA. The three new studies outlined in our proposal and reported here are:

- **Task 1: Compile Detailed Demographic Breakdowns of the OSSA PI Data Base Developed in the Initial CU Study.** Determine the number of PIs by state and by discipline, by region, by NASA Center (including JPL), determine the fraction of foreign-born PIs in the data base, and determine the breakdown by discipline, and by employer type.

- **Task 2: Compile a Demographic Data Base for All Co-Investigators in the NASA AO Mailing List.** This new data base is identical in its attributes to the data base described in Task 1 for OSSA PIs. The purpose of this task is to document demographic differences between PIs and Co-Is. To do so, we repeated the research done in our initial study for all Co-Is contained in the OSSA AO data base. We then determined the age distribution, gender ratio, education level, and employer-type for the Co-I population in the OSSA AO Data Base.

- **Task 3: Construct Pipeline Analyses of PI Sources and Sinks to Predict the Requirements for and Future Population of Space Science PIs Through 2010.** Using the CU PI data base, we analytically modelled the retirement and attrition rates of PIs for the years 1991-2000. These results, together with anticipated OSSA-demand, were employed to generate a "demand" analysis for future PI needs in this time period. We used historical data from the period 1969-1989 to predict the expected replacement rate of space science PIs, and recently-compiled data on retirement/attrition rates of the entire US academic population to model the future attrition and replacement rates of space science PIs. The difference between the combined replacement plus retirement/attrition rates minus estimated demand is used to forecast the expected PI deficit, or surplus, as a function of time during the period 1991-2010.

- **Task 4: Report Our Results.** The results of the three proposed Task Studies were reported to OSSA Assistant Associate Administrator Alexander in a presentation on November 9, 1990 and in this final report. This report describes the scope, methodology, and results of the three study tasks outlined above. Accompanying this report, as described in Appendix A, we also deliver to OSSA diskettes containing the CU PI/Co-I data base, and a description of the data contained on those diskettes.

IV. Demographics of the OSSA Principal Investigator Population

Methodology

To identify OSSA PIs, we employed a computerized mailing/data base list maintained by OSSA that identifies individuals and organizations receiving NASA Announcements of Opportunity (AOs) and other funding solicitations. Because the AO mailing list provides the mechanism by which PIs, and potential PIs, are informed of funding opportuntities, it is strongly to the advantage of current and prospective PIs to be on this list. This data base is continuously updated and contained over 7300 names at the time we initiated our work. In what follows we will refer to this source as the AO Data Base (AODB).

Not all of the mailing records in the AODB are actual PIs; 403 identified themselves a Co-Is; another 3385 did not identify themselves as either Principal Investigators or Co-Investigators. Further, some are generic, institutional addresses, and others presumably represent prospective PIs. In the study performed here, we eliminated from the list all "generic" institutional addresses (259 records), as well as those records in which the individual stated that he or she was not, at present, a PI or Co-I. We then assumed that the remaining list of 3253 individuals is both *nearly comprehensive and actually representative of* the entire PI population. The validity of these assumptions will be discussed below, under the subsection entitled Sources of Error.

As stated above, we restrict our interest here to the 3253 individuals in the AO Data Base who identified themselves as Principal Investigators. A PI is the lead researcher responsible for one or more grants or contracts. As such, PIs represent the experienced "leadership" population of the NASA research community.

We selected eight parameters for study: gender, year of birth, country of birth, level of highest degree, year of highest degree, primary research field, type of employer (e.g., academe, NASA, other government), and state of residence. To obtain this information, we searched the following four primary biographical sources:

- *American Men and Women of Science* (16th Edition, R.R. Bowker Co., New York, 1986);

- *Who's Who in Frontiers of Science and Technology* (1st Edition, Marquis Who's Who, Inc., New York, 1985);
- *Who's Who in America* (various editions); and,
- The membership records of the American Astronomical Society and the American Geophysical Union (both in Washington, D.C.);

Individuals not identified through these sources were either contacted by telephone or looked up in *Dissertation Abstracts*[2]. Of the 3253 records associated with PIs in the AO Data Base, we ultimately located and found information on 2874 names.

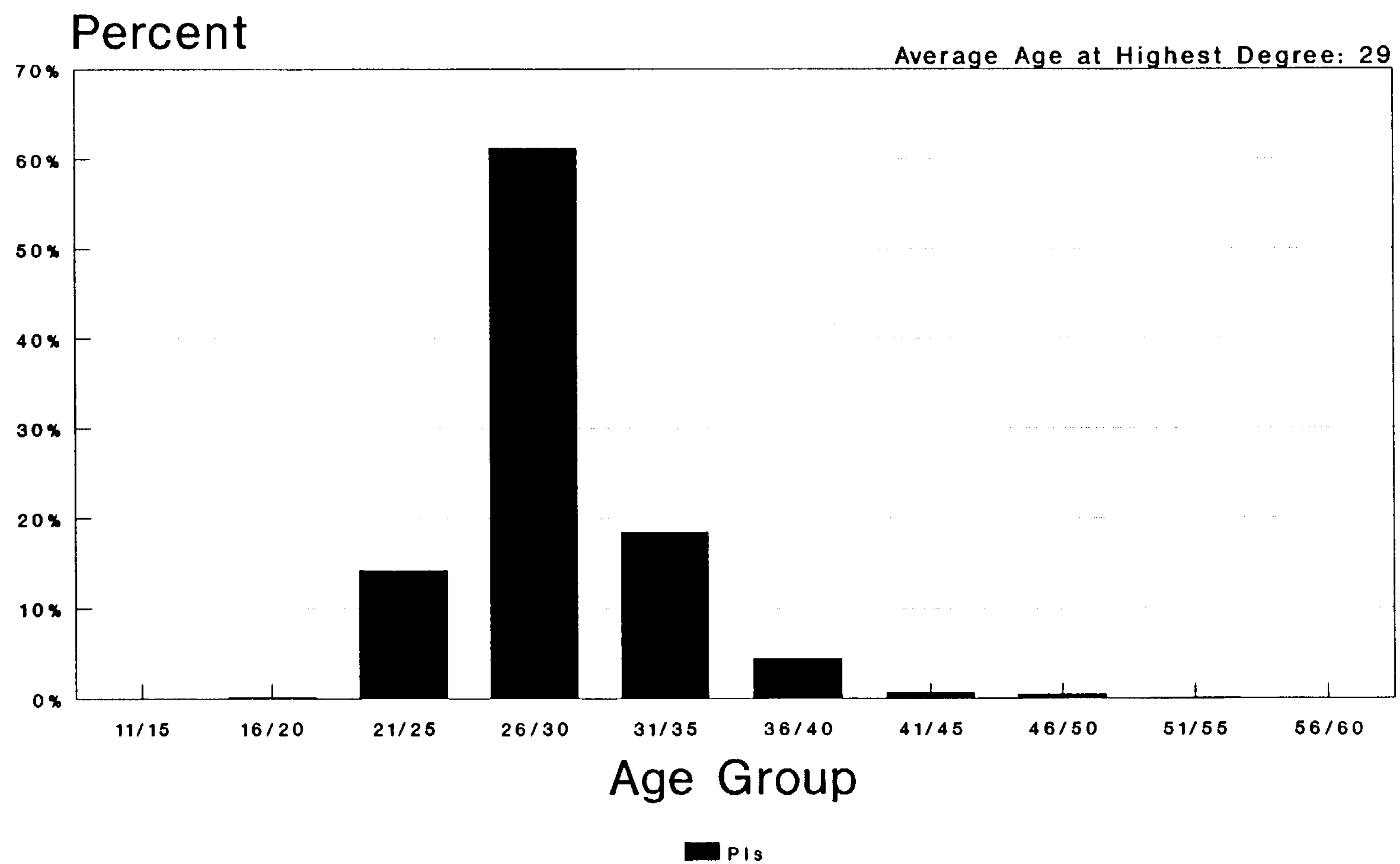
For individuals located in one of the four primary biographic data sources given above, all of the eight demographic parameters were documented. Approximately 2232 individuals were located in this way. This corresponds to 69% of the AODB PI records (259 discards excluded).

For individuals whose age could not be located in the four biographic sources, we used PhD *Dissertation Abstracts*[2] to determine the year in which the individual obtained his or her PhD. For the PIs found in *Dissertation Abstracts* (about 19% of the AODB PIs), we employed the year of PhD award to calculate a proxy for birth date; the remaining 12% of the OSSA PIs given in the AODB were not located in any source. The device of using PhD award date as a proxy for age was empirically justified by our finding that of the $\approx$2232 PIs whose age could be explicitly identified, the age at PhD award clustered around a mean age of 29 ± 4.6 years (1σ). We improved on this estimate by using a decade-by-decade average age at time of PhD Figure 1 shows the age at PhD award for the population located in the biographical sources described above.

Figure 2 shows the mean age at PhD award as a function of the decade at which the PhD was awarded. This graph demonstrates a definite trend toward progressively older age at time of PhD award. PIs graduating in the 1980s were, on average, about 3 years older than PIs graduating in the 1940s.

We obtained a linear fit to the data in Figure 2 in order to make use of year-of-degree data to find a proxy for year of birth. For those $\approx$ 642 individuals whom we located in *Dissertation Abstracts*, we applied this proxy to estimate their year of birth. To further

Age of PIs At Highest Degree
(Only PIs with year of birth data)

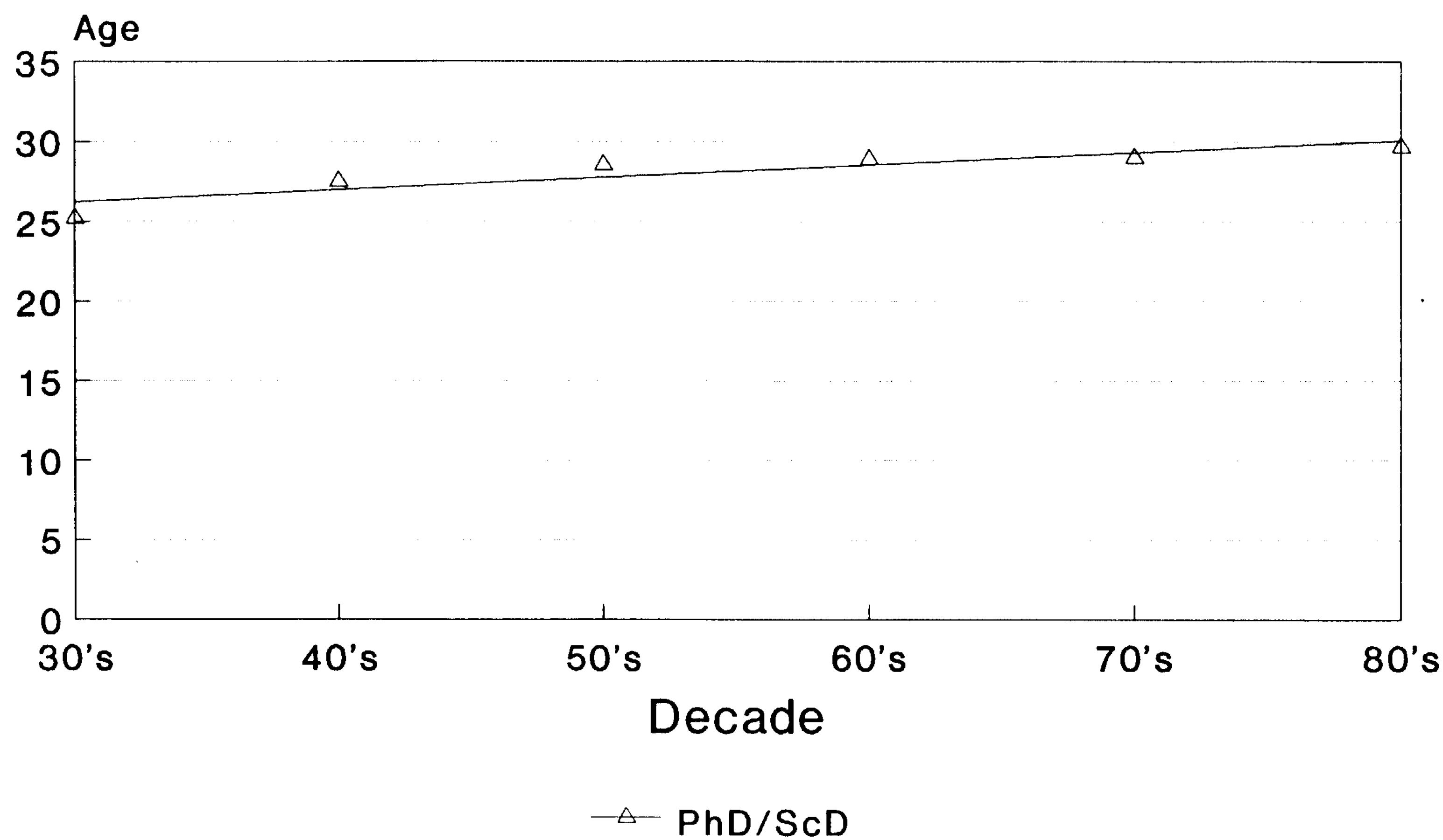


N = 2217

Figure 1

Produced: 9/90

Average PI Age
At Time of PhD



N = 2026

Figure 2

Produced: 9/90

validate this assumption, we called some 100 individuals for whom the proxy was required, and obtained their year of birth directly. For these 100 individuals, we found that the year-of-degree, proxy-derived age histogram, once summed into three years bins, was virtually identical to the actual age distribution.

Figure 3 depicts both (a) the actual age distribution of those PIs for whom we found year-of-birth information, and (b) the entire OSSA PI population, using the year-of-PhD proxy-derived ages when year-of-birth information was not available. The latter curve is somewhat younger, which we suspect is due to the fact that younger PIs (for whom we generally had to use the date-of-PhD proxy) are less likely than older PIs to be in the bibliographic sources such as Who's Who.

Including proxy-derived ages, we ultimately derived age data on 88% of the PIs in the AODB. Other information (besides age) was found on the 69% whom we located in the four full biographic sources. The information gathered was entered into a computerized data base for analysis, which we report in the PI Results subsection below. In what follows we will refer to this computerized, demographic data base as the Colorado OSSA Investigator Demographic Data Base. Table 1 summarizes our methodology.

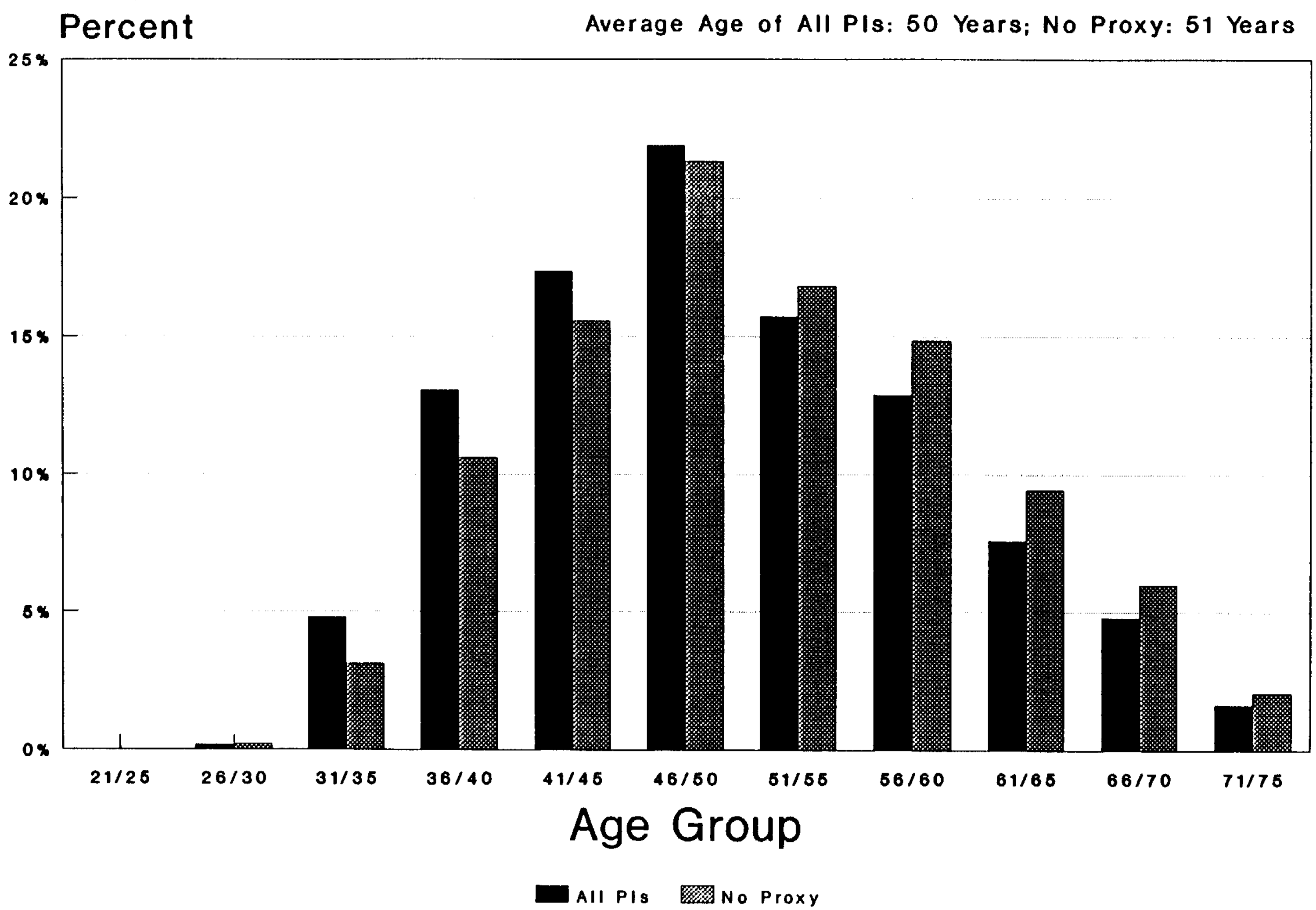
Sources of Error

In the findings which follow, we assume that the individuals in the AO Data Base well-represent the total population of OSSA PIs in the United States. The validity of this assumption rests on (1) the fact that over 95% of all non-defense space research conducted by the Federal Government is conducted with NASA funds[4] and (2) that we were able to obtain demographic information on over 88% of the OSSA PI population (see above).

The results obtained below are, however, subject to several potential sources of error. These include errors due to statistical sampling techniques, errors in locating and transcribing data about PIs from the biographic sources, computer data entry errors, and incompleteness of the OSSA AO Data Base.

Statistical sampling errors were eliminated by the decision to enumerate (rather than statistically sample) the data base. By capturing the great majority of PIs in the AO Data Base, our results are insensitive to any reasonable age distribution of the remaining,

Age of All PIs



All: N = 2855; No Proxy: N = 2217

Figure 3

Produced: 9/90

STUDY METHODOLOGY: TASKS 1 AND 2

Quantify Current PI and CO-I Demographics

- Enumeration (NOT Sampling) Strategy

- Used AO mailing list and Biographical Data Sources (e.g., American Men & Women of Science) to Locate Information on Investigators (3253 PIs, 403 CO-Is in the AO Data Base).

  - Birth Date and Country
  - Gender
  - Terminal Degree

- Cross Checks Used to Verify Accuracy of the Search

- Data Entered into Computerized Data Base

- Commercially Available Software Used to Analyze Data

Table 1

Produced: 10/90

unlocated PIs in the data base. The error rate in our data was documented to be <1% through a system of quality control cross checking between three researchers. Data entry errors were minimized by cross checking computer records against hardcopy data entry forms.

The remaining sources of possible descrepancy between our findings and the actual OSSA PI population center on the completeness of the AO Data Base. We used the 1985-1988 *NASA University Program: Management Information System* documents to cross-match funded PIs against PIs in the AODB. We found that although the ratio varied from university to university, approximately 75% of the PIs in the AODB base were listed by NASA as having received funding between 1985 and 1988; this strongly suggests that the AO data base results are indeed representative of the OSSA PI community.

PI Findings

In this subsection, we present the demographic results obtained in our study of the OSSA PI population. We begin by describing the demographic characteristics of the PI population and then proceed to describe the age distributions of the entire PI community, as well as various subsets of that community.

The PIs contained in our data base are 95% male. As shown in Figure 4, some 89% were born in the United States. Of those who are foreign born, 61% come from Canada and Europe, 25% from Asia, and 14% from other places. Of those from Europe, the U.K. comprises the largest share; of those from Asia, those from China and India together make up 75%.

As depicted in Figure 5, approximately 93% of the PIs have PhD or ScD degrees; 4% earned Master's degrees as their terminal degree; 2% hold only Bachelor's degrees; and 2% hold medical degrees (e.g., MD, DDS, DVM). When examining the education level of foreign born OSSA PIs, we found similar results to the total population, with a moderate preference for medical degress over the domestic-born PI population: 95% have PhD/ScD degrees, 3% have medical degrees, and 2% have Master's; none hold only Bachelor's degrees.

Figure 6*a* depicts the employment-sector distribution of the PI population. No-

Origin of PIs And Place of Birth

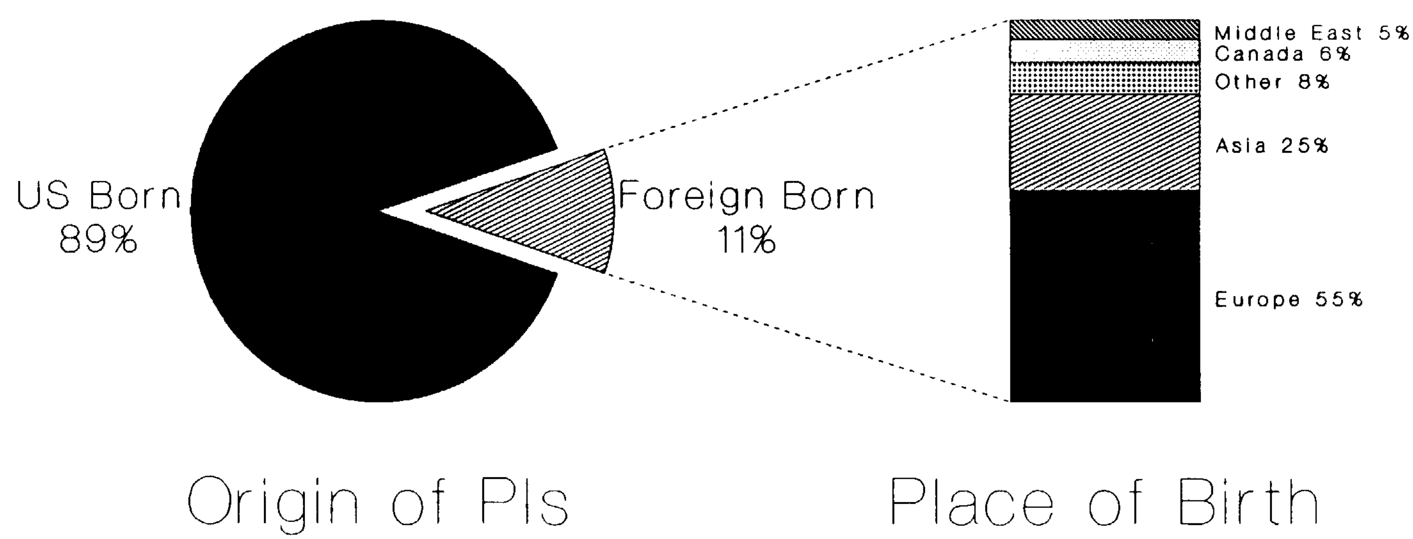
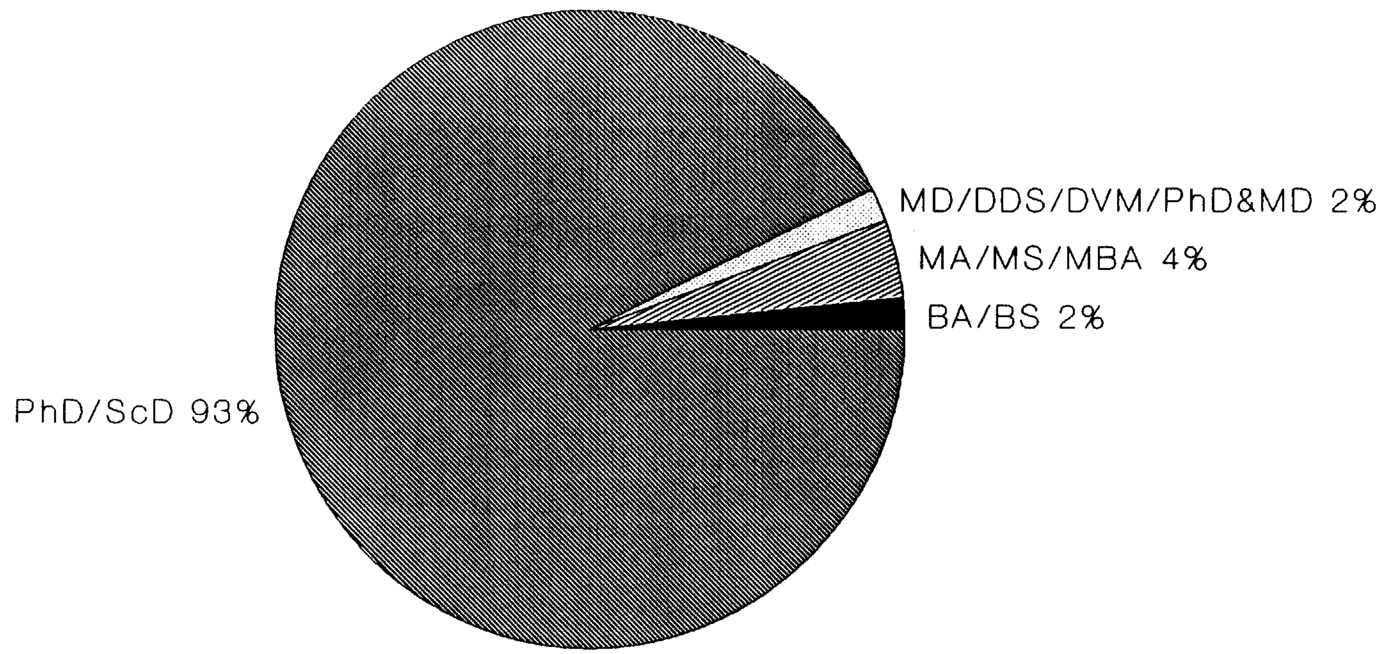


Figure 4

Produced: 9/90

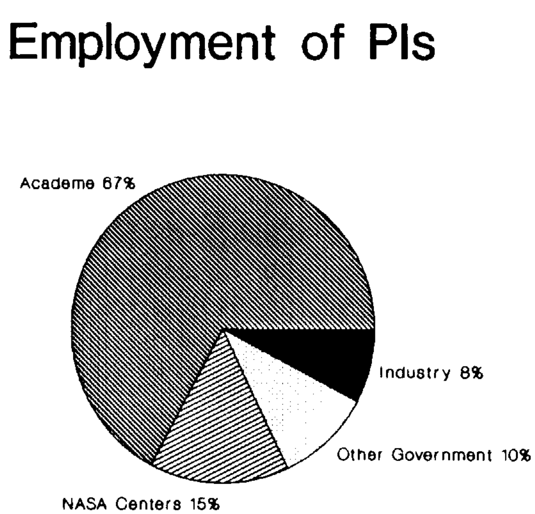
Distribution of Degrees for PIs



N = 2864

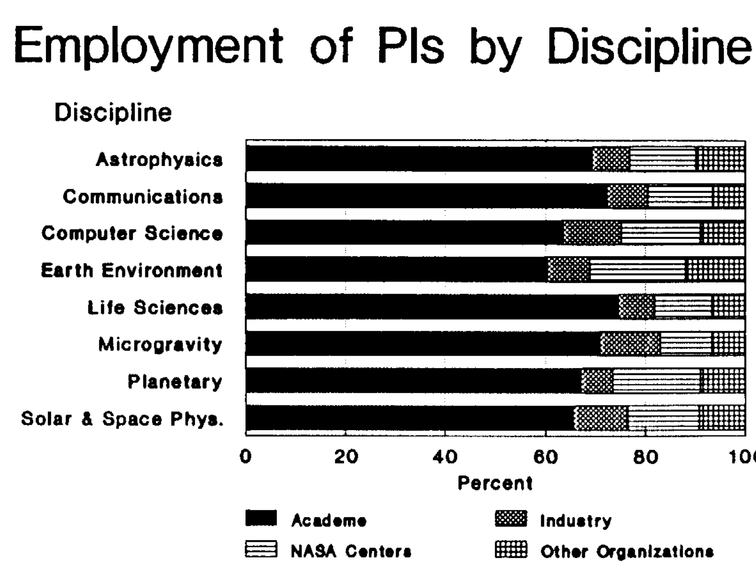
Figure 5

Produced: 9/90



N • 2866

Panel a



N • 2874

Panel b

Figure 6

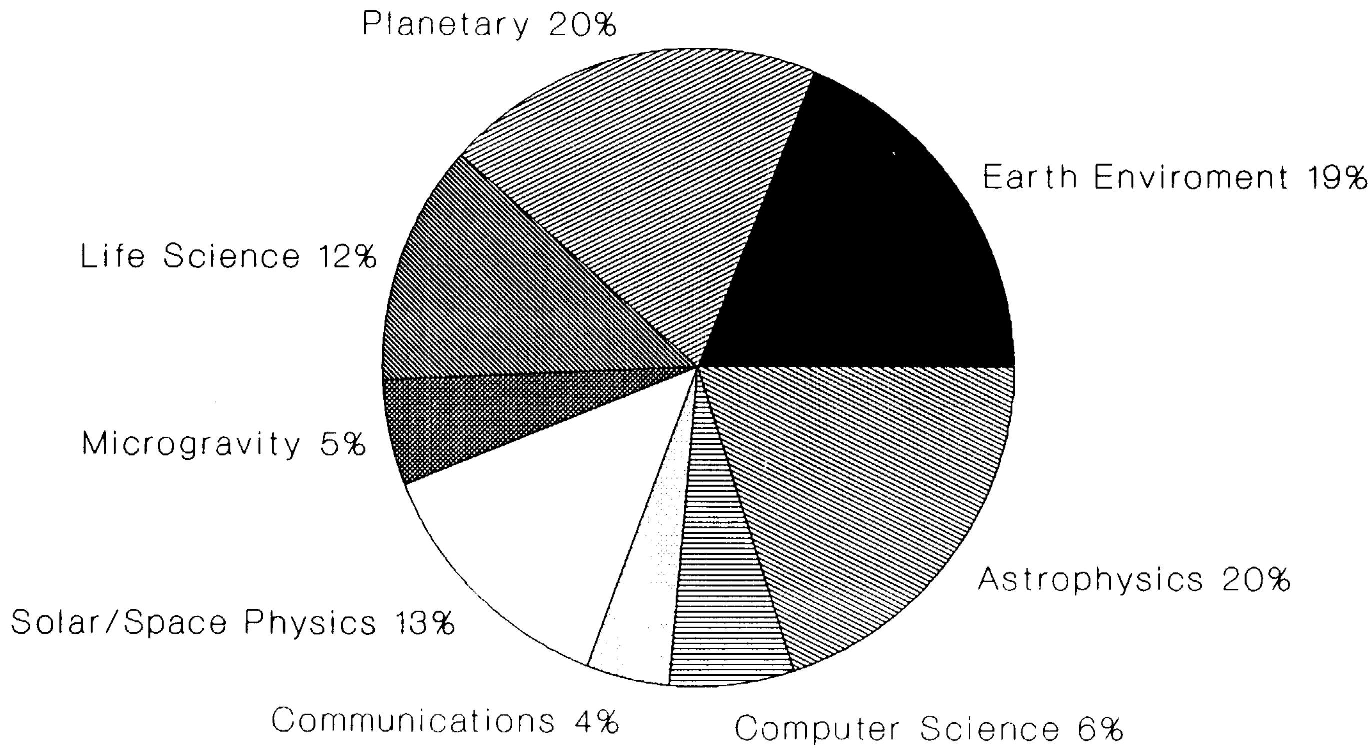
Produced: 12/90

tice the importance of academic researchers to the PI population: two-thirds of the PIs are employed in academe. The second major employment sector for OSSA PIs is the NASA centers (15%); industry (8%) and other government agencies (10%) employ the remainder. By examining the distribution of employment sectors of OSSA PIs as a function of their primary research discipline (Figure 6*b*), we found that the general ratios of academe: NASA: industry: other government are approximately equal in all fields.

When we broke down the employment sector distribution by degree level (i.e., PhD, Master's, Bachelor's, or medical), we found similar degree-level distribution. However, we find it worth noting that 1/3 of those PIs with only Bachelor's or Master's degrees work for NASA; although this is expected in the sense that one might expect a higher percentage of non-PhD PIs to reside outside academe, it also implies that NASA center-employed PIs (including JPL) typically have lower education levels than the general PI population. We also note that of those OSSA PIs employed by NASA, the largest fraction (35%) are at GSFC, while 28% are at JPL, and 17% are at ARC; other NASA centers comprise only 18% of the NASA-employed PIs, or 77 individuals. Finally, we found that the mean age of PIs is inversely correlated with education, so that the mean age is youngest for PhDs, older for Master's level PIs, and older still for those with only Bachelor's degrees. By examining the age distribution of those PIs with Bachelor's- and Master's-level degrees, we found most of these individuals entered the workforce at the beginning of the space program, when the demand for investigators was growing rapidly.

In Figure 7 we depict the breakdown of PIs as a function of the research disciplines in which they expressed interest in receiving NASA Research Announcements (NRAs). These data were compiled exclusively from the AODB. Notice that an approximately equal number of PIs report involvement in the three largest discipline sectors, earth environment, planetary science, and astrophysics. Life sciences and space physics then fall into a second category with about 12-13% of the PIs reporting involvement in each, with much smaller numbers comprising the microgravity, computer science, and communications disciplines. We find it worthwhile to note that by combining these data with those in Figure 5, we find that the vast majority of life sciences PIs in our data base do not have medical degrees, but

Interest Areas of PIs



N = 2874

Figure 7

Produced: 9/90

CENSUS GEOGRAPHIC REGIONS AND DIVISIONS OF THE UNITED STATES

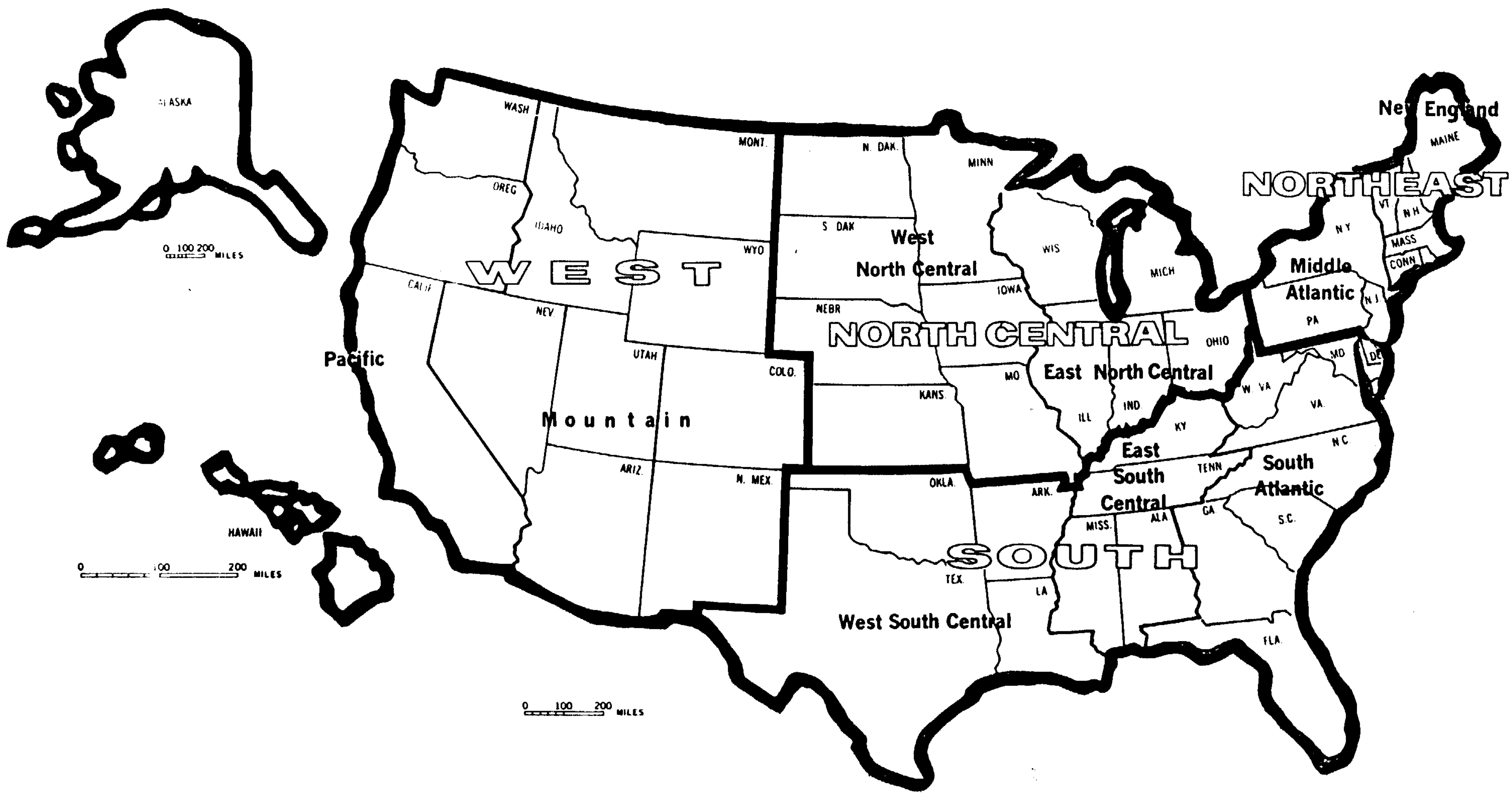
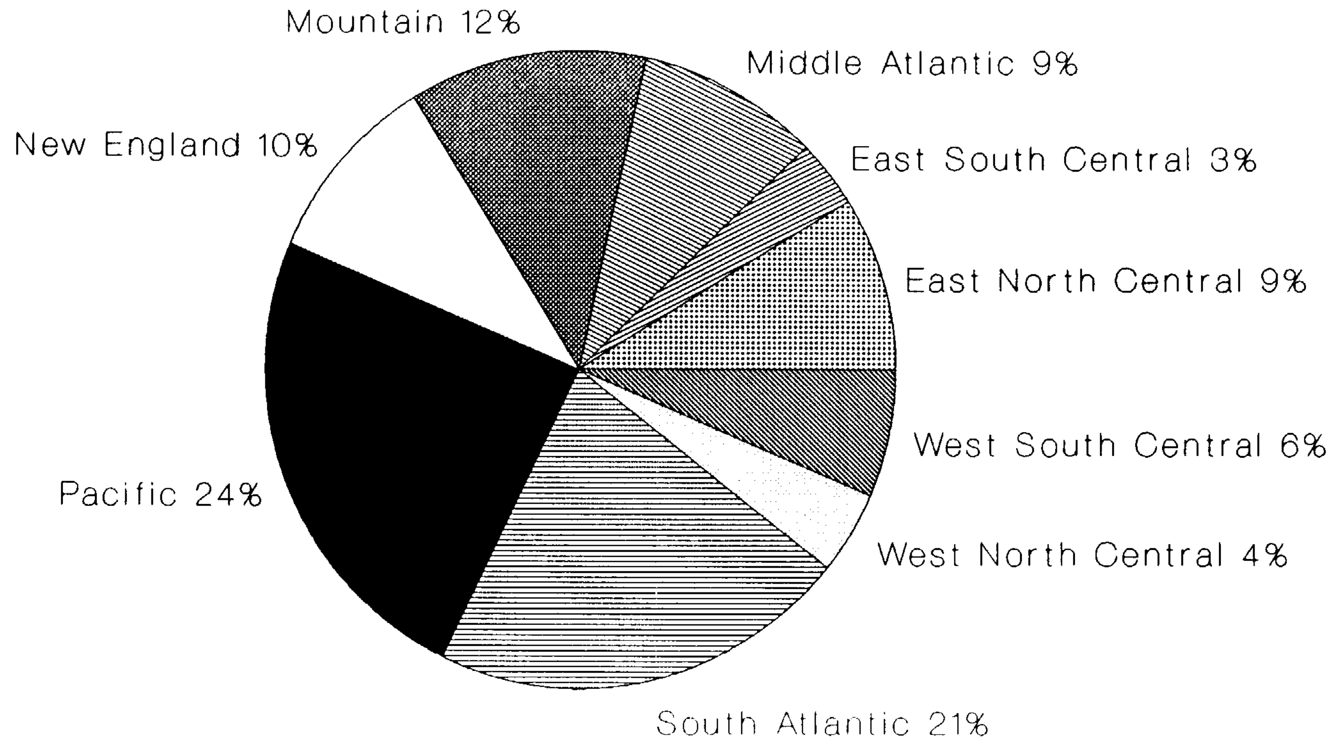


Figure 8

U.S. DEPARTMENT OF COMMERCE
BUREAU OF THE CENSUS

Location of PIs



N = 2872

Figure 9

Produced: 9/90

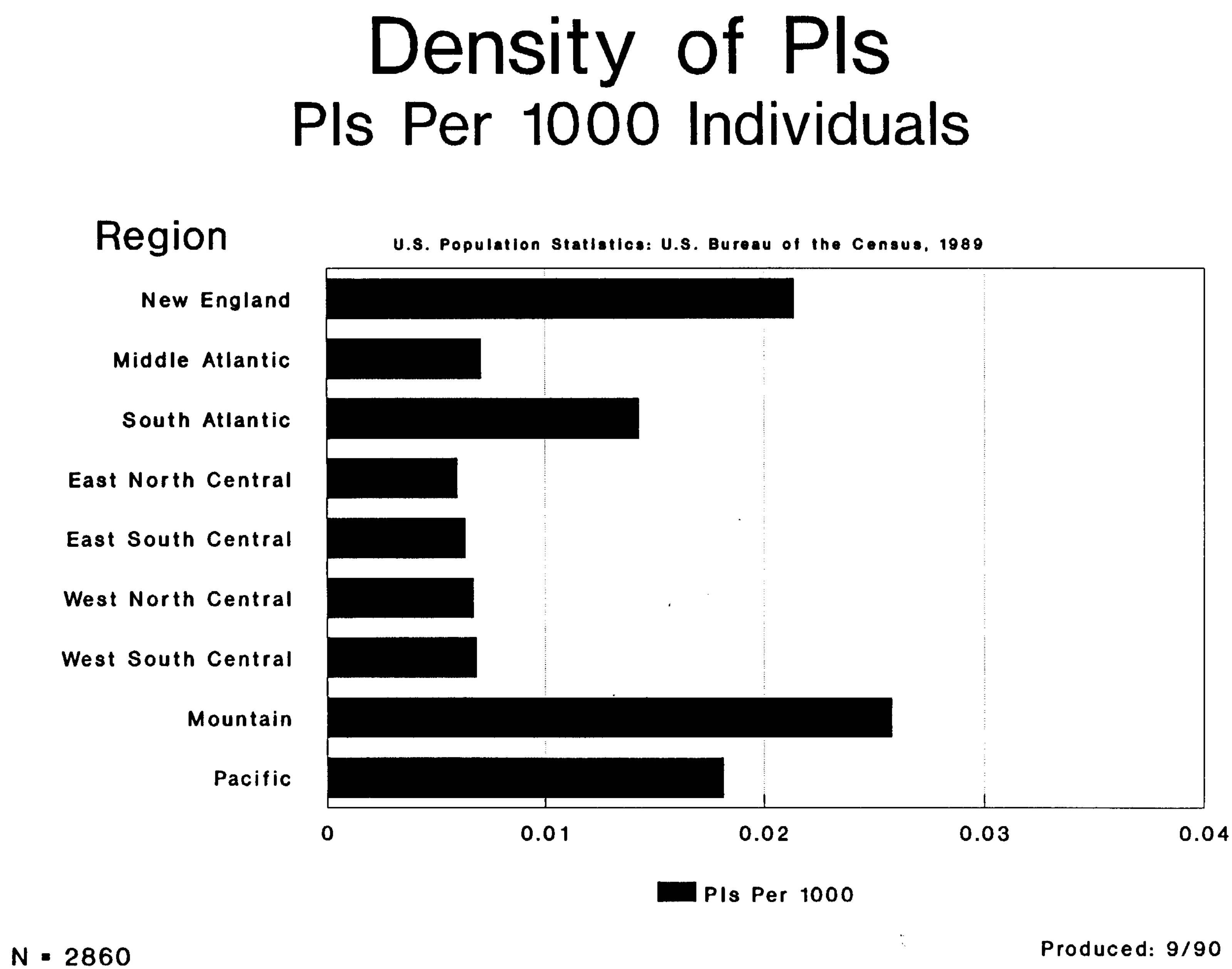

Density of PIs
PIs Per 1000 Individuals
Region
U.S. Population Statistics: U.S. Bureau of the Census, 1989
New England
Middle Atlantic
South Atlantic
East North Central
East South Central
West North Central
West South Central
Mountain
Pacific
0
0.01
0.02
0.03
0.04
PIs Per 1000
N = 2860
Produced: 9/90

Figure 10

instead hold PhDs. This may reflect the fact that most funded space life sciences research is not clinical in nature.

We now turn to the breakdown of OSSA PIs by their location in the U.S. We chose to adopt the U.S. Census Bureau's geographic definitions for regions, as depicted in Figure 8. In Figure 9, we show the percentage of PIs in the data base who reside in each region. The south Atlantic and Pacific regions alone contain half of the PIs. Figure 10 presents these data in a slightly different form. Rather than absolute percentages of PIs per region, Figure 10 depicts the number OSSA PIs per capita, using data from the U.S. Census Bureau. These results show there is a bi-modal distribution of PIs/per capita, with a PI-poor group from the mid-Atlantic, east-North Central, east-South Central, west-North Central, and west-south Central regions, and a PI-rich set (with some 2-3 more PIs/capita) from the New England, Mountain and Pacific regions.

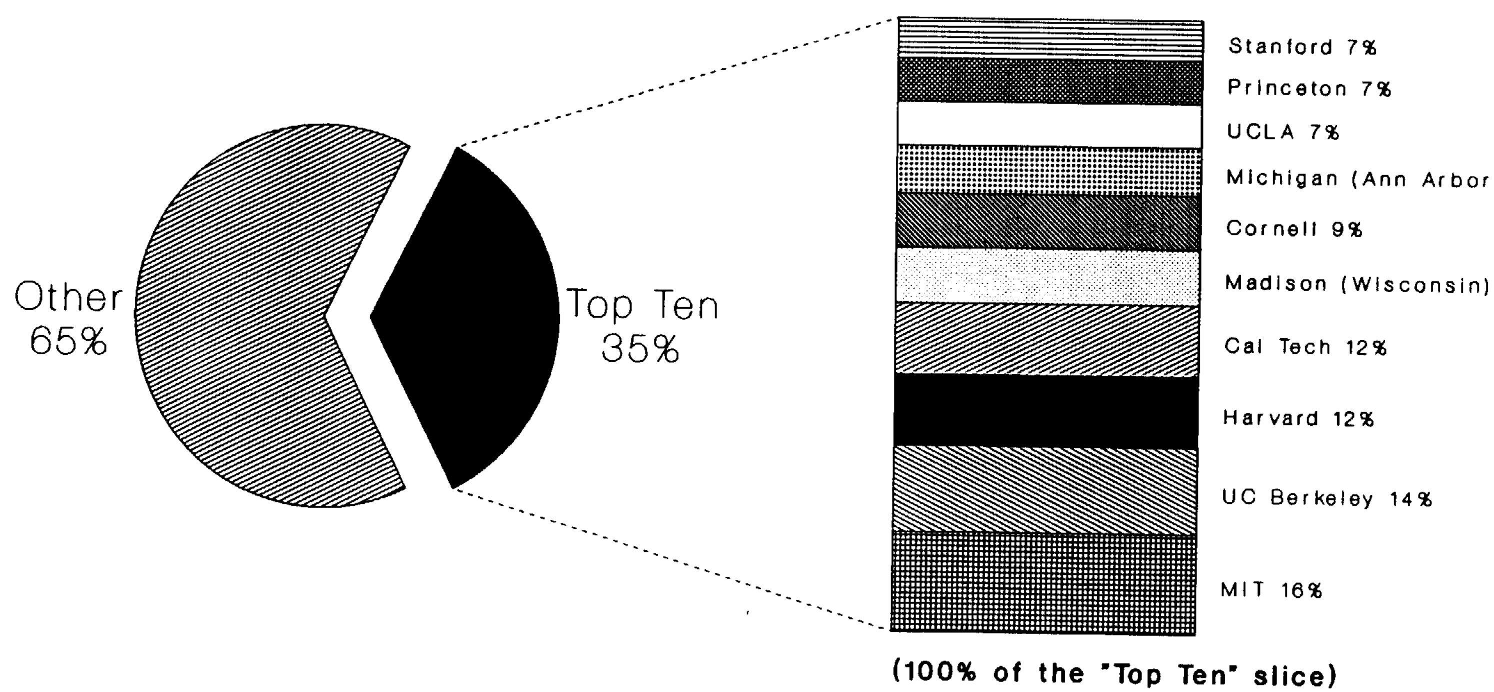
Figure 11 depicts the breakdown of OSSA PIs by their institution of highest degree. Fully 35% of the OSSA PIs we located were trained in just 10 institutions.

We now turn to the age structure of the OSSA PI population. Figure 12 presents the overall distribution of ages of all PIs contained in our data base. The peak lies in the 46-50 year old group. Integrating over these data, we find two key results. First, the PI population is dominated by the 40-60 age group; only 22% of the PIs are younger than 40 or older than 60. Secondly, and more importantly, 43% of the present-day PIs are over 50 years of age, and thus within 15 years of "standard" retirement age; 65% are within 20 years of retirement. Shortly below, we compare the age structure of the OSSA PI population to scientists supported by other Federal Agencies.

We now compare the age structure of male and female OSSA PIs. As shown in Figure 13, the female PI population is substantially younger (about 6 years different in the mean). These data clearly demonstrate a recent influx of females into the NASA-funded PI ranks.

Figure 14 depicts the age structure of foreign born OSSA PIs. Comparing this chart to those in Figure 12, we see that foreign born PIs are on average about 6 years older than the general OSSA PI population. Taking the foreign born PIs out of the population, we find that the mean of the US-born PIs is reduced slightly to 49 years of age.

Education of OSSA PIs By Univeristy



Produced: 12/90

Figure 11

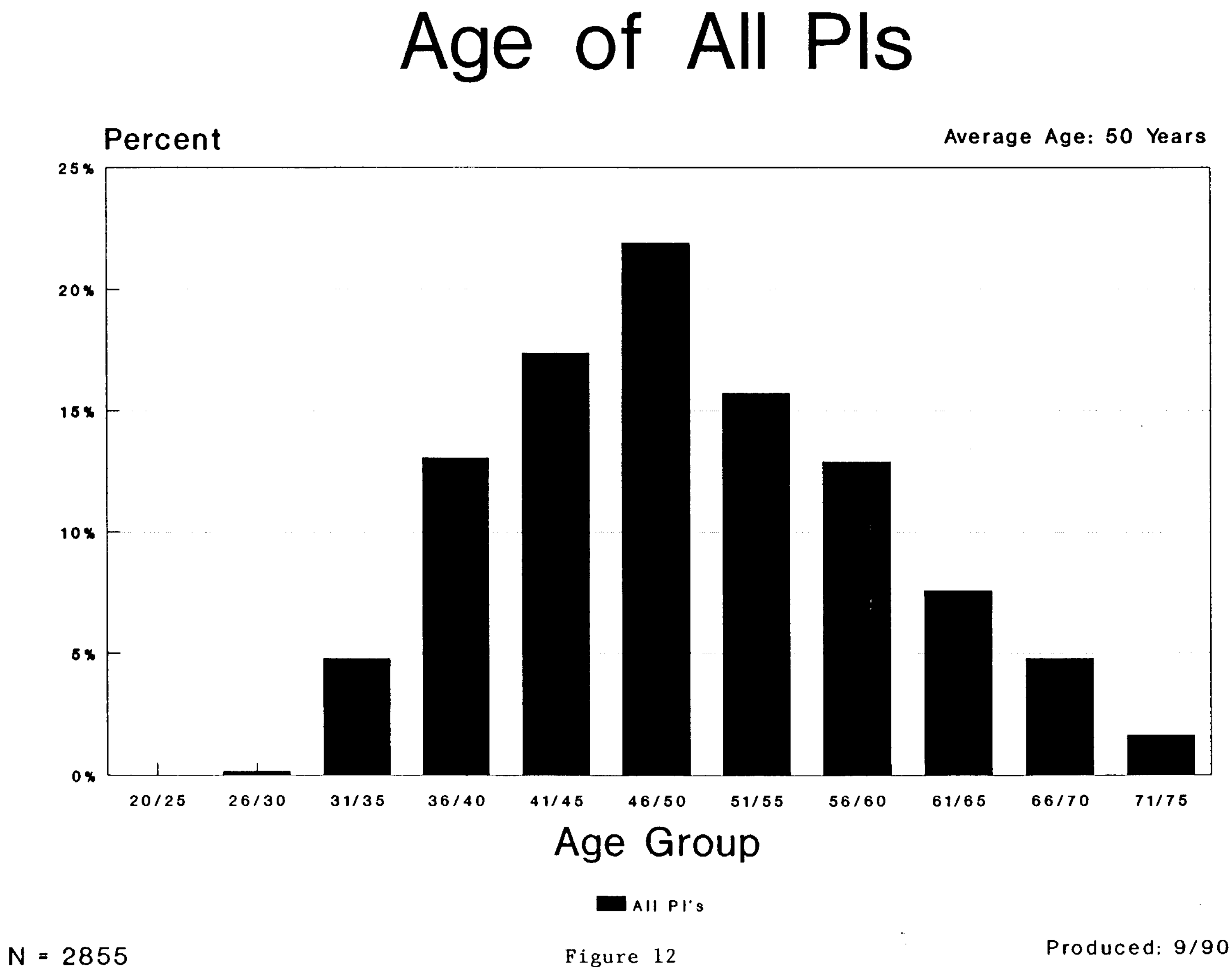
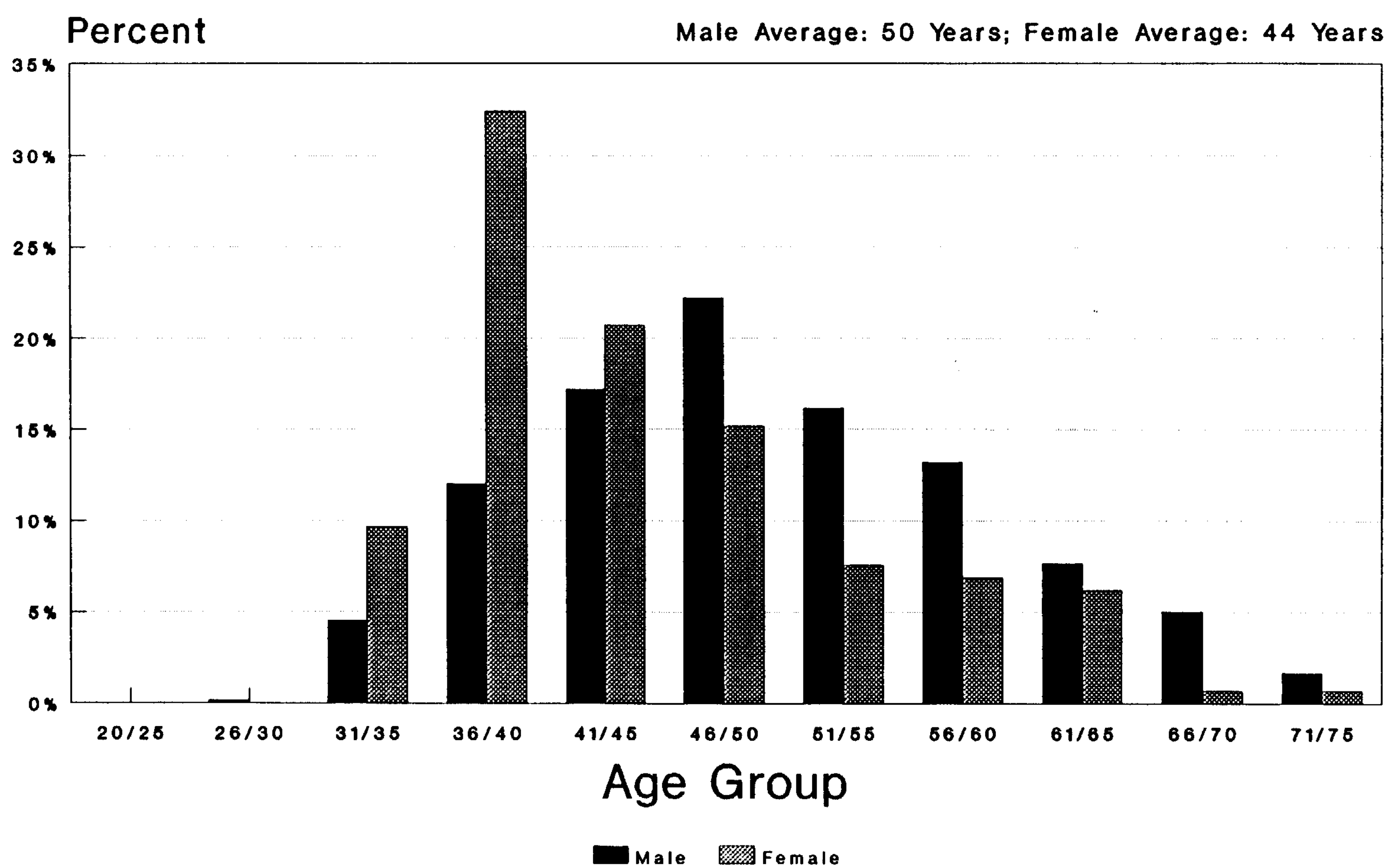

Age of All PIs
Percent
Average Age: 50 Years
25%
20%
15%
10%
5%
0%
20/25
26/30
31/35
36/40
41/45
46/50
51/55
56/60
61/65
66/70
71/75
Age Group
All PI's
N = 2855
Produced: 9/90

Figure 12

Age of PIs
Male And Female

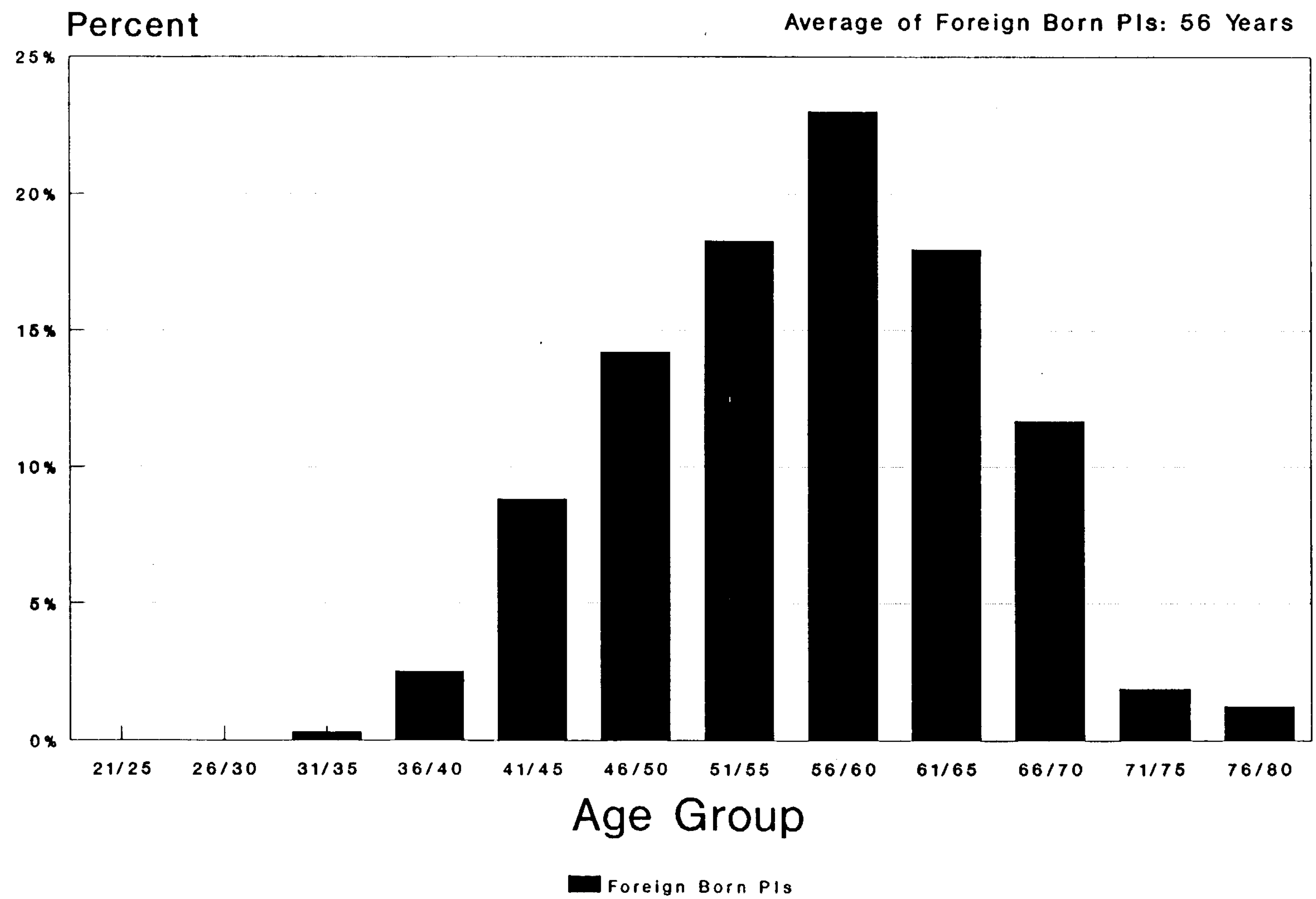


Male: N = 2708; Female: N = 145

Figure 13

Produced: 9/90

Age of Foreign Born PIs



N = 318

Figure 14

Produced: 9/90

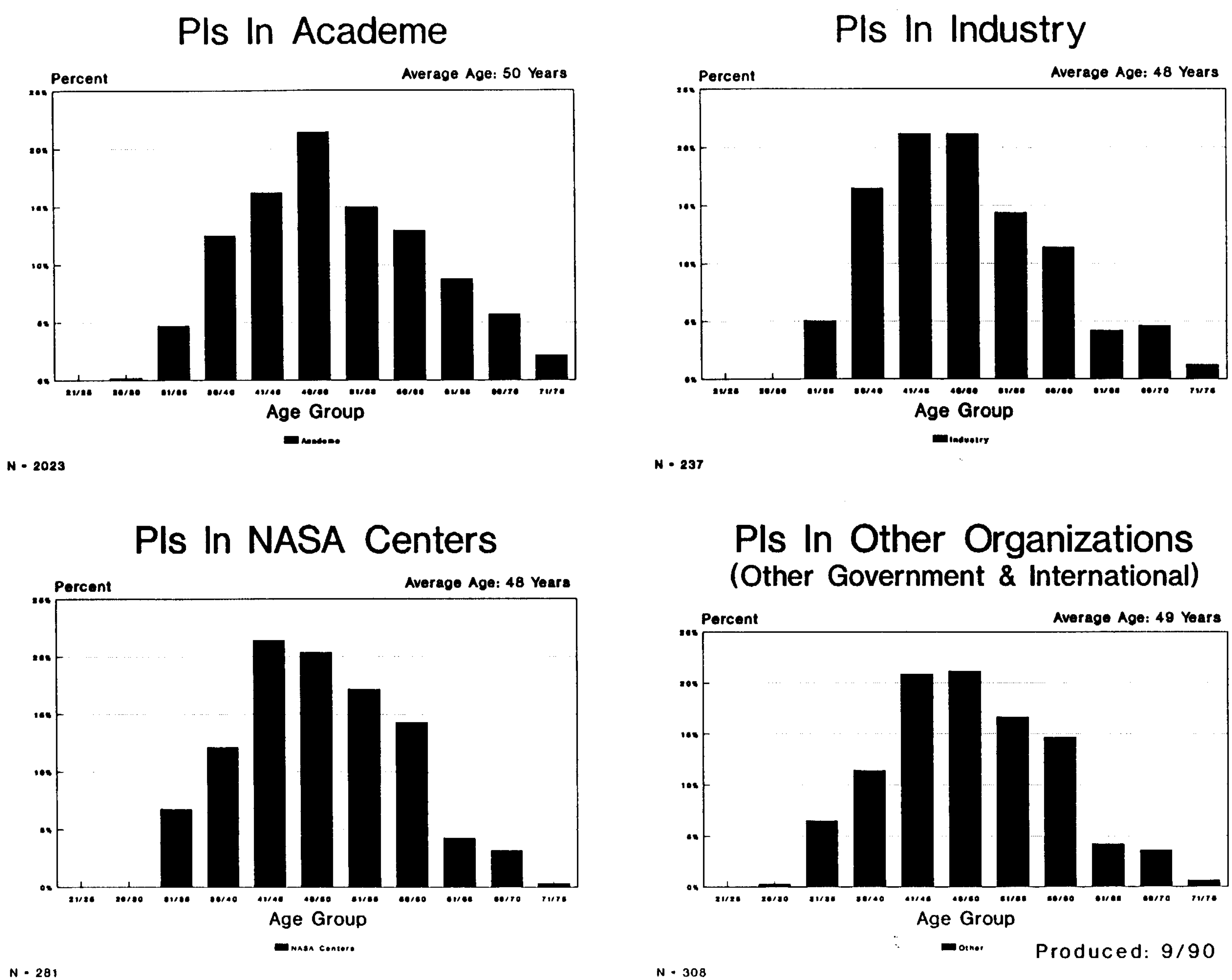
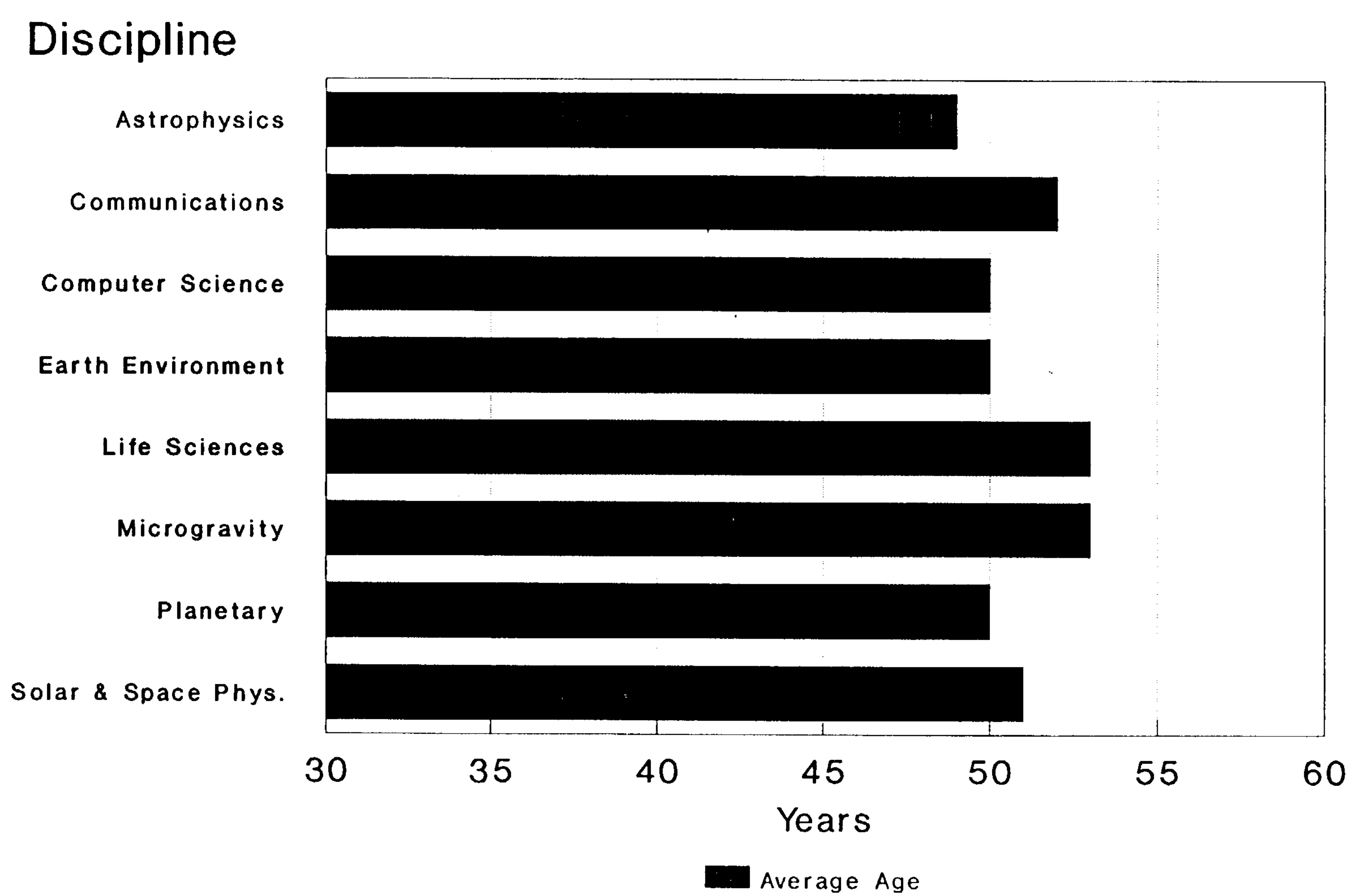

PIs In Academe
Percent
Average Age: 50 Years
Age Group
N - 2023
PIs In Industry
Percent
Average Age: 48 Years
Age Group
N - 237
PIs In NASA Centers
Percent
Average Age: 48 Years
Age Group
N - 281
PIs In Other Organizations
(Other Government & International)
Percent
Average Age: 49 Years
Age Group
N - 308
Produced: 9/90

Figure 15

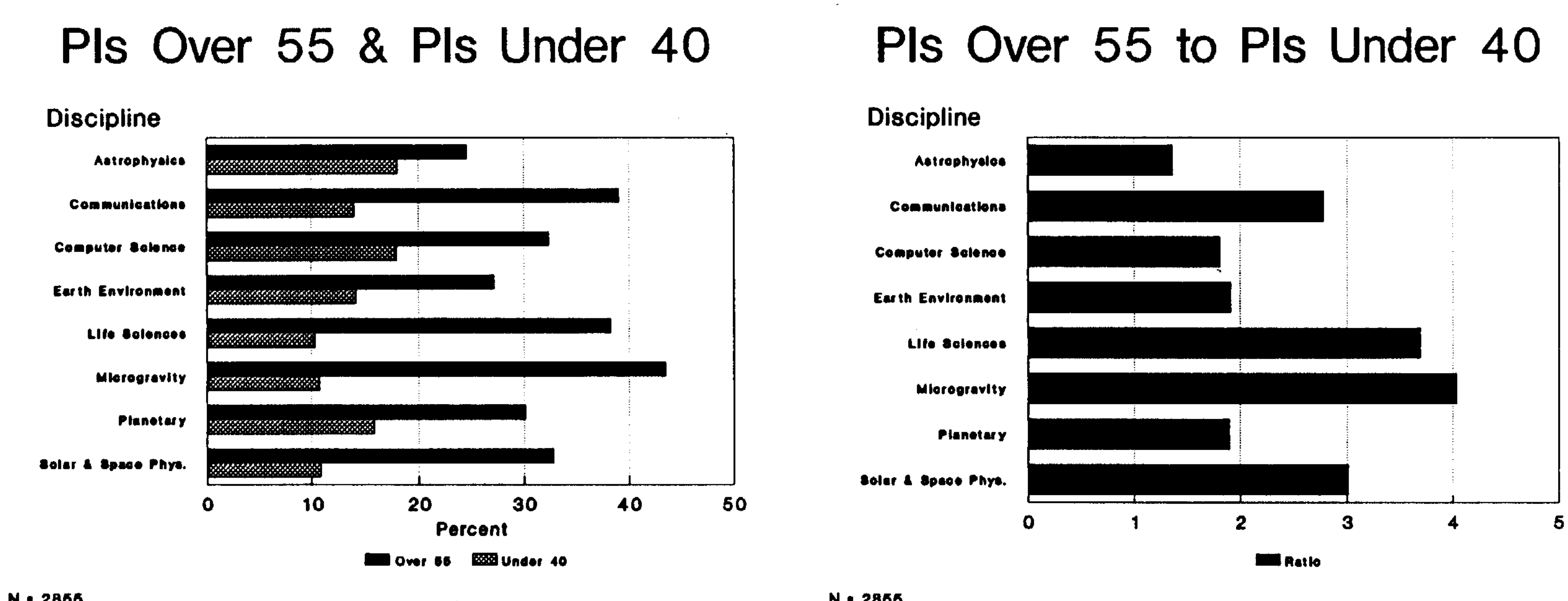
Average Age of PIs by Discipline



N = 2855

Figure 16

Produced: 9/90



Panel a

Panel b

Figure 17

Produced: 12/90

Turning to Figure 15, we now compare the age distributions of OSSA PIs as a function of their employment sector. The important conclusion here is that all four employment sectors show a large, asymmetric skew toward older ages.

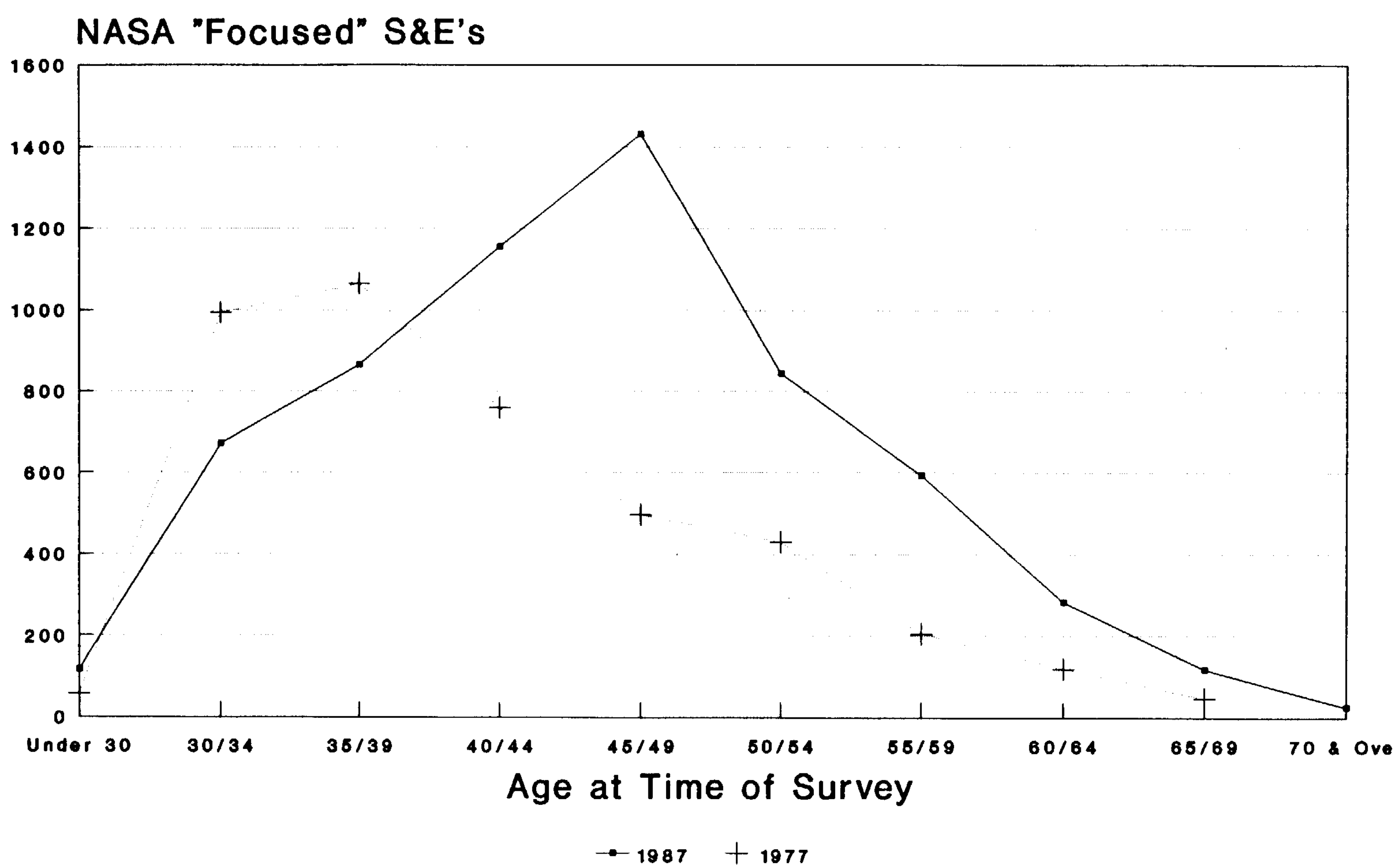
Now consider Figure 16, which compares the age distribution of OSSA PIs as a function of their research interests. Figure 16 shows that, to first order, all OSSA disciplines have the same mean PI ages. This implies that all disciplines will experience similar retirement losses in the next two decades.

Figure 17, which compares the number of "old" (over 55) PIs to "young" (under 40) PIs as a function of discipline, shows that in all disciplines except astrophysics, there are many more PIs significantly older than the average age compared to those significantly younger than the average age. Typically, the "old PI/young PI" ratio is about 1.7-2.7. This is probably a natural consequence resulting from (a) the increased experience of older PIs and (b) the reduced rates of people entering most OSSA disciplines since the "Apollo generation" completed their education around 1975. However, by comparing disciplines, we see that Life Sciences and Microgravity fields have atypically large old/young PI ratios, which may be due to the infrequent flight opportunities (and thus researcher-base stagnation) in these fields; interestingly, astrophysics displays the lowest old/young PI ratio.

Relationship of the OSSA Principal Investigator Population in the Broader Context

The "graying" of the space science community is by no means unique to this particular program or field of scientific endeavor. The buildup of the space program in the 1960s was part of the general post-war expansion of national research and development capabilities that also included a large enhancement of university-based research and graduate education in scientific and engineering disciplines. The period of most rapid growth included the buildup of the U.S. space program from the late 1950s into the middle of the 1960s. Given this historical coincidence, coupled with the wider phenomenon of the aging of the baby-boomers, we expect to see a similar graying of the professional scientific workforce across the spectrum of disciplines and Federal funding agencies.

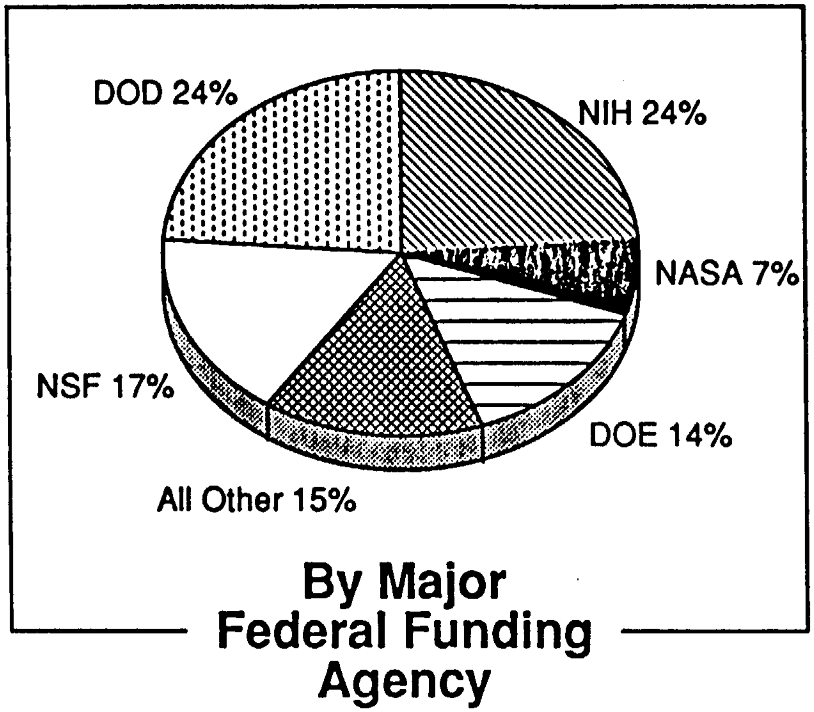
Comparison of S&E Doctorate Age Distributions: 1977,1987

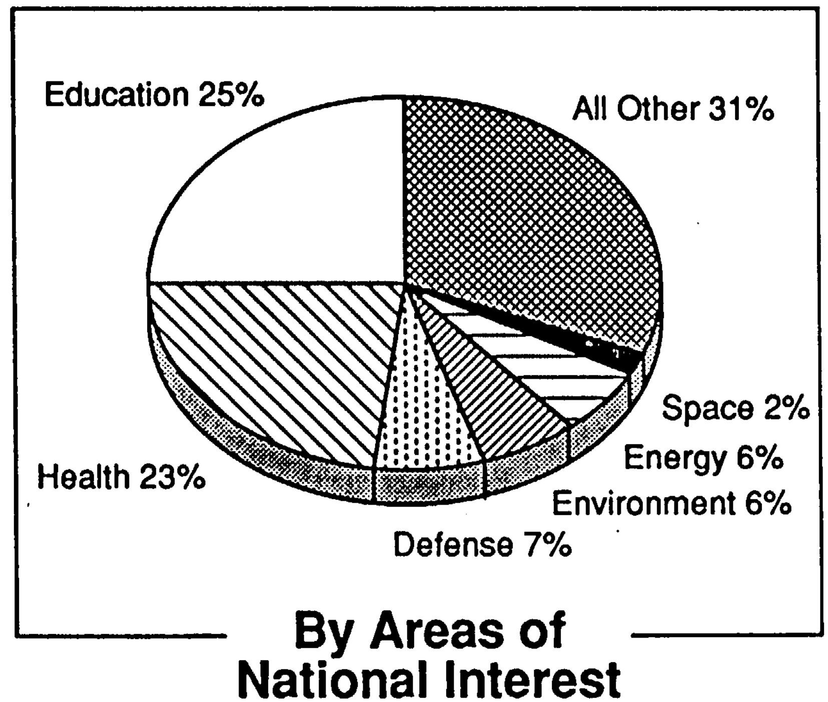


Source: NRC/OSEP

Figure 18

Distribution of Federally Supported Doctoral Scientists and Engineers, 1987





Source: NRC/OSEP

Figure 19

To provide a broader context for our study findings, this section provides some historical data obtained from a biennial survey of the employment characteristics of U.S.-educated doctoral scientists and engineers, collected by the National Research Council's (NRC's) Office of Scientific and Engineering Personnel. The survey is sponsored by the National Science Foundation (NSF) which also publishes the results. As part of this study, we asked the NRC to make some special tabulations that would provide age distributions by scientific field for both 1977 and 1987 to allow comparisons of longer term trends.

The aging of NASA-supported scientists and engineers is evident in Figure 18. Notice the age of the population peak increased by nearly 10 years (from age 35 to 45) over a real time span of 10 years. The fact that more scientists are in the 1987 distribution reflects the fact that even while aging, the size of the space science PI population has continued to expand.

Figure 19*a* presents the percent of the federally supported scientists who reported some NASA support. Panel *b* depicts the complete breakdown of federally supported scientists by area of national interest. As depicted, panel *a* shows that about 7% of US-supported S&Es reported that they received some NASA funding in 1987. In contrast, panel *b* shows that only about 2% of the national pool of doctoral-educated S&Es reported their principal area of work is "space."

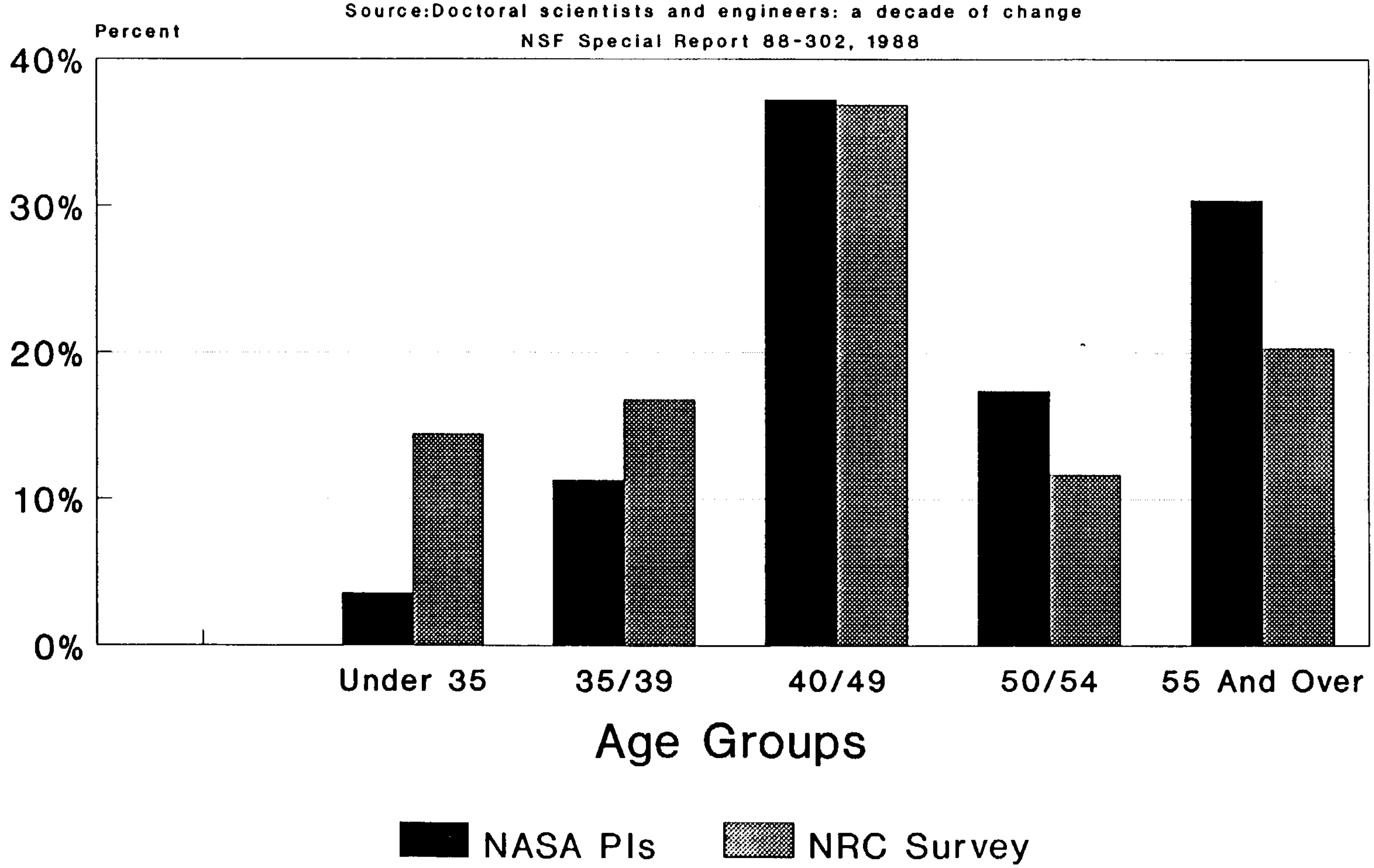
By examining the data in Figure 20, one can see that on a percentage basis, the OSSA PI population is substantially older than the national population of doctoral S&Es. Notice that although the two populations peak in the same bin (ages 41-50), the NASA population contains both *more older and fewer younger* PIs. This suggests that while NASA is not unique in experiencing an "aging" investigator phenomenon, NASA (like DOE) has many less young investigators than do NIH and NSF.

Figure 21 presents a comparison of the age structure of the S&E doctoral population supported by various Federal agencies, including NASA. Notice the NASA population is clearly more heavily skewed toward older than *all* other agencies.

This concludes our description of the Task 1 (PI population) methodology and results. Table 2 gives a brief summary of this work.

Age of OSSA PIs & All NRC Surveyed Doctoral Physical Scientists

Source:Doctoral scientists and engineers: a decade of change
NSF Special Report 88-302, 1988

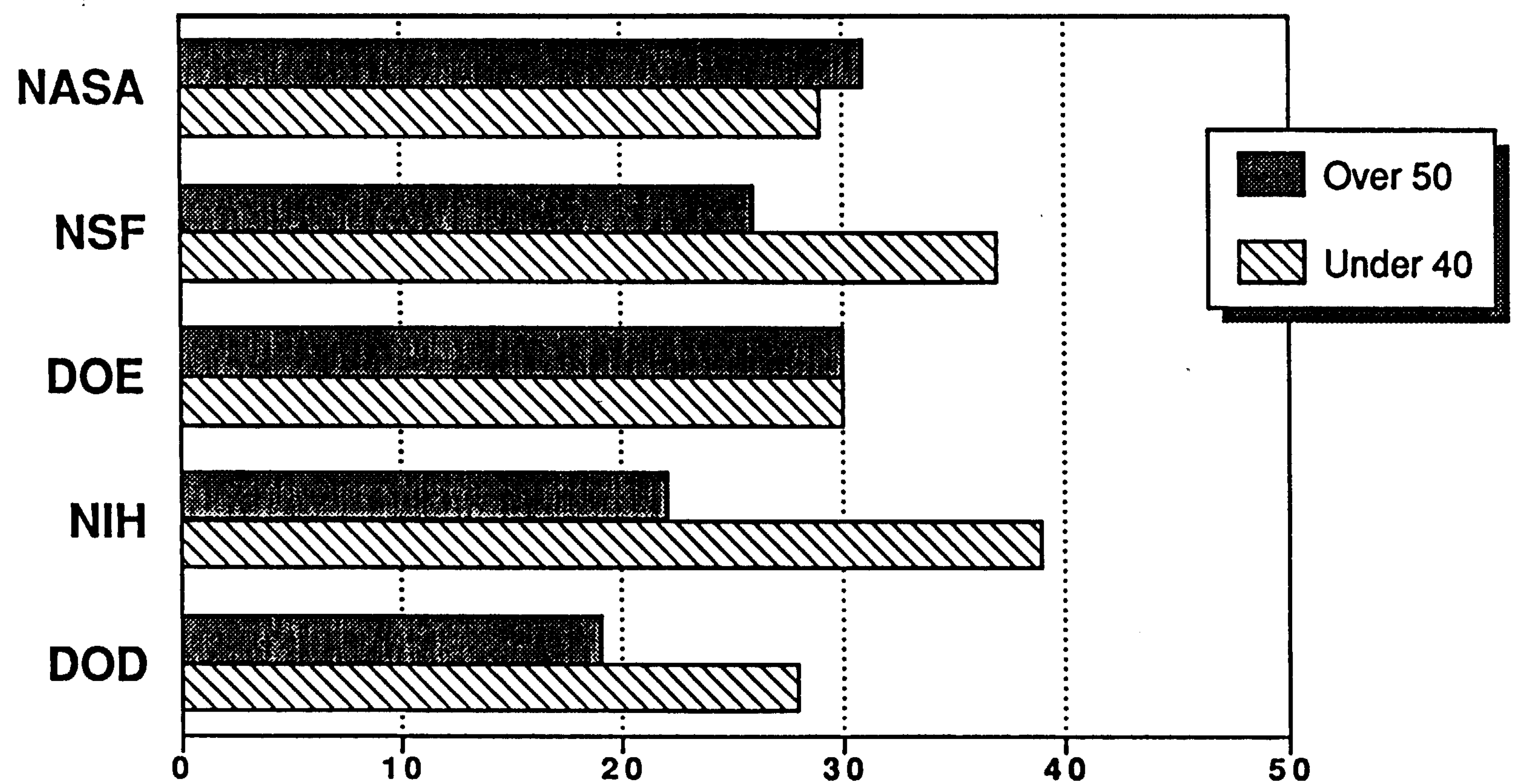


NASA PIs: N = 2874; NRC: N = 84,800

Figure 20

Produced: 9/90

Comparison of Age Distributions for Major Funding Agencies, 1987



Source: NRC/OSEP

Note: Ages at time of 1987 survey

Figure 21

SP-046-1a
5/29/90

SUMMARY TASK 1 CONCLUSIONS: PI DEMOGRAPHICS

- Information Located on 88% of PIs in AO Data Base: 2874 Individuals
- Typical PI:
  - Male
  - Born in U.S.
  - 50 Years Old
  - Received PhD at Age 29
  - Employed in Academe
- 60% of PIs Report Involvement in Astronomy, Earth Environment, or Planetary
- Age Distribution is Asymmetric With 27% Over 55 and 18% Under 40
  - Age Distribution is Approximately Independent of Employment Sector and Discipline
- OSSA PI Age Distribution is Substantially Older Than NRC PIs

Table 2

Produced: 10/90

V. Demographics of the OSSA Co-I Investigator Population

Methodology

The methods employed here were identical to those described for PIs under the Methodology subsection of Section IV, above.

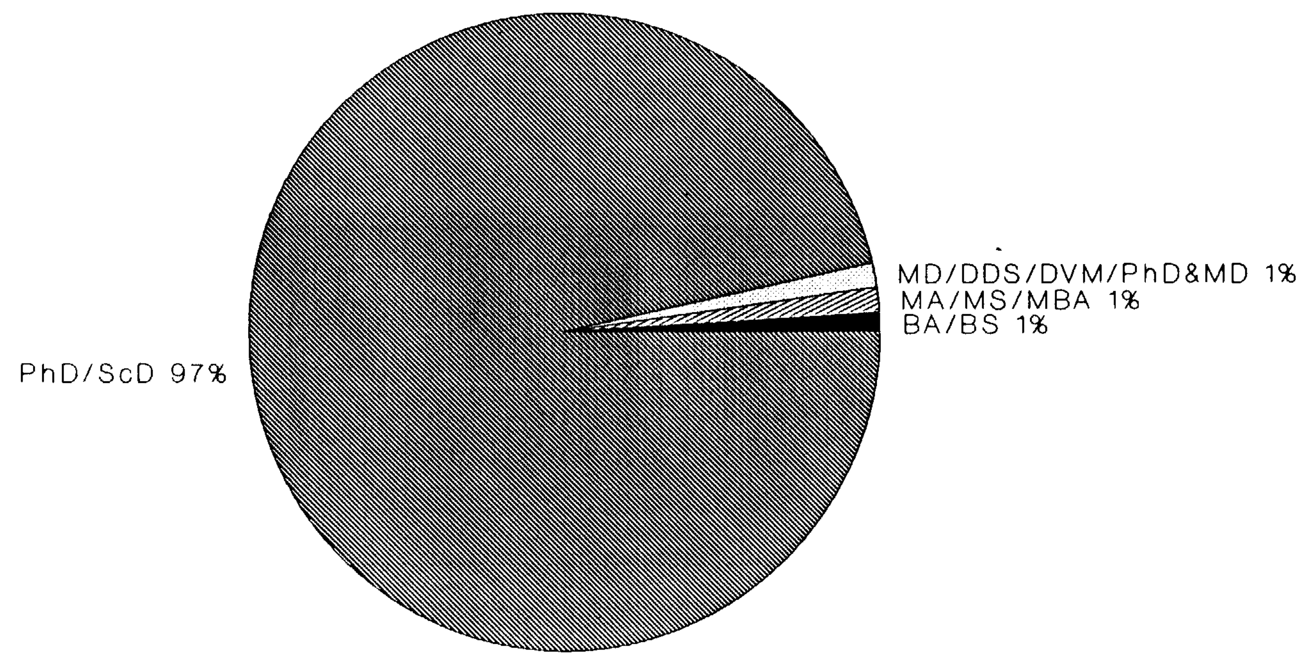
Of the 403 Co-I records contained in the OSSA AODB, we ultimately located age information on 69%. The fact that fewer Co-Is were located through the standard biographical data sources probably reflects the fact that Co-Is are generally younger, and thus less likely to have been invited to be a part of national scientific biographic compendiums. The 69% of the AODB Co-Is located represents a total of 279 individuals. The information gathered on these individuals was entered into our computerized demographic database.

Sources of Error

Unlike the PIs, we do not believe that the Co-Is in the AO Data Base well-represent the full population of OSSA Co-Is in the United States. This is not because we were able to locate data on a smaller fraction of those in the AODB (69% of the Co-Is vs 88% of the PIs), or because of sampling techniques or internal error sources, which were of the same order as for the PIs. This suspicion is based on two grounds. First, there are far fewer Co-Is than PIs in the AODB itself, when in fact, there are many more Co-Is than PIs on a typical proposal. Second, unlike PIs, Co-Is need not be on the AO mailing list to receive notice of OSSA AOs (i.e., since their supervisors or PI colleagues would be on the NASA mailing list and simply inform them of a relevant proposal). Thus, the 403 Co-Is in the AODB may be both a small fraction of the total OSSA Co-I population and, perhaps, an unrepresentative one (made up of "curiosity types" or those Co-Is aspiring to become PIs). In effect, because the AODB contains a sample whose relationship to the whole is unknown, we found ourselves facing a completeness problem that cannot be overcome using the AODB.

In what follows, we will analyze the demographics of the Co-Is in our data base, but we caution against applying these results to the entire OSSA Co-I population.

Distribution of Degrees for Co-Is

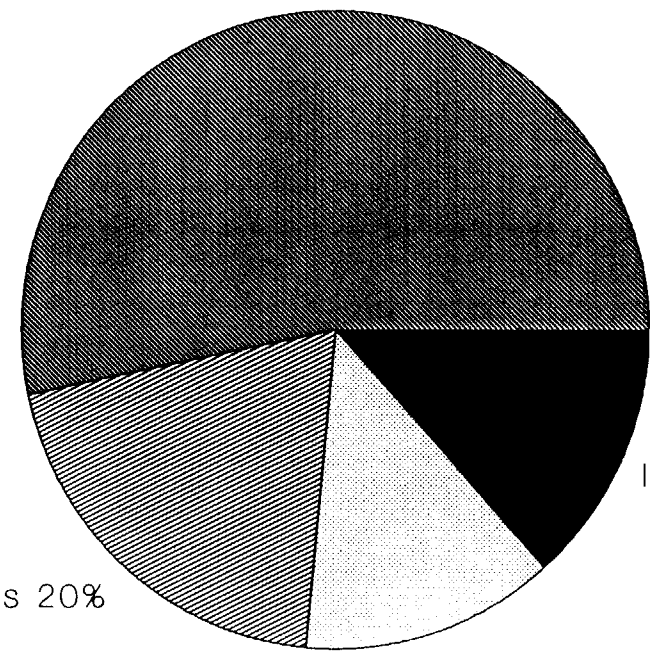


N = 403

Figure 22

Produced: 9/90

Employment of Co-Is

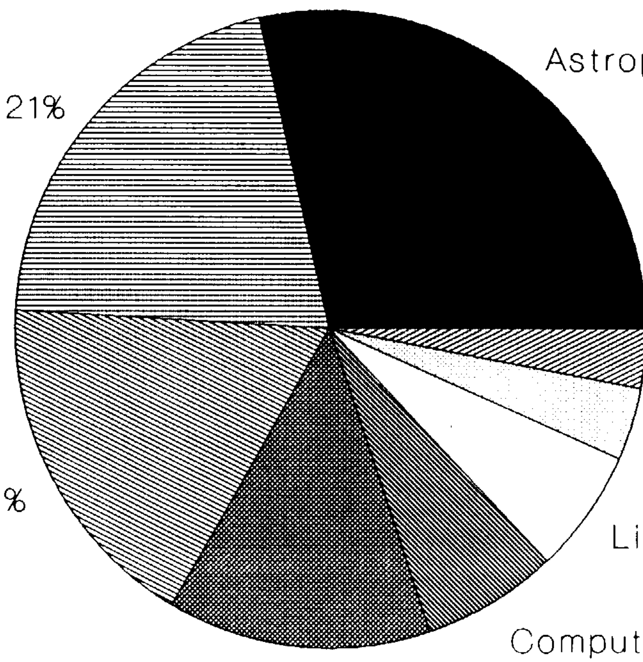


N = 403

Figure 23

Produced: 9/90

Interest Areas of Co-Is

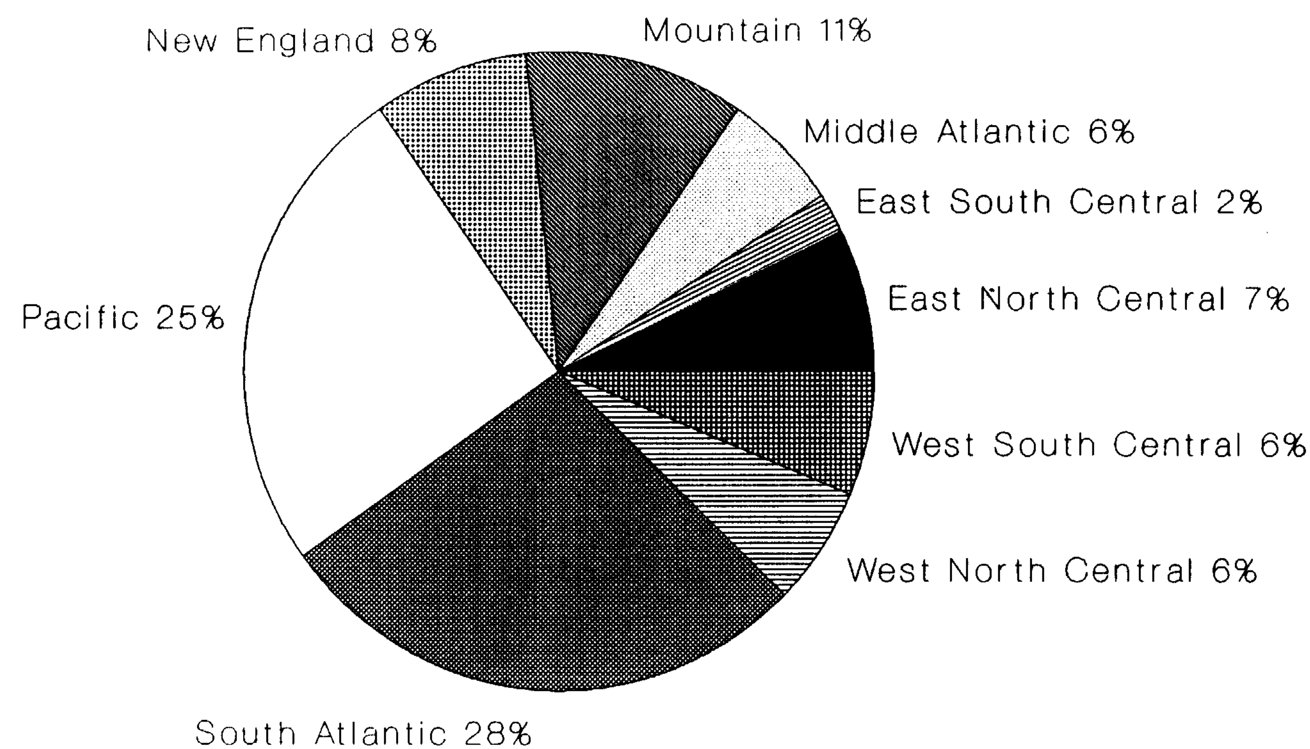


N = 403

Figure 24

Produced: 9/90

Location of Co-Is



N = 398

Figure 25

Produced: 9/90

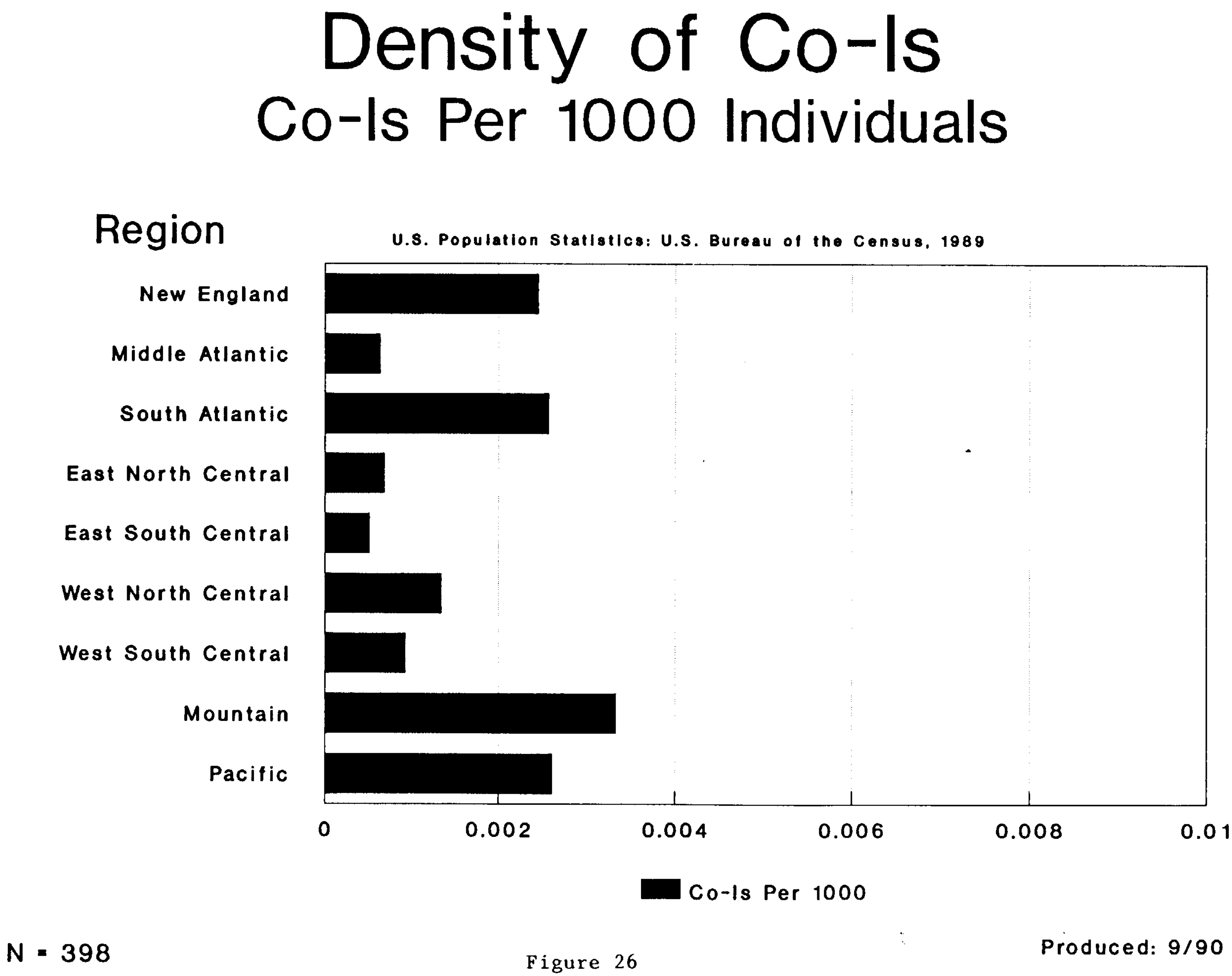

Density of Co-Is
Co-Is Per 1000 Individuals
Region
U.S. Population Statistics: U.S. Bureau of the Census, 1989
New England
Middle Atlantic
South Atlantic
East North Central
East South Central
West North Central
West South Central
Mountain
Pacific
0
0.002
0.004
0.006
0.008
0.01
Co-Is Per 1000
N = 398
Produced: 9/90

Figure 26

Co-I Findings

As offered in our proposal's Statement of Work (see Section III, Scope above) we present here the basic demographics of the AODB Co-I population. However, we remind the reader of the reservations expressed above about the completeness and validity of the AODB Co-I population.

The Co-Is contained in the data base are predominatly male: 95%. This is the same percentage as the PIs in the data base. Some 95% were born in the United States. Of those who are foreign born, 82% come from Canada and Europe, the remaining 18% are from Asia.

As depicted in Figure 22, some 97% of the Co-Is have earned PhD or ScD degrees. The other 3% is approximately equally divided between Master's, Bachelor's, and medical degrees.

Figure 23 depicts the employment-sector distribution of the Co-I population. Notice that 53% of the Co-Is are employed in academe, the second major sector (20%) is NASA centers; other government agencies make up 13%, with the remaining 13% in industry. Compared to PIs, the Co-I population is less-heavily concentrated in the academic sector and more heavily concentrated in the NASA and Other Government sectors.

In Figure 24 we depict the breakdown of Co-Is by their reported research interests. These data were compiled exclusively from the AODB. Notice that the Co-Is in Astronomy make up the largest share of the CO-Is in the data base (29%), followed by Planetary (21%), Space Physics (18%), Earth Environment (13%), and the smaller fields. Computer Sciences, Life Sciences, microgravity, and Communications are each below 10%.

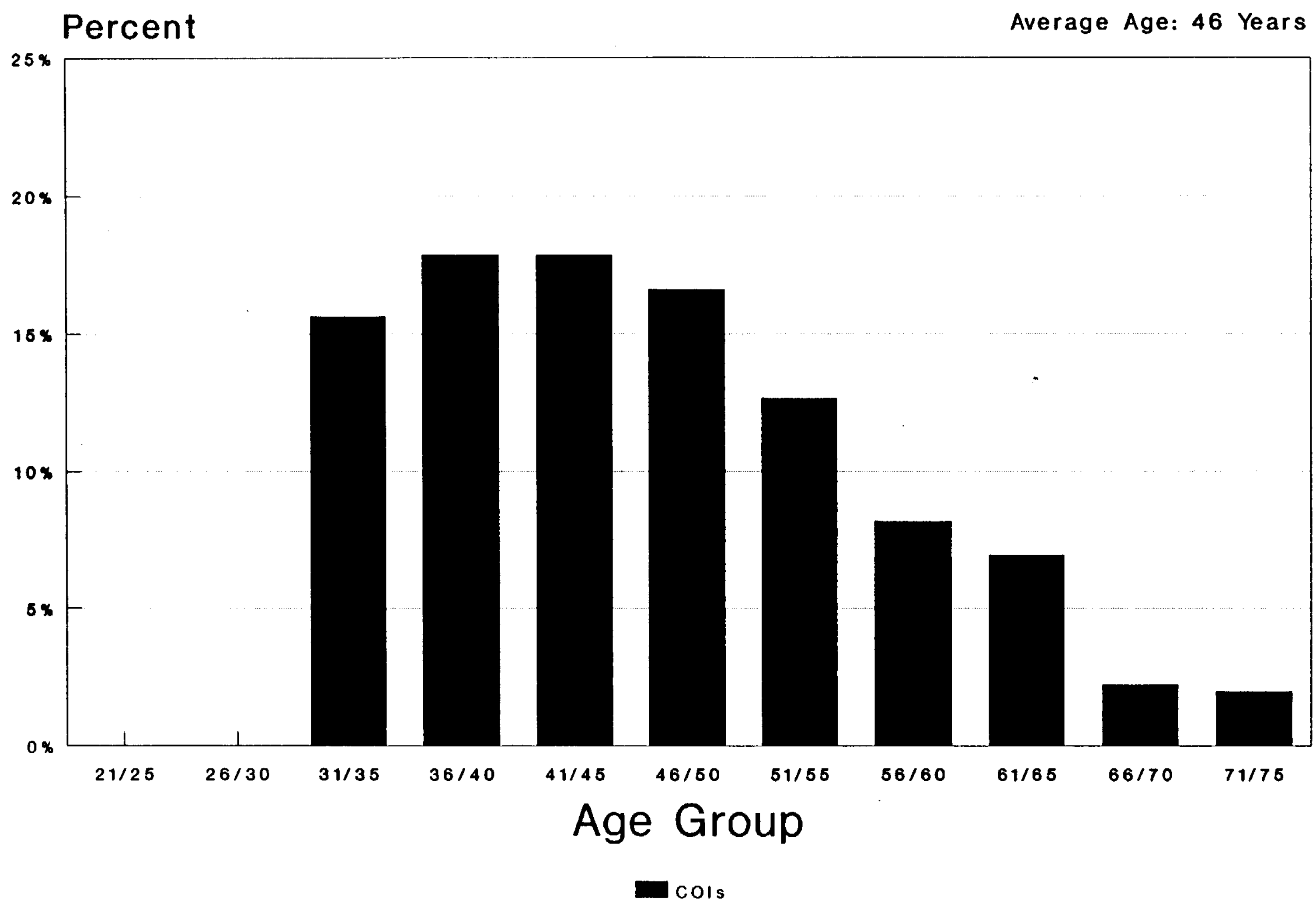
We now turn to the breakdown of OSSA Co-Is by their location in the U.S. As with PIs, we chose to adopt the U.S. Census Bureau's geographic definitions for regions, as depicted in Figure 8. In Figure 25, we show the percentage of Co-Is in the data base who reside in each region. The south Atlantic and Pacific regions alone contain over half of the Co-Is. Figure 26, presents these data normalized on a per capita basis using data from the U.S. Census Bureau. These results show that, like the PI population, there is a tendency toward a bi-modal distribution of Co-Is/per capita, with a Co-I-poor group comprised of the mid-Atlantic, east-North Central, east-South Central, west-North Central, and west-south Central regions, and a PI-rich set (with many times more PIs/capita) from the New England, Mountain and Pacific regions.

We now turn to the age structure of the OSSA Co-I population. Figure 27 presents the overall distribution of ages of all Co-Is contained in our data base. The peak is broadly distributed between ages 36 and 50. Notice that, unlike the PIs, the distribution is strongly skewed toward younger ages.

Finally, consider Figure 28, where we compare the age distributions of OSSA Co-Is as a function of their employment sector. These data show that the Co-I skew toward younger ages is almost independent of employment sector (notice that although the Industry-based Co-I age distribution is somewhat different, only 13% of the AODB Co-Is are in Industry).

This concludes our description of the Task 2 (Co-I population) methodology and results. Table 3 gives a brief summary of this work.

Age of Co-Is



N = 403

Figure 27

Produced: 9/90

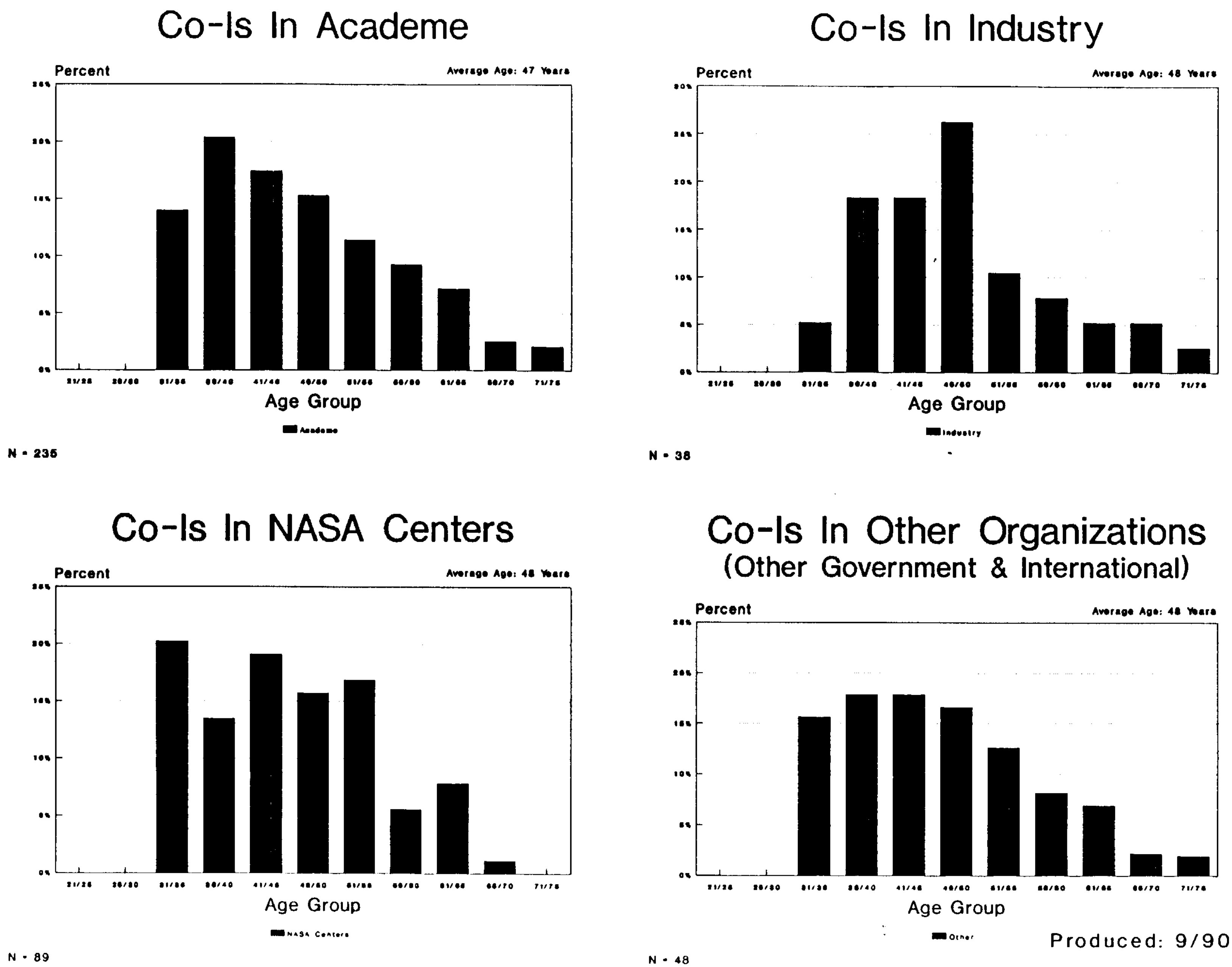

Co-Is In Academe
Percent
Average Age: 47 Years
Age Group
N • 235
Co-Is In Industry
Percent
Average Age: 48 Years
Age Group
N • 38
Co-Is In NASA Centers
Percent
Average Age: 48 Years
Age Group
N • 89
Co-Is In Other Organizations
(Other Government & International)
Percent
Average Age: 48 Years
Age Group
N • 48
Produced: 9/90

Figure 28

SUMMARY TASK 2 CONCLUSIONS: Co-I DEMOGRAPHICS

- AO Data Base Suspect for Co-I Studies Because:
  - Only 403 CO-Is vs 3253 PIs
  - No Strong Incentive for CO-Is to Enroll in Database

- Information Located on 69% of Co-Is in AO Data Base: 279 Individuals
- Typical Co-I:
  - Male
  - Born in U.S.
  - 46 Years Old
  - Received PhD at Age 29
  - Employed in Academe
- 20% of Co-Is Over 55 and 31% Co-Is Under 40
- 53% of CO-Is Employed in Academe vs 67% for PIs
- 97% of Co-Is Received PhD vs 93% for PIs

Table 3

Produced: 10/90

VI. Pipeline Studies and Future Predictions

Methodology

Here we describe the methods by which the net supply of OSSA PIs between 1991 and 2010 were estimated. Our supply forecasts were then contrasted with four demand scenarios to determine under what circumstances OSSA is likely to experience either a deficit or surplus of PIs over the next 20 years.

In what follows, all calculations were performed using all 3253 "real" PI records in the AO data base; we assumed that the age distribution of the 379 PIs for whom we lacked age data was identical to that of the 3253.

To project the supply of PIs, the attrition and new production (i.e., entry) components were computed separately. The population of PIs at any time in the future is simply given by,

$$P(t) = (\text{PIs Today}) - (\text{Attrition by year t}) + (\text{New Production by year t}) \qquad (1)$$

We describe the method used to estimate attrition first. As discussed in the previous sections, our data base contains the current age distribution for OSSA PIs. The number of PIs remaining from the this group and the age distribution at some year in the future can be computed by moving the current age distribution through time in five year steps and applying the probability that a PI of a given age will survive the interval. These "age specific" survival probabilities are derived by combining the probability that a PI will survive retirement, death and leaving the profession for other opportunities during each five year interval[5]. Bowen and Sosa estimated age specific survival probabilities for the entire U.S. population of Arts and Science faculty. Use of the Bowen and Sosa derived probabilities for the portion of the OSSA PI population that were employed in academe is justified because the Bowen and Sosa results apply to the age characterists of academics; almost 70% of OSSA PIs are in academe.

There are significant differences between the career paths in the civil service and academe which argue against using the probabilities from Bowen and Sosa for PIs not employed in academe. For instance, the rapid drop in university employed professionals in

Age-Specific Survival Ratios: Standard-Quit Assumptions

Five Year Survival Ratio - Retirement Rate

Age Group	Quitting	Retiring	Dying	Combined Ratio
30-34	0.9100	1.0000	0.9955	0.9059
35-39	0.8853	1.0000	0.9936	0.8796
40-44	0.9270	1.0000	0.9890	0.9168
45-49	0.9441	0.9921	0.9821	0.9199
50-54	0.9516	0.9552	0.9735	0.8849
55-59	0.9527	0.8264	0.9622	0.7576
60-64	0.9525	0.4537	0.9413	0.0673
65-69	0.9525	0.0780	0.9054	0.0000
70+		0.0000		0.0000

(Source: W. G. Bowen and J. A. Sosa, *Prospects for Faculty in the Arts & Sciences,* (1989))

Five Year Survival Ratio- NASA/Civil Service

Age Group	Quitting	Retiring	Dying	Combined Ratio
30-34	0.9100	1.0000	0.9955	0.9059
35-39	0.8853	1.0000	0.9936	0.8796
40-44	0.9270	1.0000	0.9890	0.9168
45-49	0.9441	0.9921	0.9821	0.9199
50-54	0.9516	0.9552	0.9735	0.8849
55-59	0.9527	0.7500	0.9622	0.6875
60-64	0.9525	0.2500	0.9413	0.2241
65-69	0.9525	0.0500	0.9054	0.0431
70+				0.0000

(*op.cit.* Bowen, Sosa, Konkel)

Table 4

the 30-34 age group reflects the early competition for tenure, which has no parallel in the civil service arena. Consequently, there is more attrition in the early years of academic PI careers than among PIs employed in government institutions. Based on these differences, the age specific survival probabilities for the remaining 30% of OSSA PIs who are largely employed by government institutions were estimated using aggregate NASA personnel data. We then used these probabilities as a proxy for PIs in all government institutions. The survival probabilities used for PIs employed in academe and government institutions are given in Table 4. Based on the present-day PI population in the data base and this two-track attrition model, the attrition term in Equation (1) can be calculated. This term represents the number of PIs expected to be remaining from the 1990 PI population as a function of time from 1991 to 2010; it is illustrated in Figure 29.

The first result we obtain from Figure 29 is its nearly linear decline, which indicates that the attrition rate will remain nearly constant throughout the next two decades, and that a "retirement wave" of OSSA PIs is not likely to actually occur. Instead, we find an approximately equal number of retirements will take place every year. These results implicitly assume no dramatic change in OSSA's funding of investigators, which would likely cause the rate of attrition to change inversely with the change in OSSA funding. For example, if OSSA funding of investigators were to significantly decrease, an exodus from space science fields would likely result, and a retirement wave might indeed occur.

Estimating the production of PIs is more difficult than forecasting attrition, since our data base provides a "snapshot" of the PI population in 1990, but does not directly provide information about the rate of past PI production. One obvious method of approaching the problem is to construct a model of the function (which we call a "funnel") that predicts the production of PIs from the total pool of maturing workers in the United States. Such a function must of course be based on many factors, including the fraction of the college age population that chooses space science fields, the fraction of these students that graduate with a bachelors degree and the fraction of these that continue on to graduate school in space science fields etc.; Figure 30 illustrates this method. The difficulty of this task is compounded by the requirement that each of these parameters must be estimated as a

Projected Remaining OSSA PIs
(After Attrition)

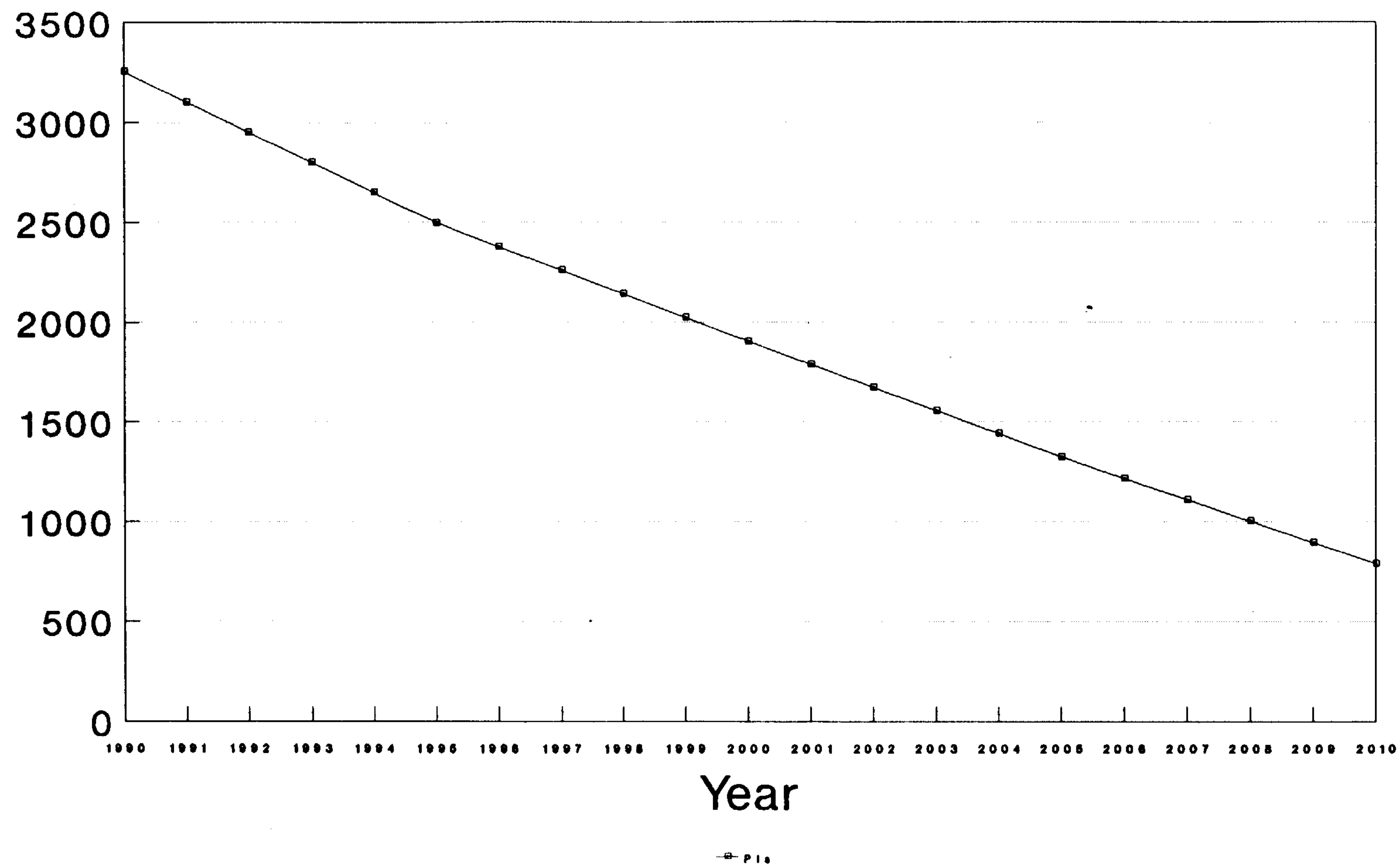
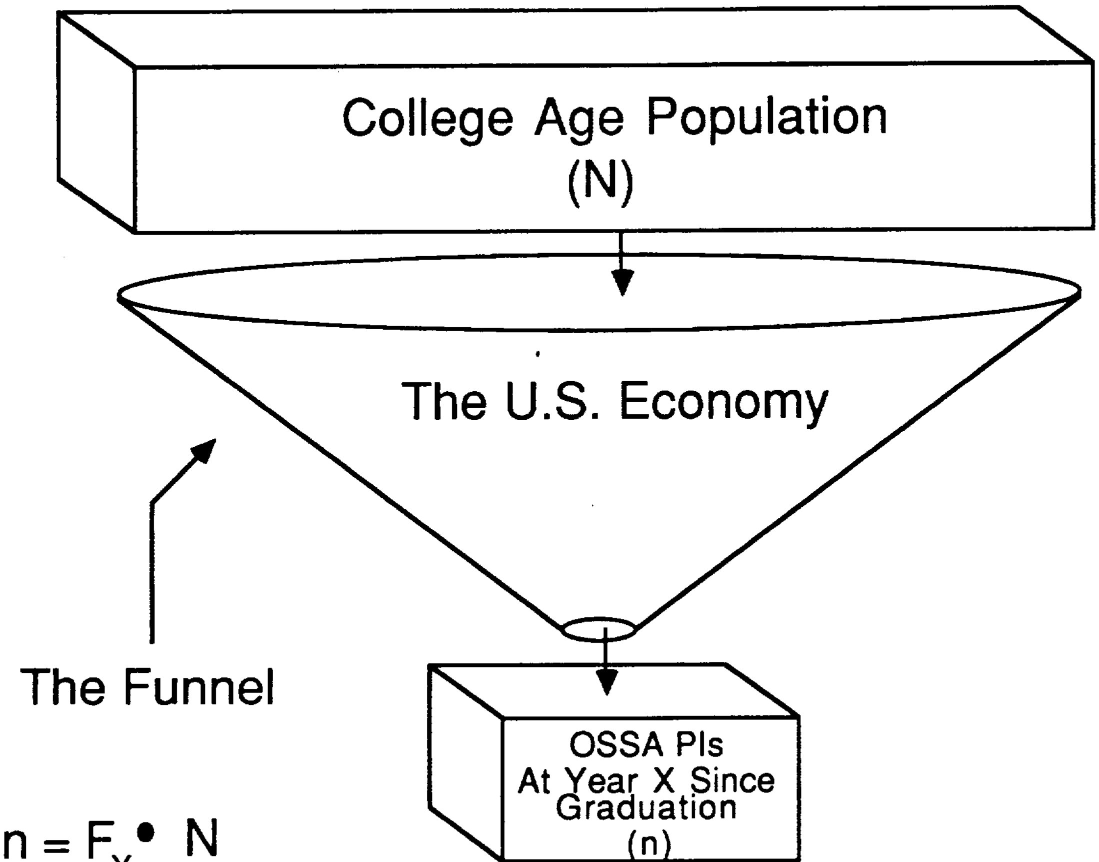


Figure 29

Produced: 9/90

Modeling "The Funnel"



- $n = F_X \bullet N$

- F_X is a Function of:
  - Fraction of College Students That Select Space Science Fields
  - Fraction of Space Science Students that Complete Graduate School
  - Fraction of Space Science Graduates that Pursue Space Science Careers
  - Number of Individuals from other Nations & Fields who Pursue Space Science Careers
  - Fraction of Graduates that Pursue Space Science Careers and Successfully Compete for NASA Funding
  - etc.

- Each Parameter is a Function of Time

Produced 10/90

Figure 30

function of time over the next two decades.

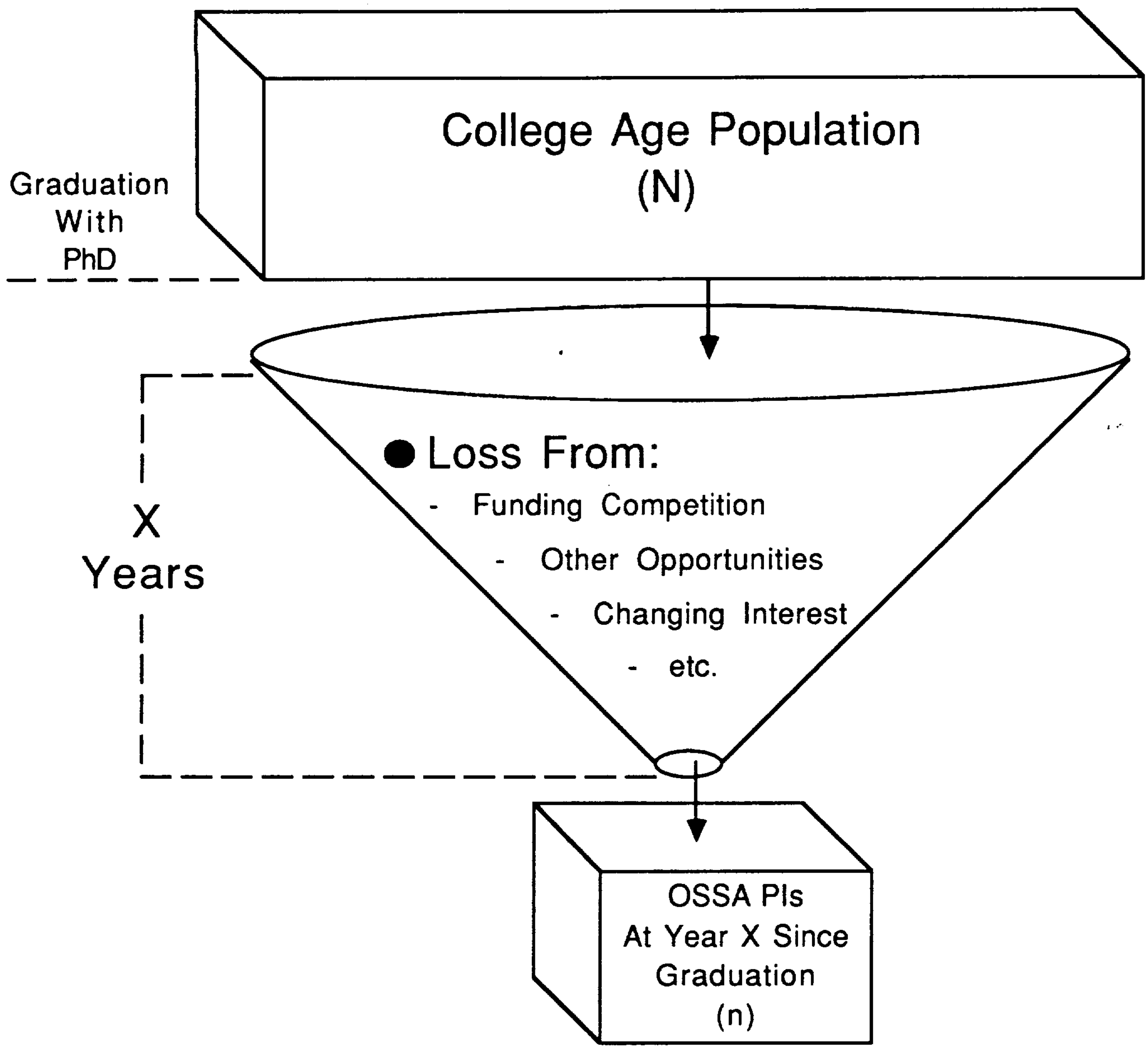
We rejected the complex task of modelling the funnel and its many free parameters in favor of a less intuitive, but more empirical approach. We instead estimated the production pattern of OSSA PIs from a given doctoral graduating class by using the data contained in our data base and U.S. Bureau of Census population data; see Figure 31. Since all the members of our database are presently PIs and the age at which they received their highest degree is also a known quantity, there exists a function that maps each year from 1939 to 1989 into the number of PIs presently in our data base from the doctoral graduating class of that year. This function can be interpreted as the fraction of existing PIs from each graduating class as a function of time since their graduation. Figure 32 illustrates this interpretation.

Another function we constructed maps each year from 1939 to 1989 into a number which is the proportion of the age 20-24 population in the year when each doctoral graduating class was age 22 that eventually became PIs. This function can be interpreted as the fraction of the age 20-24 population that will become OSSA PIs within n years of receiving their highest degree.

The contribution of a doctoral graduating class n years ago to the cumulative production of OSSA PIs in a given year can then be found by multiplying the age 20-24 population from the year in which each given doctoral class was 22 by the number in the above series which is the fraction of the age 20-24 population that will become PIs within n years of graduation with a doctorate. As seen in Figure 32, few PIs are produced within the first 7 years of graduation with a doctoral degree. Thus, for small n, the contribution to the cumulative production by a given year is small. As n increases, the contribution also increases until it reaches a maximum approximately 20 years after graduation. For a doctoral class that graduated more than 20 years ago, the fraction of individuals who are PIs then decreases.

To predict the cumulative production of OSSA PIs by any year between 1991 and 2010, the positive contributions from all doctoral graduating classes prior to the year of

Production of OSSA PIs



- Fraction of College Age Population That Will Become OSSA PIs Within X Years of Graduation:

$$F_X = \frac{n}{N}$$ (This Data in CU Demographic Data Base)

- The Production of New PIs Can Be Estimated Knowing Only the Function F_X and College Age Populations

- Include One Free Parameter: "Funnel Factor"
  - Characterizes Funnel's Time Dependence

Produced 10/90

Figure 31

Years Since PhD For OSSA PIs

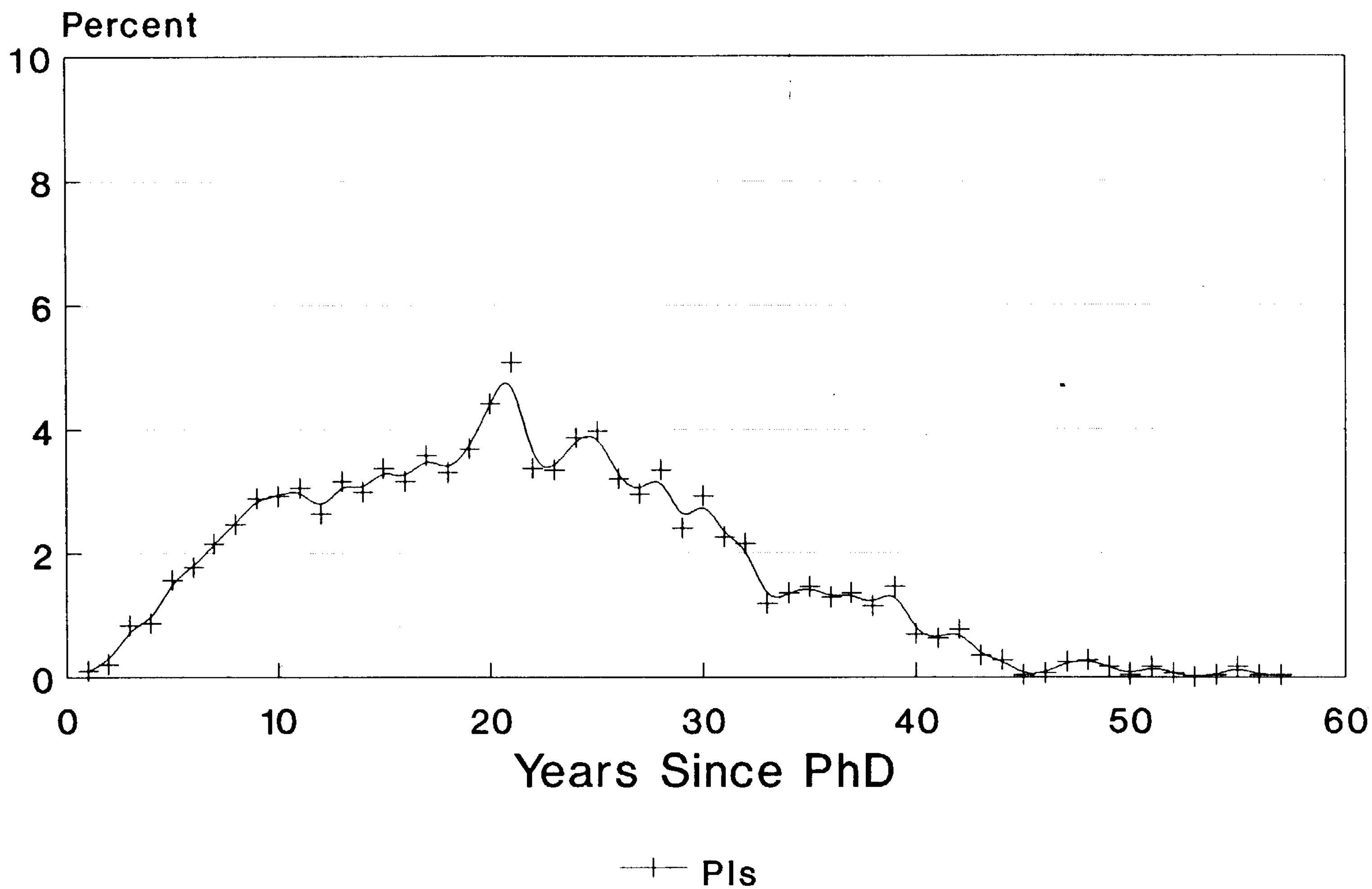


Figure 32

Produced: 9/90

interest are summed. The number of PIs produced by year N is given by,

$$\text{PIs(N)} = \Sigma_{n=1}^{N_{max}} F_n P_{N-n-7} \quad (2)$$

where N_{max} is the number of years after graduation in which the maximum number of PIs are created; as stated above, we found $N_{max} = 20$. In Equation (1), F_n is the fraction of the 20-24 year old population that becomes an OSSA PI by n years after graduation, and P_{N-n-7} is the national population of 20-24 year olds in year the class of interest was 22 years old. The 7 year offset is the difference between the mean age at PhD for OSSA scientists (29 years old; see Section IV, above) and age 22, the median of the 20-24 age bracket used for Census projections. The sum in Equation (2) allows us to add up the contributions from all classes, and thereby estimate the number of PIs produced from all past graduating classes in each future year of interest.

For example, to estimate the number of PIs produced by 1994 the positive contributions from all doctoral graduating classes from 1953 to 1993 must be calculated and summed. A computer program was written to carry out the calculations described above for $1990 < t < 2010$.

In this program, the age 20-24 population for the years between 1991 and 2005 was estimated by using U.S. Bureau of Census data for the current population and age specific death rates. We point out that any individual who will be 20 by 2005 is already born and therefore population projections carry with them negligible error. Figure 33 illustrates the age 20-24 population derived from Census Bureau data. Notice that the age 20-24 population declines steadily until 1997 and then rises again to approximately the 1990 level by 2005 (in what is commonly called the "baby boom echo").

The most important assumption in this model is that the average rate of individuals becoming OSSA PIs over the next twenty years will be identical to the last twenty years, so that the total rate of PI production for each class is the same, and follows the same curve, dispaced only in time by its date of graduation, and in magnitude only by the relative size of the 20-24 year old age group when the specified class graduated.

Because the rate of OSSA PI prodution over the past 20 years may not in fact the same over the next 20, a free parameter was added to our model. Called the "Interest Factor,"

U.S. Population (1960 - 2005)
Age 20 - 24

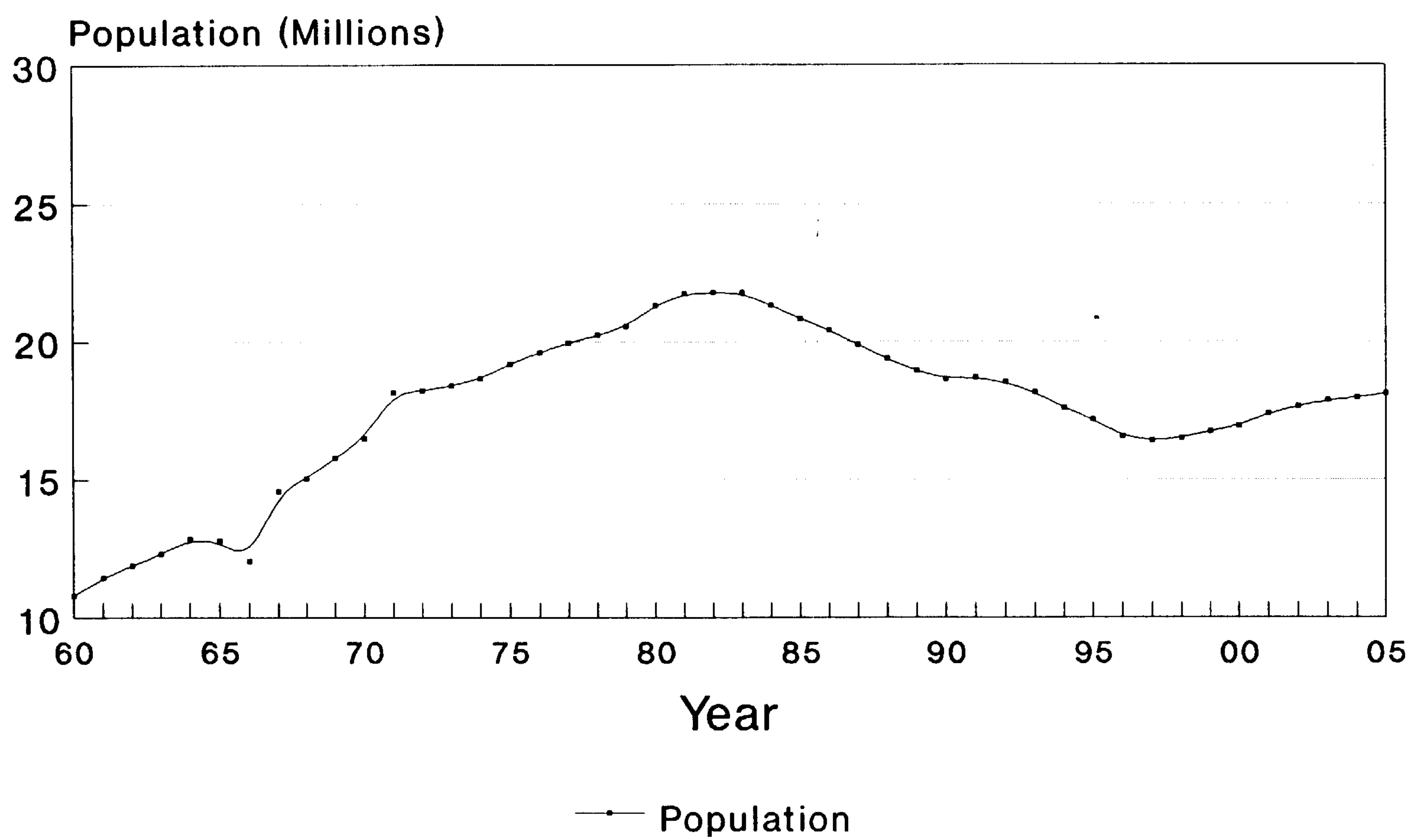


Figure 33

Produced: 12/90

this term is designed to account for changes in F_n due to factors such as the relative interest in space science fields among students, job opportunities, and OSSA research funding levels. Figure 34 shows the predicted rate of net PI production over the next 20 years, as a function of the Interest Factor. Figure 35 shows the projected *cumulative* production (i.e., the integral of Figure 34) of OSSA PIs for three possible Interest Factors I=2/3 (PI production is harder in the future by a factor of 3/2), I=1 (nominal case), I=4/3 (PI production is easier by a factor of 3/4). The descreasing rate of PI production after 1994 (and hence the turnovers in Figure 35) are caused by the fact that the peak graduating class size was the class of 1978, which after working its way through the PI funnel, is followed by smaller numbers of PIs each year.

The demand for PIs was estimated by assuming that the number of PIs required by OSSA is directly proportional to the OSSA budget. This assumption immediately led to the choice of three possible budget scenarios: (i) no real (i.e., inflation adjusted) growth in the OSSA budget, (ii) the present OSSA budget doubles by 2000, and (iii) the present OSSA budget doubles by 2010. Case (i) is the baseline, pessimistic case; case (ii) is based on the growth scenario described Dr. Fisk in Congressional testimony required carry out the EOS program[7]; case (iii) is an intermediate growth case. A fourth demand scenario, the R&A Growth Model, was also constructed. This scenario, case (iv), was arrived at by one of us (Konkel) who performed a detailed analysis of the approved agency runout budget for the various OSSA divisions, using the baseline FY1991 budget and assuming a full-scope EOS program. The budget-based components of the forecast were extended to the year 2010 based on the average annual growth factor experienced over the decade 1985-1995. This analysis is likely to be the most realistic growth case calculation of our set, since it does not assume the PI demand is directly proportional to OSSA budget growth, but instead uses actual R&A growth predictions. These demand scenarios are depicted in Figure 36.

Results

We now present the results of our OSSA PI projection calculations. In what follows, we therefore perform the sum of terms in Equation (1) and compare these net PI population

Projected Rate of Production of OSSA PIs

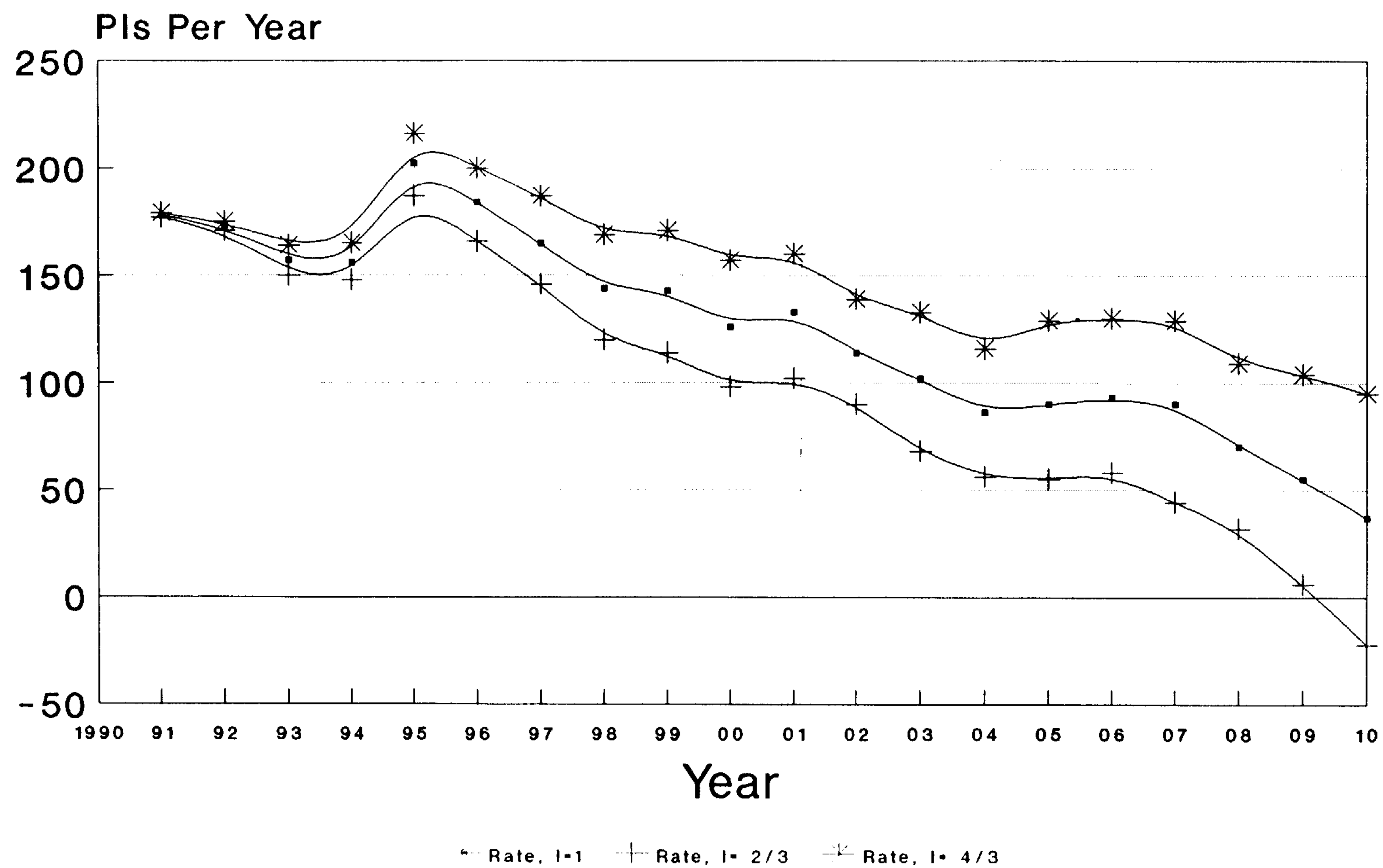


Figure 34

Produced: 9/90

Projected Cumulative Production of OSSA PIs

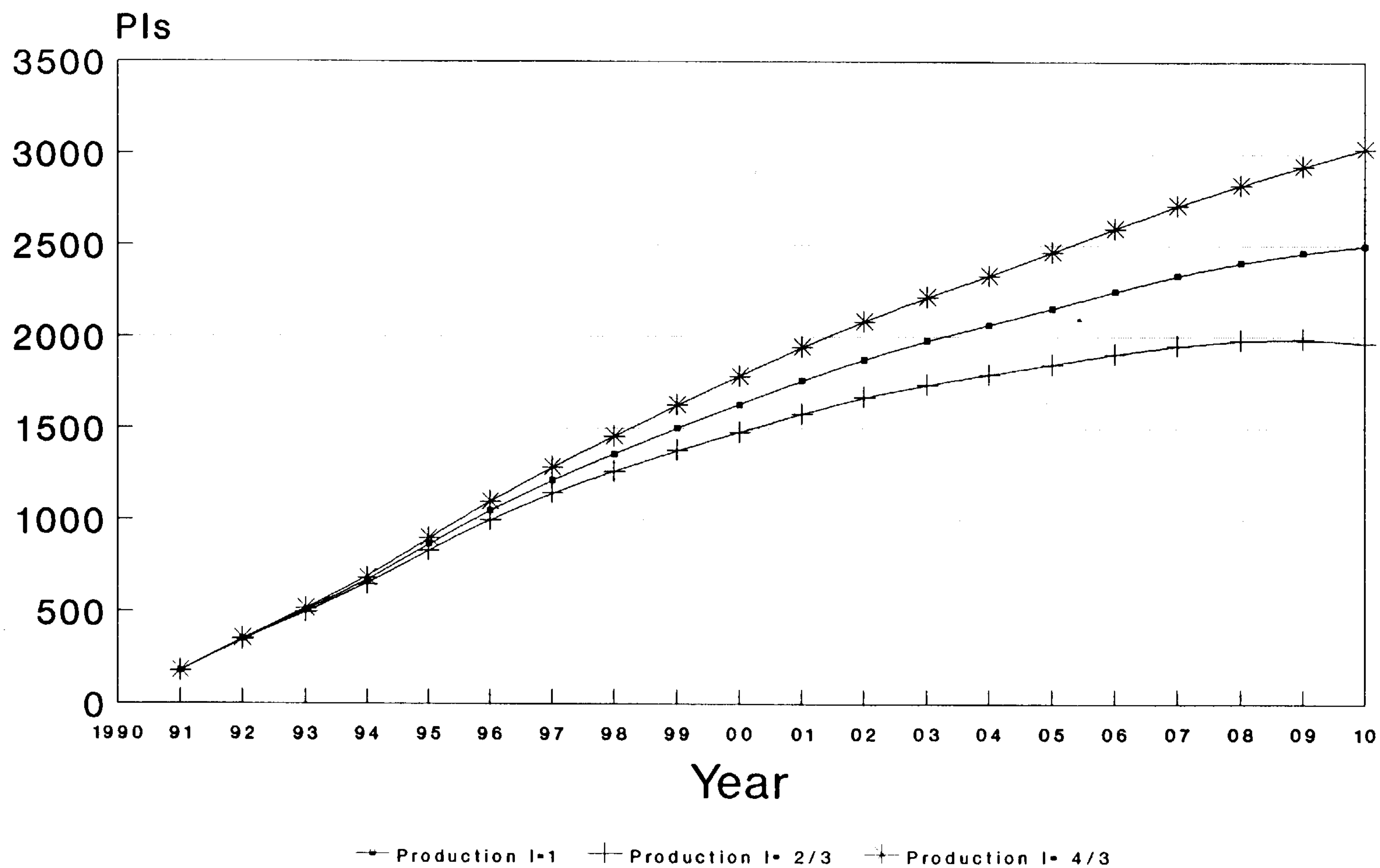
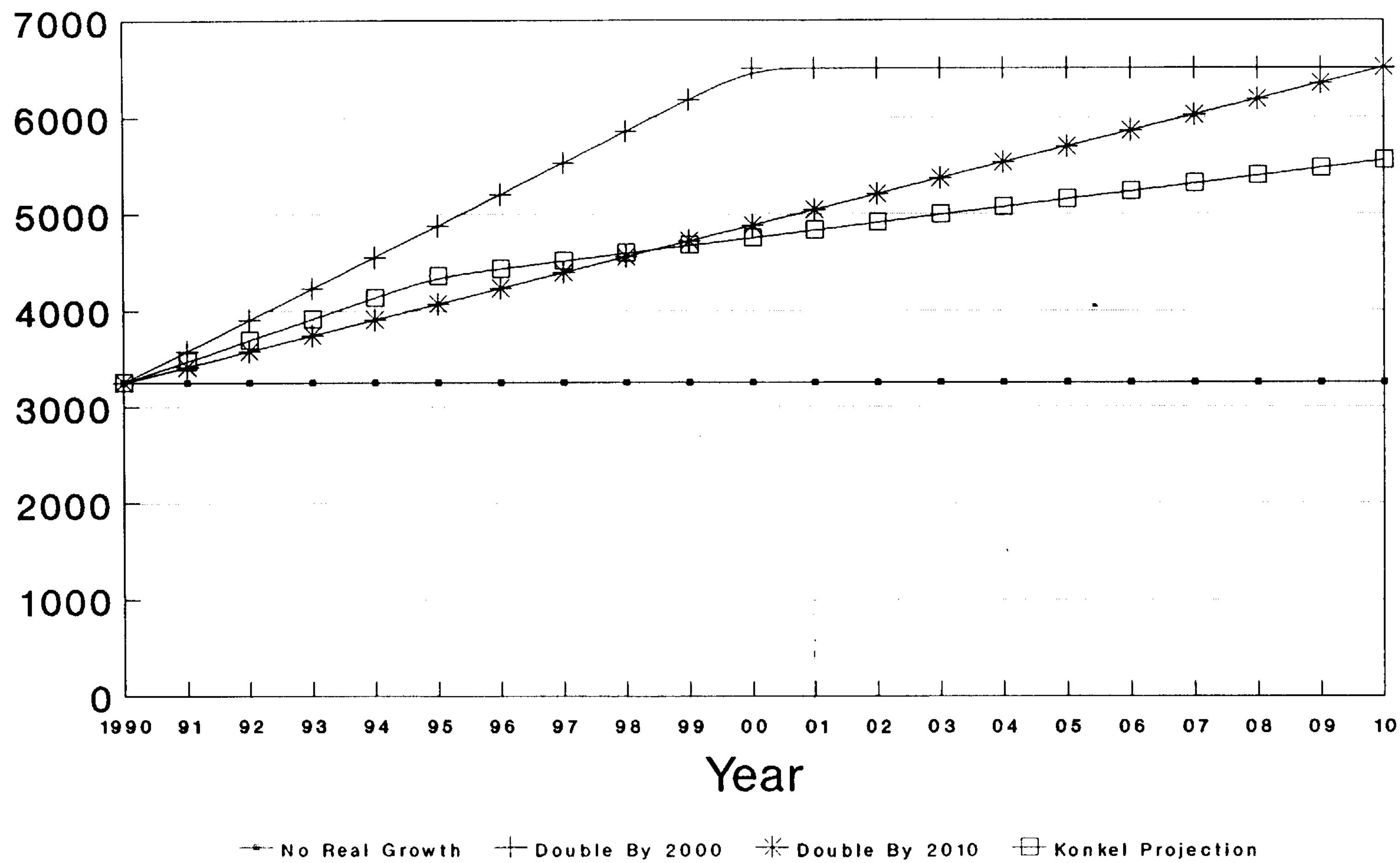


Figure 35

Produced: 9/90

Projected OSSA Cumulative
Demand for PIs



Produced: 9/90

Figure 36

projections to the four demand scenarios given above.

Figures 37-39 show the projected net supply minus demand of PIs in the four demand scenarios for each of the three Interest Factors for which cumulative scenarios were generated. The most important conclusion to be drawn from these Figures is that under any significant growth scenario, OSSA will face a shortage of PIs. Only in cases where OSSA experiences approximately no growth, is the net supply of PIs expected to adequately meet demand.

Examining the Interest Factor I=1 case in more detail (Figure 37), we draw several conclusions. First, in the no growth scenario, the model predicts a slight surplus of PIs over most of the period 1991-2010. This is largely driven by the influx of new PIs from the large graduating classes of the late 1970s and early 1980s, who, with increasing seniority, will make up a larger and larger fraction of the PI population until the late 1990s. We stress, however, that the resolution of our model is unlikely to be as good as ± 500PIs, so although a formal surplus is shown, the actual result is indistinguishable from strict equilibrium. Continuing, in both the R&A based and intermediate demand scenarios (cases iii and iv), the model predicts a shortfall of 1500-2000 PIs by the year 2000; the hi-growth scenario (case ii) predicts an even more severe shortfall. A shortage of 1500 PIs in cases (ii) and (iii) in the year 2000 represents about one-third of the projected PI requirement.

We now turn to Figure 38 (I=2/3) and Figure 39 (I=4/3). Since the general trends in these results are intuitive, we simply note here that even if the I=4/3 case obtains (and 33% more OSSA PIs result from each college graduating class than the 1969-1989 average), a shortfall of $\approx$ 1000 PIs is still predicted by the year 2000 for cases (iii) and (iv). To mathematically eliminate these predicted shortfalls, we found a doubling in the Interest Factor is required. Strictly interpreted, this implies an enormous growth requirement in the number of space science senior research population (the PIs); we will discuss the alternatives to this in Section VII.

In conclusion, our projections indicated that if significant budget growth is achieved, OSSA must either recruit and/or retain more PIs, or make each PI more effective, if it expects to adequately staff the scientific teams that will analyze the data from its upcoming

Projected Net Supply of OSSA PIs
Interest Factor = 1.0

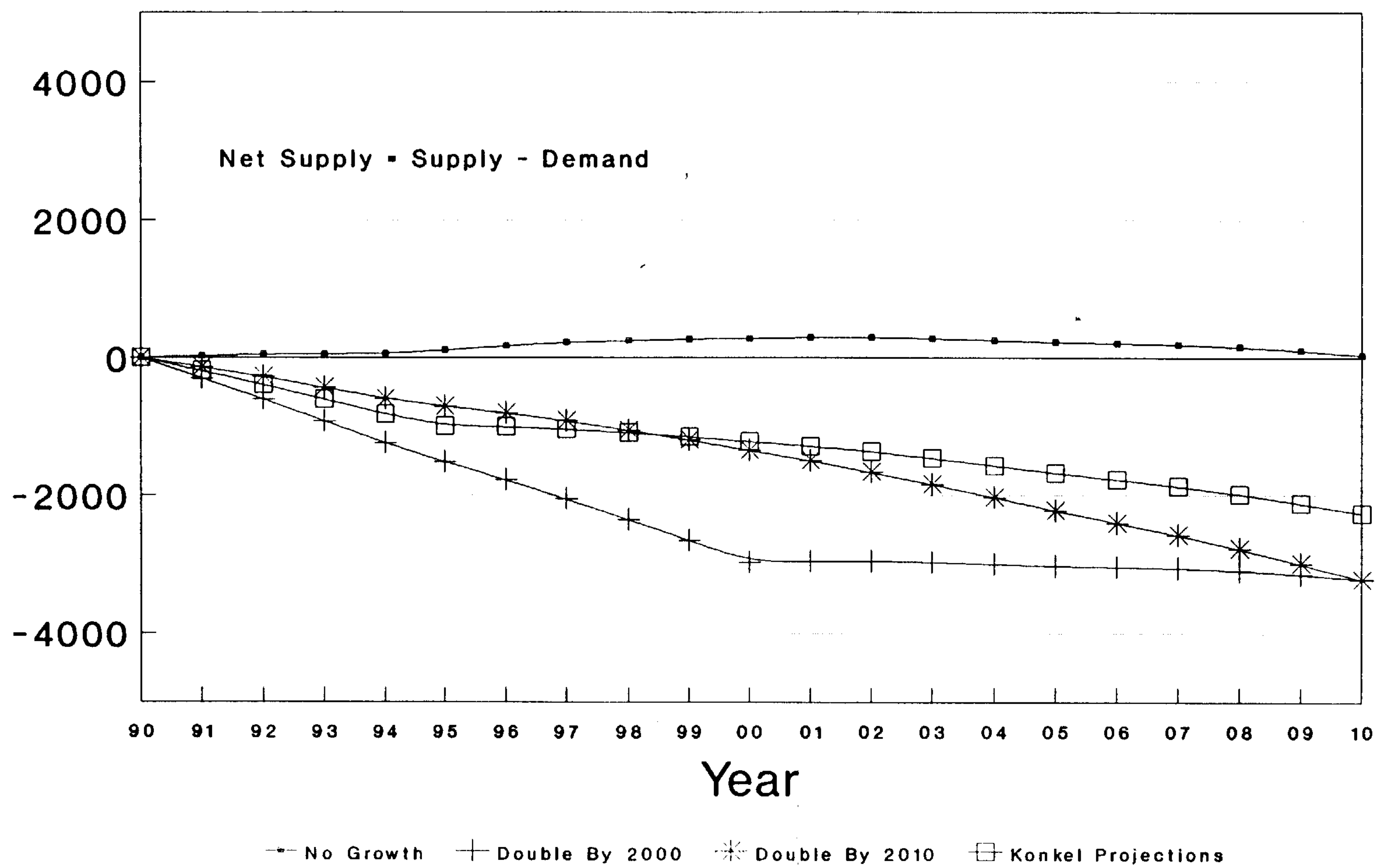
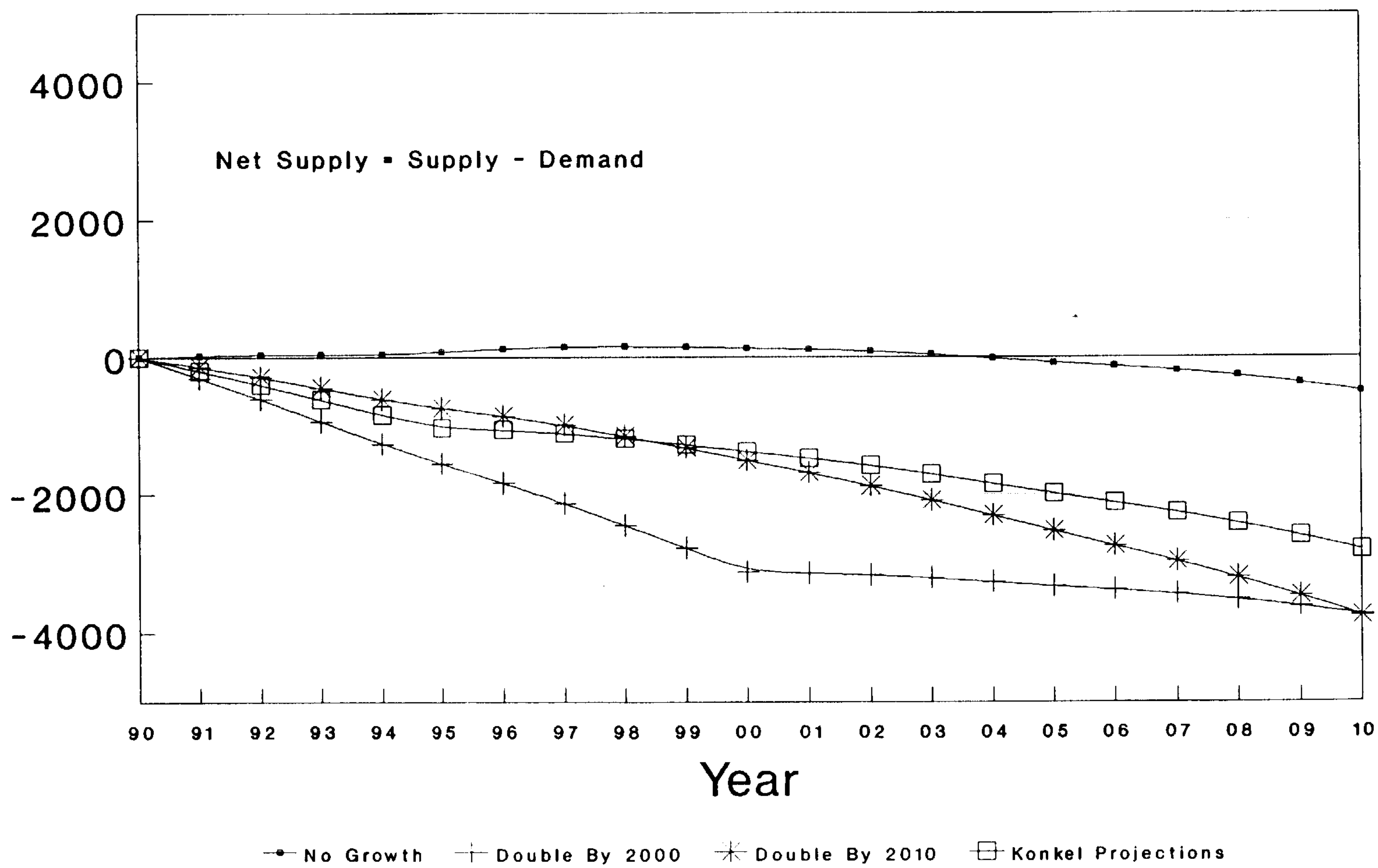


Figure 37

Produced: 9/90

Projected Net Supply of OSSA PIs
Interest Factor = 2/3



Produced: 9/90

Figure 38

Projected Net Supply of OSSA PIs
Interest Factor = 4/3

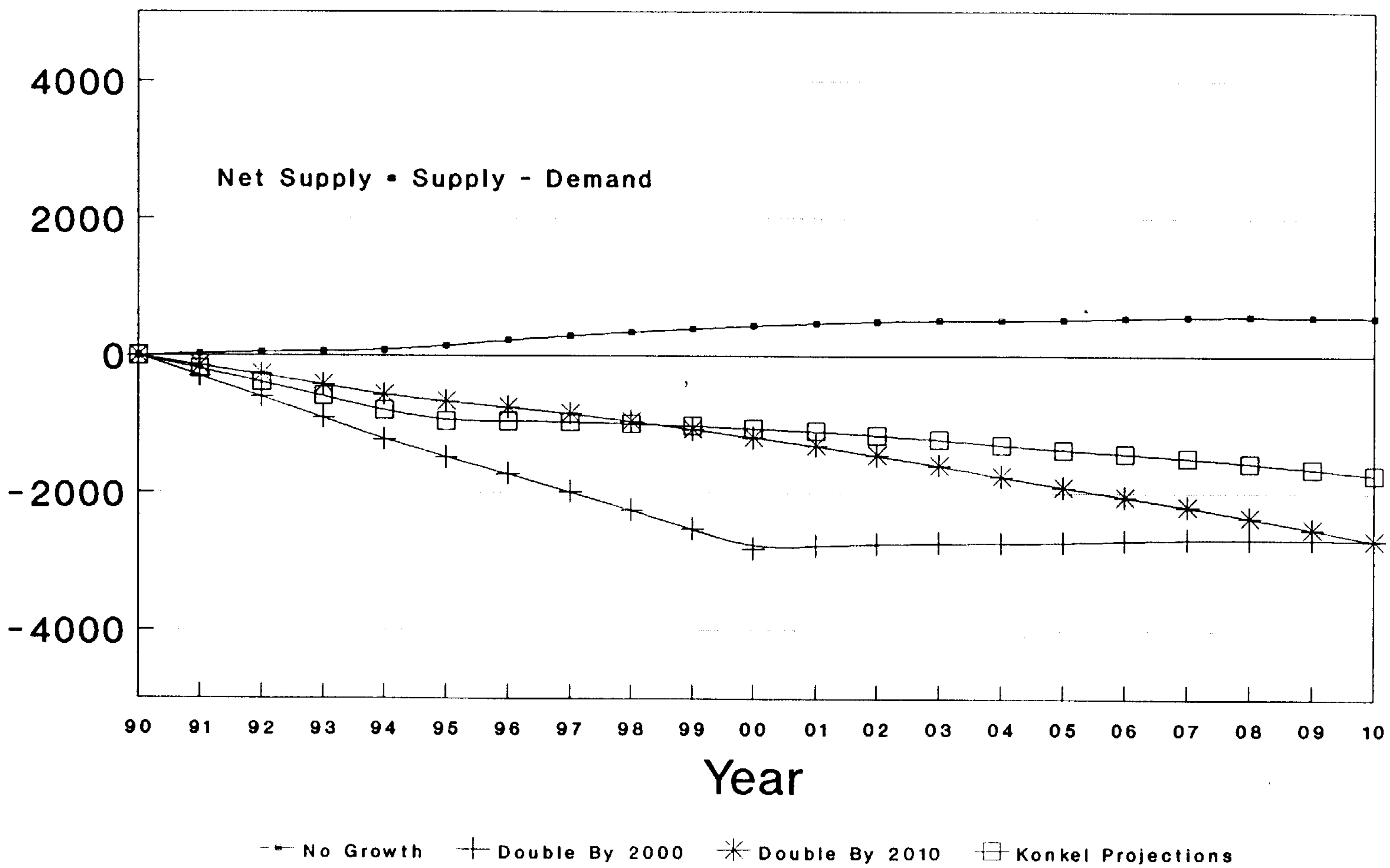


Figure 39

Produced: 9/90

missions.

This concludes our description of the Task 3 (PI Projection) methodology and results. Table 5 gives a brief summary of this work.

SUMMARY TASK 3 CONCLUSIONS: PI PROJECTIONS

- If OSSA Experiences No Growth, We See No Dramatic PI Shortage

- Under Substantial Growth Scenarios, OSSA is Likely to Experience Serious Problems in Meeting Projected Demand

- Long Lead Time in Training PIs and the Tightening U.S. Technical Labor Market Argue Against Easy Solutions. One Must Either:

  - ✓ Reduce Demand
  - ✓ Produce/Import/Retain More PIs
  - ✓ Make PIs More Effective

Table 5

VII. Recommendations

In this study, we have documented the demographic character of 88% of the OSSA PI population, and the demographic state of the unknown fraction of the OSSA Co-I population which subscribes to OSSA NRAs. We have also modelled the future population of OSSA PIs, using a model based on the present-day PI population. We have found that if OSSA grows significantly, then the current rate of PI attrition and replacement will not be able to satisfy the projected demand for PIs. *Perhaps even more important than quantitative shortfalls, however, is the inevitable loss of highly-experienced investigators who were exposed to much higher flight rate opportunitites in the 1960s and 1970s*[8,9]*; this concern is more acute for instrumentalists than modellers or theorists. We therefore point out that beyond making up any future quantitative shortfall in the OSSA PI population, OSSA must also address the serious potential for the likely qualitative decrease in experience level among the aggregate PI population.*

Table 6 summarizes a series of recommendations we make in light of our work. These recommendations are simply suggestions, based on our findings and experience, and are not supported by rigorous research. They concern how OSSA might (I) improve its knowledge base about historical PI/Co-I population trends, (II) rapidly increase the PI population if the need arises, and (III) increase the effectiveness of each PI.

Recommendation I concentrates on how OSSA could obtain a better forecast of the predicted number of PIs in future years, and better understand the relative experience level of hardware PIs in the 1990s vs. the 1960s and 1970s. As we pointed out in the main body of this report, we believe the greatest weaknesses in the study we made is that it is based on the OSSA AODB which does not contain historical data on the past number of PIs as a function of time and strongly undersamples the Co-I population. Recommendation I therefore suggests a historical study of past PI populations in order to put the data we have developed into longitudinal context. This survey would address our stated concern that the 1989-1990 population snapshot may not represent the true 20-year average for the period 1970-1990. Performing such a study would further allow one to judge the response of the PI population to funding and other "environmental" changes, so that a

RECOMMENDATIONS

I. *If OSSA Wishes To Obtain Better Perspective And Predictive Ability, OSSA Should:*

- Conduct A Historical Survey (By Discipline) that Includes Time Dependence of Funding and Average Hardware Experience Per PI to Determine
  - Time-Dependent PI Population Trends
  - Time-Dependent Co-I Population Trends
- Conduct A Replacement Survey (By Discipline) of
  - Young PIs
  - Co-Is
  - Match NASA Training Programs (Pre & Post Doc) to Replacement Rates

II. *If OSSA Wishes To Increase the PI Population Quickly, it Could:*

- Import Investigators from Outside Scientific Disciplines
- Encourage Space Science PI Matriculation and Retention by Targeted, Competitive Feeder Programs With Stable Multi-Year Funding and/or Industry/NASA "Scientific Service" Employment Opportunities

III. *If OSSA Wishes To Increase the Effectiveness of PIs, OSSA Should:*

- Institute a Para-Professional Career Track For Space Science Researchers

Table 6

Produced: 10/90

quantitative prediction of the coupling between factors such as research budget growth and the Interest Factor could be achieved. Because to accomplish such a goal one is interested in data on individuals *not* in the AODB, we believe that these studies could most efficiently be conducted by asking department heads at major research universities and labs to complete a historical survey questionaire as opposed to a canvasing of researchers themselves. Recommendation I also suggests a nationwide study to survey a majority of the OSSA Co-I population (as opposed to the much smaller, presumably biased AODB Co-I population). Such a study would provide better information on this important component of PI replacement (other components include the importation of foreign nationals in space science, and the importation of scientists from fields outside space science)

Recommendation II addresses several ways in which the loss rate of PIs and potential PIs could be decreased. Such a decrease would alleviate the need to train new PIs to make up the shortfalls predicted here.

We do not believe that increasing the training of new graduates in space studies is particularly effective. This is because of the timescale mismatch between the expected demand and training time. It now takes 9-12 years to train a new PhD (beginning with an entering freshmen). Thus, an immediate increase in space science degree students at the freshman level would not result in new PhD until after the year 2000, and would not materially affect the number of PIs until ~2007. Even if post-baccalaureate graduate students in other fields could be converted to space science-related PhD tracks, a 5-7 year lag still occurs, and significant increases in the PI population would not occur until ~ 2002. Windall[6] has shown that the smaller population of college age individuals after the baby boom inevitably leads to a reduction in the number of U.S. nationals entering the scientific workforce, which exacerbates the inherent problems in increasing space science PhD production. In the long run (i.e., post-2000), the declining post-baby boom population trend might be counteracted by tapping an increasing number of female and foreign nationals to fill vacancies in the space science profession; however, space science will have to compete against other professions, including the defense, electronics, telecommunications, and materials science for industries these new sources of PhDs.

As an alternative, importing new space science investigators from other nations or research fields in the US is one method to rapidly increase the ranks of OSSA PIs, at least in principal. However, some areas of space science are so highly specialized that this is unlikley to apply to all potential problem areas. Further, this alternative will be effective only if the scientific "emigres" perceive space science to be intellectually enticing and have a measure of long-term career stability. If OSSA choses this strategy, it must incentivize this immigration.

Another alternative is that OSSA improve the matriculation and retention rate of space science-related PIs. This alternative is much more effective than attempting to reduce retirement rates because it offers a much longer term (30 year vs. few year) solution. In this regard, the most effective step we believe OSSA could make would be to institute "people programs" designed to reduce early career attrition, and thereby increase the PI population rate. To decrease the attrition rate, OSSA must make becoming and remaining a PI more attractive than leaving the field. Career stability is a key ingredient in retaining young space science investigators, and we suggest that increasing the stability of funding for young investigators in tradionally soft-money positions is one method to accomplish this goal. Another is to provide a 'Scientific Service Internship' program for young researchers. As we envision it, individuals selected for such a program would spend 2-4 years in industry or at NASA centers doing a mix of scientific research of their choosing (perhaps within the bounds of their proposal to become a PhD intern) and contribute 50-70% of their time to the development of space missions or data systems at their intern institution. Beyond providing a career-broadening choice and early funding stability, the intern program would also address the experience loss that will result from the retirement of those PIs who experienced the enormous opportunities of the 1960s and 1970s.

Recommendation III is designed to increase the effectiveness of each PI, and thereby to reduce the total demand for PIs. Based on the conclusions reached in Section VI, if each present-day PI could conduct and manage twice as many research projects, then the manpower shortfalls predicted in cases (ii)-(iv) above would be alleviated altogether. As described in Table 7, such an increase in effectiveness could be achieved by instituting a

PARA-PROFESSIONAL CAREER TRACK FOR SPACE SCIENCE RESEARCHERS

- Master's Level "Independent" Research Lead Investigators
- Follow Para-Legal, Para-Medical, Oil Industry Precedents

Advantages:
- Responsive
- Flexible
- Multiplies Effectiveness of PIs

Issues:
- ✓ Prejudice
- ✓ Stability
- ✓ Incentives
- ✓ Quality Control
- ✓ Implementation (e.g. Industry, University or NASA Based?)

Table 7

Produced: 10/90

career track for "Para-professional" researchers trained at the Masters level.

Para-professionals are effectively used in medicine, oil exploration, and the legal profession to alleviate the workload on senior practitioners. The fostering of a para-professional career track would provide for the development of a space science research population of mature researchers (*not* students or post-docs) who could staff research goups and, with sufficient experience, undertake independent but leading roles under a senior PI. These Independent Research Leads (IRLs) would serve as a "multiplier" for the existing PI population. Our experience with Masters-level industry personel, though anecdotal, indicates that a significant number of individuals would be interested in more research rather than applications oriented career tracks.

The advantages of para-professionals include (a) the fact they could be much more rapidly obtained from industry and graduate schools than new PhDs, and (b) that by virtue of their less specific education, they would presumably be more flexible and thereby able to move between scientific specialties in space science as demands shift.

Interestingly, the results presented in Section IV above, show that most of the Masters-level PIs now supported by OSSA were trained in the 1950s and 1960s and successfully entered space science fields during the high demand period of the "First Golden Era."

The potential concerns we see in this Recommendation center on the perecieved prejudices of academic PhDs (the majority of the OSSA PI population) against Masters level-trained individuals; many professional scientists consider a Masters-level degree to be a sign of failure to accomplish a PhD. Other issues concerning the para-professional IRL recommendation center on its immplementation: How would job stability be encouraged? What career incentives would exist (e.g., for promotion and recognition)? How would quality control be maintained among the IRL population?

These are issues beyond the scope of our study, and we therefore offer Recommendation III in the same spirit as Recommendations I and II, as ideas which OSSA might wish to consider.

References

1. McDougal, W. (1985). *The Heavens and The Earth: A Political History of the Space Age*, Basic Books, Inc., New York.

2. *Dissertation Abstracts (1861-1988)* (1990). Dialog Information Services, Inc. Copyright University Microfilms International Inc., Ann Arbor.

3. Stern, S. A., Konkel, R., and Byerly, R. (1990). "Demographics of NASA-Funded Space Research Principal Investigators", *Space Policy*, **6**, No. 3, 350.

4. Aeronautics and Space Report of the President: 1986 Activites, NASA Headquarteres (Washington, D.C. 1986), Appendix E-2.

5. Bowen and Sosa (1989). *Prospects for the Faculty in the Arts and Sciences.*, W.G. Bowen and J.A. Sosa. Princton Univ. Press. 1989.

6. Windall, S. E., (1988). "AAS Presidential Lecture: Voices from the Pipeline." *Science*, **241**, 1740.

7. Testimony by Dr. L. Fisk. Hearings before the Subcommitte on Space Science and Applications of the Committee on Science, Space, and Technology. Volume II, (Y4.Sci2:101-129). 101^{st} Congress, Second Session, p242. United States House of Representatives. (1990).

8. Rosendhal J.D. and L.J. Lanzerotti, (1989). *Issues in Science and Technology*, **V**, No. 2, 61-66.

9. Space and Earth Science Advisory Committe, NASA Advisory Council, *The Crisis in Space and Earth Science*, Washington, D.C.: NASA, 1986.

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Figure 21. A comparison of the relative age distributions of the NRC doctorates broken down by their principal funding agencies.

Appendix A

The Colorado OSSA Data Base (1990): Contents and Instructions for Use

The Colorado OSSA Demographic Database is contained on four 720K, 3.5-inch diskettes formatted for use with Microsoft's DOS. There are two versions of the Colorado OSSA Demographic Database. The first version is contained on the two diskettes labeled "Colorado PI/Co-I OSSA Demographic Database, PICOI;" the second version is contained on the two diskettes labeled "Colorado PI/Co-I OSSA Demographic Database, STAT." Table A-1 provides a list of the files found on each diskette.

The files on the PICOI diskettes contain the PI/Co-I data collected from OSSA and the biographical sources. Individual PI records in these files include information directly obtained for each PI. Table A-2 describes the fields found in each record of the PICOI database. The records in the files on the STAT diskettes contain a portion of the data found in the PICOI files, as well as derived information, in a convenient form for generating statistical tables. All lengthy text fields were eliminated, i.e. names, addresses with institution names, and numerous calculated fields were added to each record. Table A-3 contains a detailed description of the fields found in each record of the STAT version that differ from those found in the PICOI version.

The primary reason for separating the database into two versions was to facilitate manipulation of the data on the IBM PCs available to the study. Prior to the creation of the STAT file, our PCs would experience memory shortages and excessively long execution times when manipulating the database.

Not surprisingly, separating the database into two versions caused some difficulty in maintaining the integrity of the data. Since the STAT version was most often used, the data in these files are superior to the data in the PICOI files. If a conflict is encountered, the data in the STAT version should be used instead of the data in the PICOI version.

The database management program *Reflex* was used to manipulate and examine the data. *Reflex* is available from Borland International Inc., 1800 Green Hills Road, P.O. Box 660001, Scotts Valley, CA 95066-0001, although many software stores carry the program.

The program is inexpensive, retailing for less than $200.00. Extensive documentation of capabilities, uses, and features of *Reflex* are provided in the manual accompanying its sale.

After *Reflex* has been acquired and installed on an IBM PC compatible system (a recommended base configuration is a 386SX based machine with a large hard disk drive and 1 MB of RAM), the next step is to merge the files from each version into a large STAT file and PICOI file. This can be accomplished from *Reflex* by loading the first file of a particular version and then repeatedly appending each of the remaining files of that version to it in memory. This merged file should then be saved to the hard disk (the size of the STAT version and the PICOI version will each exceed 1 MB). Once the database has been merged into a single file, *Reflex* can be used to manipulate and examine the data.

Although *Reflex* has the capability to produce limited graphics, the figures for this report were prepared using Harvard Graphics available from Software Publishing Corporation, P.O. Box 7210, 1901 Landings Drive, Mountain View, CA 94039-7210, although most software stores should carry the program.

Explanation of Files on the Distribution Diskettes

Colorado PI/Co-I Demographic Database; STAT, Volume 1

AESTAT.R2D	Reflex Version 2.0* formatted PI/Co-I statistical records for investigator last names that begin with "A" through "E".
FLSTAT.R2D	Reflex Version 2.0* formatted PI/Co-I statistical records for investigator last names that begin with "F" through "L".

Colorado PI/Co-I Demographic Database; STAT, Volume 2

MRSTAT.R2D	Reflex Version 2.0* formatted PI/Co-I statistical records for investigator last names that begin with "M" through "R".
SZSTAT.R2D	Reflex Version 2.0* formatted PI/Co-I statistical records for investigator last names that begin with "S" through "Z".

Colorado PI/Co-I Demographic Database; PICOI, Volume 1

AE.R2D	Reflex Version 2.0* formatted, original PI/Co-I records for investigator last names that begin with "A" through "E".
FL.R2D	Reflex Version 2.0* formatted, original PI/Co-I records for investigator last names that begin with "F" through "L".

Colorado PI/Co-I Demographic Database; PICOI, Volume 2

MR.R2D	Reflex Version 2.0* formatted, original PI/Co-I records for investigator last names that begin with "M" through "R".
SZ.R2D	Reflex Version 2.0* formatted, original PI/Co-I records for investigator last names that begin with "S" through "Z".

* Files with an "**.R2D**" extension can only be used with Reflex Version 2.0.

Table A-1

Produced: 2/91

Explanation of Data Fields:

Records in the PICOI Files

Field	Description
pi_name	Name of Investigator
salut	Salutation
suffix	Suffix to use if applicable, e.g. Jr.
record	Record Number. WARNING: These are not unique!
institution	Name of institution that employs investigator.
addr1	Investigator's address.
addr2	Investigator's address.
addr3	Investigator's address.
state	Investigator's state of residence.
zip	Investigator's zip code.
phone	Investigator's telephone number.
CoIonly	Is the investigator a Co-I only: y yes n no
involve	Type of work that the investigator is involved in: p Principal investigator c Co-Investigator m Management/Administration g General Interest f Flight Project s Suborbital Investigation d data analysis r basic research p Advance planning/Mission Design w Science Working Group a NAS/NRC Advisory Committee n NASA Advisory Committee/Council
n_involve	The number of work areas that the investigator is involved in.
discipline	Disciplines that the investigator is involved in: a Astronomy c Communications i Computer Science/Information Systems e Environmental Observations l Life Sciences m Microgravity p Planetary s Solar And Space Physics
n_discipline	The number of disciplines that the investigator is involved in.

Table A-2

Field	Description
sex	Sex of investigator: m Male f Female
forn_born	Was the investigator born in a foreign country: n No y Yes
yr_birth	Investigator's year of birth (last two digits only).
age	Age of investigator (computed from year of birth).
adj_age	If year of birth data was not present, the year that highest degree was awarded is used to compute age (see text for justification).
h_degree	Highest degree that investigator received.
yr_h_degree	Year that highest degree was received (last two digits only).
age_h_degree	Age of investigator at time highest degree was awarded (computed from year of birth and year of highest degree).
university	University where the investigator received highest degree. Coding corresponds to the rank of the degree granting institution in producing Ph.D.s (See attachment to this table).
memo	Some records have a brief message.
i_type	Type of institution the investigator works for: u College or University i International Organization m Minority Business c NASA Center n Non-Profit Corporation g Other Government p Private Industry s Small Business
employed	This field duplicates much of the information contained in "i_type" but it is not well documented.
e_division	OSSA division that the investigator is involved in: z Astrophysics c Communications e Earth sciences i Information Systems b Life Sciences n Microgravity m Shuttle Payloads l Planetary s Space Physics x No OSSA involvement

Table A-2

Field	Description
no_e	If no OSSA involvement, this field is set to "y".
n_division	The number of OSSA divisions that the investigator is involved in.

The following fields were used in locating investigators and are now obsolete: source, page, status, m_list.

Table A-2
(Attachment)

NSF Data on Doctorate Production

Top 100 Doctorate Producing Institutions

(September 26, 1990)

Rank	Doctorates	University
1	5798	Univ. of CA, Berkeley
2	4566	Univ. of WI, Madison
3	4342	Univ. of IL, Urbana
4	4220	MIT
5	3749	Stanford Univ.
6	3656	Univ. of MI
7	3629	Cornell Univ.
8	3339	Ohio State Univ.
9	3328	Purdue Univ.
10	3299	Univ. of CA, Los Angeles
11	3248	Univ. of MN
12	2878	Michigan State Univ.
13	2810	Harvard College
14	2664	Univ. of TX, Austin
15	2527	Penn State Univ.
16	2511	Univ. of WA
17	2478	Columbia
18	2387	Univ. of CA, Davis
19	2231	Univ. of Chicago
20	2155	Texas A & M
21	2136	Univ. of PA
22	2114	Iowa State Univ.
23	2112	Univ. of MD
24	2094	Univ. of FL
25	2028	Northwestern Univ.
26	1907	New York Univ.
27	1877	Yale
28	1872	Univ. of AZ
29	1847	Rutgers
30	1822	Univ. of NC
31	1725	Princeton
32	1714	Univ. of MA
33	1703	Univ. of IN
34	1697	Univ. of CO, Boulder

Produced: 2/91

Table A-2
(Attachment)

NSF Data on Doctorate Production

Top 100 Doctorate Producing Institutions

(September 26, 1990)

Rank	Doctorates	University
35	1695	SUNY, Buffalo
36	1669	UCLA
37	1659	CUNY
38	1623	NC State Univ.
39	1597	Univ. of Pittsburgh
40	1540	Univ. of GA
41	1511	U.S. International Univ.
42	1472	Univ. of KS
43	1466	Virginia Polytech Institute
44	1441	Univ. of CA, San Diego
45	1434	Univ. of TN
46	1432	Colorado State Univ.
47	1398	Johns Hopkins
48	1386	Univ. of MO, Columbia
49	1380	Duke
50	1364	SUNY, Stony Brook
51	1327	CalTech
52	1282	Univ. of Rochester
53	1262	Oregon State Univ.
54	1217	Univ. of UT
55	1216	Univ. of NE
56	1194	Washington State Univ.
57	1183	Univ. of IA
58	1167	Univ. of VA
59	1148	Case Western Reserve
60	1145	Univ. of CT
61	1094	Oklahoma State Univ.
62	1083	Univ. of CA, Santa Barbara
63	1073	Univ. of HI
64	1071	Univ. of WA, St. Louis
65	1040	Boston Univ.
66	1031	Florida State Univ.
67	1009	Univ. of Cincinnati
68	989	Brown

Produced: 2/91

Table A-2
(Attachment)

NSF Data on Doctorate Production

Top 100 Doctorate Producing Institutions

(September 26, 1990)

Rank	Doctorates	University
69	981	Wayne State Univ.
70	966	Univ. of CA, Riverside
71	930	Univ. of OK
72	924	Univ. of OR
73	909	Syracuse Univ.
74	904	Univ. of KY
75	893	Temple University
76	887	George Washington University
77	857	Kansas State Univ.
78	842	Carnegie-Mellon
79	832	Louisiana State Univ.
80	775	Univ. of Houston
81	744	Rensselaer
82	744	Vanderbilt Univ.
83	709	Univ. of SC
84	706	Rice
85	694	Univ. of WV
86	686	Georgia Tech.
87	678	Notre Dame
88	666	Arizona State Univ.
89	659	Univ. of CA, Irvine
90	625	Univ. of NM
91	624	Univ. of DE
92	612	Texas Tech.
93	594	Univ. of RI
94	580	SUNY, Albany
95	576	Univ. of Miami
96	569	Univ. of IL, Chicago
97	539	Univ. of AR
98	526	Brandeis Univ.
99	517	Auburn Univ.
100	495	Hofstra Univ.

Explanation of Data Fields:

Records in the STAT Files

Field	Description
pi_name	Name of Investigator
state	Investigator's state of residence.
zip	Investigator's zip code.
Region	Determines what U.S. Bureau of Census region that the investigator resides in by using the following fields: Mt. W. S. Central E. S. Central S. Atlantic M. Atlantic N. Eng. E. N. Central W. N. Central
involve	Type of work that the investigator is involved in: p Principal investigator c Co-Investigator m Management/Administration g General Interest f Flight Project s Suborbital Investigation d data analysis r basic research p Advance planning/Mission Design w Science Working Group a NAS/NRC Advisory Committee n NASA Advisory Committee/Council
n_involve	The number of work areas that the investigator is involved in.
discipline	Disciplines that the investigator is involved in: a Astronomy c Communications i Computer Science/Information Systems e Environmental Observations l Life Sciences m Microgravity p Planetary s Solar And Space Physics

Table A-3

Figure	Description
Astronomy:	Used to determine the number of investigators involved in the eight disciplines described under "discipline" above. Based on the lower case letters present in the discipline field, the appropriate fields of the following eight are set to 1. For example, if the investigator indicated involvement in astronomy and planetary, an "a" and "p" would be entered in the discipline field and the "Astronomy:" and "Planetary:" fields would both be set to 1.
Communications:	See "Astronomy:" explanation above.
Comp Sci. & Info. Systems:	See "Astronomy:" explanation above.
Environmental Obs:	See "Astronomy:" explanation above.
Life Sciences:	See "Astronomy:" explanation above.
Microgravity:	See "Astronomy:" explanation above.
Planetary:	See "Astronomy:" explanation above.
Solar & Space Phys:	See "Astronomy:" explanation above.
n_discipline	The number of disciplines that the investigator is involved in.
CoIonly	Is the investigator a Co-I only: y yes n no
sex	Sex of investigator: m Male f Female
forn_born	Was the investigator born in a foreign country: n No y Yes
CofB	Country of Birth.
Continent	If the investigator was born in a foreign country, determine what continent the investigator is from using the following fields: W. E. A. As. Af. SA. ME.
yr_birth	Investigator's year of birth (last two digits only).
From Call	This field is only applicable for those that indicated that they are a Co-I only. Merely indicates if the year of birth was obtained by calling the investigator.
age	Age of investigator (computed from year of birth).
adj_age	If year of birth data was not present, the year that highest degree was awarded is used to compute age (see text for justification).

Table A-3

Figure	Description
Age Group	"Age Group" and "AG04" compute the five year age group that the investigator falls into using two different formulas.
AG04	See "Age Group" above.
h_degree	Highest degree that investigator received.
yr_h_degree	Year that highest degree was received (last two digits only).
age_h_degree	Age of investigator at time highest degree was awarded (computed from year of birth and year of highest degree).
Degree Age Group	Computes the five year age group that the investigator fell into when he received his highest degree.
DHD	Compute the decade in which the investigator received his highest degree.
memo	Some records have a brief message.
i_type	Type of institution does the investigator work for:
	u College or University
	i International Organization
	m Minority Business
	c NASA Center
	n Non-Profit Corporation
	g Other Government
	p Private Industry
	s Small Business
employed	This field duplicates much of the information contained in "i_type" but it is not well documented.
e_division	OSSA division that the investigator is involved in:
	z Astrophysics
	c Communications
	e Earth sciences
	i Information Systems
	b Life Sciences
	n Microgravity
	m Shuttle Payloads
	l Planetary
	s Space Physics
	x No OSSA involvement
no_e	If no OSSA involvement, this field is set to "y".
n_division	The number of OSSA divisions that the investigator is involved in.

The following fields were used in locating investigators and are now obsolete: source, page, status, m_list.

Table A-3