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Manpower Simulation for the Power Plant Design Engineering

Byung Soo Moon and Poong Eil Juhn

Korea Advanced Energy Research Institute
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발전소 설계 인력 수요의 통계적 분석

문 병 수·전 풍 일

한국 에너지 연구소
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Abstract

Some observations from the examination of actual manhour curves for the power plant design engineering obtained from Sargent & Lundy Engineers and of a few of the model curves proposed by Bechtel, are analyzed in this paper. A model curve representing typical design engineering manhour has been determined as a probability density function for the Gamma Distribution. By means of this model curve, we strategically forecast the future engineering manpower requirements to meet the Government's long range nuclear power plan. As a sensitivity analysis, the directions for the localization of nuclear power plant design engineering, are studied in terms of the performance factor for the experienced versus inexperienced engineers.

요 약

이 논문에서는 Sargent & Lundy 회사로 부터 입수한 발전소 설계 인력 분포에 관한 49개 실적치 커브와 Bechtel사가 제안한 수 개의 모델 커브를 분석하였다. 이들 커브로 부터 발전소 설계에 소요되는 인력분포를 Gamma분포로 가정하고 그 확률함수를 하나의 모델커브로 선정하였다. 이 모델커브를 이용하여 정부의 장기 원자력 발전소 설계계획에 따른 인력 수요를 년도별로 산출하였다. 또한 감응도 분석의 하나로서 엔지니어들의 숙련도에 따른 설계 인력 수요의 변화를 분석하였다.

1. Introduction

A manhour curve is a set of points in a plane with x-coordinate being the month number and y-coordinate being the number of hours spent for a particular project during a period of one month. A project, here, is the total design work for one unit of power plant construction.

In this paper, we look at some of the actual manhour curves obtained from the project history file at Sargent & Lundy Engineers (S & L), and some from Bechtel Engineering Company (BEC). The curves we examine are for various types of power plants such as Nuclear Initials (NUI), Coal-Fired Initials (CFI), Coal-Fired Duplicats

(CFD) and Gas-Fired Initials (GFI).

Those curves obtained from S & L are separated into six groups for different engineering disciplines. They are Structural Engineering (SE), Structural Design & Drafting (SD), Mechanical Engineering (ME), Mechanical Design & Drafting (MD), Electrical Engineering (EE) and Electrical Design & Drafting (ED). Technical & Administrative Services are considered not very important and they are left out in this paper.

We examine these actual manhour curves to see if one can set up a statistical model for the manhour curves, and to see if one can single out some of the factors that are needed to project the manpower requirements for the national long range nuclear power plan.

Those factors that we consider in this paper are such as relative weight of the menhours for individual engineering discipline, manhour ratios for the deplicate plants versus the initial plants, and performance factor between experienced and inexperienced engineers.

2. Manhour Curve as a Gamma Distribution

In this section, we set up a statistical model for the manhour curves, estimate the parameters involved, and compute some of the factors mentioned above.

2.1. Statistical Model for Manhour Curves

Assume that a manhour curve consisting of a total of N manhours is formed by the hours charged to this particular project by N different engineers.

We may, then consider the manhour curve as a statistical observation of the event that in which month of the project, the engineers will charge his hour to it. That is, the manhour curve represents the waiting time since the authorization date for the engineers to charge his hour to it.

In this respect, and by the shape of the curves as seen in Fig 1, it is natural to take the Gamma distribution as our statistical model. A well known example of a Gamma distribution is the life time of a particular kind of animals.

Another reason for the choice of gamma distribution function for our statistical model is that no other known probability density functions fit better. Normal distribution will not fit very well since most of the manhour curves are lack of the symmetry.

The computed results show that the average of the errors between the actual and the fitted is about 4% for the Gamma distribution, while that is about 6% for the normal distribution. A problem with Beta distribution is that it must have a clear ending point which manhour curves do not have.

We therefore choose the Gamma distribution, for which probability density function is defined by equation (1) in our statistical model (Ref [1]).

$$f(x)=\frac{1}{\Gamma(\alpha+1)\ \beta^{\alpha+1}}\, x^{\alpha} e^{-\frac{x}{\beta}} \tag{1}$$

In the following, we will estimate the parameters α and β in equation (1) by least square method.

2.2. Estimation of the parameters

The least square curve fitting by the density function for the Gamma distribution (1) is not an easy task without a fairly accurate initial values for the parameters. One of the reasons is that there are infinitely many curves with their peaks at the same x-coordinate.

To select the initial values α_0, β_0 we normalized the actual manhour curve and computed the mean and variance to obtain the following two equations;

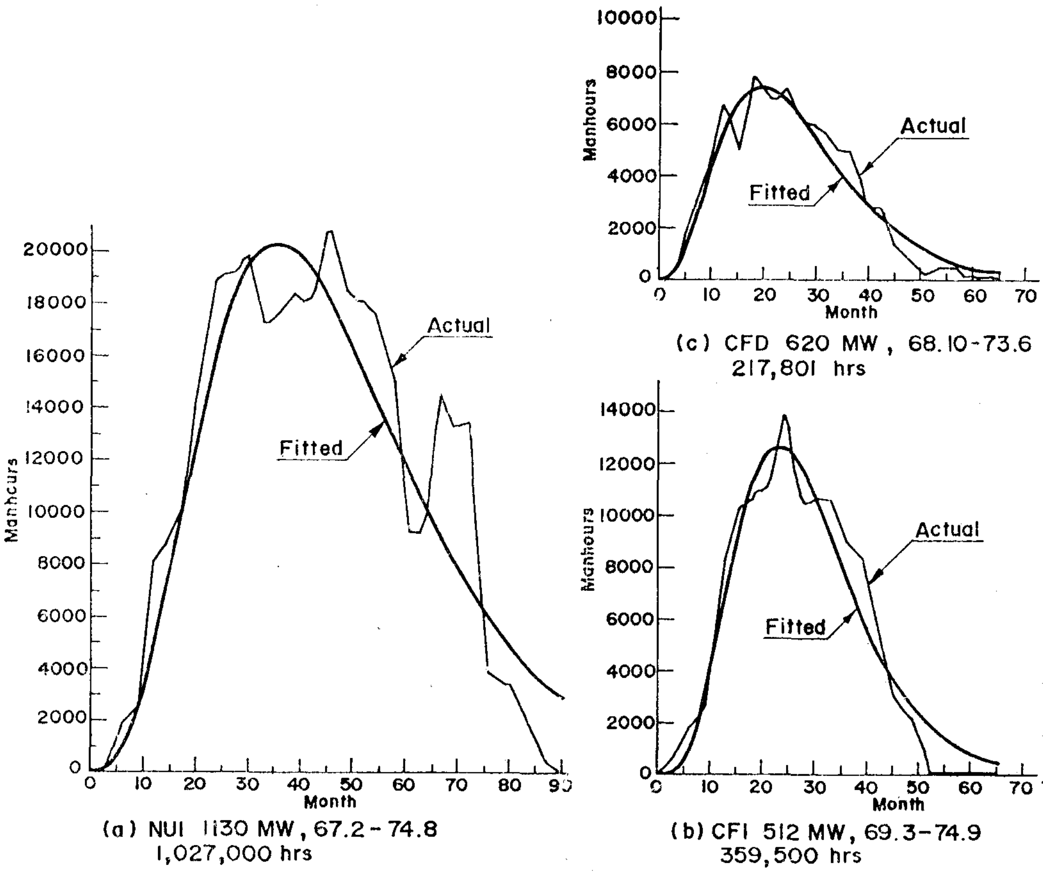


Fig. 1. Manhour Curves, Fitted vs. Actual.

$$\mu_1=\sum_{i=1}^{N} x_i y_i=\int_0^\infty xf(x)\,dx=(\alpha+1)\beta \tag{2}$$

$$\mu_2=\sum_{i=1}^{N}(x_i-\mu_1)^2 y_i=\int_0^\infty (x-\mu_1)^2 f(x)\,dx =(\alpha+1)\beta^2 \tag{3}$$

where x_i's are relative month numbers and y_i's are the manhours corresponding to the month x_i. From equations (2) & (3), we obtain

$$\beta_0=\frac{\mu_2}{\mu_1},\quad \alpha_0=\frac{\mu_1^2-\mu_2}{\mu_2} \tag{4}$$

Using the computed values for α and β in equation (4) as initial values, we proceed with least square curve fitting process by the Subroutine ZXSSQ in IMSL (See Ref [2]).

From the computed values for the parameters α and β we compute the means and peaks for the 49 curves, whose results are listed in Table 1.

When the curve fittings for the normal and gamma distributions are compared, the 'error' for the normal distribution is found to be substantially higher, as seen in Table 2. Here, the 'error' is defined as the square root of the sum of the squares of the differences for each month.

2.3. Analysis of the manhour curves

In this section, we consider two important observations that one can make from the actual manhour curves. One is the relative weight of the manhours for the three branches of engineering, and the other is the comparison of the mean month by the fitted manhour curves for these branches.

Firstly, we compute the relative weight of the manhours for each engineering discipline.

Table 1. Computed Values for the 49 Curves

Plant Type	Parameter \ Discipline	ME	EE	SE	MD	ED	SD	Total
NUI	Mean	34.306	37.072	35.693	35.738	63.178	33.100	36.585
	Peak	31.780	31.550	34.003	32.841	61.018	32.305	33.125
NUI	Mean	41.725	47.558	28.236	52.360	51.659	27,190	46.881
	Peak	31.659	40.169	22.142	39.757	48.517	21.636	35.520
CFI	Mean	29.940	29.508	19.888	27.459	36.390	19.330	28.466
	Peak	25.643	25.338	16.327	24.168	34.219	16.000	23.157
CFI	Mean	23.326	26.930	16.960	22.009	28.500	17.083	23.211
	Peak	18.069	20.211	12.654	19.134	24.704	12.843	18.097
CFD	Mean	28.128	28.958	17.577	20.563	33.336	18.174	26.213
	Peak	18.664	25.471	13.388	16.250	30.275	13.729	19.549
CFD	Mean	28.807	37.238	23.338	25.886	36.706	21.444	30.256
	Peak	18.336	32.915	15.310	22.042	31.897	15.273	22.546
GFI	Mean	29.005	29.763	26.514	29.643	34.559	27.233	29.529
	Peak	26.321	27.550	25.714	28.051	32.671	26.218	27.744

Table 2. Comparison between the two Distributions

fitted curver \ error range	below 4%	4~6%	6~10%	above 10%	Average Error
Gamma	25	20	3	1	4.02%
Normal	13	21	10	6	5.97%

Table 3. Manhours for Individual Discipline

	NUI	NUI	CFI	CFI	CFD	CFD	GFI
ME	64,840	176,500	58,574	63,761	23,655	16,874	16,737
EE	15,481	61,735	29,182	24,963	14,799	9,193	10,207
SE	9,213	18,453	9,209	11,270	3,948	3,950	3,348
MD	93,540	363,440	124,300	116,540	64,370	50,500	51,240
ED	68,110	251,930	70,170	108,390	75,420	47,090	18,220
SD	61,320	154,620	68,090	90,370	35,610	34,220	34,080
Total	312,504	1,026,678	359,525	415,294	217,802	161,827	133,832

Table 3 shows manhour breakdown for the six different disciplines of the seven different power plants whose design work was done by S & L.

To find the optimal breakdown ratio x_i for the ith discipline, we minimize the following function;

$$f(x_1, x_2, x_3, x_4, x_5, x_6) = \sum_{j=1}^{7} \sum_{i=1}^{6} (x_i - A_{ij})^2 + F\left(\sum_{i=1}^{6} x_i - 1\right)^2 \quad (5)$$

Where A_{ij} is the manhours in Table 3, i being the rows. By taking a large value for F in equation (5), we make sure that the sum of the values x_i equals 1. By setting $F=1000$, we obtain the result shown in Table 4.

Table 4. Manhour Ratio vs. Discipline

X_1(ME)	X_2(EE)	X_3(SE)	X_4(MD)	X_5(ED)	X_6(SD)
0.1477	0.0646	0.0240	0.324	0.2418	0.1976

The manhour breakdown that Bechtel estimated in October 1975 is shown in Table 5.

Tables 4 and 5 can be summarized as shown

Table 5. Manhour Breakdown by Bechtel (Oct. 27, 1975)

Discipline	Architect	Civil/Struct.	Elect.	Mech.	Plant Design
Manhours	40,000	238,000	240,000	280,000	240,000
Percentages	3.1	18.5	18.5	21.5	18.5
Discipline	**Conrtrols**	**Nuclear**	**Others**	**Admin-Services**	**Total**
Manhours	95,000	92,000	75,000	200,000	1,500,000
Percentages	7.4	6.9	5.6	—	115.385

Table 6. Manhour Breakdown for Three Eng. Branches

	S & L	BEC	Ave.
Structural	22.16%	23.4%	23%
Mechanical	47.17	48.7	48
Electrical	30.64	27.9	29

in Table 6 to find the breakdown for the three big branches of engineering.

In getting the Bechtel's breakdown in Table 6 from Table 5, the 'others' portion is divided into 3 equal parts, and 'Plant Design' and 'Nuclear' portions are added to the Mechanical Branch. 'Controls' portion is added to Electrical, and 'Architectural' portion is added to the 'Structural' branch.

Secondly, we look at the comparison of the mean month of the fitted manhour curves. From Table 1, we obtain the following summary table.

The values in Table 5 is obtained by taking the average of the mean values for the fitted Gamma distribution curves. The mean is the expected month number for an engineer to charge his hour to the particular project, where the month number starts with 1 in the month when the authorization occurs.

Table 7. Mean Month of the Manhour Curves

	Engineering	Design/ Drafting	Average
Structural	24.030	23.365	24
Mechanical	30.748	30.523	31
Electrical	33.861	40.618	37

Note that the mean is slightly different from the month when most engineers will charge their hours to this project, which is the peak of the manhour curve.

We notice here that the means for the three branches of engineering come in order as Structrual, Mechanical, and Electrical with 6~7 month apart. By looking at Table 1, we note also that for the nuclear power plants, the means are substantially higher, which is mainly due to the fact that nuclear power plants take longer period of time for the design engineering because of the regulartory requirements.

Table 8 is the result of the model manhour curves BEC has proposed for the nuclear plants. The difference between the means in Table 7 and Table 8 is probably due to the 'others' manhours which are to be spread over to the remaining three branches.

2.4. Model Curves

By taking the averages of the means and peak month numbers, we obtain Table 9.

In computing α and β, we use the following equation(6):

Table 8. Means for BEC's Model Curves

Discipline	Structural	Mechanical	Electrical	Others	ON-Shore Total
Mean	26.573	30.897	34.659	44.561	35.675

Table 9. Parameters for Model Curves

	Mean	Peak	β	α
Structural	23.70	18.84	4.86	3.8765
Mechanical	30.64	25.23	5.40	4.6740
Electrical	37.24	32.16	5.18	6.3307
Total	31.59	25.68	5.91	4.345

$$\text{Mean} = (\alpha+1)\beta$$
$$\text{Peak} = \alpha\beta \qquad (6)$$

Thus, our three models for manhour curves are;

Total:

$$f(x) = \frac{F}{\Gamma(5.345)\times(5.91)^{5.345}}\, x^{4.345} e^{-\frac{x}{5.91}}$$

Structural:

$$f(x) = \frac{F_1}{\Gamma(4.8765)\times(4.86)^{4.8765}}\, x^{3.38765} e^{-\frac{x}{4.86}}$$

Mechanical:

$$f(x) = \frac{F_2}{\Gamma(5.674)\times(5.4)^{5.674}}\, x^{4.674} e^{-\frac{x}{5.4}}$$

Electrical:

$$f(x) = \frac{F_3}{\Gamma(7.3307)\times(5.08)^{7.3307}}\, x^{6.3307} e^{-\frac{x}{5.08}}$$

where $F_1=0.23F$, $F_2=0.48F$, $F_3=0.29F$ with F the total manhour estimate for the plants of given capacity and of type; initial or duplicate.

3. Nuclear Design Engineering Manpower Simulation

In this section, we attempt to simulate the future nuclear design engineering manpower requirements by means of the model curves obtained in the previous section.

We then take a stratigical point of view, to examine a few scenarios for the national nuclear power plan, along with several options for the localization effort.

First we must clarify some of the uncertainties involved in the actual computations.

3.1. Basic Assumptions

The following assumptions are used in computing the manpower forecasts for all of the scenaions discussed in this paper.

1) The engineering manhours for the design of an individual nuclear power plant, may be simulated in a form as the probability density function for the Gamma distribution, shown by equation (7).

2) The estimate for the total manhour variation versus the plant capacity is an exponential scaling relation of the form

$$\left(\frac{MW_{new}}{MW}\right)^k$$

where k is taken to be 0.3 (Ref [4]).

3) When two nuclear units are scheduled to be built at the same site with an appropriate time interval, say 1 year, the design engineering manhours for the second unit can be reduced a great deal.

In this study, the manhours for the duplicated unit are assumed to be saved as much as 46% compared with those of the initial unit. (Ref [4]).

4) The field engineering works which usually require more manhours than the home office works do, are not considered in this study and one man month is considered as 173.3 manhours.

3.2. Scenarios

1) Nuclear Growth Scenario

According to the 5th 5-year Economic and Social Development Plan, nuclear power will gradually be the major electric power source in our country. There will be 13 nuclear power plants in operation by 1991 whose installed capacity will reach more than 11 GWe.

Since there is no Government projection beyond 1991, however, the three different nuclear growth scenarios studied by KAERI (Ref [5]) are examined in this paper. They are shown in Table 10 and Figure 2.

Table 10. Nuclear Growth Scenario

(Addition in MWe×No. of Unit)

Year	Scenario		
	Low Growth	Optimum Growth	High Growth
1978	the same as the optimum growth	587×1	the same as the optimum growth
83		650×1	
84		950×1	
85		950×1	
86		950×1	
87		950×1	
88		950×1	
89		950×1	
90		900×1	
91		900×1	
Total	11,216/13	11,216/13	11,216/13
92	900×2	900×2	900×3
93	900×1	900×2	900×2
94	900×2	900×2	900×3
95	900×1	900×2	900×2
96	900×2	900×2	900×3
97	1,200×1	1,200×2	1,200×2
98	1,200×2	1,200×2	1,200×3
99	1,200×1	1,200×2	1,200×2
2000	1,200×2	1,200×2	1,200×3
Total	25,616/27	29,816/31	34,916/36

2) Performance Factor

The design engineering manhours must vary depending upon the performance level of the engineers.

After the first three 600 *MWe* nuclear units were designed and constructed by turnkey basis, the participation ratio for our local design engineers is increasing gradually for the following units. But their experience is still very limited.

We assume that the performance factor (PF) can be expressed as following;

$$IF\ SI=0,\ PF=1$$

$$IF\ SI\neq 0,\ PF=\min\left(0.5+\frac{0.5}{12SI}x,\ 1\right) \quad (8)$$

Where x is the month numbers and SI is the number of years to accumulate experiences for self-independency.

We considered the six cases with $SI=0, 5, 10, 15, 20, 25$ years, respectively.

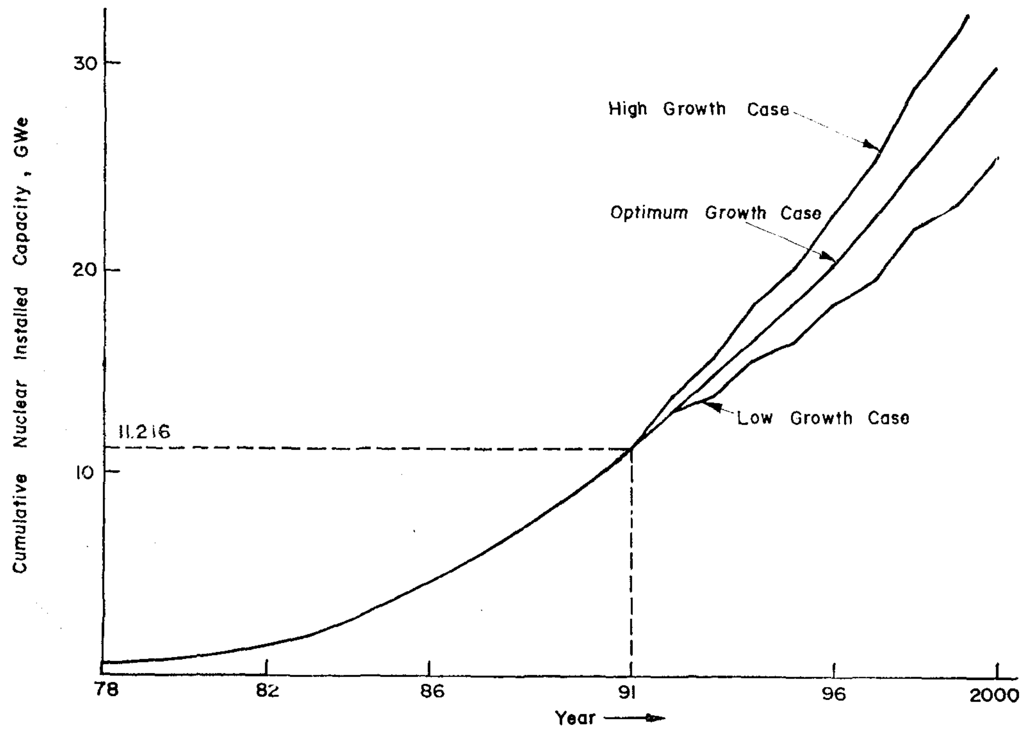


Fig. 2. Nuclear Power Growth Scenario

3.3. Computed Results

The model curves given by equation (7) with $F=1.127\times10^6$ manhours and the assumptions in section 3.1, can be applied to compute the manpower projections for the three different scenarios in Table 10.

The computation was done for the six different

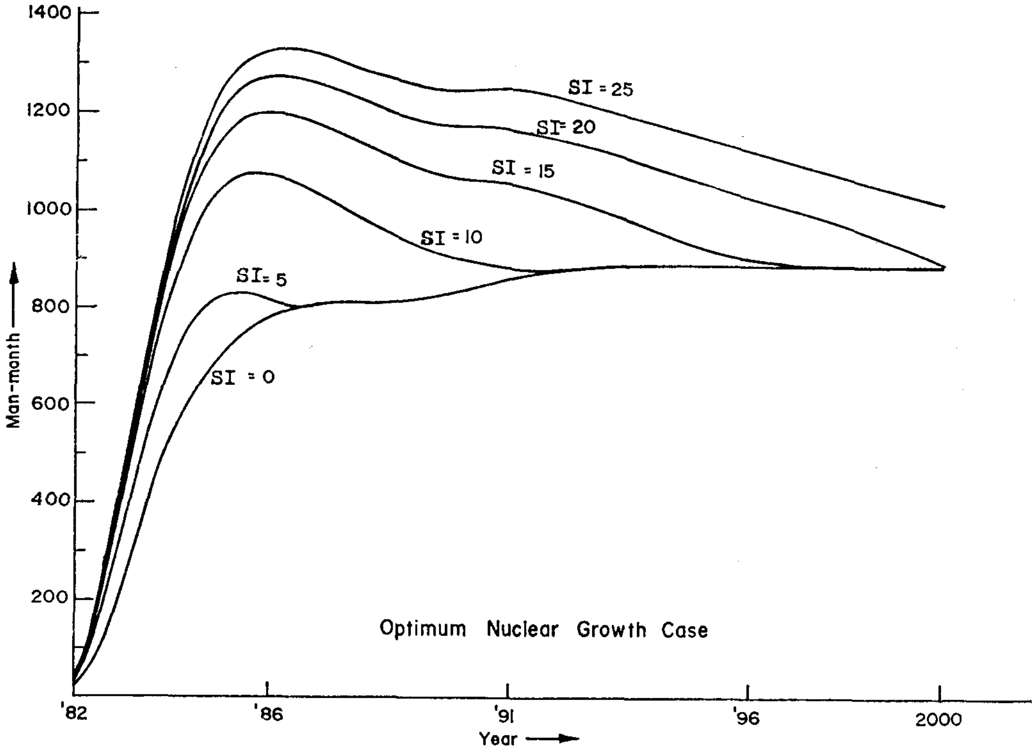


Fig. 3. Nuclear Engineering Manpower Requirement vs. Self-Independency

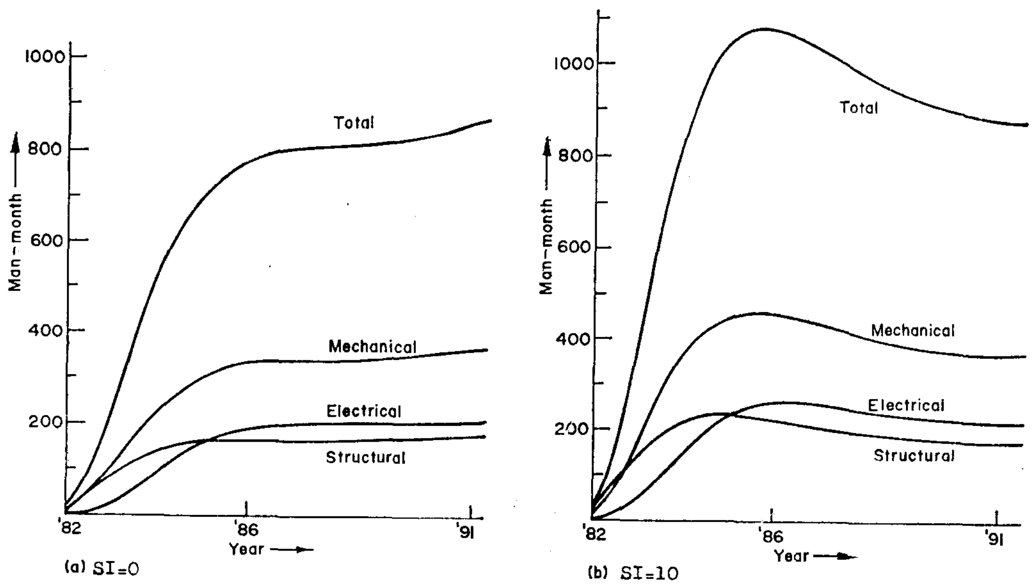
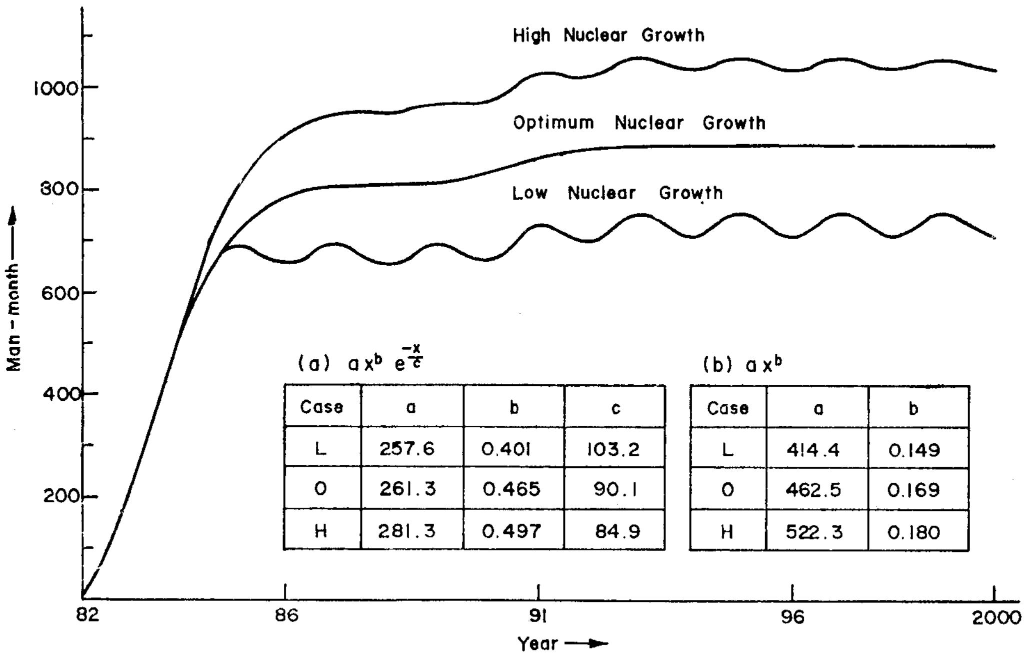


Fig. 4. Nuclear Engineering Manpower Breakdown



(a) $ax^b e^{\frac{-x}{c}}$

Case	a	b	c
L	257.6	0.401	103.2
O	261.3	0.465	90.1
H	281.3	0.497	84.9

(b) ax^b

Case	a	b
L	414.4	0.149
O	462.5	0.169
H	522.3	0.180

Fig. 5. Future Nuclear Engineering Manpower Growth Curve Fit. (SI=O)

cases of the self-independency, and the results are shown in Figure 3, from which one can see that the local design engineering manpower varies significantly with the engineer's performance level.

Figure 4 shows the breakdown of the total projected manhours for the three branches of engineering as described in Table 6.

The results of least square curve fit for the accumulated manhour curve by two different functions, one with two-parameters function ax^b and the other with three-parameter function ax^be^{-x}, are shown in Figure 5.

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