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SURVEY OF RESEARCH REACTORS

National Academy of Sciences

SURVEY

OF

RESEARCH REACTORS

SUBCOMMITTEE ON RESEARCH REACTORS

COMMITTEE ON NUCLEAR SCIENCE

NATIONAL RESEARCH COUNCIL

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SUMMARY

This report presents the results of a survey of research reactor usage conducted by the Subcommittee on Research Reactors of the Committee on Nuclear Sciences of the National Research Council. The survey was limited to research reactors licensed by the Atomic Energy Commission to operate in the 10 kW-10 MW (thermal power) range. Reactors operated above 10 MW are classed as test reactors and were excluded from the survey. The survey also excluded reactors located at AEC-operated laboratories.

The principal factors of reactor usage surveyed were: power level; hours of operation per quarter year; number of research users; number of samples irradiated; types of facilities used; scientific disciplines of users; and kinds of research supported.

When the survey began, in 1966, there were 71 licensed reactors in operation with 48 of them within the power spread specified by the survey. These 48 reactors represented a combined licensed power of 45 MW. From 32 of these reactors, representing a combined licensed power of 25 MW, data were submitted for the period October 1, 1967, through March 31, 1968, or two quarters. The locations of the 32 reactors were: university, 25; industry, 5; and government installations (extra-AEC), 2.

Significant facts about research reactor usage are:

1. On the average, the higher the power level at which a research reactor operates, the greater its usage. This is true whether based upon hours of use of the reactor or upon the number of people using it. (Exceptions to this general rule are present, however, demonstrating the excellent capabilities of some individuals working with the lower-powered reactors.)
2. For a typical quarter of a year, the 32 research reactors surveyed produced about 12,000 radioactive samples and supported about 285 research users of these samples. In addition, there were about 220 users of beam ports and other experimental facilities. (These figures illustrate very forcibly that a large number of research projects were carried out using research reactors.)
3. In combination, the figures show that 500 different people had their research supported by the 32 research reactors. They indicate that over 700 research people probably were supported by the total of 48 reactors falling within the survey. These reactors represented a combined licensed power of 45 MW. It is clear that no single reactor at 45 MW could support 700 people during a three-month period.

4. The 16 reactors not included in the survey results were licensed to operate at somewhat greater average power than the 32 reported on here. Applying Fact 1 to these 16 reactors, one can conclude that they would show somewhat greater usage than those that actually reported.

5. The research reactors supported research in many different disciplines. Beam ports, thermal columns, in-core facilities, which often involve complicated pieces of research equipment, are used most by nuclear engineers and physicists. However, the reactors also supported chemists, biologists, medical people, geologists, and others.

6. The existence of research reactors around the country greatly expands the use of radioisotopes. This is particularly true of the short-lived isotopes, which would otherwise be unavailable to many scientists.

GENERAL

During the past 15 years a substantial number of research reactors were constructed in the United States. They varied considerably in size, power, ownership, and specialized capability. As of the end of 1966, there were 71 such reactors licensed by the Atomic Energy Commission. In addition, about 15 others had been constructed in the national laboratories of the AEC and were operating at that time. Whereas the utilization of the AEC national laboratory research reactors was to some extent known because of AEC reporting requirements, much less was known about the licensed reactors. These were the object of this survey.

The survey was restricted to reactors outside of AEC-operated laboratories. The criterion was that the reactor was subject to the control of the licensing and regulation division of AEC. This meant that the group of reactors surveyed had relatively comparable problems for their operation. The survey was further limited to reactors operating at 10 kW to 10 MW (thermal power). Reactors operating at 10 MW or above are regarded as test reactors rather than research reactors.

THE SURVEY

The Subcommittee developed a questionnaire as the means of obtaining the required data. Specifically, it developed a format for the reactor directors to use in submitting data, so that certain statistical analyses could be performed.

The following types of information were sought:

General operational data
Production of radioisotopes
On-site usage of the reactor
Kinds and numbers of research people supported
Kinds of research supported

A copy of the Utilization Data Form is included as Appendix A. Data were to be submitted on a quarterly basis.

It was the original intention of the Subcommittee to determine the actual utilization and also trends in utilization of the reactors, over a two-year period. However, it took considerable time for the reactor installations to form the habit of collecting the data requested on the Utilization Data Form. For this reason, the Subcommittee amended its aims. In the summer of 1967 it decided to attempt to learn what the reactor utilization might be in a typical quarter and to forgo any attempt at that time to determine possible trends. It was decided that the survey would study two quarters--the fourth quarter of 1967 and the first quarter of 1968--to obtain a typical picture of what was being done with the reactors.

THE REACTORS

When the survey began, in 1966, there were 71 licensed reactors in the United States, falling into the six categories shown in Table 1. Twenty-three of these reactors operated at less than

TABLE 1 Reactor Types Surveyed

Type	Number
I AGN 201	15
II TRIGA	14
III Argonaut	6
IV Pool type	26
V Tank type	5
VI Homogeneous	5
	71

TABLE 2 Reactor Ownership

	In Survey	Not in Survey
University	25	3
Industrial	5	8
Government	2	5

10 kW (thermal power) and were not included in the study. The balance of 48 reactor directors were invited to collect data in uniform format for the study, and 38 reactor directors indicated that they would supply data if at all possible. Four directors indicated that they could not participate; and six did not respond at all. An alphabetical list of the 48 reactors about which the survey requested data is included as Appendix B.

In the end, data were received about 32 reactors. Not reported on were a number of reactors which were not operated during the specified quarters because they were being modified. Two other reactor directors cited "company proprietary rights" as barring submission of sufficient data to be utilized. The distribution of ownership of the 48 reactors is shown in Table 2.

Table 3 lists the licensed power of each of the 48 reactors, those included in the survey and those not included, as of the end of 1967. It will be noted that the average licensed power of the survey group was slightly lower than that of the group not covered by the survey. Of the 32 reactors in the survey group, 78 percent are operated by universities. Twelve reactors of the survey group had licensed powers of 1 MW or higher. The remaining 20 reactors ranged in power from two at 250 kW to seven at 10 kW.

Although the group surveyed is not a perfect cross section of the entire group of 48, it represents a large fraction of the total group, and the data obtained accordingly permit certain conclusions.

RESULTS OF THE SURVEY

Detailed results of the survey are presented in Tables 4 and 5. The reactors are designated by number only, because the Subcommittee had agreed in advance to preserve anonymity of the various facilities. The reactors are listed in descending order of licensed power. University reactors are indicated with a "U." Totals and average values appear at the bottom of each column. The number in parentheses after

TABLE 3 Reactor Powers

In Survey		Not in Survey	
1.	5000 kW	1.	5000 kW
2.	5000	2.	5000
3.	2000	3.	3000
4.	2000	4.	2000
5.	2000	5.	1000
6.	1500	6.	1000
7.	1500	7.	1000
8.	1000	8.	1000
9.	1000	9.	1000
10.	1000	10.	250
11.	1000	11.	100
12.	1000	12.	75
13.	250	13.	50
14.	250	14.	30
15.	200	15.	10
16.	100	16.	10
17.	100		1283 kW average power
18.	100		
19.	100		
20.	100		
21.	100		
22.	100		
23.	100		
24.	100		
25.	18		
26.	10		
27.	10		
28.	10		
29.	10		
30.	10		
31.	10		
32.	10		
	803 kW average power		

TABLE 4 Fourth Quarter of 1967

		Licensed Power (kW)	Hours of Operation	Hours of Use	Average No. of 40-h Shifts	Integrated Power in MWh	Total No. of Samples	No. of Users	Beam Port h	Thermal Column h	Sample Irrad. Facility h	Bulk Irrad. Facility h	In-core Exp. h	No. of Facility Users
1.	U	5000	1,207.9	1,488.8 (3)	2.954 (3)	5,847.2 (1)	773 (5)	31 (2)	5,244.0 (2)	597.0 (2)	1517.0 (1)	352.0 (2)	1090.0 (4)	13 (4)
2.	U	5000	404.1	744.0 (9)	1.476 (9)	1,619.5 (6)	616 (7)	8 (12)	1,213.5 (5)	X	44.8 (10)	14.7 (8)	45.5 (12)	14 (3)
3.		2000	1,877.5	2,105.0 (1)	4.176 (1)	3,710.4 (2)	82 (13)	8 (13)	108.5 (11)	0	455.9 (2)	0	3332.4 (1)	10 (7)
4.	U	2000	1,812.0	1,932.0 (2)	3.833 (2)	3,460.0 (3)	574 (8)	32 (1)	12,110.0 (1)	X	347.0 (4)	9,659.0 (1)	0	39 (1)
5.		2000	1,270.0	1,427.0 (4)	2.831 (4)	2,532.0 (4)	-	-	2,529.0 (3)	1326.0 (1)	10.0 (17)	7.0 (10)	3122.0 (2)	-
6.		1500	1,113.0	1,178.0 (5)	2.337 (5)	1,669.5 (5)	0	0	X	X	0	0	1113.0 (3)	1 (28)
7.		1500	217.0	282.0 (19)	0.559 (19)	<0.1	0	0	X	X	0	151.0 (3)	66.0 (11)	5 (16)
8.	U	1000	446.9	755.6 (8)	1.499 (8)	1,012.8 (7)	372 (12)	16 (6)	2.8 (18)	0	332.6 (5)	0	493.4 (5)	19 (2)
9.	U	1000	535.0	560.0 (10)	1.111 (10)	532.0 (8)	131 (17)	12 (8)	737.0 (6)	1.0 (10)	181.0 (7)	4.0 (12)	0	12 (5)
10.	U	1000	429.2	463.0 (11)	0.919 (11)	390.4 (9)	34 (26)	5 (19)	378.9 (8)	X	386.4 (3)	0	0	4 (18)
11.	U	1000	275.8	390.0 (15)	0.774 (15)	14.5 (15)	41 (25)	5 (20)	54.0 (14)	0	10.0 (18)	0	0	3 (24)
12.	U	1000	225.0	300.0 (18)	0.595 (18)	170.0 (10)	400 (11)	7 (14)	4.0 (17)	0	8.0 (19)	25.0 (6)	0	3 (25)
13.	U	250	503.8	807.5 (6)	1.602 (6)	72.5 (11)	182 (16)	11 (10)	422.5 (7)	68.5 (4)	133.5 (8)	0	111.5 (9)	9 (10)
14.		250	161.0	226.0 (21)	0.448 (21)	36.2 (13)	1,285 (2)	20 (4)	X	X	0	0	94.0 (10)	6 (13)
15.	U	200	285.0	415.0 (14)	0.823 (14)	2.1 (20)	646 (9)	6 (18)	290.0 (9)	X	33.0 (12)	0	128.0 (7)	-
16.	U	100	762.9	792.0 (7)	1.571 (7)	65.6 (12)	218 (14)	21 (3)	2,371.4 (4)	X	0	25.5 (5)	0	11 (6)
17.	U	100	349.1	363.3 (16)	0.721 (16)	16.3 (14)	72 (22)	7 (15)	210.5 (10)	78.5 (3)	0	0	0	4 (19)
18.		100	67.8	339.0 (17)	0.673 (17)	7.0 (17)	2,619 (1)	10 (11)	X	X	13.0 (16)	55.0 (4)	0	10 (8)
19.	U	100	153.7	238.0 (20)	0.472 (20)	8.4 (16)	453 (10)	4 (22)	94.2 (13)	39.6 (5)	6.3 (21)	0	0	6 (14)
20.	U	100	145.0	226.0 (22)	0.448 (22)	1.4 (22)	204 (15)	7 (16)	0	0.5 (12)	0	0	7.0 (16)	3 (26)
21.	U	100	116.8	207.2 (23)	0.411 (23)	6.0 (19)	76 (20)	-	7.0 (16)	8.0 (7)	0	8.0 (9)	127.0 (8)	4 (20)
22.	U	100	50.0	200.0 (24)	0.397 (24)	0.5 (23)	1,050 (4)	3 (24)	X	X	0	0	0	0
23.		100												
24.	U	100	14.0	38.0 (29)	0.075 (29)	0.2 (26)	13 (27)	2 (25)	2.0 (19)	6.0 (8)	0	7.0 (11)	0	4 (21)
25.		18	338.0	446.5 (12)	0.886 (12)	5.3 (18)	1,171 (3)	16 (7)	X	X	322.0 (6)	0	0	6 (15)
26.	U	10	389.3	430.5 (13)	0.854 (13)	1.6 (21)	515 (6)	18 (5)	96.0 (12)	6.0 (9)	42.0 (11)	1.0 (13)	202.0 (6)	10 (9)
27.	U	10	78.0	138.0 (25)	0.274 (25)	0.3 (25)	218 (13)	12 (9)	14.0 (15)	1.0 (11)	17.0 (14)	16.0 (7)	11.0 (15)	9 (11)
28.	U	10	52.2	85.5 (26)	0.169 (26)	<0.1	64 (23)	4 (23)	0	16.1 (6)	2.3 (22)	0	32.8 (13)	6 (15)
29.	U	10	55.2	75.1 (27)	0.149 (27)	0.4 (24)	76 (21)	7 (17)	1.9 (20)	X	60.2 (9)	0	16.7 (14)	4 (22)
30.	U	10	36.0	66.0 (28)	0.131 (28)	<0.1	6 (28)	2 (26)	X	X	16.3 (15)	0	0	2 (27)
31.	U	10	29.5	35.7 (30)	0.071 (30)	0.1 (28)	104 (18)	5 (21)	1.0 (21)	0	28.5 (13)	0	0	4 (23)
32.	U	10	18.0	27.5 (31)	0.055 (31)	0.2 (27)	48 (24)	-	0	0	7.0 (20)	0	0	5 (17)
TOTAL:		.	13,418.7	16,782.2		21,182.7	12,043	279	25,892.2	2146.2	3973.8	10,325.2	9992.3	226
AVERAGE:			433	541		683	401	9.96	1,079	119	128	333	322	7.79

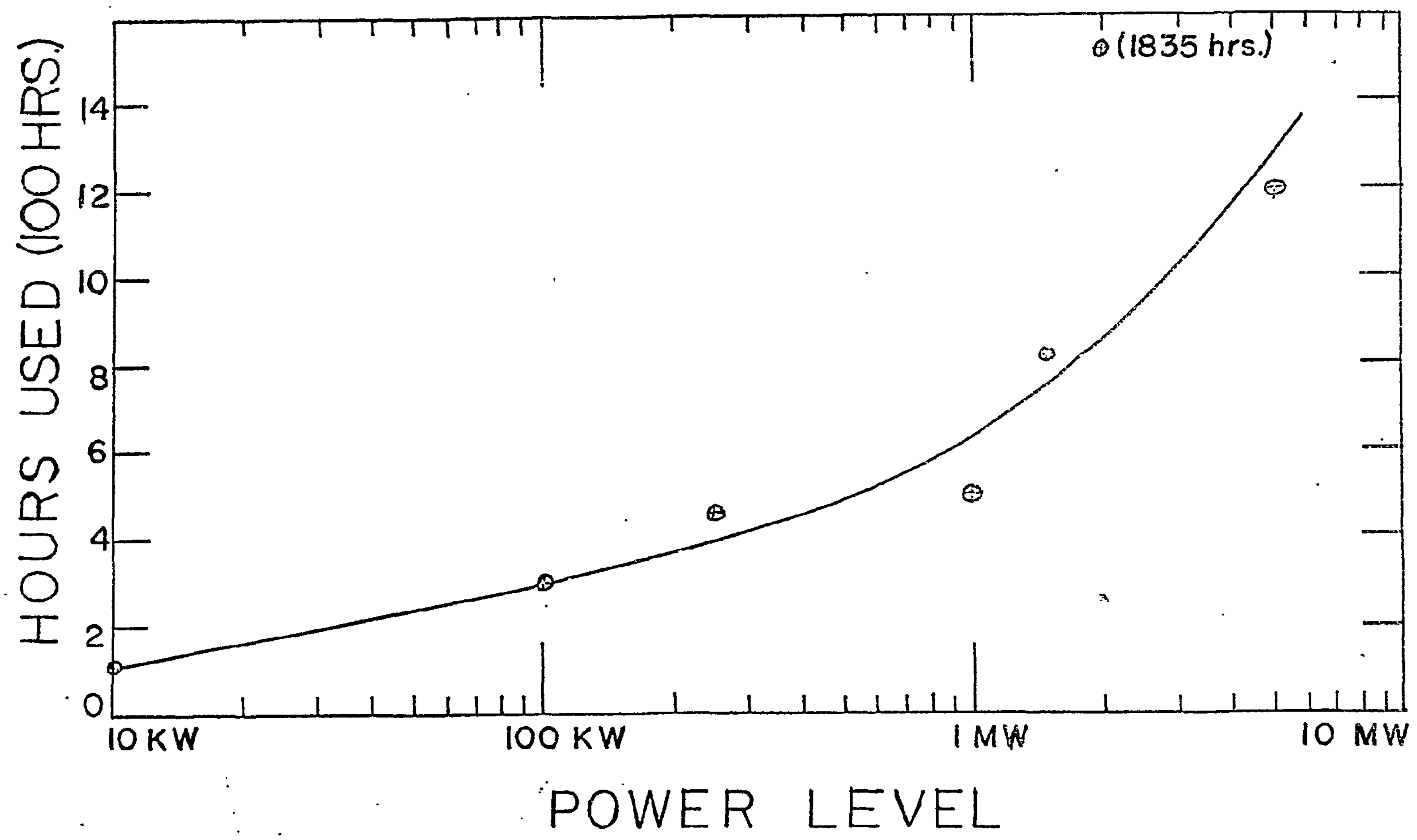
U denotes university reactor.
Numbers in parentheses represent the rank (1 highest) of that reactor in each category.
X indicates that this facility does not exist at that reactor.

TABLE 5 *First Quarter of 1968*

		Licensed Power (kW)	Hours of Operation	Hours of Use	Average No. of 40-h Shifts	Integrated Power in MWh	Total No. of Samples	No. of Users	Beam Port h	Thermal Column h	Sample Irrad. Facility h	Bulk Irrad. Facility h	In-core Exp. h	No. of Facility Users
1.	U	5000	1,257.9	1,531.4 (4)	2.991 (4)	6,075.9 (1)	732 (6)	40 (1)	3,636.0 (2)	283.0 (2)	1569.0 (1)	321.0 (2)	800.0 (4)	11 (6)
2.	U	5000	677.9	984.0 (7)	1.921 (7)	2,365.9 (6)	561 (8)	12 (8)	2,033.7 (5)	X	354.3 (5)	10.9 (8)	600.4 (5)	16 (2)
3.		2000	1,695.4	2,184.0 (1)	4.266 (1)	3,357.6 (2)	44 (24)	11 (9)	500.4 (7)	0	100.3 (8)	0	4,579.2 (1)	11 (7)
4.	U	2000	1,784.0	1,976.0 (2)	3.859 (2)	3,348.0 (3)	521 (10)	29 (2)	11,812.0 (1)	X	362.0 (4)	11,993.0 (1)	0	12 (4)
5.		2000	1,241.0	1,388.0 (5)	2.711 (5)	2,594.0 (4)	-	-	2,050.0 (4)	1569.0 (1)	-	0	4,245.0 (2)	0
6.		1500	1,633.0	1,698.0 (3)	3.316 (3)	2,449.5 (5)	0	0	X	X	0	0	1,633.0 (3)	1 (27)
7.		1500	51.0	116.0 (26)	2.260 (26)	-	0	0	X	X	0	0	51.0 (12)	6 (14)
8.	U	1000	359.8	499.3 (10)	0.975 (10)	139.3 (10)	520 (9)	0	115.8 (12)	128.3 (3)	460.8 (3)	0	220.7 (7)	33 (1)
9.	U	1000	968.0	995.0 (6)	1.943 (6)	956.0 (7)	109 (19)	11 (10)	1,470.0 (6)	4.0 (9)	600.0 (2)	14.0 (6)	0	11 (8)
10.	U	1000	305.0	365.0 (14)	0.713 (14)	210.7 (9)	54 (23)	6 (15)	155.0 (9)	X	0	315.5 (3)	0	4 (18)
11.	U	1000	228.1	305.0 (16)	0.596 (16)	47.7 (12)	70 (20)	5 (17)	77.5 (14)	6.5 (8)	15.0 (16)	0	0	4 (19)
12.	U	1000	300.0	390.0 (12)	0.762 (12)	243.0 (8)	390 (11)	4 (21)	0	0	17.0 (15)	11.0 (7)	0	4 (20)
13.	U	250	309.0	615.0 (9)	1.201 (9)	27.6 (14)	137 (17)	10 (11)	150.5 (10)	0	133.5 (7)	0	117.5 (10)	3 (22)
14.		250	127.0	192.0 (22)	0.375 (22)	28.6 (13)	1,255 (3)	19 (5)	X	X	0	0	64.0 (11)	4 (21)
15.	U	200	178.0	284.0 (19)	0.555 (19)	1.6 (22)	696 (7)	4 (22)	49.0 (16)	4.0 (10)	9.0 (19)	0	272.0 (6)	-
16.	U	100	785.6	819.0 (8)	1.599 (8)	68.7 (11)	171 (16)	20 (4)	2,145.2 (3)	X	0	0	6.0 (15)	10 (10)
17.	U	100	246.0	292.0 (18)	0.570 (18)	10.7 (16)	62 (21)	5 (18)	134.3 (11)	41.1 (4)	0	0	0	5 (15)
18.		100	51.4	257.0 (20)	0.502 (20)	4.9 (18)	1,357 (1)	10 (12)	X	X	14.0 (17)	37.0 (4)	0	11 (9)
19.	U	100	103.3	238.0 (21)	0.465 (21)	4.9 (19)	893 (5)	9 (14)	54.2 (15)	20.0 (6)	30.7 (9)	0	0	14 (3)
20.	U	100												
21.	U	100	153.7	298.7 (17)	0.583 (17)	4.6 (20)	33 (26)	5 (19)	3.0 (20)	0	0	2.0 (10)	134.8 (9)	2 (25)
22.	U	100	30.0	100.0 (27)	0.195 (27)	0.1 (28)	1,000 (4)	2 (25)	X	X	0	0	0	0
23.	U	100	63.8	72.8 (29)	0.142 (29)	0.6 (24)	31 (27)	6 (16)	3.8 (19)	0	9.5 (18)	0	6.1 (14)	9 (11)
24.	U	100	288.0	378.0 (13)	0.738 (13)	24.5 (15)	43 (25)	3 (24)	251.0 (8)	0	30.0 (10)	7.0 (9)	0	3 (23)
25.		18	374.9	469.2 (11)	0.916 (11)	5.9 (17)	1,316 (2)	19 (6)	X	X	337.8 (6)	0	0	8 (12)
26.	U	10	297.4	327.4 (15)	0.639 (15)	0.9 (23)	327 (13)	22 (3)	87.0 (13)	38.0 (5)	28.0 (12)	0	144.0 (8)	7 (13)
27.	U	10	79.0	150.0 (23)	0.293 (23)	0.4 (25)	333 (12)	10 (13)	30.0 (17)	1.0 (12)	30.0 (11)	0	47.0 (13)	12 (5)
28.	U	10	91.1	136.5 (25)	0.266 (25)	0.2 (27)	180 (15)	5 (20)	-	18.2 (7)	20.7 (13)	0	0	2 (26)
29.	U	10	65.6	146.0 (24)	0.285 (24)	1.9 (21)	261 (14)	19 (7)	0	X	18.6 (14)	0	1.4 (16)	-
30.	U	10	95.0	35.0 (30)	0.068 (30)	0	59 (22)	1 (26)	X	X	8.8 (20)	19.6 (5)	0	3 (24)
31.	U	10	10.2	12.0 (31)	0.023 (31)	0.1 (29)	19 (28)	4 (23)	1.0 (21)	0	6.0 (21)	0	0	5 (16)
32.	U	10	28.0	77.5 (28)	0.151 (28)	0.3 (26)	126 (18)	-	6.0 (18)	2.0 (11)	2.5 (22)	0	0	5 (17)
TOTAL:			13,879.1	17,331.8		21,974.1	11,300	291	24,765.4	2115.1	4157.5	12,731.0	12,922.1	216
AVERAGE:			448	559		732	377	10.0	1,077	111	139	411	417	7.4

U denotes university reactor.
Numbers in parentheses represent the rank (1 highest) of that reactor in each category.
X indicates that this facility does not exist at that reactor.

FIGURE 1 Correlation of reactor power and the hours used. The increased use at higher power is quite dramatic.



a particular item indicates the rank of that reactor (1 being highest) in that column for the category being considered.

General Operational Data

Tables 4 and 5 include entries for hours of operation and hours used during the three-month periods covered. By hours of operation is meant the actual hours the reactor was "at power." In many installations, additional time is involved in changing experiments and other activities, and this requires that the reactor "not run." The entries for hours of use include this required "down time." Numbers in parentheses indicate the rank of each reactor in the entire group, from the standpoint of hours used.

Note that there is a strong correlation between reactor power and hours used, as shown in Figure 1, in which the average hours the reactors were used are plotted against their licensed power. All reactors having the same power have been averaged together. The increased use of the higher powered reactors is rather dramatic.

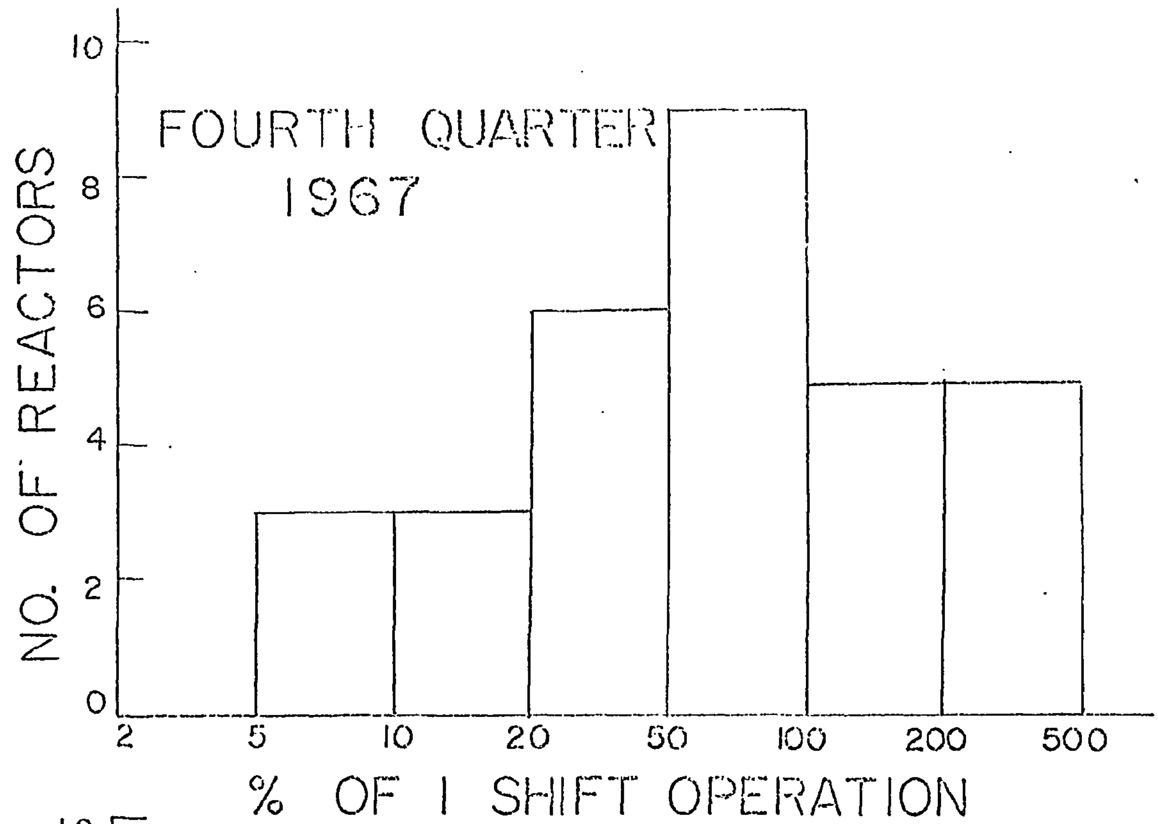
Number of Work Shifts

It is customary to hire reactor operators for a 40-h week, which they fulfill on an intermittent basis. In the fourth quarter of 1967 the standard 40-h-week shift, adjusted for vacations, equaled 504 h. Under the column in Table 4 marked "shifts," the number of 504-h standard shifts for that quarter is given. It is noted that one reactor indicates over 4.17 standard shifts, which means that it ran continuously without shutdown for the entire quarter. The table shows that 10 out of the 31 reactors reporting hours of use and operation were operated for more than a one-shift period. During the first quarter of 1968 there were 512 h in a standard 40-h-week shift. It will be seen that the reactors reporting averaged slightly more than a one-shift operation during both quarters. Figure 2 indicates the distribution of the reactors in terms of the percentage of one-shift operation.

Although most reactors are run for less than one shift (i.e., less than 8 h per day), the 12 that operated at or above 1 MW ran for an average of 2.2 40-h shifts per week. The eight reactors operating above 1 MW ran for an average of 2.9 40-h shifts per week.

Figures 3 and 4 present data on integrated power (megawatt hours) of the reactors. This is indicative of fuel consumption,

FIGURE 2 Comparison of the usage of the reactors in terms of one-shift operation. The majority of the reactors are operating for one shift or less.



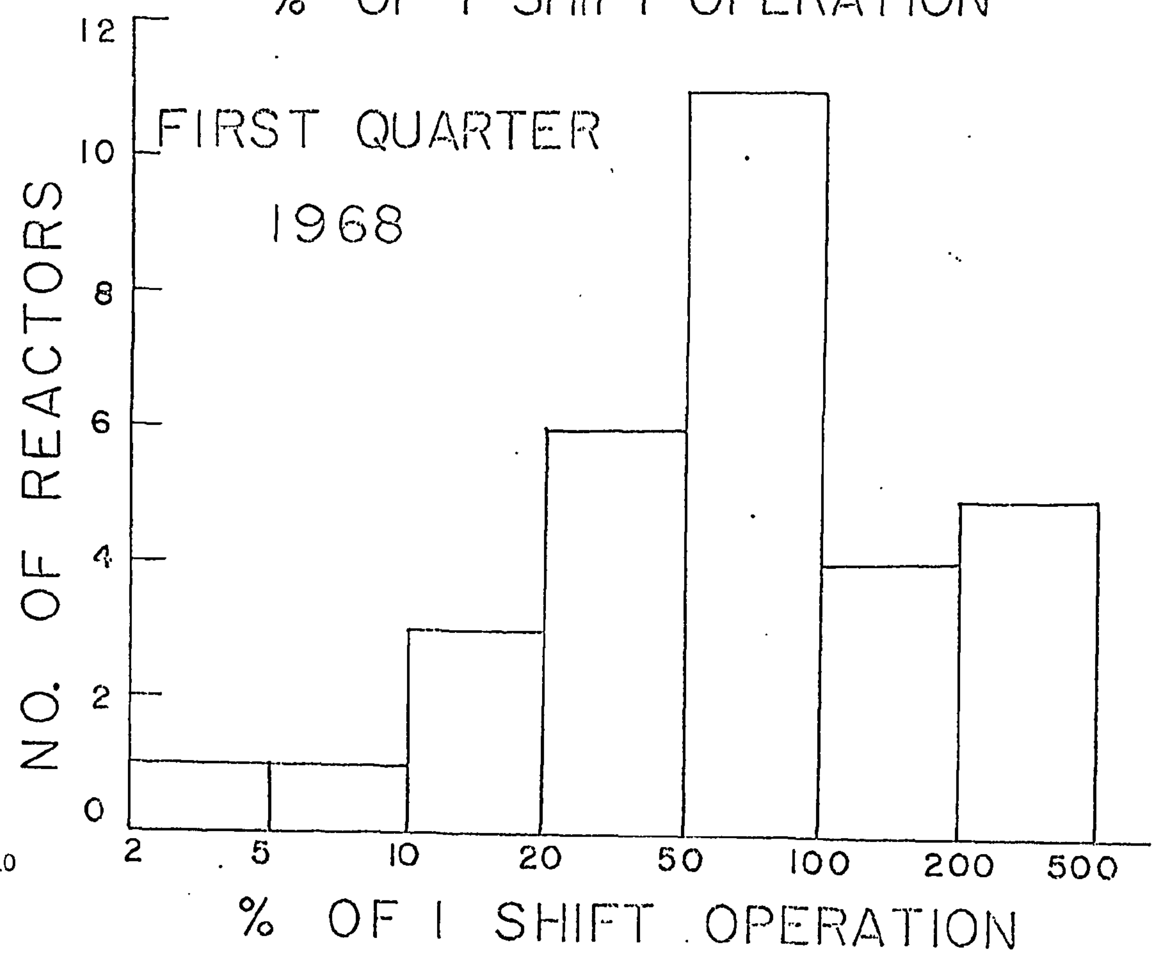


FIGURE 3 The average integrated power, indicative of fuel consumption, fuel costs, and operating costs, is correlated with the licensed power levels of the reactors. Comparison with Figure 1 substantiates, as would be expected, that usage and costs are directly related.

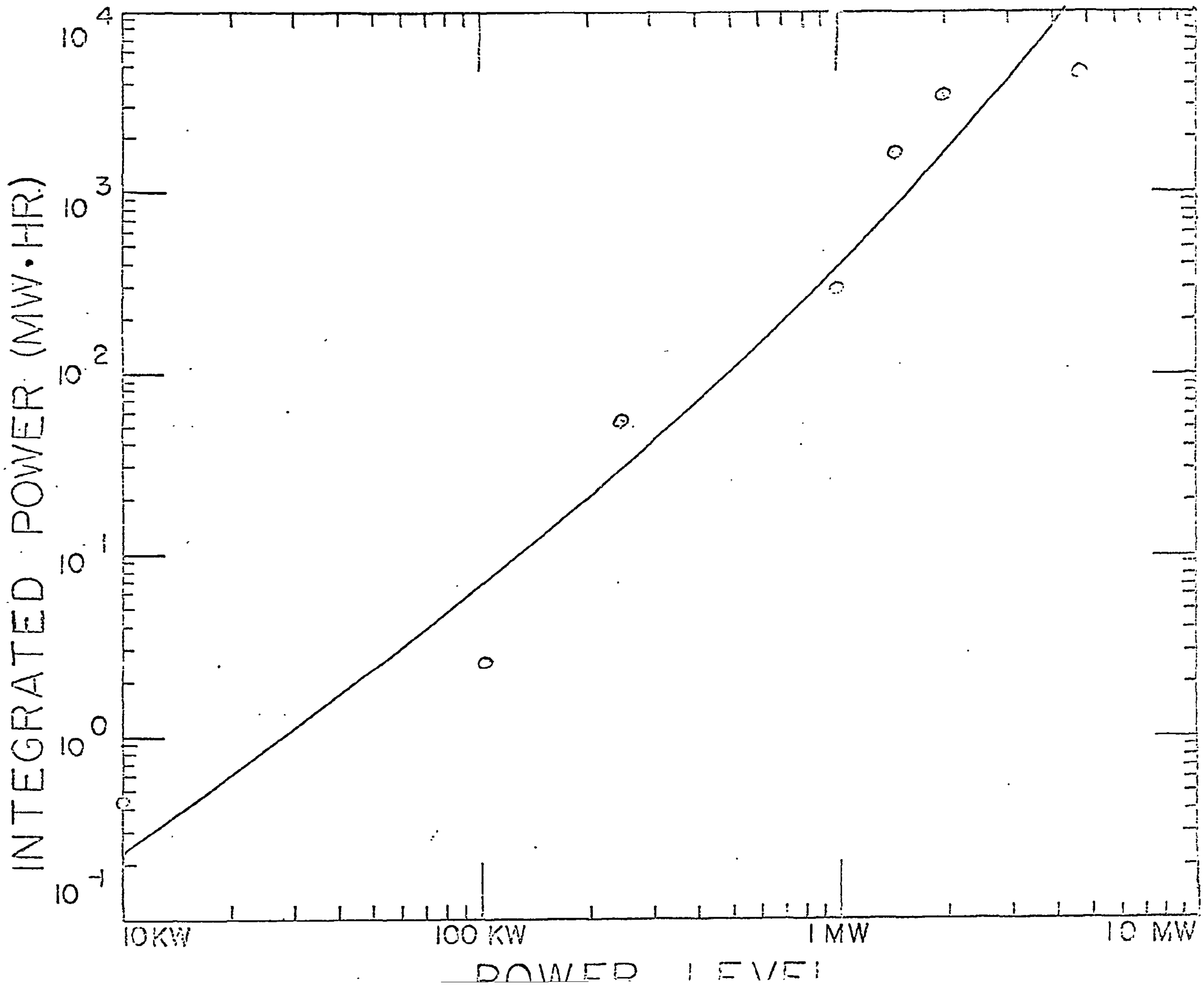
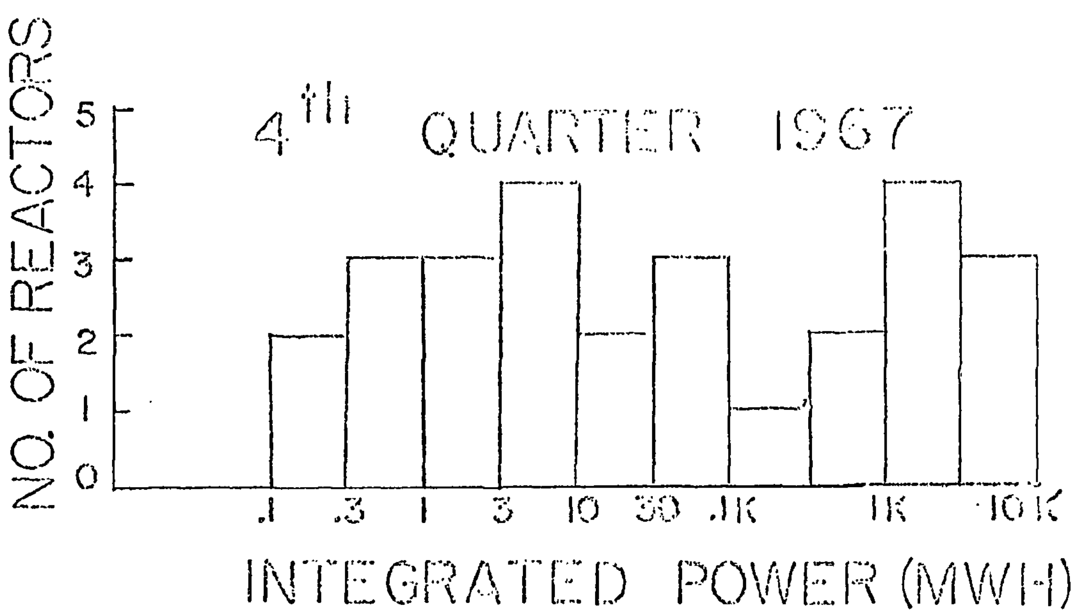
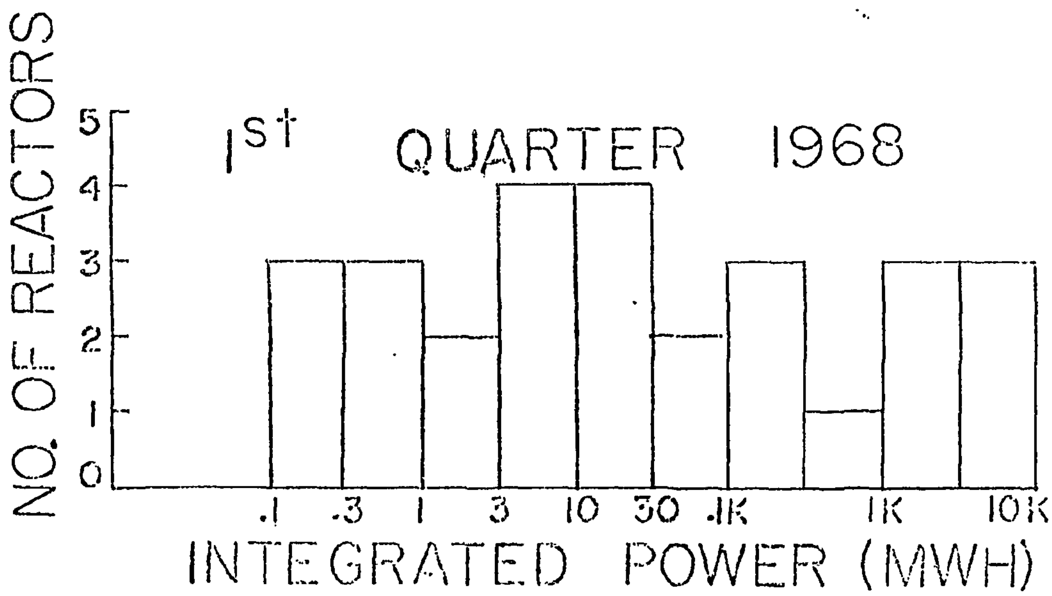


FIGURE 4 Reactor usage by megawatt-hours.





fuel costs, and operating costs and is correlated with the licensed power levels of the reactors. As would be expected, usage and costs are directly related. The higher-power reactors burn more fuel because they are at higher powers; they also were used the most. The range of energy consumption by these reactors is wide, with an average of 700 MWh. From this figure one can predict an average power of 1.4 MW for a 500-h quarter. This again emphasizes the fact that the higher-powered reactors are used most, since the licensed power of the median reactor in the surveyed group is 100-200 kW.

Production of Radioisotope Samples

The survey determined one aspect of research reactor operation that had not previously been documented--the extent to which reactors assist in research efforts by the generation of radioisotope samples. This aspect of the reactors surveyed here is shown in Tables 4 and 5, which show the number of radioactive samples generated by each reactor. The number in parentheses is the rank number (highest to lowest) of the samples made. Thirty of the reactors surveyed provided records on radioactive samples generated. Twenty-eight of them did generate samples during the quarters surveyed, for an average of 400 samples per quarter. The median number was 200 samples. Using the figure of approximately 65 working days in a quarter, all the reactors were supplying on the order of six or more samples each per day of operation. The top reactor supplied 41 radioactive samples per working day during one of the quarters.

All the reactors surveyed seem to be capable of generating radioisotope samples for research users. In Figure 5 the average number of samples made by the various types of reactors is plotted against licensed power levels. One finds no particularly dramatic trend. Figure 6 shows the distribution of reactors relative to number of samples manufactured per quarter. The bar graphs for the two quarters surveyed show relatively similar results.

The survey examined in general the kinds of radioisotope samples being produced by the research reactors studied, via the length of the periods of irradiation. Tables 6 and 7 indicate the irradiation times of the samples generated. The results indicate rather clearly that most of the samples were irradiated for less than 1 h. Although short-lived samples predominated, all types of radioisotopes were apparently generated. The study divided them into three groups: samples involving irradiation of less than 1 h; samples irradiated from 1 to 8 h; and samples irradiated for longer than 8 h. It might be noted that samples irradiated for more than 8 h were undergoing this process for rather long periods of time (i.e., 60 h or 150 h).

FIGURE 5 Production of radioactive samples is correlated with reactor power. Distribution indicates that this is independent of power level.

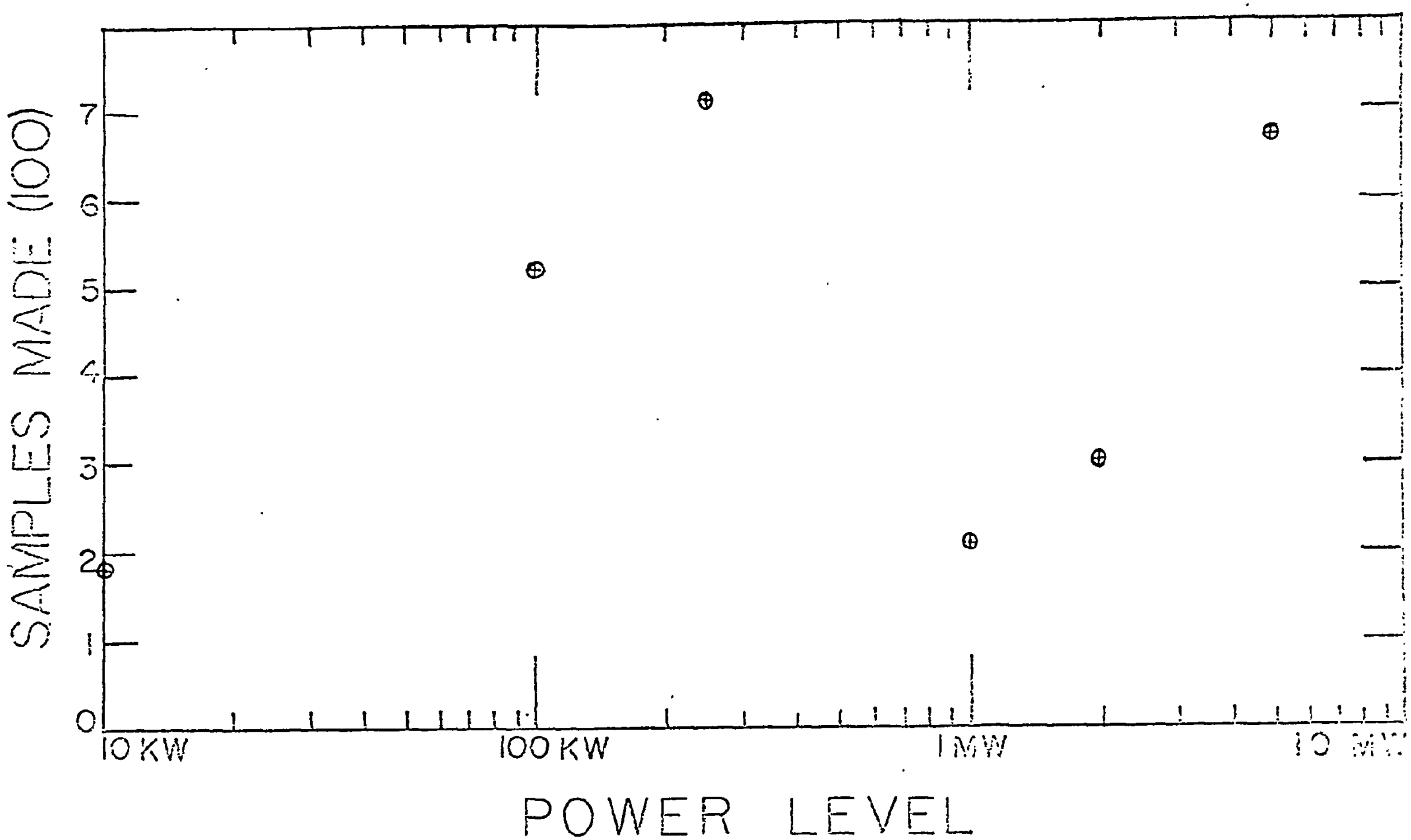
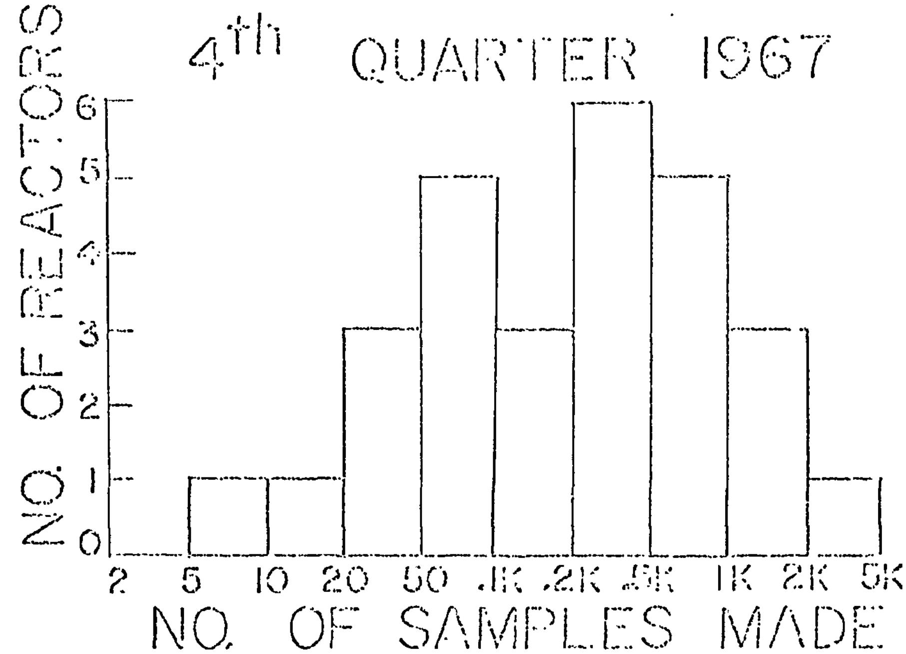
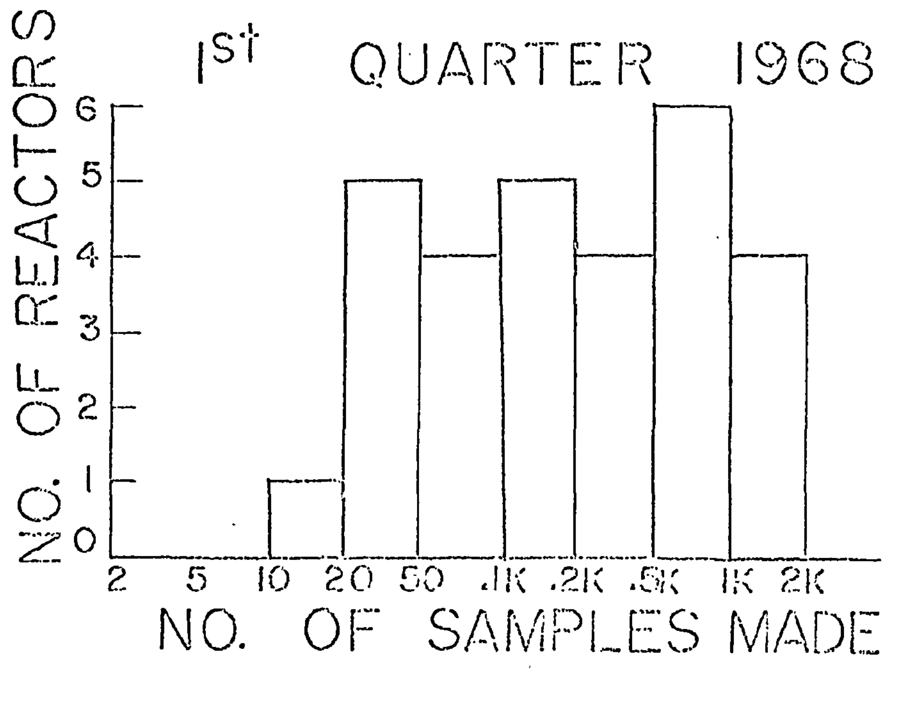


FIGURE 6 Radioactive sample production in terms of number of reactors and number of samples is given for the two calendar quarters studied.





TA3 · 5 Fourth Quarter of 1967

	Licensed Power (kW)	< 1 h No. of Samples	1-8 h No. of Samples	Hours	> 8 h No. of Samples	Hours	Total No. of Samples	No. of Users
1.	5000	571	165	249	37	1049	773	31
2.	5000	595	19	1072	2	120	616	8
3.	2000	50	25	80	7	3775	82	8
4.	2000	412	106	361	56	9233	574	32
5.	2000	–	–	–	–	–	–	–
6.	1500	0	0	0	0	0	0	0
7.	1500	0	0	0	0	0	0	0
8.	1000	78	178	595	116	934	372	16
9.	1000	117	7	27	7	101	131	12
10.	1000	19	8	19	7	322	34	5
11.	1000	36	5	10	0	0	41	5
12.	1000	200	200	1000	–	–	400	7
13.	250	148	16	58	18	221	182	11
14.	250	1210	75	525	0	0	1285	20
15.	200	341	291	1106	14	112	646	6
16.	100	131	67	193	20	2119	218	21
17.	100	62	10	42	–	–	72	7
18.	100	2619	–	–	–	–	2619	10
19.	100	54	399	1826	0	0	453	4
20.	100	203	1	7	0	0	204	7
21.	100	28	48	105	–	–	76	–
22.	100	1000	50	100	0	0	1050	3
23.	100	–	–	–	–	–	–	–
24.	100	13	0	0	0	0	13	2
25.	18	619	552	597	–	–	1171	16
26.	10	201	297	1366	17	148	515	18
27.	10	195	23	45	–	0	218	12
28.	10	64	–	–	–	–	64	4
29.	10	39	31	72	6	93	76	7
30.	10	0	6	96	0	0	6	2
31.	10	103	1	1	–	–	104	5
32	10	23	25	237	0	0	48	–
TOTAL:		9131	2605	9789	307	18,227	12,043	279
AVERAGE:		304	87	326	10	608	401	10

TABLE 7 First Quarter of 1968

	Licensed Power (kW)	< 1 h No. of Samples	1-8 h No. of Samples	Hours	> 8 h No. of Samples	Hours	Total No. of Samples	No. of Users
1.	5000	620	59	185.0	53	1022.0	732	40
2.	5000	546	3	30.0	12	7546.4	561	12
3.	2000	25	12	49.2	7	5110.4	44	11
4.	2000	362	73	130.0	86	11863.0	521	29
5.	2000	-	-	-	-	-	-	-
6.	1500	0	0	0	0	0	0	0
7.	1500	0	0	0	0	0	0	0
8.	1000	250	254	696.4	16	625.9	520	0
9.	1000	78	13	25.0	18	839.0	109	11
10.	1000	8	34	39.0	12	949.0	54	6
11.	1000	62	8	25.0	0	0	70	5
12.	1000	240	150	750.0	0	0	390	4
13.	250	66	69	133.3	2	24.3	137	10
14.	250	1220	35	105.0	0	0	1255	19
15.	200	177	518	2200.0	1	8.8	696	4
16.	100	47	94	281.1	30	1454.2	171	20
17.	100	57	4	15.0	1	24.0	62	5
18.	100	1357	0	0	0	0	1357	10
19.	100	407	486	1114.9	0	0	893	9
20.	100	-	-	-	-	-	-	-
21.	100	0	33	110.0	0	0	33	5
22.	100	1000	0	0	0	0	1000	2
23.	100	31	0	0	0	0	31	6
24.	100	37	6	18.0	0	0	43	3
25.	18	752	564	594.6	0	0	1316	19
26.	10	81	233	815.0	13	112.0	327	22
27.	10	311	16	16.0	6	234.0	333	10
28.	10	153	27	42.0	0	0	180	5
29.	10	250	11	14.6	0	0	261	19
30.	10	57	2	7.5	0	0	59	1
31.	10	17	2	10.0	0	0	19	4
32.	10	107	19	323.0	0	0	126	0
TOTAL:		8318	2725	7729.6	257	29,813.0	11,300	291
AVERAGE:		277	91	257.7	8.6	993.8	377	9.7

TABLE 8 Fourth Quarter of 1967--Port Usage

Port Hours Used	Hours Reactor Used	Average Number of Ports Used
12,110.0	1932.0	6.27
5,244.0	1488.8	3.52
2,529.0	1427.0	1.77
2,371.4	792.0	2.99
1,213.5	404.1	3.00
737.0	560.0	1.32
422.5	807.5	0.52
378.9	463.0	0.82
290.0	415.0	0.70
210.5	363.3	0.58
108.5	2105.0	0.05

On-Site Facility Use

The survey catalogued on-site facility use under five general areas, as indicated in Tables 4 and 5. They are: beam port, thermal column, sample irradiation, bulk irradiation, and in-core activity. For much of this activity it is not possible to determine appropriate averages. In some cases (as indicated by an "X"), the reactor did not have the specified type of facility. In others, the reactors did not keep accurate data as to usage. For reactors that did indicate usage in their reports, Tables 4 and 5 set forth in parentheses the rank of the facilities in order of usage (from highest to lowest).

Because many of the reactors surveyed did have beam ports, and used them during the quarters studied, they were requested to provide data on total port-hours of usage. This total, divided by the total hours of reactor usage, yields the average number of ports used at the reactor, as shown in Table 8. The higher-powered reactors showed better port usage.

The survey indicates that there was a wide variation in the use of reactor facilities. Most reactors showed a rather large use of in-core experiments (see Tables 4 and 5).

Research Reactor Users

Users of research reactors were divided into two categories: users of radioisotope samples and on-site users of facilities.

Isotope Sample Users The number of research people involved in the use of isotope samples is, of course, an important indicator of reactor use. As shown in Tables 4 and 5, an average of 10 different people used radioisotope samples from each reactor during a typical quarter. The median for the group was 7; the maximum number of users was 32. This indicates that the reactors are supporting research for a rather large number of people at the various laboratories and universities. As can be seen in Tables 4 and 5, the range in the number of users of radioisotope samples is not nearly so great as the range of the number of samples.

Although the number of samples produced by the reactors showed no strong trends related to power levels, it is clear that the number of sample users did increase with increasing power level. This is indicated in Figure 7, a graph of average number of sample users for the group of reactors of the various power levels. (An inconsistency appears with respect to 1.5-MW reactors, probably due to the fact that the two reactors represented are considered as pulse

FIGURE 7 The number of users of radioactive samples is correlated with licensed reactor power level. The higher-power reactors do support more users.

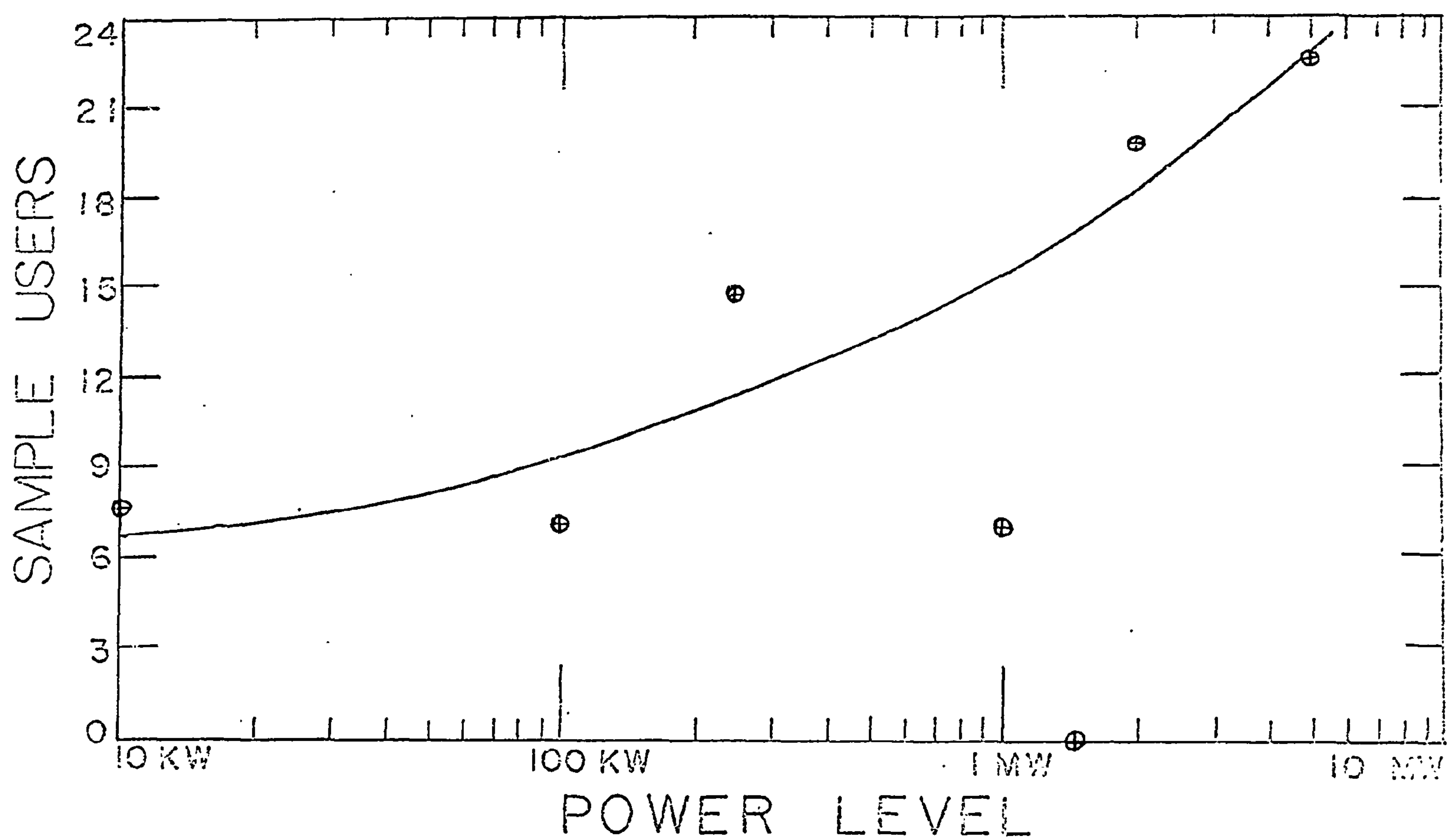
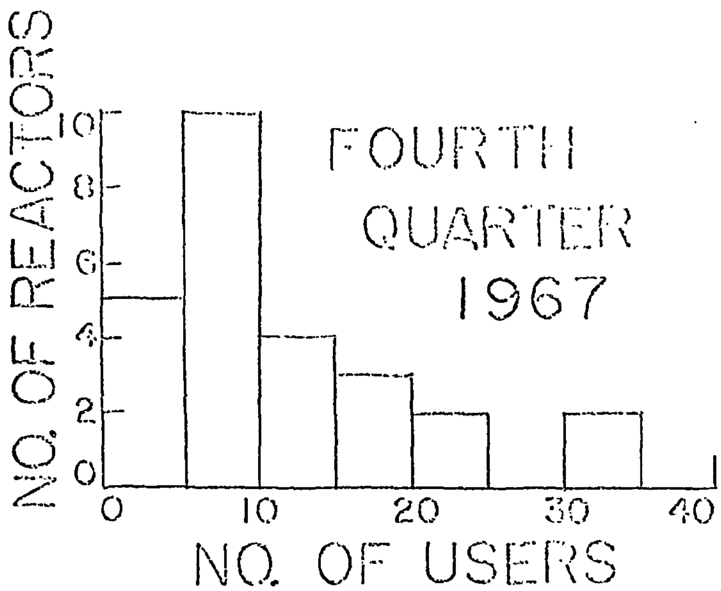


FIGURE 8 Number of reactors supporting various numbers of radioisotope users.



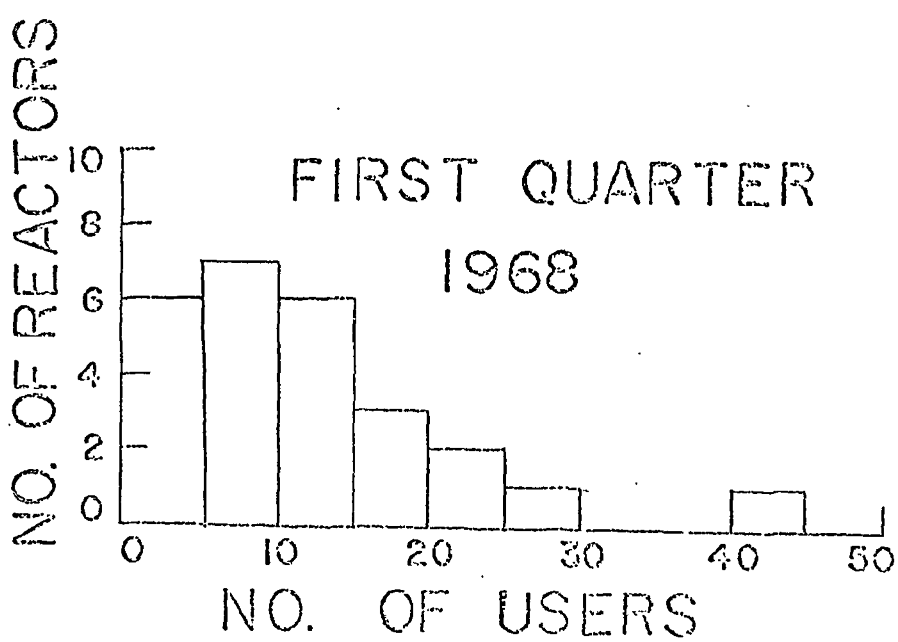


FIGURE 9 The number of users of reactor experimental facilities is correlated with licensed reactor power level. An increase is noted as the power of the reactor increases.

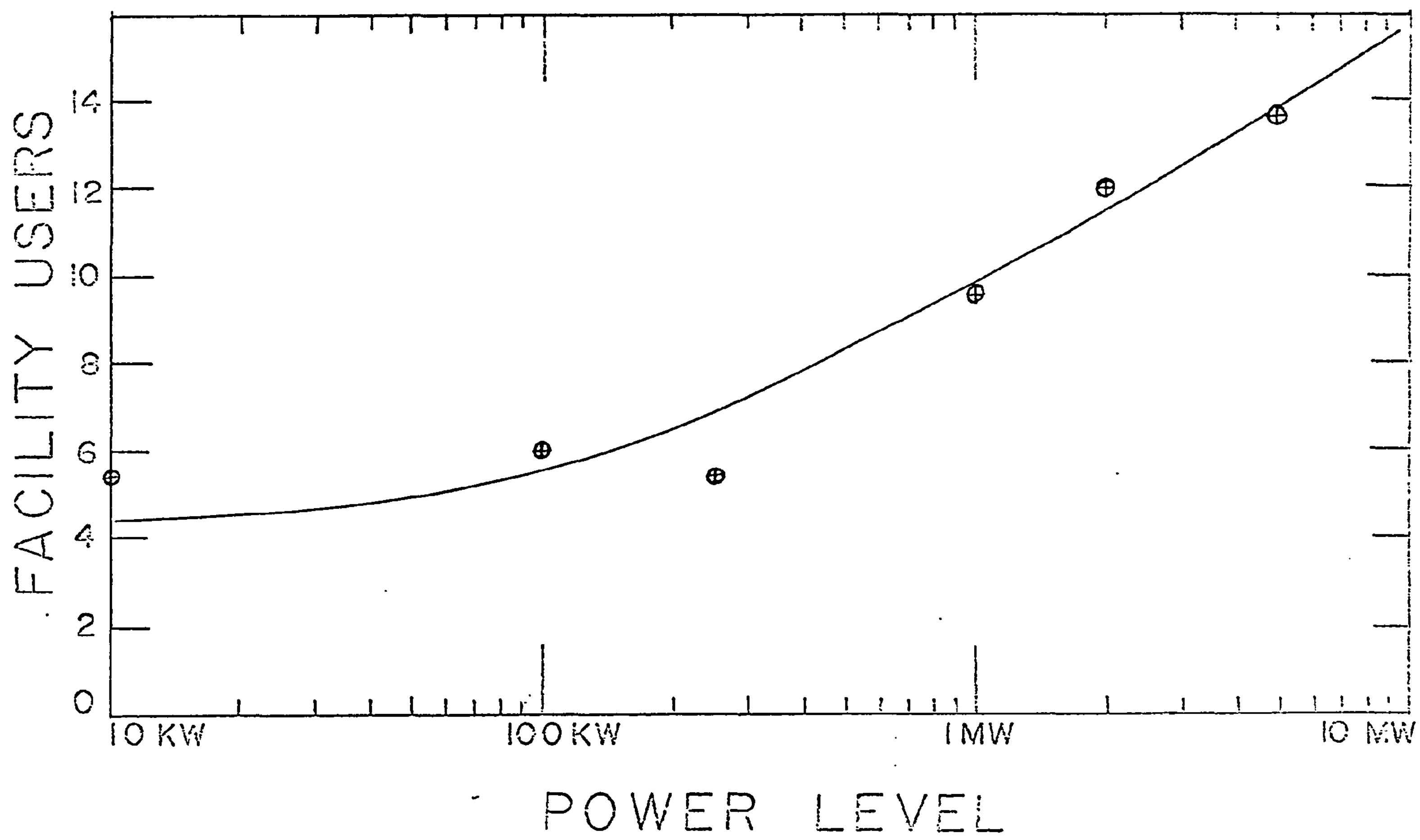
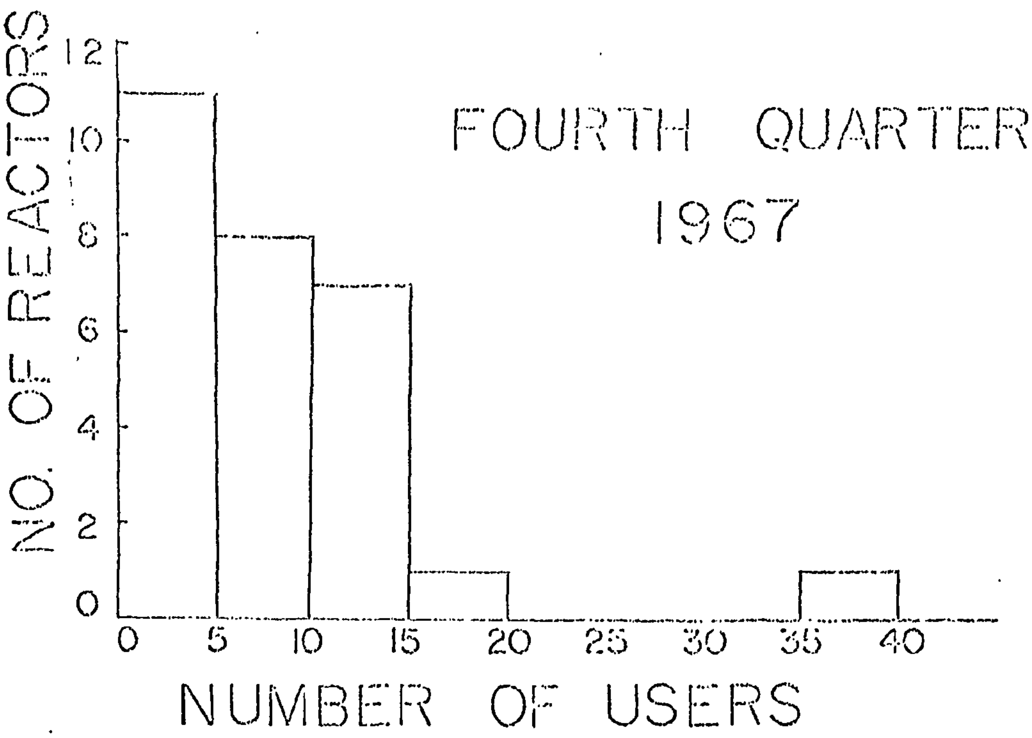


FIGURE 10 Number of reactor facilities having various numbers of facility users.



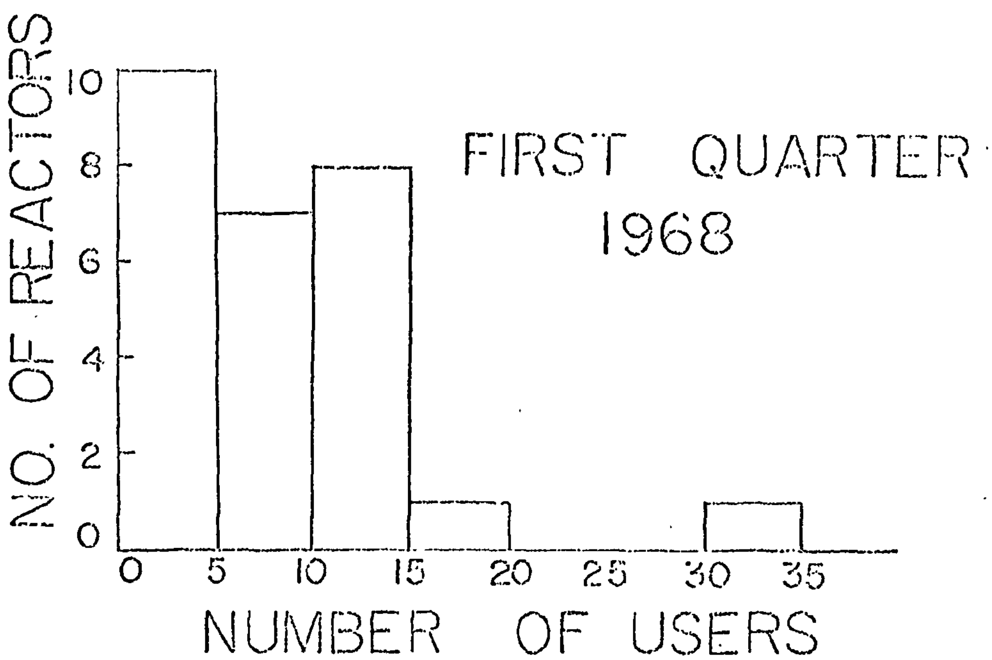


TABLE 9 Sample Users by Background

Background	Percentage of Total	
PHYSICAL SCIENCE		
Physics	12	
Chemistry	26	
Geology	6	
		44
BIOLOGICAL SCIENCE		
Biology	7.5	
Medicine	5.5	
Health Physics	4.5	
		17.5
ENGINEERING		
Nuclear	26	
Electrical	2	
Mechanical	1	
		29
MISCELLANEOUS	9.5	
		9.5
		100.0

TABLE 10 Facility Users by Background

Background	Percentage of Total	
PHYSICAL SCIENCE		
Physics	20	
Chemistry	10	
Geology	2	
		32
BIOLOGICAL SCIENCE		
Biology	5	
Medicine	5	
Health Physics	5	
		15
ENGINEERING		
Nuclear	44	
Electrical	0	
Mechanical	2	
		46
MISCELLANEOUS	7	
		7
		100

reactors and not normally used for generating radioisotope samples. The data are included for completeness.) Figure 8 shows the distribution of number of users at the various reactors, for the two quarters studied.

On-Site Users of Facilities Hitherto, there has seemed to be little data concerning the number of people using such facilities at reactors as beam ports, thermal columns, and in-core experiments. Tables 4 and 5 indicate the number of users of such facilities at the reactors surveyed; the number in parentheses indicates the rank of each reactor in the particular category of use. It will be seen that the reactors average eight users during a typical quarter, the median being six.

The average number of users of facilities for the various groups of reactors at specified power levels is shown in Figure 9. Here again it is clear that there are markedly more users of facilities at the higher-powered reactors. Figure 10 presents the distribution of on-site users of facilities at the various reactors, for both quarters studied. There is no particular difference between the two quarters. It should be noted that one reactor reports over 30 users in both quarters.

Background of Research Reactor Users

The technical background of the users of the research reactors surveyed is shown in Table 9 (sample users) and Table 10 (facility users), using the broad groupings of physical science, biological science, and engineering. Since not all the reactors surveyed submitted data on background of users, these tables indicate percentage of total users rather than actual numbers of users. Approximately two thirds of the users of the survey reactors are identified, however, so the results do have some significance.

Most of the reactor installations are operated by nuclear engineering groups. It is accordingly not surprising to find nuclear engineering as a large user category, on a percentage basis, in Table 9 and an even larger user in Table 10. At the same time, the tables show that use of the reactors is by no means limited to nuclear engineers.

As shown in Table 9, chemists and nuclear engineers were the largest groups of users of radioisotope samples, although physicists and biologists were well represented. Approximately 60 percent of the users of samples were involved in activation analysis, using over 90 percent of all the radioisotope samples reported. The types of activation analyses conducted are listed in Appendix C. On the average, the users of radioisotope samples received about 40 samples per quarter.

The facility users, shown in Table 10, are those who utilize such facilities as the reactor beam ports, the thermal columns, and the in-core facilities. As would be expected, these facilities are used primarily by nuclear engineers and physicists. The research often involves large and complicated items of equipment that must be located at the reactor site. Substantial use of the facilities is also made by research workers from chemistry and the biological sciences.

Types of Research Activity

As part of the survey, information was requested about the research programs conducted using the research reactors. A partial list of programs is set forth in Appendix C. Most of the work is identifiable under the following headings: activation analysis, radiation effects, tracer work, radiological chemistry, biomedical engineering, nuclear physics, engineering, radiographic radiation, and materials.

This list indicates the broad multidisciplinary character of the research performed by use of a nuclear reactor. Both isotope users and facility users indicated a large and impressive variety of research.

With further reference to Table 10, it is possible to deduce from the questionnaire responses that the following disciplines were represented among the people using experimental facilities in connection with the research reactors surveyed: radio or nuclear chemistry, nuclear physics, solid-state physics, radiation biology, medicine, veterinary medicine, plant physiology, materials engineering, nuclear engineering, electrical engineering, mechanical engineering, radiological health physics, and geology.

This discipline list is incomplete but represents a wide variety of disciplines involved in the conduct of experiments using reactor radiations. The users of activation analysis data represented the largest range of disciplines and included such groups as police departments and state and local legal organizations.

The broad and important character and ingenuity of the research is readily apparent from a perusal of the experiment lists in Appendix C. For example, in biomedical engineering, research is being performed to enlarge the understanding of certain human and animal body functions necessary to treating disease. Activation analysis is rapidly becoming an indispensable analytical tool used in many branches of science and engineering. Radiation-effects studies are most important to our future space-exploration programs and (to the Department of Defense) in connection with the development of radiation-resistant missile systems.

APPENDIX A

RESEARCH REACTOR UTILIZATION DATA

Name of Reactor ______________________ (   ) Quarter of 1966

Reported by ______________________

Address ______________________ Telephone ____________

____

I. REACTOR OPERATION

Hours reactor is in operation __________ hrs

Hours reactor is used (include scheduled down time for experiment change, checkouts, etc.) __________ hrs

Integrated power __________ megawatt hours

II. IRRADIATIONS

A. Time Used for Irradiations

TIME	NO. OF SAMPLES	# OF SAMPLES X HOURS
Less than 1 hr		
1 - 8 hrs		
Above 8 hrs		
Grand Total		

B. Users of Irradiations (Please list any publications of the research below an entry if such occurs during period of report.)

USER IDENTITY (Names of Persons, Company, etc.)	NO. OF SAMPLES	DEPARTMENT, DIVISION AND/ OR DISCIPLINE	TYPE OR TITLE OF RESEARCH

III. EXPERIMENTAL FACILITIES (Includes Ports, Thermal Column, etc.) Under type designate each port or facility by some suitable method.

A. Time Used

FACILITY	TYPE	TIME (HRS)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
	Total	

B. Port or Facility Users (Please list any publications of the research below an entry if such occurs during period of report.

FACILITY #	USER IDENTITY	DEPARTMENT, DIVISION AND/ OR DISCIPLINE	TYPE OR TITLE OF RESEARCH

IV. REACTOR SYSTEMS

A. Time Used for Reactor Systems

	TIME (HRS)

B. Systems Investigators (Please list any publications . . . . etc

USER IDENTITY (Names of Persons, Company, etc.)	DEPARTMENT, DIVISION AND/ OR DISCIPLINE	TYPE OR TITLE OF RESEARCH

V. MISCELLANEOUS NON-RESEARCH OPERATION

Type of Activity	Hours

APPENDIX B

RESEARCH REACTORS

Name	Authorized Power Level (as of Dec. 31, 1967)
Aerojet-General Corp. (Industrial Reactor)	250 kW
Armed Force Radiobiology Research Institute	100 kW
Babcock & Wilcox Co.	1000 kW
Battelle Memorial Institute	2000 kW
Cornell University	100 kW
General Electric Co.	30 kW
Georgia Institute of Technology	1000 kW
Gulf General Atomic, Inc.	250 kW
Gulf General Atomic, Inc.	1500 kW
IIT Research Institute	75 kW
Industrial Reactor Laboratories, Inc.	5000 kW
Iowa State University	10 kW
Kansas State University	100 kW
Lockheed Aircraft Corp.	3000 kW
Massachusetts Institute of Technology	5000 kW
National Aeronautics and Space Administration	100 kW
North Carolina State University	10 kW
Northrop Corporate Laboratories	1000 kW
Ohio State University	10 kW
Pennsylvania State University	1000 kW
Purdue University	10 kW
Rhode Island & Providence Planations AEC	1000 kW
Stanford University	10 kW
Texas A&M University	100 kW
Union Carbide Corporation	5000 kW
U.S. Army Materials Research Agency	2000 kW
U.S. Naval Research Laboratory	1000 kW
University of Arizona	100 kW
University of California	100 kW
University of California	1000 kW
University of Florida	100 kW
University of Illinois	250 kW

University of Kansas	10 kW
University of Maryland	10 kW
University of Michigan	2000 kW
University of Missouri	200 kW
University of Missouri	5000 kW
University of Texas	10 kW
University of Virginia	1000 kW
University of Washington	100 kW
University of Wisconsin	1000 kW
V.A. Hospital	18 kW
Virginia Polytechnic Institute	100 kW
Walter Reed Army Institute of Research	50 kW
Washington State University	1000 kW
Western New York Nuclear Research Center	2000 kW
Worcester Polytechnic Institute	10 kW

APPENDIX C

ACTIVATION ANALYSIS

Activation analysis of fallout samples
Archaeological investigation by activation analysis
Identification of trace impurities by the use of activation analysis
Trace-element detection
Neutron activation using cobalt-60m
Determining uranium content by fission tracks in mica
Forensic application
Arsenic content in cigarettes
^{80}Br analysis
Activation analysis of archaeological specimens
Activation analysis to measure trace quantities of elements in rainwater to evaluate the effectiveness of various cloud-seeding techniques
Activation analysis to evaluate the halogen contents of natural and pollution aerosols, atmospheric precipitation, and surface water
Age of mica determination by formation of fission tracks
Activation analysis for measuring gold in urine of patients who have undergone gold therapy
Activation analysis to determine sodium in alumina ceramic
Evaluate a technique to determine elemental composition of the top layers of materials
Activation analysis to determine trace-element anomalies in drinking water supplies and relating their distributions to the epidemiology of heart disease
Activation analysis to determine the age, physiological state, mating, species or strain, and food products of insects
Determination of organic chloride in pesticide molecules
Neutron activation analysis of trace elements in textile fibers
Activation-analysis determination of herbicide residues
Activation-analysis determination of DDT residues in cucumbers
Production of cobalt and zinc activation-analysis standards
Irradiation of redwing blackbird bones and beaver teeth for activation-analysis studies
Neutron activation of trace elements in blood serum and tissue
Trace-element analysis in seawater
Forensic applications of neutron activation analysis
Activation analysis source production
Neutron activation analysis of organic samples
Trace-element studies in rock samples
Activation analysis of organic semiconductors

Activation analysis for Au determination in urine, blood, and body tissues
Fluoride in treated cloth
Fluorine in hydrocarbone
Vanadium in oil
Oxygen in metals
Mercury in foodstuffs
Barium and antimony in gunshot residues
Uranium in ore samples
Bromine in foodstuffs
Antimony in bullet lead
Silver in rainwater
Coding elements for industrial tagging
Trace elements in hair
Sodium in fingernails
Trace elements in blood
Rare-earth elements in rocks, minerals, and ores
Neutron activation analysis of marine sample
Identification of fission products
Rare-earth abundances
Neutron activation of marine samples
Development of techniques for activation analysis and radiochemical experimentation
Capture gamma activation analysis
Prompt gamma activation analysis

RADIATION EFFECTS

Radiation effects on organic coolants
Radiation effects on crystalline materials
Radiation damage of Si Crystals
Damage studies in Cu
A study of thermal neutron capture recoil damage by observing thermoluminescence spectra, electrical conductivity changes, electron spin resonance characteristics, and Mössbauer spectra
Expose thin mica films to fission fragments to produce microporous films to study liquid-phase diffusion of molecules
Radiation effects in solids
Effects of radiation on electronic components
Radiation effects of organic coolants

TRACER WORK

Age dating
Sn migration in teeth
^{18}F production for clinical studies
Tool wear studies
Iodine detection
Develop a technique to determine traces of phosphate ion in natural waters in the range of 4-200 parts per billion of phosphorous
Irradiate tungsten carbide for tool wear determinations
Irradiate sand and dust for engine wear studies
Provide labeled oil for oil consumption determinations
Production of ^{51}Cr as trace chromium in NiO samples
Coding elements for industrial tagging

RADIOLOGICAL CHEMISTRY

High-velocity recoil atom reactions
High-energy chemical reactions induced by thermal neutron fission and (n,γ) recoil processes
Rapid and specific chemical techniques for isolation of radioactive products
Development of very rapid (10-60 sec) electrolytic separation techniques for radioactive isotopes with half-lives of the order of 2 to 100 sec
Halogen reactions in cyclohexane
Chemical effects of isomeric transition
Solvent extraction for fused salts

BIOMEDICAL ENGINEERING

Sn migration in teeth
Sodium transport across rumen epithelium
K and Na transport in blood
Use of short-lived isotopes for diagnosis
Effect of various drugs on the distribution of radioactive potassium, cesium, and rubidium in rat tissues
Potassium determination in patients undergoing open heart surgery
Heart scanning in dogs
Determination of total body potassium in humans
Kidney uptake studies in dogs
Studies of the relationship between potassium levels in cells and amino acids

Studies of the relationship between potassium levels and hippocampal seizures
Blood-flow studies
Activation analysis to determine the age, physiological state, mating, species or strain, and food products of insects
^{18}F production
Effect of mixed neutron and gamma-ray radiation on grass seed
Cancer therapy research
Neutron-capture therapy research
RBE determination of the medical therapy
Drug responsiveness in the preirradiated and postirradiated animal
The behavioral decrement and incapacitation response to acute radiation injury
The organ and system response to acute radiation injury
The effects of ionizing radiation upon lysosomes of mammalian tissues
The clinical response of the total animal to acute radiation injury
Effects of ionizing radiation on discrimination in the primate
Neutron capture in tissue
Chromosome variation in chickens following acute radiation
Fast neutron biological irradiations

NUCLEAR PHYSICS

Isomer studies
Decay Scheme of ^{37}A
Decay Scheme Studies
Beta- and gamma-ray spectroscopy of short-lived fission products
Study of de-excitation of fission fragments produced in neutron-induced fission
Production of radioactive sources for level scheme determinations
Supply sources in conjunction with studies of low-lying nuclear-energy levels
Fission product decay (short-lived isotopes)
Decay scheme analysis
Decay scheme of ^{111}Ag
Search for ^{52}Ti
Level structure of ^{117}Sn and ^{119}Sn decay schemes of ^{131}Te
Decay of ^{88}Rb
Decay schemes for ^{135}I and ^{135}Xe
Angular correlation studies on ^{129}Te and ^{131}Te rays
Decay of ^{124}Sb and ^{124}I to ^{124}Te
Decay scheme of ^{69}Zn isomers. Yields of Zn fission products
Atomic beam studies of ^{75}Ge
Neutron time-of-flight energy system

Spectroscopy of neutron capture gamma rays
Neutron decay spectroscopy
Ternary fission
Preliminary studies for delayed neutron source work
Fission physics
The study of the photofission of heavy nuclei near the fission threshold

ENGINEERING

Coated fuel evaluation
Argon activation for monitor calibration
Radiographs of fuel rods and plates
Radiographs of fuel
Radiographs of rods and pins
Conduct study of type and extent of radioactivities that might be induced in the ground surrounding reactor
Feasibility study for production of ^{60}Co calibration sources
Subcritical pulsing
Lattice physics research
Void effects in fuel rod clusters
Magnetohydrodynamic studies
Laser reactor radiation coupling
Importance function measurements
Void coefficient measurement
Development of a pile oscillator and measurement of the reactor transfer function
Experimental study of radiation-induced nucleation of bubbles in superheated water
Doppler effect in ^{238}U as a function of surface-to-mass ratio
Capture gamma-ray shielding

RADIOGRAPHY, RADIATION

Ferromagnetic prism refraction of neutrons
Refractive bending of a neutron beam by a magnetic field
Single-slit diffraction of neutrons
Basic mechanisms and controls of the dose in reactor exposure volumes
Flux and dose studies and modifications related to the LINAC facility
Development of dosimeters to measure tissue dose and the components contributed by the various types of radiation

Spectrum measurements
AmBe neutron source investigations
Neutron flux measurements--self-powered detector
Spark counter studies
Laser reactor radiation coupling
A fast neutron spectrometer using polyethylene radiators and solid-state detectors for measuring fast neutron spectra
Feasibility study of using small diamond flats as a dosimeter (EPR measuremen
Development of neutro. -adiographic techniques
Determination of neutron spectra in lattices by foil activation
Single-crystal neutron spectrometer for reactor spectrum measurement and associated experiments
Neutron radiography
Resonance fluorescense with recoil-broadened gamma rays
Mechanical simulation of Doppler broadening
Radiographic technique tests
Fission-product production
Radiographs of fuel rods and pins
Radiographs of fuel rods and plates
Radiographs of fuel
Isotope production
Gamma dosimetry
Use of radioactive wires under the skin of mice to monitor daily activities in large natural enclosures
Irradiate tantalum wires
Irradiation of LiF or ^{3}He to produce ^{3}H
Fission fragments in glass
Autoradiography of a ruby
Fission recoil in CsI
Production of ^{72}Ge sources for nuclear spectroscopy studies
Feasibility study for production of ^{60}Co calibration sources
Production of ^{51}Cr as trace chromium in NiO samples
Production of low-level ^{60}Co sources and development of flux wire method of power calibration
Production of ^{198}Au sources
Production of $^{51}Cr/^{58}Co$ scintill-spectrometer calibration source
Range of fission fragments in ^{235}U
Indium, Kr, Ar, CS_2, Nd activation
^{56}Mn source
Production of short-lived isotopes

MATERIALS

Heat of fission studies
High-temperature study of iron magnetic scattering amplitudes
Studies of (222) forbidden germanium reflection
Studies of coherent paramagnetic scattering by vanadium
Study of Kondo effect in a dilute alloy
Neutron diffraction
A triple-axis crystal spectrometer for neutron inelastic scattering measurements
A four-rotor velocity selector for neutron inelastic scattering measurements
A polarized-beam crystal spectrometer for neutron elastic scattering measurements on magnetic materials
A crystal spectrometer for general neutron elastic scattering measurements
Operate a crystal spectrometer for neutron elastic scattering studies
Molecular-structure research
Neutron diffractometer
Radiation damage of Si crystals
Expose thin mica films to fission fragments to produce microporous films to study liquid-phase diffusion of molecules
Evaluate a technique to determine elemental composition of the top layers of materials