HYBRID LOG-NORMAL ANALYSIS OF WORKER DOSES IN SPECIAL JOBS AT RESEARCH REACTORS JRR-2 AND JRR-3

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INTRODUCTION

The reduction effort proportionate to the magnitude of doses to workers is theoretically proved to result in the hybrid log-normal (HLN) type of dose distribution (1,2). The HLN distribution was applied to the analysis of distributions of worker doses in the United States(3). It showed that the shape of nationwide dose distributions by industry category changes from the lognormal (LN) to the normal via the HLN distribution according to the degree of exposure reduction.

This paper presents some properties of job-specific dose distributions rather than nationwide ones by using the HLN analysis.

HYBRID LOG-NORMAL DISTRIBUTION

The hybrid log-normal distribution is applied to the distribution of doses X so that $Y=\ln\rho X+\rho X$ ($\rho>0$) is normally distributed with parameters (μ, σ^2). The HLN distribution function, $\Omega(x)$, is given by

$$\Omega(x) = \int_0^x \frac{1}{\sqrt{2\pi}\,\sigma}\left(\frac{1}{x}+\rho\right)\exp\left(-\frac{\{\ln\rho X+\rho X-\mu\}^2}{2\sigma^2}\right)dx . \qquad (1)$$

The HLN distribution is derived from a stochastic process of reducing dose accumulation as shown in Fig. 1. The dose ΔX_j at the j-th step is proportional to the previous amount X_{j-1} and the feedback mechanism to reduce ΔX_j controls the factor ε_j so as to decrease it based on the magnitude of ΔX_j: ε_j varies randomly depending on a role and behavior of workers at workplace in terms of dose rate and working time. The sum of ε_j over n hypothetical steps in a fixed working period is

$$\sum_{j=1}^{n}\varepsilon_j = \sum_{j=1}^{n}\left(\frac{1}{X_{j-1}}+\rho\right)\Delta X_j = \int_{\rho X_0}^{\rho X_n}\left(\frac{1}{t}+1\right)dt = \left[\ln t + t\right]_{\rho X_0}^{\rho X_n} . \qquad (2)$$

According to the central limiting theory, as the standardized sum of ε_j will be normally distributed when $n\to\infty$, $\ln\rho X_n+\rho X_n$ will be normally distributed (2). This HLN genesis theory implies that the HLN type dose distribution will approach the LN for workers weakly controlled to reduce dose ($\rho\to 0$) and approach the normal for those strongly controlled ($\rho\to\infty$) as shown in Fig. 2.

APPLICATION METHOD

The HLN probability plot is used to interpret the effect of dose reduction on worker dose distribution. The LN probability plot uses a log scale of X on probability paper. Analogously the HLN probability plot uses a hybrid scale of dimensionless dose ($t=\rho X$) multiplied by ρ which means the degree of dose reduction per unit dose according to dose limitation. The hybrid scale is a function defined by lnt+t (

see in Fig. 2). It approaches a log scale for $t \ll 1$ and a linear scale for $t \gg 1$. Thus HLN probability paper is similar to LN probability paper for $t \ll 1$ and to normal one for $t \gg 1$.

The data used were obtained in a five-month series of works of repairing primary coolant valves at JRR-2 and in one year series of works of removing primary coolant equipments in the remodelling of JRR-3, as shown in Table 1. The radiation works had been well planned and prepared for a resonable goal of balancing the completion of radiation jobs and the reduction of worker doses.

RESULTS AND DISCUSSION

Minimum and maximum exposure rates of each of 74 working days at workplace of JRR-2 are plotted on HLN probability paper in Fig. 3, respectively as graphs A and B located in the region of $t \ll 1$. Their lognormality implies no effort of reducing high exposure rate day by day. However as the daily worker doses give the graph C extending $t > 1$ in Fig. 3, that hybrid lognormality implies an effective effort proportionate to the magnitude of dose to reduce the frequency of worker doses approaching the control level of 0.5 mSv/day. Besides as cumulative doses of 13 workers give the graph D located in the region of $t \gg 1$ in Fig. 3, it implies a strong effort of reducing doses not to approach the control level of 4 (later 5.5) mSv. Thus it suggests that job-specific efforts of dose reduction lead to the HLN distribution of doses to workers at workplace with the LN distribution of exposure rates.

Daily and cumulative doses to 78 workers at various workplaces of JRR-3 show parallel rows of plots extending from $t \ll 1$ to $t > 1$ on HLN probability paper in Fig. 4 (a). Their hybrid lognormality reflects a wide variety of doses and implies an explicit effort of dose reduction proportionate to the magnitude of dose approaching the control level of 1 mSv a day or 0.5～10 mSv in the whole period. Fig. 4 (b) shows HLN probability plots of four groups of daily doses according to the range of control levels of dose accumulation applied to workers. The degree of graphs extending to $t > 1$ implies the stronger effect on dose reduction due to the higher control level of dose accumulation, except the group of technical supervisors(▲) who probably took the strong self-control over the whole working period below the control level from 2.5 to 5 mSv. Another grouping of daily dose distribution, by period, exposure rate and sub-job, was also proved to be similar HLN effects on dose reduction.

CONCLUSION

The job-specific dose distribution as well as the nationwide dose distribution seems to be hybrid lognormality. The HLN probability plot depicts the effect of dose reduction according to the magnitude of doses approaching the control levels set for individual jobs.

REFERENCES

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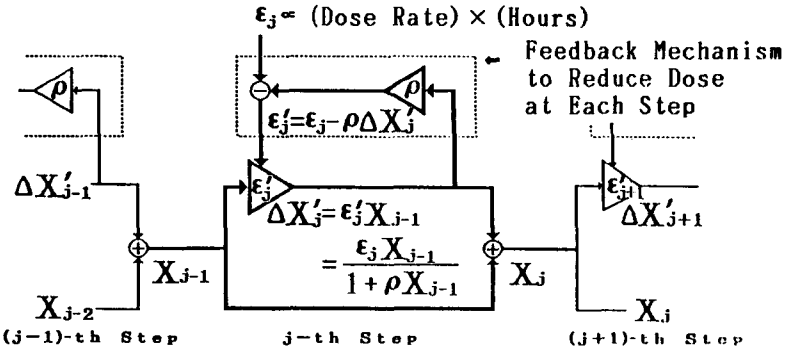

Fig. 1 A mathematical model for the control process of dose reduction

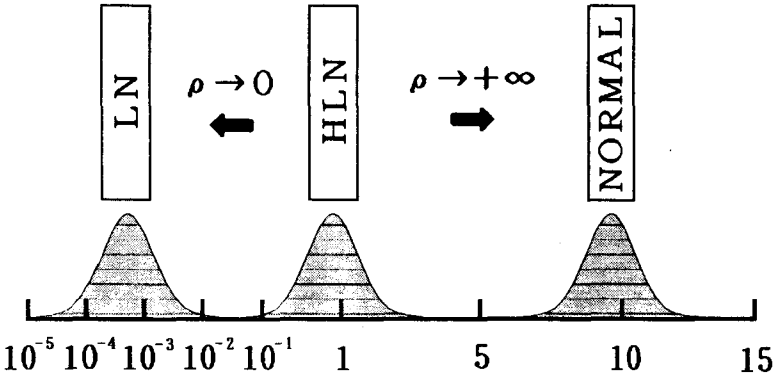

Fig. 2 Hybrid scale: hyb(t)=lnt+t. Putting t=ρX, X changes from a log scale to a linear scale according to ρ.

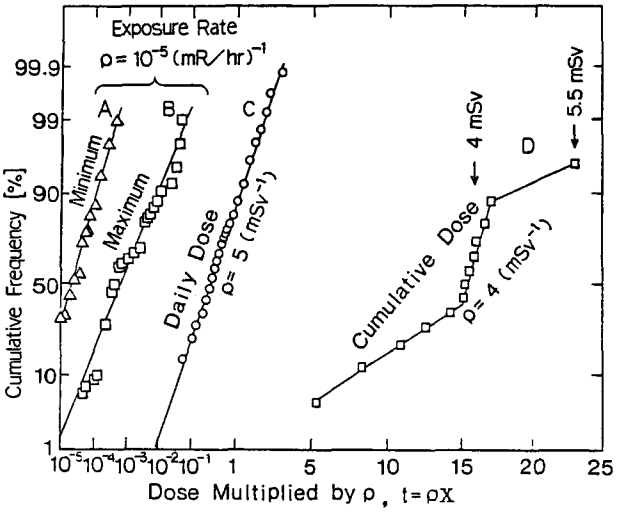

Fig. 3 HLN probability plots of exposure rates and worker doses at JRR-2.

Table I Radiation works at the research reactors to be analyzed

Reactor	JRR-2	JRR-3
Job	repairing primary coolant valves	removing primary coolant equipments
Period	May, 1980～Sept., 1980	Aug., 1985～Mar., 1986
Number of workers	13 workers about 7 workers/day total 470 worker·days	78 workers about 50 workers/day total 8000 worker·days
Control level	0.5 mSv/day 4 (later 5.5) mSv/man	1 mSv/day 0.5～10 mSv/man 200 man·mSv
Resultant dose	average 3.5 mSv total 46 man·mSv	average 15 mSv total 116 man·mSv

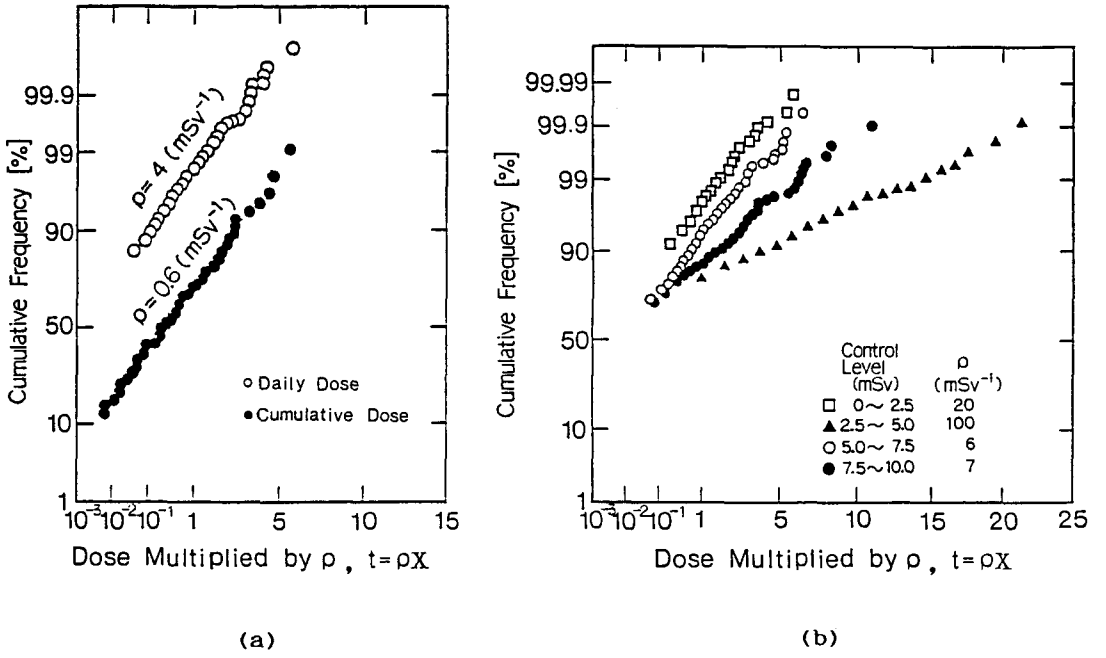

Fig. 4 HLN probability plots of daily and cumulative doses at JRR-3:
(a) daily doses and cumulative doses over the whole period,
(b) four groups of daily doses according to the range of control levels of dose accumulation applied to workers .