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Dosimetric Monitoring at Time of Chernobyl Clean-up: A Retrospective View

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INTRODUCTION

Although at time of the accident many thousands of individuals were subjected to personal dosimetric monitoring, a status of dosimetric support of clean-up activities performed in 1986-1987 remains one of the most uncertain radiological issues related to Chernobyl accident. It is known that the scope, practical coverage and methodologies of dosimetry at time of the accident significantly varied. Unfortunately, the dose records available now in a number registries and databases are dispersed and are lacking direct indications of the methods of dosimetry, locations of work and tasks performed by liquidators. Moreover, data record linkage in many cases is problematic due to lack of unique identifiers in the databases of concern. However, this information, collected in course of dosimetric monitoring is extremely valuable for epidemiological consideration of this cohort and, therefore, cannot be neglected because of problems with strait forward application of this data.

Retrospective consideration of dosimetric monitoring data was conducted along several lines. First, data sets (in some cases impersonal), related to the known dosimetric practices were studied in order to determine regularities in their dose distributions, evaluate possible distortions caused by extraneous admixtures to dose arrays and evaluate possible contribution of falsified dose records.

Another effort was directed towards individualization of information regarding affiliation and tasks of the liquidators included into the State Chernobyl Registry (SCR), which is, essentially, the main pool of subjects for observation in the framework of post Chernobyl epidemiological studies. The SCR in its original shape was missing this crucial information.

An inventory of instrumental dosimetry databases was conducted as well and results of monitoring were linked with the SCR records.

CRITICAL EVALUATION OF OFFICIAL DOSE RECORDS

There are traditional concerns regarding the possibility of falsification of dosimetric monitoring results at time of the clean-up, expressed, in particular, in administrative assignment of doses below permissible levels, whatever real doses were. Certainly there were some facts of such administrative falsification which, in general, discredit the whole Chernobyl dosimetric monitoring data. The problem in question was how often such alterations occurred and do they really affect the general picture of exposure of Chernobyl liquidators. It is well known, that population of Chernobyl liquidators is extremely heterogeneous, in particular in terms of dose management practice. This heterogeneity is also reflected in a complex structure of dose distribution which is, essentially, a mixture of many distributions corresponding to different groups of liquidators and various periods of time. Apparently, alteration of dose records had different extent in distinct bodies responsible for dose management during clean-up. Therefore, no general conclusion may be derived about falsification or trustworthiness of official dose records. Each more or less significant group of liquidators require separate consideration.

One of the most numerous, yet quite problematic group of liquidators consists of military reservists (or “partisans” in Chernobyl jargon). At first look, strange shape of dose distributions of “partisans” (Fig.1) support the discussed above concerns. Indeed, large frequency right below the dose limit and sharp cut-off above this threshold suggest strong administrative pressure on dosimetric service and assignment of “appropriate” dose values to all liquidators not respecting their real exposures. Closer consideration of the data reveals another unusual feature of official dose records – abnormally high percentage – about 65% - of round dose values. From the other hand, similar regularities may be observed in case of another realistic scenario: extremely strong dose management and the recording of dose values rounded down to integer figures. Indeed, such dose management when liquidators worked until they were released from Chernobyl upon achievement of dose limit was practiced during the clean-up. Such unique type of dose management was possible under conditions of the Soviet Union when practically unlimited resource of manpower was available for performing unskilled tasks in coarse of the clean-up. The possible reason for recording round dose values is low precision of dosimetric techniques used for monitoring of “partisans”.

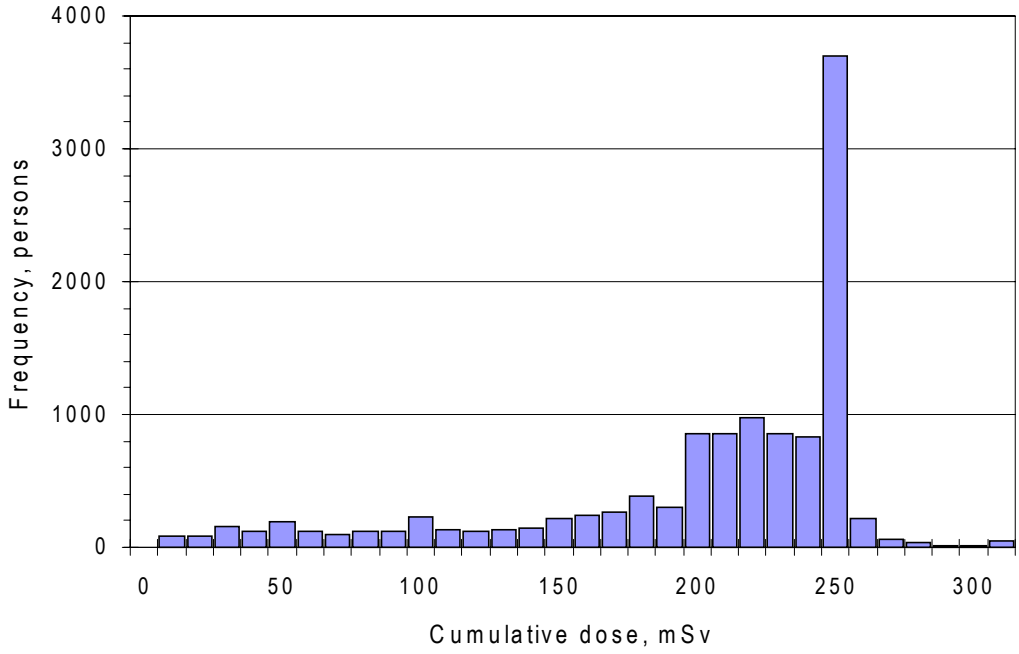

Figure 1. Frequency histogram of doses of military liquidators ("partisans") of 1986.

Thus, the question is: whether all (or majority) of official dose records of "partisans" were assigned administratively (scenario of falsification), or unusual features of dose distribution are caused by unique circumstances of work in Chernobyl (scenario of strong dose management). Obviously, analysis of dose distribution (Fig.1) itself is not sufficient for solving this dilemma. Additional information which may contribute to verification of dosimetric data is the recorded duration of work in Chernobyl. Distribution of periods of work is very broad and does not have pronounced peaks corresponding to the multiples of one week or one month. This fact rather gives indirect evidence to the advantage of the second scenario when liquidators were released from Chernobyl at random periods upon receiving maximum permissible dose. Moreover, the following transformation of cumulative dose to dose rate (daily dose):

$$d = D / t, \tag{1}$$

where ***D*** is individual dose and ***t*** is period of work (days), changes distributions significantly. As may be seen from Fig.2, daily doses ***d*** are represented by rather broad unimodal distribution which is consistent with ones observed in the most cases of occupational exposure. Taking into account that dose management in Chernobyl was practiced on daily basis, such consideration of daily rather than cumulative doses is quite justified.

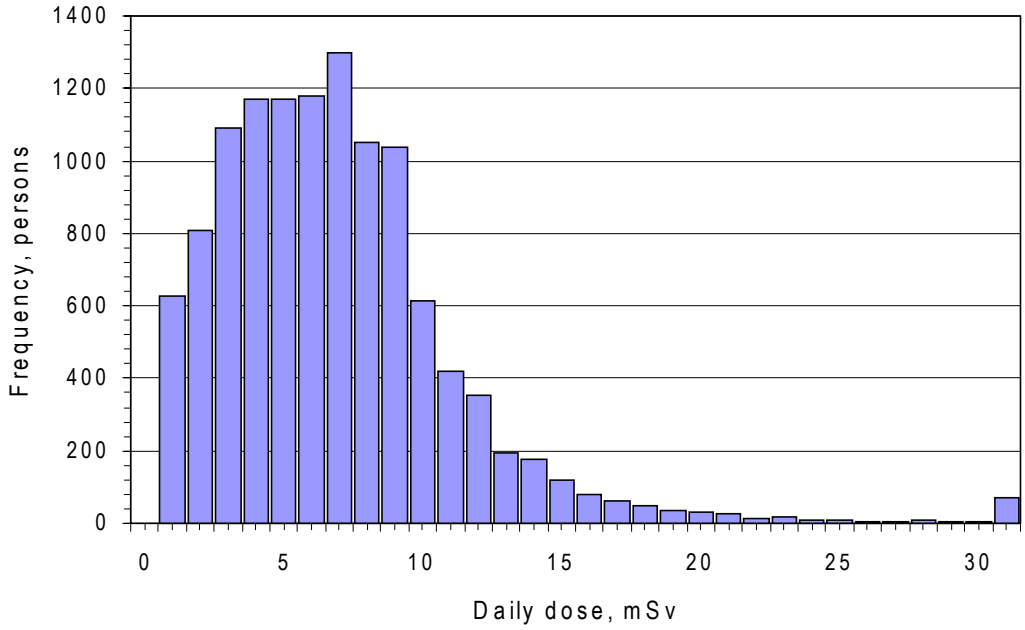

Figure 2. Frequency histogram of individual daily doses of military liquidators of 1986.

The daily dose distributions (Fig.2) were tested with respect to hybrid lognormal (HLN) hypothesis and parameters of distributions were determined using the maximum likelihood method (Groer et al, 1991). Normalized probability plot presented at Fig.3 demonstrates good agreement of experimental data with HLN law.

Values of the parameters are presented in the Table 1. For illustration, some other cohorts of liquidators were analyzed in similar way. As may be seen from the table, the values of mean daily dose **<d>** and constraint factor **ρ** are in a good agreement with expected exposure pattern. Time dependence of these parameters is consistent with evolution of dose fields and conditions of work on the Chernobyl site. The value of standard deviation is also quite indicative. As was observed (Nossovsky et al, 1996), in the most cases of occupational and accidental exposure, the value of coefficient of variance (C.V.) of doses is slightly higher than one. Too broad or too narrow distributions are unusual and give evidence of either administrative distortion of data (low C.V.) or presence of a mixture of several data sets in case of too broad distributions (high C.V.). This rule is illustrated by data related to liquidators who based in the city of Chernobyl (Table 1). Indeed, in the case with known heterogeneous population, the value of C.V. is quite high, indicating a mixed nature of the data. Data related to military liquidators (‘partisans”), in its turn, looks from the point of view of this criterion quite consistent.

Table 1. Parameters of daily dose distributions for some groups of liquidators in 1986-1987 (HLN hypothesis)

Group of liquidators	1986			1987		
(settlement of residence at time of clean-up)	<d>	σ	ρ	<d>	σ	ρ
Military reservists (Oranoje)	0.677	0.69	0.585	0.317	0.47	1.535
Mixed (Chernobyl)	0.767	1.46	0.431	0.328	0.66	1.852

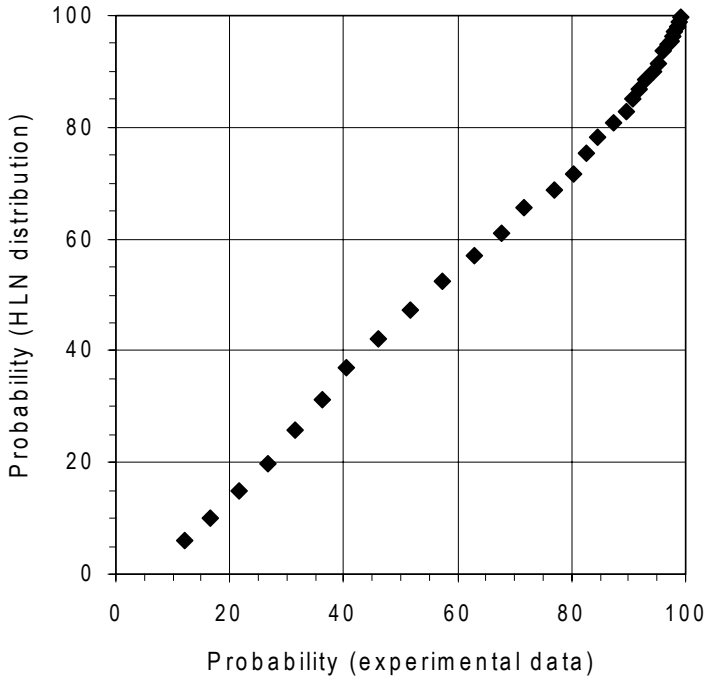

Figure 3. Normalized probability plot for distribution of daily doses of military liquidators ("partisans") of 1986. Hybrid-log-normal hypothesis.

Obviously, when dosimetric data set is not altered by some reason, the distribution of doses complies with one of the commonly accepted distribution laws. Intentional falsification of doses would be expressed in addition of some unusual dose values (e.g. close to dose limits) which result in distortion of the distribution. It is not always trivial to detect such admixtures and, particularly, to quantify their contribution to the whole data set. The following phenomenon gives a clue to solution of this problem. As was demonstrated in (Ilyin et al, 1995), the dependence of entropy coefficient **H(d)**/ln**d** on ln**d** where ***d*** is increment (bin width) of histogram does not depend on the type of distribution (normal, log-normal or uniform). However, the values of entropy coefficient are being consistently reduced when admixture of records with extrinsic properties occurs. As was demonstrated in computer experiments, degree of reduction of entropy coefficient does not depend significantly on the type (e.g. δ-function vs. narrow normal or uniform distribution) and position of admixtures. At the same time, percentage of admixed record has rather strong effect on the entropy coefficient curve and, therefore, this change may be detected and used for quantification of admixtures. In practice this mean, that entropy curve of natural (experimental) data may be compared with the curves corresponding do data containing given amounts of simulated admixtures ("calibration curves") and thus approximate number of extrinsic admixtures may be determined. Basing on this result, the conclusion about applicability of the considered subset may be derived. High percentage of extrinsic admixtures means strong effect of falsification of dose records and, therefore, makes use of whole data array problematic.

Results of testing of this distribution using this approach are presented at Fig.4. At the figure, the curve of entropy coefficient as a function of histogram increment is presented. Curves corresponding to given percentages of admixtures are also plotted for calibration purposes. As may be seen from the figure, experimental curve lays between bands corresponding to 5 and 10% of extraneous admixtures. Thus, possible percentage of "narrow" admixtures in case of military liquidators does not exceed 10% of total dose records. This positive conclusion supports the use of official dose records of "partisans" as a source of non-biased dosimetric information. In principle, such procedures should be applied to other groups of liquidators as well, leading , thus to judgement regarding trustworthiness of existing data on individual exposures of Chernobyl clean-up workers.

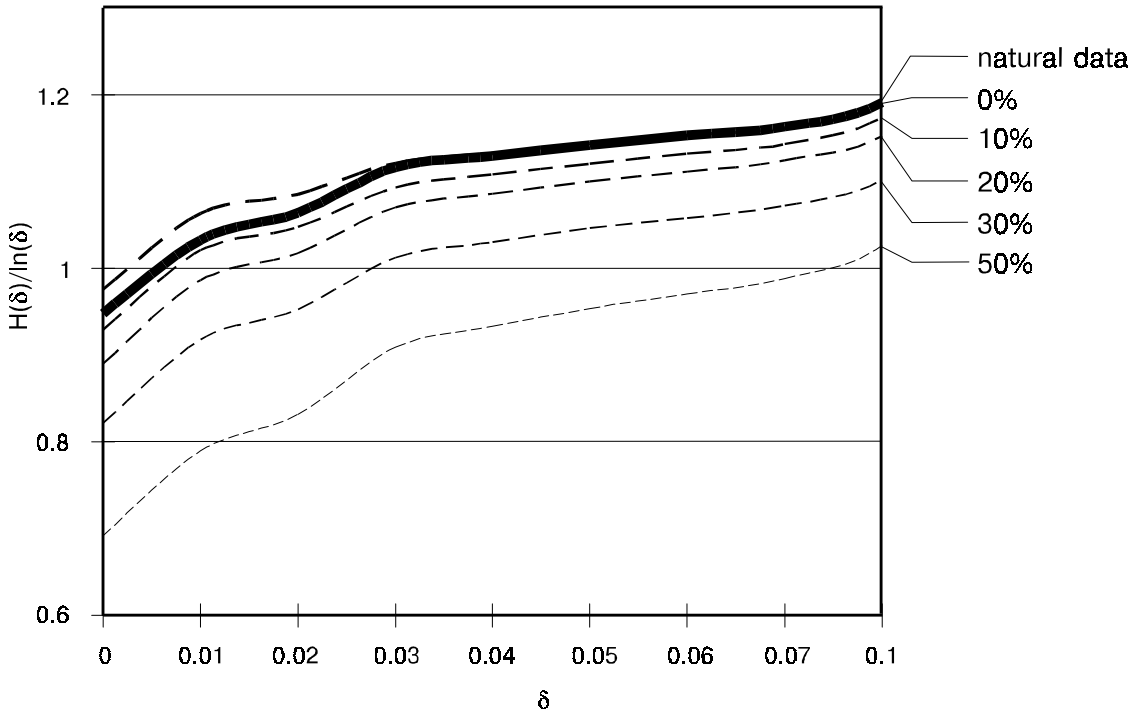

Figure 4. Experimental dependence of entropy coefficient on increment of histogram δ (solid line) and modeled dependencies corresponding to different percentage of extraneous admixture.

STUDY OF DOSIMETRIC MONITORING PRACTICES AT TIME OF CLEAN-UP

Dosimetric monitoring of hundreds thousands clean-up workers was undertaken by a number (at least four) of bodies and facilities. Clearly, the methods of dosimetry vary, depending both on the affiliation of liquidators and the period after the accident. Hence, if professional atomic workers like personnel of Chernobyl NPP or the stuff of the Administration of Construction (AC) No.605 had instrumental dosimetry with TLD or alumophosphate glass dosimeters, many thousands of military clean-up workers were roughly monitored using "group" (when only one of several dozens workers wore dosimeter, extending measured dose to the whole group of liquidators) or "group-commitment" methods. According to the latter approach, doses were evaluated by dosimetrist with respect to the dose rate at working place and period of work; such single dose assessment was assigned to the whole group of liquidators performing similar task. Obviously, the degree of precision of dose estimates obtained by different methods vary a lot. Uncertainty of dosimetry with personal TLD dosimeters does not exceed 30-40%, while "group-commitment" method may easily under- or overestimate actual doses three-fold (Pitkevich et al, 1995).

Unfortunately, the references to the methods of dose assessment are not indicated in official dose records. Furthermore, the largest liquidator-related data array – the State Chernobyl Registry of Ukraine, does not contain even indirect keys (like affiliation or type of work) to the evaluation of particular methods of dosimetry and their uncertainties.

Therefore, recovery of dosimetric monitoring practice individually to all registered liquidators is quite topical task. In order to reveal this essential information, a simplified five-entry dosimetric mini-questionnaire, dealing with their affiliation at the time of clean-up, dosimetric methods used, workplace locations and tasks executed in Chernobyl, was developed and used for postal survey of the liquidators. The question reflecting dosimetric monitoring at time of clean-up envisaged six possible responses regarding the way the doses were assessed ("personal dosimeter", "one dosimeter per group", "group-commitment", "retrospectively calculated with "time-and-motion" method", "self estimate" and "do not know") as well as the value of recorded dose.

The subjects of postal survey were selected among those liquidators who are registered in the State Chernobyl Registry and do have official dose records. The mini-questionnaire format is presented at Fig.5. Questionnaire form was printed on the reverse side of self-addressed prepaid postal card. Liquidators were asked to carefully read filling instructions, check appropriate answers and put a mini-questionnaire to a mailbox.

Figure 5. Original dosimetric mini-questionnaire form used for postal survey of liquidators (in Russian).

A total of 13,820 questionnaires were sent to liquidators, residing in the five oblasts (regions) of Ukraine (to 100% of the liquidators with known home addresses in Dnipropetrovsk and Zaporizha oblasts and to 38 to 42% of those liquidators in three other oblasts). In return, 4,634 completed questionnaires were received (34% response rate). In this way, information about affiliation, tasks, dosimetric practice and location of work was obtained for 7% of the liquidators with individual dose record in the SCR. Results of this survey are quite instructive. It shows that 86% of the liquidators in the sampled oblasts belong to the category of "partisans" (military reservists) and that the percentage of professional atomic workers with presumably good quality dosimetry is very low (less than 3%).

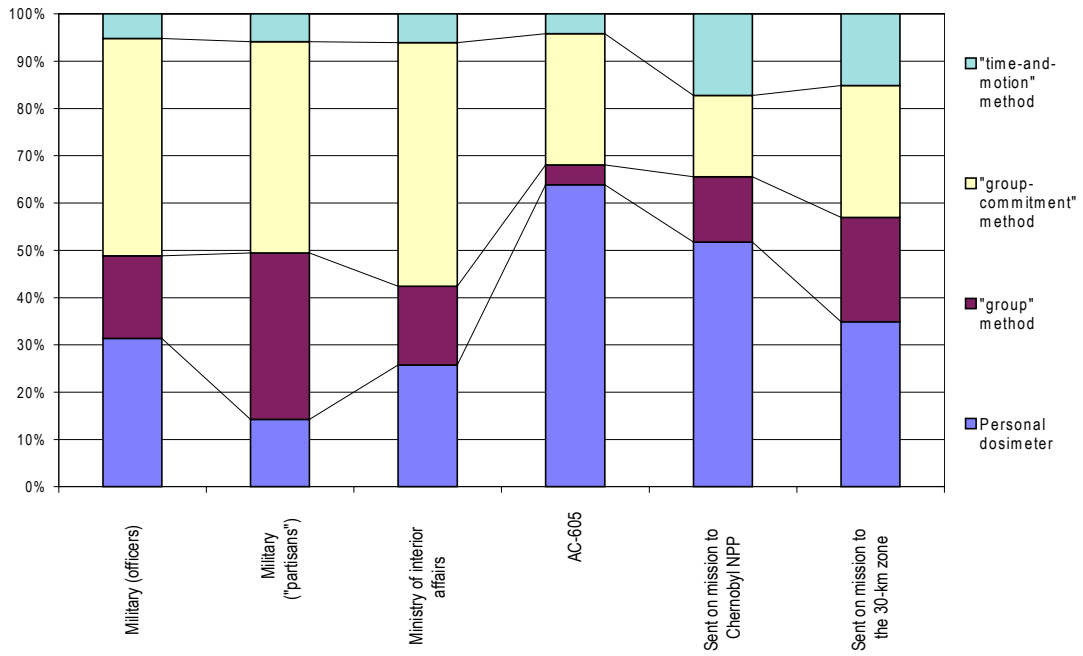

Figure 6. Dosimetric methods used for monitoring of different groups of liquidators – results of postal survey (see the main text for explanation of methods).

The results of the study of monitoring methods are quite informative. The pattern of dosimetric methods used for monitoring of clean-up workers is presented at Fig.6. The highest coverage by instrumental monitoring

was found for the staff of AC-605 (i.e. professional atomic workers). It was determined that for military ("partisans") in many cases (>90%) dose records were assigned by group method (one dosimeter for a group of liquidators) and group commitment (calculation in advance) methods. Personal dosimetry was applied only in less than 9% cases. The information acquired in course of this survey made possible stratification of the liquidator population according to dosimetric monitoring practice, tasks and places of work at time of clean-up. This data will make use for retrospective evaluation of uncertainties associated with individual dose records.

INCORPORATION OF THE RESULTS OF INSTRUMENTAL DOSIMETRIC MONITORING TO THE STATE CHERNOBYL REGISTRY

Another essential data entry is represented by the databases of various dosimetric monitoring facilities. These databases contain dosimetric record of known origin and quality and are very attractive as a source of good quality information for completing the State Chernobyl Registry. However, the problem is that after the accident all dosimetric data related to the facilities of All-Union bodies (Ministries, State Committees, etc.) were transferred to Moscow. Then, after the decay of the Soviet Union, a vast amount of information happened to stay in Russia; only limited databases related to dosimetric monitoring at local facilities remained in Ukraine.

To resolve this problem, the inventory of existing databases with dose records for civilian liquidators was conducted in the Institute of Biophysics, Moscow under contract with the National Cancer Institute. The effort was restricted to the search for computer databases with dose records derived from personal monitoring (so called "instrumental dose records"), which are considered to be the most reliable. These data were transferred to SCRM for use in the framework of the Ukrainian-American Leukemia project. Upon transfer to Kiev, a vast amount of work was invested into the verification of the database records and into their linkage with the SCR.

Table 2 contains a summary of the contents of the databases that were obtained. As may be seen from the table, the databases containing results of instrumental dosimetric monitoring often are lacking complete identifiers (i.e. full name, complete address, passport number) necessary for identification of subject and record linkage with SCR.

Table 2. Characteristics of the considered instrumental dosimetric databases for civilian liquidators[a].

Name of database	Number of records	Identifiers								Dosimetric data				
		Sur-name	First name	Patro-nymic name	Ini-tials	Year of birth	Date Of Birth	Pass-port Num-ber	Postal Addr.	Number of records with dose>0	Number of unique records with dose>0	Period of work	Period of dose availa-bility	Organi-zation
CNII	32328	+	+	+	-	13%	-	-	-	19474	18699	52%	86-90	21%
Person1	66470	+	-	-	+	71%	-	+	-	66470	57524	+	86,87	+
PBK2	16416	+	1%	1%	+	0.5%	1%	-	-	16416	14608	-	86,87	+
IDK	51323	+	-	-	+	+	-	42%	-	23382	23249	+	86,87	+
PERSON	39464	+	+	+	-	-	+	47%	+	13619	13584	-	86,87	+
UVOL	57842	+	-	-	+	+	-	22%	-	41780	40730	64%	86,87	+

[a]In this Table, "+" indicates that data are available for all liquidators; "-" indicates that data are not available for any liquidator; percentages are given when data are available for a fraction of liquidators.

As at the time of recording nobody cared of future use of this data for the needs of epidemiological study, all databases had extremely variable quality from one liquidator to another. The most typical drawbacks of the original data were blank fields of dose and incomplete sets of identifiers. Only a small fraction of liquidators had unique identifiers (like passport number); in many cases, only surnames were available, and initials for the patronymic and first names.

Therefore, work for refinement of data was needed, having a final goal of standardization of information and linkage with SCR database. This work included several of the following steps. At first, the identifiers (i.e. fields which could be used for identification of the liquidators with significant degree of reliability) were selected. They were full name and year of birth. After that, selected identifiers were transformed to unified format. Only unique records of databases (i.e. records that differed in at list one of identifiers) were used for the linkage.

As a result, 17,754 persons with dose records were found to possess all identifiers (full name, year of birth). These dose records were good for confident linkage. In all cases, the dose records were available for 1986 and 1987. Additionally, 85,102 records possessing initials instead of full names were selected for conditional linkage.

Eventually, this effort contributed 8,396 dose records related to the results of individual dosimetric monitoring for 1986-1987 clean-up workers who currently reside in Ukraine. However, only 1,893 records (out

of 17,754) were linked with certainty with the SCR, adding 1,613 new data entries, previously missing in the Registry. In addition, 16,097 records (out of 85,102 possessing initials instead of full names) were linked conditionally and require further verification.

CONCLUSIONS

It was demonstrated that that official dose records of one of the most numerous, yet problematic group of liquidators - military liquidators ("partisans") do not reveal an evidence of massive falsification or intentional distortion of the results of dosimetric monitoring. The following facts argue in favor of this conclusion: daily doses of military liquidators are distributed according to hybrid-log-normal law; parameters of the distributions are consistent with *a priori* and empirical considerations; testing of behavior of entropy coefficient of these distributions also had revealed relatively low contribution of extrinsic (administratively introduced) admixtures. However, this conclusion does not mean high accuracy of dose records themselves – "dose commitment" method used for dosimetric support of these activities by its nature is very inaccurate and the errors endowing this data are quite large.

Extension of such analysis to other groups of liquidators require acquisition of additional information (e.g. on dosimetric monitoring practices) needed for appropriate categorization of liquidator population. This task is being approached by a wide scale postal survey of liquidators. First results of this work are presented in respective section of this paper; this work is being continued now having the aim of coverage of a representative sample of liquidators with the information on affiliations at time of clean-up, dosimetric practices and types of work.

Since uncertainty of recorded doses depends on the method of dose evaluation at time of clean up, the acquired information about the dosimetric practices should be used for evaluation of uncertainties associated with individual records. This work, being in progress now, involves both assignment of beforehand known uncertainty intervals to the records yielded by well known methods (like TLD dosimetry) and retrospective evaluation of errors for some less precise methods by applying independent dosimetric methods to the same subjects.

Thus, the present paper has addressed some selected, yet critical points in evaluation of results of dosimetric monitoring in Chernobyl. However, the ultimate answer to the question about quality and accuracy of individual dose records may be received only after validation of dose records by means of independent dosimetric techniques, in particular -retrospective.

The discussed work, done on a retrospective basis, allows verification of a good deal of dosimetric information and make sensible use of many thousands of individual doses records of the Chernobyl clean-up workers.

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