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PERSONNEL RADIATION EXPOSURE IN HTGR AND LWR PLANTS

by
B. A. ENGHOLM

Prepared under
Contract DE-AT03-76ET35300
for the San Francisco Operations Office
Department of Energy

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1. SUMMARY

Occupational radiation exposures at HTGR plants were compared with those at typical LWR facilities. Actual man-rem accumulations at the Peach Bottom 1 HTGR and at the Fort St. Vrain HTGR have been substantially lower than those at LWRs with similarly rated powers, when compared on the basis of man-rem/GW(e)y.

The expected exposure rate for a large HTGR steam cycle or gas turbine unit is 70 man-rem/GW(e)y, while the design basis is 180 man-rem/GW(e)y.

The results from Peach Bottom and FSV lend credence to these predictions, as do the exposures experienced in CO_2-cooled reactors with PCRVs. The comparable figure for actual LWR experience is 570 man-rem/GW(e)y.

2. LWR INFORMATION

2.1. TOTAL EXPOSURE

Numerous reports and articles have appeared in recent years pointing up the increasing problem of occupational radiation exposures at LWR plants. The most convenient collection of such information, especially for earlier data extending back to 1961, is Pohl's article, Ref. 2-1. Figures 1 through 6 from this article have been combined, augmented, and redrawn as Figs. 3-1, 4-1, 5-1, 5-2, and 5-3 of this report. The LWR comparisons which follow are based on these figures.

2.2. REFUELING EXPOSURE

Information on occupational exposure during LWR refueling is available from Ref. 2-2. The actual experienced exposure is ∿39 man-rem per LWR refueling in 1976. Westinghouse has projected an exposure of 10.5 man-rem for rapid refueling (Ref. 2-3).

3. PEACH BOTTOM 1

3.1. TOTAL EXPOSURE

The Peach Bottom HTGR, operated by Philadelphia Electric Company, generated a total of 1200 GW(e)h of net power during its operating life of March 3, 1966 to October 31, 1974 (Ref. 3-1).

Personnel exposures during Peach Bottom operation, maintenance, and refueling were exceptionally low, according to records of Philadelphia Electric health physicists (Ref. 3-2).

Yearly and cumulative exposure and power generation data are listed in Table 3-1.

Since the Peach Bottom HTGR produced 40 MW(e) and was a prototype reactor, comparisons are made with the following early, low-power LWRs:

Big Rock	63 MW(e)
Humbolt	63
Lacrosse	48

Exposure data for these LWRs were obtained from Ref. 2-1 and are plotted in Fig. 3-1, which depicts the cumulative occupational exposures for all four plants. The rate of man-rem exposure at Peach Bottom 1 [183 man-rem/GW(e)y] can be compared with the LWR accumulation rate of over 2000 man-rem/GW(e)y.

3.2. REFUELING EXPOSURE

No separate data are available for Peach Bottom refueling exposures, but the personnel exposure is estimated by this author to be less than 1 man-rem per refueling.

TABLE 3-1
PEACH BOTTOM HTGR OPERATING EXPERIENCE

Year of Operation	Man-Rem Exposure		Net Power Generation [GW(e)y]		Cumulative Occupational Exposure [man-rem/GW(e)y]
	By Year	Cumulative	By Year	Cumulative	
1967	∿3	∿3	0.017	0.017	176
1968	∿3	∿6	0.015	0.032	188
1969	∿3	∿9	0.0157	0.048	188
1970	∿3	∿12	0.0163	0.068	176
1971	∿4	∿16	0.024	0.088	182
1972	∿3	∿19	0.012	0.102	186
1973	∿3	22	0.021	0.1205	183
1974	NA	NA	0.0183	0.140	NA

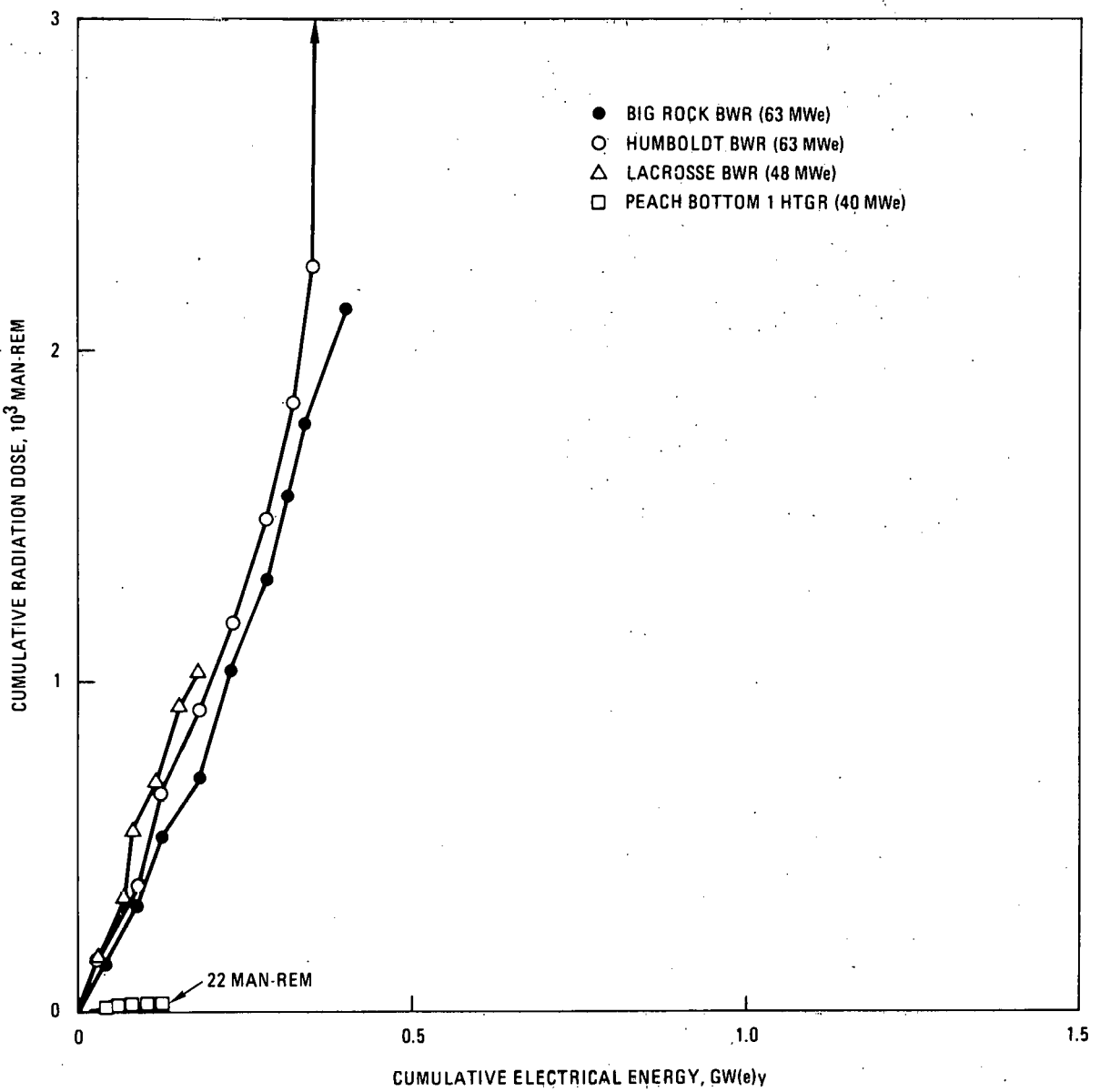

Fig. 3-1. Cumulative occupational exposures for early, low-power nuclear plants

4. FORT ST. VRAIN

4.1. TOTAL EXPOSURE

The Fort St. Vrain Nuclear Generating Station had accumulated 953 GW(e)h of net power output up to the February 8, 1979 shutdown for refueling, according to reports of Public Service Company of Colorado (PSC). Net power generation for calendar 1977 and 1978 is also available from these reports.

The PSC Health Physics office maintains detailed records of personnel radiation exposure, in compliance with State and Federal regulations. Data for 1977 and 1978 were obtained from Dr. Don Alexander, head of PSC Health Physics.

Information needed for a comparison with LWR experience is summarized in Table 4-1.

It is believed appropriate to compare FSV experience with the following LWRs:

Dresden 1	200 MW(e)
Ginna	490
Indian Pt. 1	265
San Onofre 1	436
Yankee Rowe	175

In addition, operating data for the British Oldbury GCR plant (which utilizes a PCRV) were collected from Nuclear Engineering International magazine for purposes of an independent comparison. The results, in

TABLE 4-1
FSV MAN-REM EXPERIENCE

Personnel	Exposure	Averaged Man-Rem	Net Power Generation [GW(e)y]	Rate of Accumulation [man-rem/GW(e)y]
1977				
946	None	0		
55	<100 mrem	2.75		
1	100-250 mrem	0.175		
		2.9	0.0256	113
1978				
896	None	0		
34	<100 mrem	1.7		
0	100-250 mrem	0		
		1.7	0.0695	24
Cumulative		4.6	0.0951	48

Fig. 4-1, show that the FSV curve barely rises above the zero ordinate, closely following the early operational experience at Oldbury and San Onofre. All the other LWRs show up poorly by comparison.

4.2. REFUELING EXPOSURE

The first refueling of the Fort St. Vrain HTGR took place in March and April 1979. During these refueling operations, numerous gamma dose rate measurements were made by PSC health physicists and by GAC personnel. A comparison between measurements and calculations is being prepared for issuance as a GA report (Ref. 4-1).

Most of the refueling dose rates were so low as to require the use of a microrem meter by PSC health physicists. For instance, the average dose rate on the accessible surface of the fuel handling machine (FHM) when loaded with spent fuel was less than 1 mrem/hr. The only time personnel are near the loaded FHM is during unbolting, crane, and bolting operations, about half an hour per fuel region. Assuming six personnel and six fuel regions, the man-rem exposure for this part of refueling would be:

$$\frac{6 \times 6 \times 0.5 \times 1}{1000} = 0.018 \text{ man-rem} \quad .$$

Control rod drive (CRD) handling operations were equally inconsequential in exposure, except for one CRD which had activated clevis pins. In this case, the dose rate at some distance from the auxiliary transfer cask (ATC) was about 4 mrem/hr (i.e., at the change area). Hence, it is possible that another 0.02 man-rem could have been accumulated in moving this CRD to the storage wells.

Health physicists made one-time measurements at greater elevations of the Fort St. Vrain FHM and ATC, where the surface dose rates are intentionally higher than those within an 8-ft height above the refueling floor. It is possible that a few tenths of a man-rem could have been accumulated by these health physicists in this fashion.

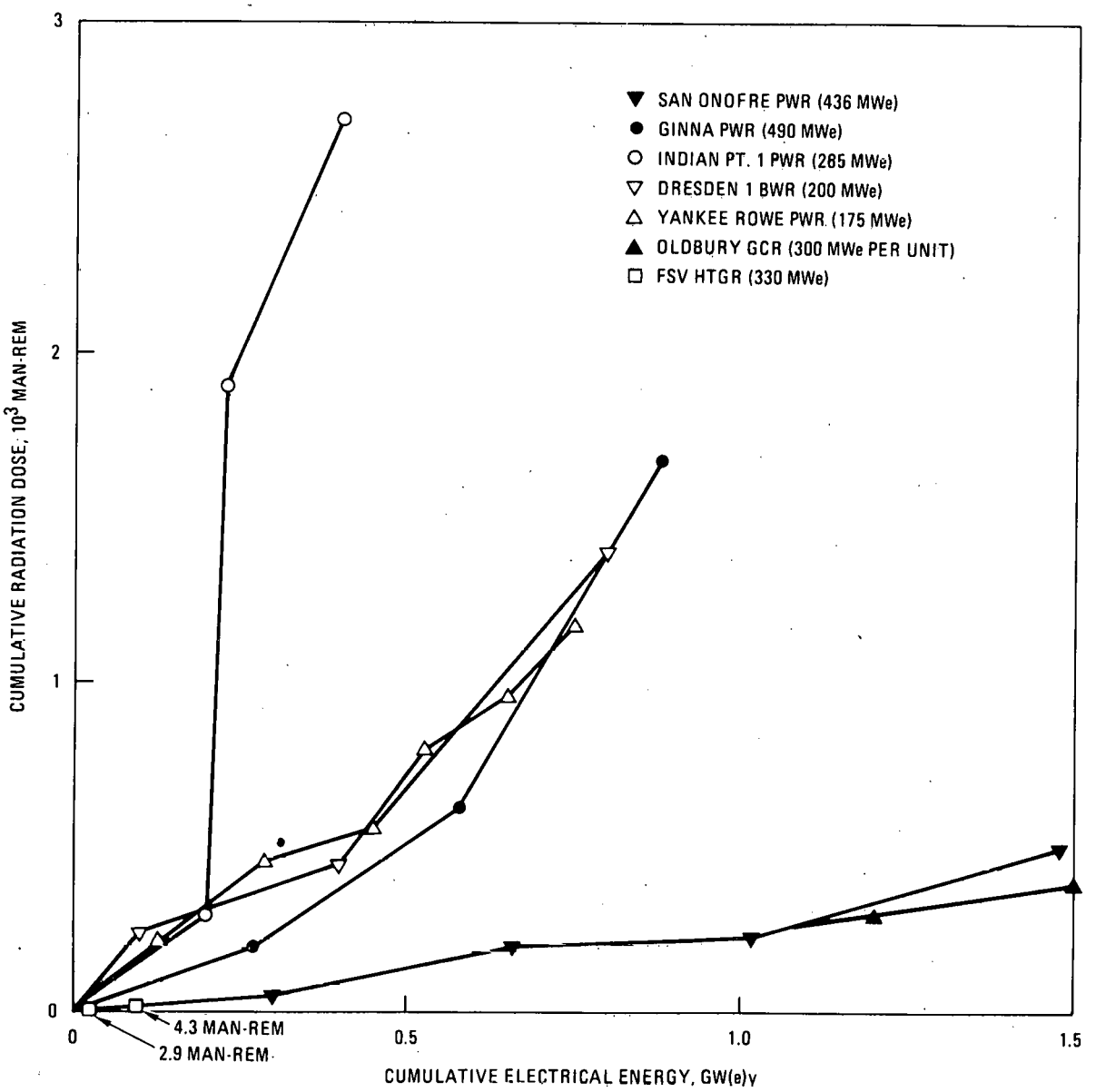

Fig. 4-1. Cumulative occupational exposures for medium-power nuclear plants

Public Service of Colorado will in due course publish tabulations of personnel exposure during the first FSV refueling. It is expected that the total accumulation was less than 0.5 man-rem.*

In order to compare this figure with LWR experience, it should be remembered that (1) FSV had not exceeded ∿65% of full power rating, i.e., the plant had been generating about 200 MW(e); and (2) the spent fuel had decayed for a period of 45-60 days. The 60-day decay time reduces the La140 inventory in the fuel blocks by a factor of 25.

On the other hand, if the design dose rate of 10 mrem/hr had existed on the surface of the FHM, somewhat more stringent access control and personnel scheduling measures would have been taken. Hence, it is probable that the refueling personnel exposure under full power normal operating conditions will be less than 5 man-rem. This figure, when scaled to 1000 MW(e), becomes 15 man-rem, still considerably lower than current experience in most LWR plants.

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*Preliminary information obtained through K. R. Van Howe of S. M. Stoller Corp. indicates an actual accumulation of 0.22 man-rem.

5. LARGE HTGR STEAM CYCLE

Information on occupational exposure for the Large HTGR-SC was based on a comprehensive study of a 900 MW(e) plant design (Ref. 5-1).

Only preliminary work has been done on assessing man-rem exposures associated with the Gas Turbine HTGR. Reference 5-2 reports that the exposure for turbomachine removal is 2.1 man-rem, but no predictions have been made regarding subsequent decontamination and disassembly. Until more information becomes available, it would be expected that the occupational exposure for the GT-HTGR would be the same as that for the HTGR-SC.

Man-rem results for the HTGR-SC are summarized in Table 5-1.

The expected accumulation rate for the LHTGR is plotted with recent LWR data in Figs. 5-1 through 5-3. Also shown is information on the British Wylfa GCR plant (using a PCRV), obtained from Nuclear Engineering International.

The results show that the expected rate of man-rem accumulation in the LHTGR is about a factor of 8 below that of LWR plants.

TABLE 5-1
MAN-REM PREDICTIONS FOR LHTGR-SC

Type of Operation	Annual Man-Rem Exposure for 900 MW(e) Unit	
	Expected	Design Basis
Refueling	5.5	20
Reactor Operation and Surveillance	7.0*	20
NSS Maintenance and ISI	10.1	20
BOP Maintenance	25.0**	50
Special Maintenance	$\frac{3.2}{50.8}$***	$\frac{20}{130}$
Rate of Accumulation [900 MW(e), 80% load factor]	$\frac{50.8}{0.9 \times 0.8} = 70 \frac{\text{man-rem}}{\text{GW(e) y}}$	$\frac{130}{0.9 \times 0.8} = 180 \frac{\text{man-rem}}{\text{GW(e)y}}$

*From low-level noble gas activity in containment building.

**Assumed; no information is available from an architect-engineer.

***Tube plugging every year @ 1.0 man-rem; steam-generator removal every 10 years @ 1.65 man-rem; circulator removal every 2 years @ 1.0 man-rem.

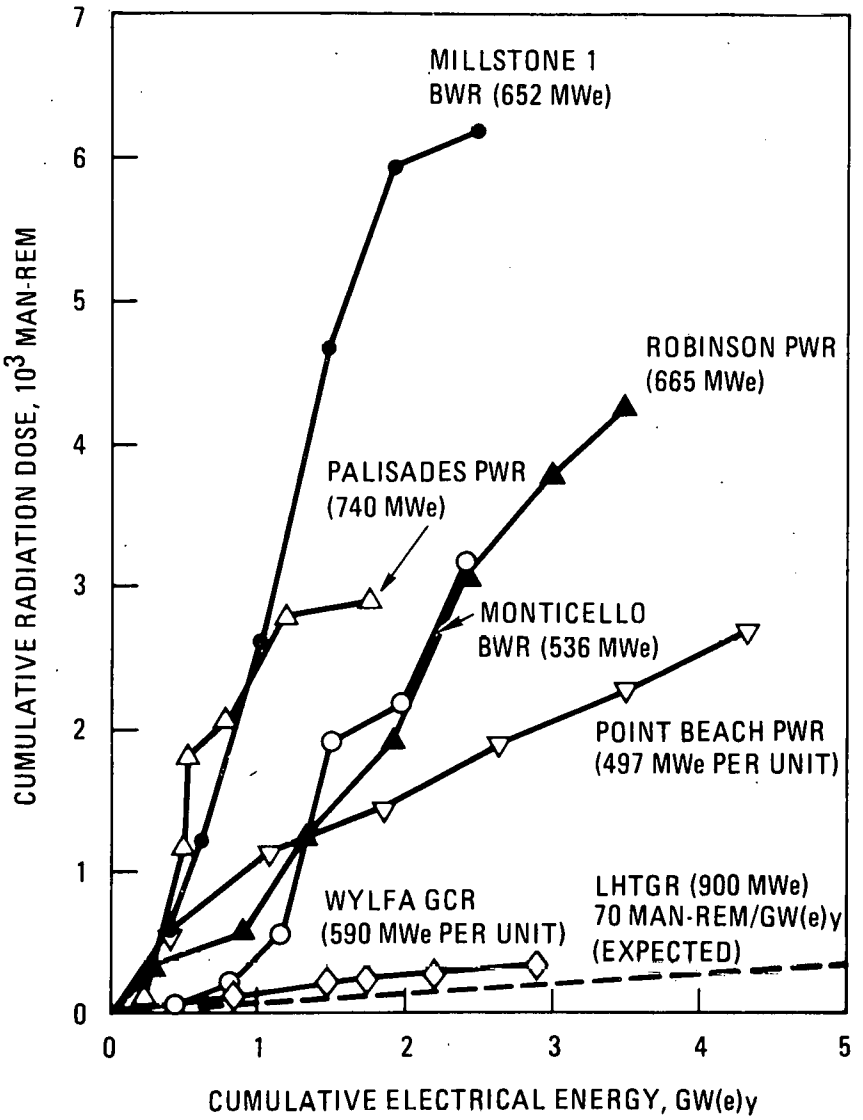

Fig. 5-1. Cumulative occupational exposure for large nuclear plants (Part 1)

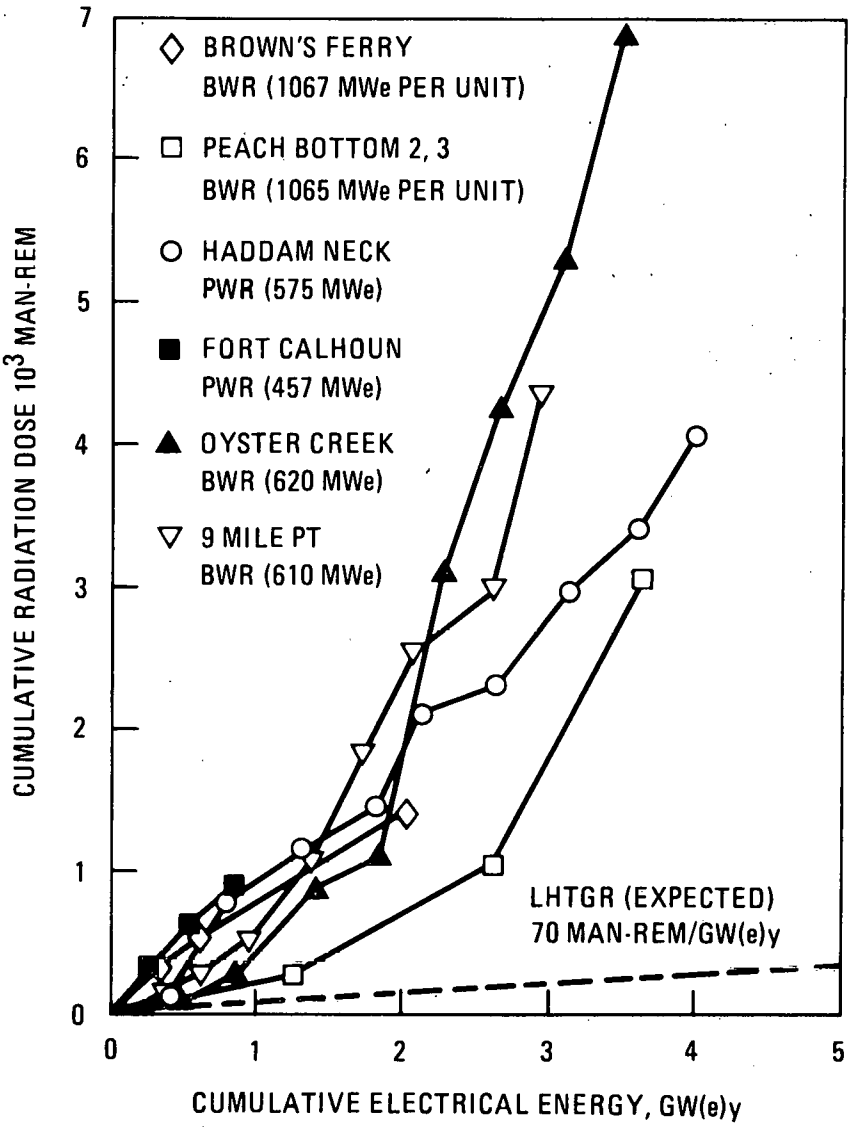

Fig. 5-2. Cumulative occupational exposure for large nuclear plants (Part 2)

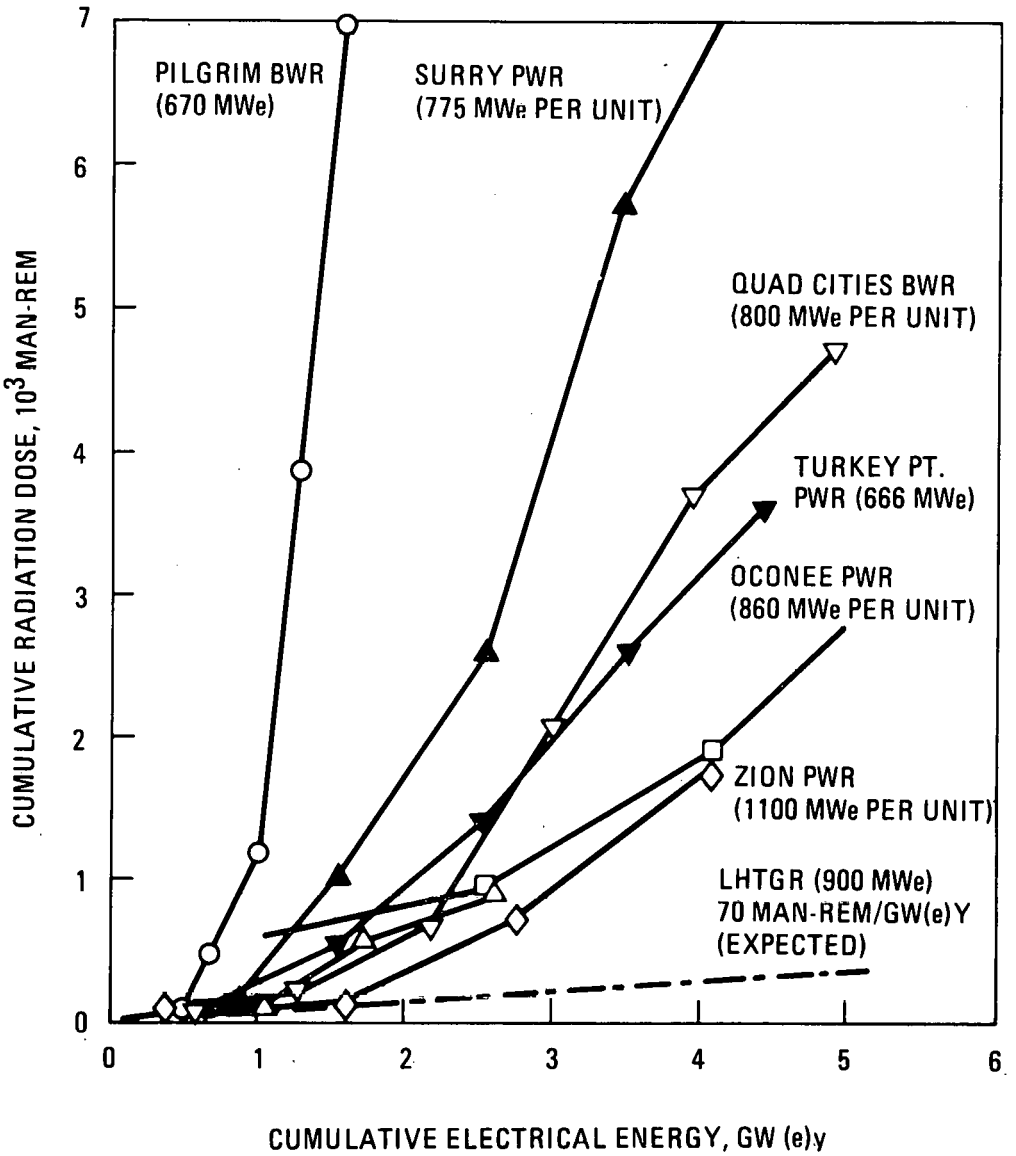

Fig. 5-3. Cumulative occupational exposure for large nuclear plants (Part 3)

6. CONCLUSIONS

Available data on man-rem exposures of working personnel at nuclear plants from Refs. 2-1, 2-2 and elsewhere, clearly indicate that GCRs are experiencing less dose accumulation than LWRs. Reactors of the HTGR type, both Peach Bottom and Fort St. Vrain, as well as LHTGR designs, fall in line with this observation, having man-rem/GW(e)y accumulations about an order of magnitude less than LWRs.

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