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Notes about the Chernobyl liquidators

1. Introduction and terminology

The explosion occurred on 26 April 1996 at block 4 of the Chernobyl Nuclear Power Plant was classified by Soviet authorities initially as an incident (Ilyin, 1995). Officials believed that the situation was manageable and that consequences of the Chernobyl accident could be eliminated in short time. This was a reason why people who were engaged in clean up operations named as “liquidators” (Il'in *et al*., 1995). The word "liquidator" is derived from the Russian verb, which means "to eliminate” or narrowly “to eliminate consequences of an accident". It became clear very soon after the explosion that the Chernobyl accident was the major breakdown in the history of atomic energy use and its consequences could not be “eliminated” but only “reduced”. Nevertheless the word “liquidator” was in common use already and a decision was made do not change it (Il'in *et al*., 1995).

Chernobyl research very soon became a fast growing international industry. The second reason for the popularity of the word “liquidator” is the existence of the same word in English. It has a completely different meaning: “a person who liquidates assets” or “an official appointed by court of low to direct the liquidation of business”[1]. As it was stated above, in Russian it has an additional meaning of an accident rescuer. We can classify the word “liquidator” as a neologism when a known English word is used in a meaning, which came from the Russian language.

It is looks like liquidator is the most popular name for the clean-up workers of the Chernobyl accident in scientific literature. Nevertheless, there are a few synonyms for this word: “emergency workers” (Ivanov *et al*., 1997a), “Chernobyl emergency accident workers” (Svirnovski *et al*., 1994), “mitigation workers”, “clean-up workers” (Granath *et al*., 1996; Lazutka, 1996), “accident recovery workers” (Souchkevitch, 1996), “salvage personal” (Emerit *et al*., 1995) or “salvage workers” (Zabludovsky *et al*., 1996), “rescuers of consequences” of the Chernobyl accident (Novikov *et al*., 1996), “decontamination workers” (Snigireva *et al*., 1994) and “ameliorators” of the Chernobyl accident (Sevan'kaev *et al*., 1994)

2. Number of the Chernobyl liquidators

The Chernobyl liquidators story is complex. Even the number of them has not yet been established. Ilyin in his book gives the most realistic estimation of 300,000 - 320,000 persons (Ilyin, 1995). Surprisingly that very competent and professional report from OECD Nuclear Energy Agency gives the figure of “up to 800,000” (Chernobyl..., 1995). The international conference in Vienna carefully distinguished that “about 200,000 'liquidators' worked in the region of Chernobyl during the period 1986-1987 … among some 600,000 to 800,000 persons who were registered as involved in activities relating to alleviating the consequences of the accident” (One..., 1996). According to the main, parental All-Union (later State) Distribution Register (USSR, 1986-1989) the number of liquidators is 293,100 (Ilyin, 1995). The latest (on 1 January 1996) published data form the Russian National Medical Dosimetric Registry (Ivanov

[1] Webster’s dictionary

et al., 1997a) gives number of 168,000 liquidators in Russia which with 123,536 liquidators 1986-1987 years from Ukraine (Liktarev and Chumak, 1996) and 63,500 liquidators from Belorus (Ilyin, 1995) give number around 355,000. The First International Conference of the European Commission, Belarus, the Russian Federation and Ukraine on the Consequences of the Chernobyl Accident in Minsk gives a similar figure to the Vienna conference assessment - about 600,000 people (Radiological..., 1996). Papers from scientific journals give also a wide range in order 200,000 - 600,000 liquidators of 1988-1997 years (Vorobtsova *et al*., 1994; Jensen *et al*., 1995).

The main reasons of such differences in figures are:

- direct mistakes in estimation. Ilyin in his book (Ilyin, 1995) names it as "a manifest error" due to "reporters' negligence, terminological inaccuracies and incorrect translation". He calculated that the common figure of 600,000 liquidators could originate from a incorrect summing of liquidators who were working in the 30 km zone with people evacuated from the 30 km zone.
- low attention to the study design and the use of different definitions of liquidators for the cohort formation
- politics concerning the Chernobyl liquidators varies in different states of the former Soviet Union
- the attractive social status of the Chernobyl liquidators could affect figures. There is trend of increasing the number of liquidators even 10 years after the accident (compare (Tsyb *et al*., 1989; Tsyb *et al*., 1991; Tsyb and Ivanov, 1997; Ivanov *et al*., 1997a)

Because of the uncertainties stated above we after Ilyin (Ilyin, 1995) assume "for the purpose of subsequent analysis…(since we have no other alternative) that the total number of decontamination workers who were in the 30 km zone in 1986-1989 constituted about 300,000".

3. Definition of a liquidator and liquidator's documents

Now I would like to discuss briefly the liquidator's definitions. Who are liquidators? It is quite a difficult question because we should distinguish at least three different sets of definitions:

1. The legal definitions of liquidator are according to USSR and current Russian, Ukrainian, Belarusian and other countries legislation, which used to be part of USSR. The great importance of these legal definitions is that all state Chernobyl registers are formed according to them. The legal liquidator status is essential for receiving pensions and other compensation. This could be a reason why some people who never have been at Chernobyl have a Chernobyl liquidator status.
2. Definitions from various officials reports ((Chernobyl..., 1995), for instance) or international medical and radiological organisation like WHO or IAEA.
3. Definitions which have been published in scientific papers and special books, for example by Prof.Ilyin (Ilyin, 1995).

There are a few different legal definitions of Chernobyl liquidators due to legal changes in independent states after the dissolution of the Soviet Union.

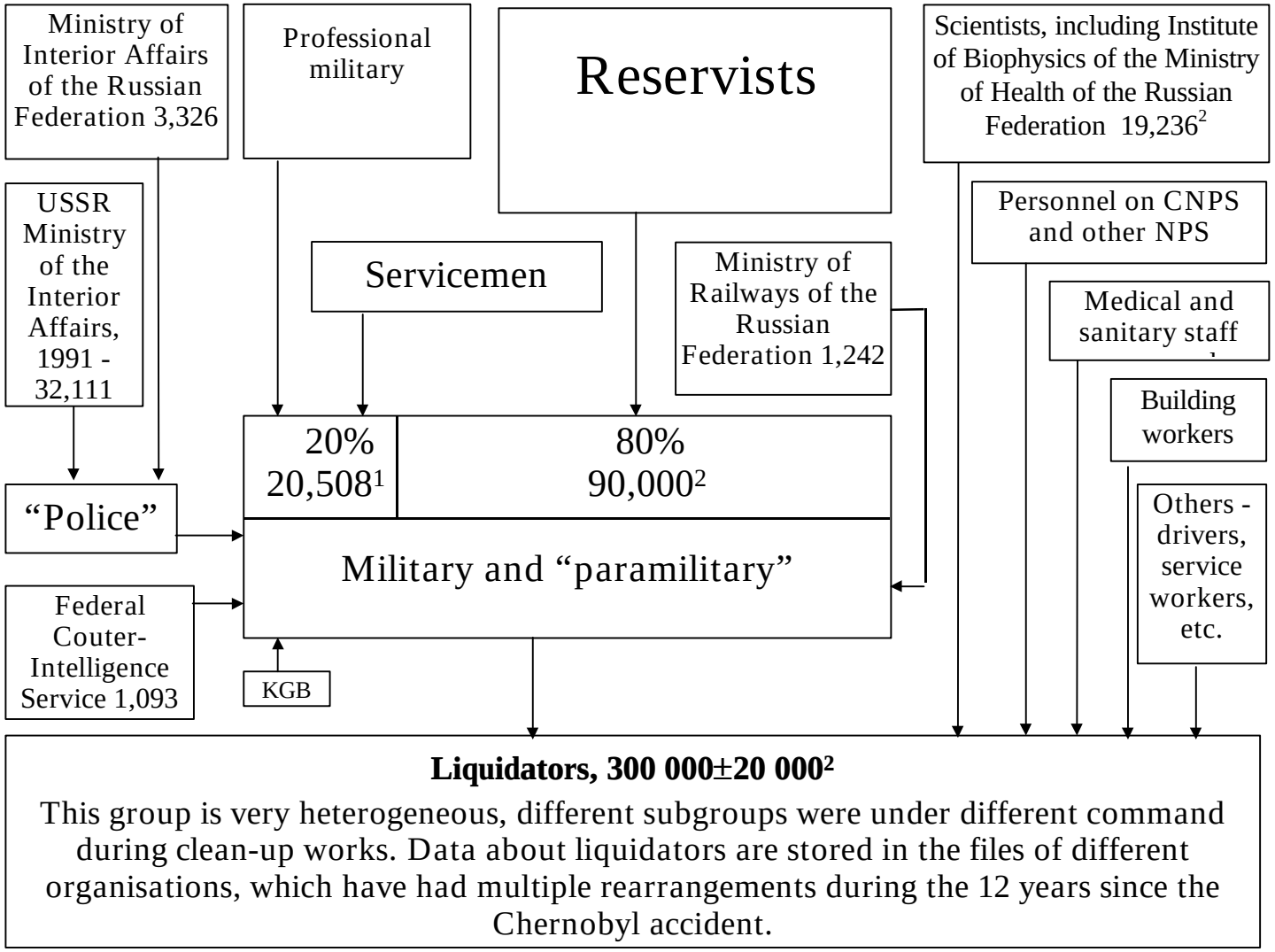
- If a liquidator currently is a Russian citizen then his status should be regulated by the Russian sets of the legal acts, which essentially constituted the Soviet Union legalisation. In this case this person should have a special liquidator document (certificate) and a badge as described in "The legal definition of a Chernobyl liquidator" paper[2].
- If a liquidator is a Belorusian citizen then his status should be defined by the Belarusian legalisation. Unfortunately little is known about current Chernobyl legalisation in Belarus. Nevertheless, an old USSR's Chernobyl liquidator certificate is currently in use in Belarus. The problem here is that this document could be issued after 1991 (year of the Soviet Union dissolution) by some Belorusian authority according to its own regulations.
- If a liquidator is a Ukrainian citizen, he should have a new Ukrainian certificate, established by the Ukrainian government in 1991-1992. There are a few different certificates depending on the time spent in Chernobyl and year of work. According to Romanenko (personal communication, 1998) in Ukraine are now about 250,000 liquidators certificate holders. It is definitely an overestimation. According to Prof.Ilyin (Ilyin, 1995) in 1991 there were about 100,000 Ukrainian liquidators. Currently the Chernobyl liquidator's status is being reconfirmed in Ukraine.
- Little is known about Chernobyl legalisation in other republics, but all of them should be based on old USSR legal acts. There are exceptions in the Baltic states which have their own legal acts about the Chernobyl victims.

Another important document which a liquidator could have is a "military book" with a special addition where the time of his stay in Chernobyl and "physical" ("documented") doses are noted. A liquidator should definitely have this if he was contracted for work in Chernobyl through the system of military conscription. A very sufficient number of liquidators was comprised of military reservists i.e. ordinary civilians, conscripted for "military training exercises" (see **Figure 1)**

To complete this part, a simple work definition from Prof.Ilyin's book could be recommended, where liquidators aredefined as "decontamination workers who were in the 30 km zone[3] in 1986-89" (Ilyin, 1995).

[2] http://www.graylab.ac.uk/usr/belyakov/lhp/russian.html
[3] Please, see explanation of this term in paper "The legal definition of a Chernobyl liquidator" at http://www.graylab.ac.uk/usr/belyakov/lhp/russian.html

Figure 1 The Origin of liquidators, an attempt of organisational structure-task oriented classification, composed from various sources.



[1] Data from Ministry of Defence of the Russian Federation
[2] 1986 [Iliyn, 1995]

4. Doses

4.1. Physical dosimetry and "documented" doses[4]

What where the doses received by the Chernobyl liquidators? There are a few sources of information concerning this matter

- physical dosimetry and official documented doses which are kept by registries.
- retrospective biodosimetry
- retrospective computational dosimetry (very little)

I would like to note that in most cases "documented" doses are not results of "physical" dosimetry. Pitkevich (Pitkevitch *et al.*, 1997) distinguishes three main sources of these "documented" doses:

- dose recorded by an individual dosimeter (the maximum error is about 50%). Only 2-3% of liquidators had a dosimeter during all time of their work (Salassidis *et al.*, 1994; Ilyin, 1995; Salassidis *et al.*, 1995)
- "group" dose assigned to the members of a group performing an operation in the zone, based on the readings of an individual dosimeter held by one member of the group: the dose uncertainty in the group can be as high as 300%. The majority of liquidators' dosimetric data comes from this source.
- "Marching route" dose estimated from a dose rate in the zone and the duration of stay of the group there: the dose uncertainty in the group can be as high as 500%. A real, precise retrospective computational dosimetry estimation is very difficult and expensive. As far as I know, it was done only for a small group of "early" liquidators (Kruchkov and Nosovsky, 1996)

4.2. Retrospective biodosimetry

Enormous efforts have been spent during the last few years for verification of the documented doses by complicated methods of biodosimetry. Results till now have been discouraging. There was found a significant difference in dose distribution from documented sources versus biodosimetry, see for example **Table 1**[5] (Moore *et al.*, 1997)**.** Multiple end-point assessment of the effects of exposure on the liquidators was performed using stable chromosome aberration analysis (FISH), a Glycophorin A test (GPA) and a HPRT mutation test in a collaboration study between LLNL, Moscow and St.Petersburg scientists. The major findings were: the correlation between the end points of the bioassays and documented doses was low and non-significant (see **Figure 2**), no correlation was found between the different methods of biodosimetry. As you can see, the shape of biodosimetry distribution is much different from that obtained using estimated doses from the liquidators dosimetry cards. There are some differences in mean figures as well, the mean population exposure based on cytogenetic analysis is 9 cGy, while the mean based on the estimated doses is 25 cGy (range from 2 cGy to 2.7 Gy). And finally, authors are more inclined to believe the results of the biodosimetry since detailed information on the source of the estimated doses is not available.

[4] "Doses" in this text mean accumulated total body external absorbed doses and measured in Gy
[5] All tables are attached at the end of the paper.

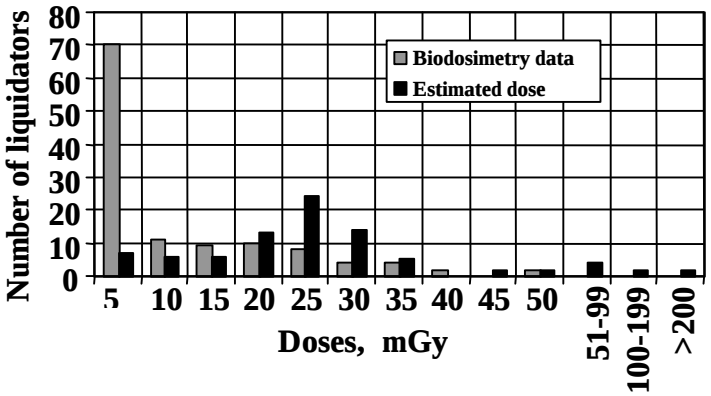


Figure 2 Distribution of exposure of liquidators to ionizing radiation (Moore *et al.*, 1997)

All published data concerning doses in the Chernobyl liquidators are accumulated in 3 tables: comparison of documented dosimetry data from the Russian National Medical and Dosimetric Registry and results of biodosimetry for liquidators of 1986-1987 (**Table 2**), 1988-1989 (**Table 3**) and for 1986-1989 (**Table 4**). Data from the Russian National Medical and Dosimetric Registry, the best source of "documented" dosimetric data for the liquidators, are dark highlighted and the most important data of retrospective biodosimetry is light highlighted. These tables represent all we know about physical and retrospective biological dosimetry in the Chernobyl liquidators. RNMDR data is based on the following publications: (Ivanov and Tsyb, 1996a; Ivanov and Tsyb, 1996b; Pitkevitch *et al.*, 1997). Other data is from the papers: (Sevan'kaev *et al.*, 1995; Bigbee *et al.*, 1996; Granath *et al.*, 1996; Schevchenko *et al.*, 1996; Snigiryova *et al.*, 1997).

Documented physical doses and biodosimetry data are generally consistent at a level of about 0.1-0.2 Gy for the whole group. Also we can see that the most affected group is the liquidators of 1986-1987.

Nevertheless, while average doses for the whole liquidators group is low, there are definitely overexposed groups. These groups are: early liquidators, subgroups of liquidators who were working in close vicinity to the destroyed reactor, people who were cleaning the roof of unit III after the explosion, helicopter crews and others. A very interesting group of overexposed people is "sarcophagus workers" (not to be confused with "Sarcophagus builders", people who actually build the Sarcophagus[6]). Sarcophagus workers is a group of 15 scientists (dosimetric data available only for 5 of them) from the Kurchatov Atomic Energy Institute, Moscow, who are monitored the status of sarcophagus in 1986-1995. The results of physical and retrospective biodosimetry for some of them can be found in **Table 5**.

The mean "documented" ("physical") dose for liquidators as whole group is 10.8 cGy according to RNMDR, the biggest registry. Data from retrospective biodosimetry and retrospective computational dosimetry for various subgroups of the Chernobyl liquidators show a wide spectrum of accumulated doses from a few up to 30 cGy, sometimes more that 1 Gy. Documented and biodosimetry doses do not always fit each other and sometimes contradict as in absolute values or character of distribution. Group overage doses look quite meaningless because of the presence of overexposed subgroups, members of which could receive up to 1 Gy and more of total body irradiation. According to Prof.Ilyin's computation, about 7% of the liquidators received doses of more than 0.25 Gy (Il'in *et al.*, 1995). Most of them were "early" liquidators (people who were on site during the explosion) and liquidators of 1986-1987.

[6] The Sarcophagus is the protective structure covering destroyed Reactor No. 4

5. Health effects in liquidators

A large number of papers concerning the health effects in liquidators have been published in various scientific journals. Unfortunately, published data is often contradictory and requires careful evaluation.

5.1. Cancer

There are a few papers published regarding this matter. The main two sources are two large scale investigations:

- liquidators-related investigations of the Russian National Medical and Dosimetric Registry (RNMDR) (Ivanov and Tsyb, 1996a; Ivanov and Tsyb, 1996b; Ivanov *et al*., 1997a; Ivanov *et al*., 1997b; Ivanov *et al*., 1998). This is the biggest project concerning liquidators (the latest published numbers of liquidators in the registry is 168,000). The main problem with this data is its low attention to cohort forming (this registry consisted of all people who were counted as liquidators officially) and very poor dosimetric data based on "documented" doses. The second problem is that this registry is constructed as a "distribution" registry. It means that they do not handle primary medical information but receive it in form of statistical figures from health authorities of different levels.
- The Estonian Chernobyl liquidators study (Bigbee *et al*., 1996; Granath *et al*., 1996; Bigbee *et al*., 1997; Inskip *et al*., 1997; Rahu *et al*., 1997; Tekkel *et al*., 1997; Vanchieri, 1997) launched by Estonian, European and American scientists in 1992. This is a very well constructed medico-epidemiological study. Contributors paid great attention to cohort forming, dosimetric data, retrospective biodosimetry and medical examinations of the patients. The sufficient disadvantage of this study is the small size of its cohort - 4,833 people.

Interesting, that these two investigations contradict each other in all points concerning cancer morbidity. Only in the case of cancer mortality the both studies show no increase between liquidators in comparison with the general population. For example, Ivanov and Tsyb (Ivanov and Tsyb, 1996a) showed that cancer mortality occurred even less in liquidators than in the general population (see **Figure 3**).

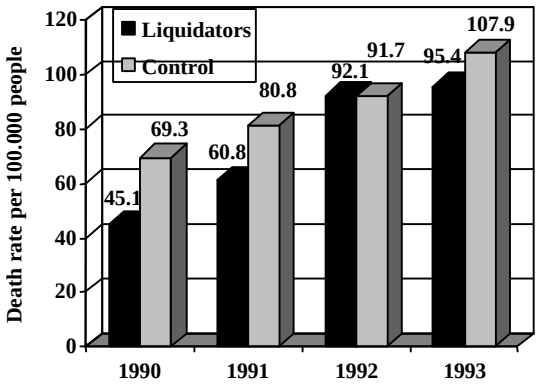


Figure 3 Death rate of liquidators from cancer in 1990-1993, RNMDR (Ivanov and Tsyb, 1996a)

5.1.1.Leukaemia

Until recently, RNMDR did not report the increased level of leukaemia morbidity between liquidators in English-language papers. One of the most recent papers (Ivanov *et al.*, 1997a) showed that there are higher levels leukaemia than were expected (the author prefer to tell "anticipated"[7]). 48 leukaemia cases were diagnosed and verified within a cohort of 114,504 Chernobyl liquidators. An excess relative risk per Gy (ERR/Gy) of 4.30 (95% CI: 0.83, 7.75) is obtained, while the excess absolute risk per 10(4) person-years (PY) Gy (EAR/10(4)PY Gy) is found to be 1.31 (95% CI: 0.23, 2.39). See **Figure 4** from this paper. Authors conclude that every second case of leukaemia could be radiation induced.

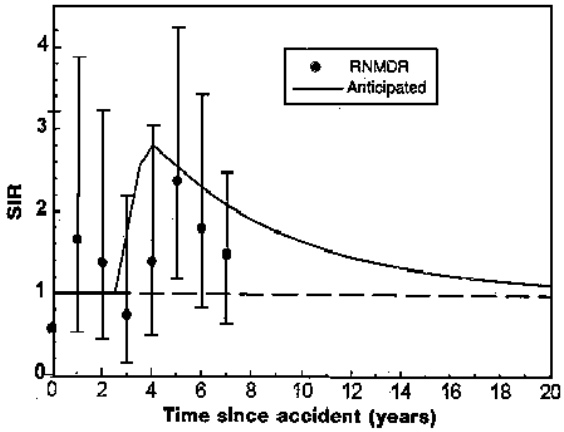


Figure 4 Anticipated (*solid line*) and observed (*dots*) SIR of leukaemia in liquidators. Bars represent 95% confidence intervals (Ivanov *et al.*, 1997a)

No increases were found in leukaemia (no cases observed, 1.0 expected) in the Estonian liquidators study (Rahu *et al.*, 1997). Also no increase in leukaemia between liquidators reported by Israeli group (Kordysh *et al.*, 1995; Cwikel *et al.*, 1997; Goldsmith and Quastel, 1997; Quastel *et al.*, 1997).

5.1.2. Thyroid cancer

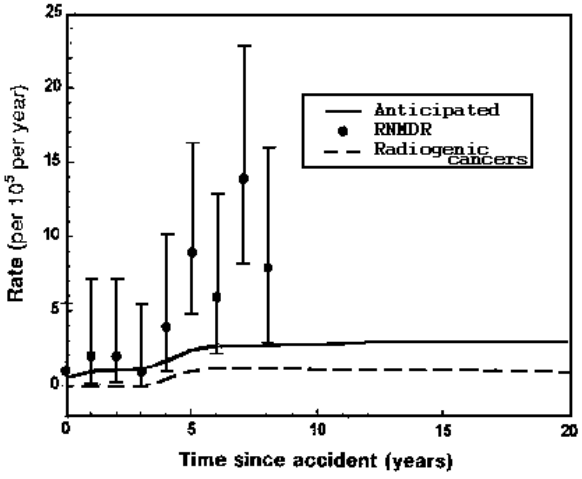


Figure 5 Anticipated (*solid line*) and observed (*dots*) thyroid cancer incidence rate among liquidators as a function of time since the accident (Ivanov *et al.*, 1997a)

Again, in a recent paper from RNMDR (Ivanov *et al.*, 1997a) and in a separate paper, dealing only with thyroid cancer (Ivanov *et al.*, 1997b) we can learn there was a greater level of thyroid morbidity among liquidators than was expected (47 thyroid cancer cases were diagnosed and verified within a cohort of 114,504 Chernobyl liquidators). The tendency here is more pronounced than in the case of leukaemia: an excess relative risk per Gy (ERR/Gy) ERR/Gy of 5.31 (95% CI: 0.04, 10.58) is obtained, and an EAR/10(4)PY Gy of 1.15 (95% CI: 0.08, 2.22). See **Figure 5** from this paper.

[7] The "Anticipared SIR (standardised incidence ratio)" authors state as "the number of leukaemias of all types, i.e. expected spontaneous number plus the cases that would be inferred from the dosimetric information and current risk estimates, was calculated by a multiplicative model with coefficient derived from the Japanese cohort of atomic bomb survivors. The term anticipated is used here to avoid confusion with expected, which in most epidemiological studies refers to the spontaneous cases , i.e. the baseline incidence only".

No similar increase reported by other groups. During a special subproject (Inskip *et al*., 1997) studying Estonian liquidators 1,984 men were examined for thyroid cancer. All liquidators worked in Chernobyl in 1986 for about 3 months, mean age at the time of arrival at Chernobyl was about 32 years. The mean documented dose was 10.8 cGy. It makes this Estonian cohort highly comparable to the RNMDR one. It was showed that there are no significant increase of rate thyroid nodularity and cancer or any significant association with documented doses and the results of retrospective biodosimetry. As possible reasons, author considered low radiation doses, the protracted nature of the exposure, errors in dose measurement, low sensitivity of the adult thyroid gland and insufficient passage of time for a radiation effect to be expressed

5.1.3.Solid tumours

There was not evidence of increase in solid tumour morbidity between liquidators published before paper from RNMDR (Ivanov *et al*., 1998). This paper presents results for 114,504 liquidators. The average documented dose was 10.8 cGy and the average age in 1986 was 34.3 years. The cancer incidence in liquidators was compared to average figures for the population of Russia and the standardised incidence ratio (SIR) has been calculated. The values of SIR with 95% confidence intervals for all solid tumours and malignant neoplasm of the digestive system were 1.23 (1.15; 1.31) and 1.11 (1.01; 1.24). A statistically significant increase in cancer incidence correlated with external radiation dose was found.

In the Estonian Chernobyl Liquidators Study (Rahu *et al*., 1997) no increases were found in all cancers (25 incident cases compared to 26.5 expected) between 4,742 liquidators. Authors concluded that exposure to ionizing radiation while at Chernobyl has not caused a detectable increase in the incidence of cancer among the Estonian liquidators.

5.2.General classes of diseases

Data of the RNMDR (Ivanov and Tsyb, 1996a; Ivanov and Tsyb, 1996b) shows an increase in nearly all general classes (with the exception of cancer) of diseases among Russian liquidators in comparison with national overage figures, see **Table 6** for details. Taking into account the small doses received by liquidators, it could be due to psychological stress-related diseases.

Interestingly, findings of similar effects were published in a few papers (Kordysh *et al*., 1995; Goldsmith and Quastel, 1997; Quastel *et al*., 1997) by an Israeli group of scientists. They have found in a small group of the Chernobyl liquidators, immigrants from the former Soviet Union and current residents of Israel, an increase in various symptoms. A typical list of liquidators' disorders is:

- Increased rate of central nervous system disorders
- Increasing rate of respiratory tract disorders
- Decreased white blood cell count
- Increasing rate of nausea
- Increasing rate of cardiovascular system disorders and hypertension disease

These effects could be considered to be a response to strong psychoemotional tension, stress and radiation phobia - only some of the effects may be due to radiation itself.

There are also publications concerning other health effects in the Chernobyl liquidators: rise in pulmonary diseases (Chuchalin *et al*., 1995; Chuchalin *et al*., 1997),

immunological disorders (Baranov *et al*., 1995), reproductive system disorders (Birioukov *et al*., 1993; Zabludovsky *et al*., 1996; Fischbein *et al*., 1997)

5.3. Psychological and psychiatric consequences

The psychological and psychiatric consequences of the Chernobyl accident are recognised as quite important. Many papers about liquidators have noted the possible involvement of strong psycho-emotional tension during clean-up work which could lead to the development of a whole spectrum of diseases. There are a few publications about the psychological testing of people affected by the Chernobyl accident (Darby and Reeves, 1991; Ginzburg, 1993; Filyushkin, 1996; Cwikel , 1997; Cwikel *et al*., 1997; Viel *et al*., 1997) and no special works concerning liquidators. Only a couple papers available in English are on the psychiatric effects in clean-up workers (Havenaar *et al*., 1997; Vyatleva *et al*., 1997).

Sometimes in Russian language papers a diagnoses of "vegeto-vascular dystonia" or "vegetative dystonia syndrome" could be found (Kovalenko *et al*., 1992; Sakhno , 1992; Valutsina *et al*., 1993; Vashchenko , 1993; Kniazeva *et al*., 1996) usually in relation to psychological and psychiatric diseases in Chernobyl patients. It is looks like that this disease does not exist in reality. This diagnose was made if an examined person was in some matter connected to the Chernobyl accident but a doctor failed to find any pathology in him (her) (Wainson 1998, personal communication). This is more a socio-political than a medical phenomena and is related to the mechanism of compensation payment in the former Soviet Union.

5.4. Disability rate and rise of suicides frequency

The increase of in disabilities in the Russian liquidators group has been reported by RNMDR. The disability rates for liquidators as a whole exceeded 2.8-3.2 times the control in Russia (Ivanov and Tsyb, 1996a). See **Table 7** for details. Despite the dose-response manner of this increase, it could be explained mainly by the attractive social status of the "disabled liquidator" and the comprehensive benefits accompanying it.

Another sad consequences in the Chernobyl liquidators has been found during the Estonian Chernobyl Liquidators project (Rahu *et al*., 1997; Tekkel *et al*., 1997; Vanchieri, 1997). The diseases directly attributable to radiation appear to be of relatively minor importance when compared with the substantial excess of deaths due to suicide. A total of 144 deaths were observed in the Estonian liquidators subgroup consisting of 4,742 people. (standardised mortality ratio (SMR) = 0.98, 95% confidence interval (CI) = 0.82-1.14) during an average of 6.5 years of follow-up. Twenty-eight deaths (19.4%) were suicides (SMR = 1.52; 95% CI = 1.01-2.19).

To conclude this part, It should be stressed that, excluding the recent data concerning the rise of cancinogenisis from RNMDR which has yet to be confirmed, an increase of disability among Russian liquidators and anelevated level of suicides in the Estonian group are the *only* observed health effects in the Chernobyl liquidators.

6. Conclusions

The Chernobyl liquidators related research has been conducted during the last 12 years by many groups of scientists. What we know about liquidators eventually?

- Different estimation of liquidator numbers
- Some knowledge about physical "documented" doses and some results of retrospective biodosimetry. Documented physical doses and retrospective biodosimetry data generally are consistent at a level of about 0.1-0.2 Gy for the whole group
- There are overexposed subgroups of liquidators, according to Prof.Ilyin about 7% of the liquidators received doses more than 0.25 Gy
- Contradictory information about health effects
- No evidence of increasing death and cancer rate was found among liquidators, contradictory information about cancer morbidity
- Only some of the other health effects may be due to radiation itself
- Psycho-social consequences play an enormous role in the Chernobyl liquidators

The most characteristic feature of all these investigations is the diversity of opinions concerning practically every point. The liquidators group is very heterogeneous and probably all figures which correspond to this group as whole are meaningless.

Therefore a question should be raised: why we do not see any obvious radiation related health effects in liquidators? A few speculative answers could be made:

- Doses received by liquidators were insignificant
- Protracted irradiation has weaker effect
- Information about doses has been distorted
- Normal population is more resistant to irradiation than was assumed
- Clean-up operations were extremely successful and the protection of liquidators was efficient
- The socio-psychological consequences from clean-up work are greater than the radiological ones
- Direct disinformation in the early stages of clean-up works by the Soviet authorities and socio-political processes of the later Soviet Union dissolution distorted the picture. The effects of the heavily affected subgroup of liquidators were diluted with a large number of none affected people.

Finally, It should be noted that the Chernobyl liquidators is not perfectly healthy group of people. There are really heavily diseased patients. But what makes them ill: radiological consequences or irresponsible state politic and hysteria around the Chernobyl accident?

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Table 1 Multiple end-point assessment of the effects of exposure on the liquidators (Pilinskaya, 1996 ; Lazutka, 1995; Moore, 1997)

Source	Number of people	Year of participation	Results of biodosimetry, Gy			Calibration curve
			Un.Ch.A. (Dic)	St.Ch.A. (FISH)	G-banding	
Moore et al, 1997	126	1986-1989?		0.09		Own, Moore, 1997
Pilinskaya, 1996	125	1986	0.07			Estimated from Bender at al, 1988
Pilinskaya, 1996	10	1986			0.30	
Lazutka, 1995	33	1986-1989?	0.50			

Table 2 Comparison of dosimetry data from the Russian National Medical and Dosimetric Registry and results of biodosimetry: liquidators 1986-1987

Source		Number of people	Mean age, in 1996	Physical dosimetry, Gy	Biodosimetry, Gy	
					Un.Ch.A.[1]	St.Ch.A.[2]
RNMDR[3], 1986 liquidators		46 575	43	0.159		
Snigiryova, Bauchinger et al, 1997; 1986 liquidators		35	41	0.19	0.23	0.19
Granath, Natarajan et al, 1996; 1986 liquidators	Construction of sarcophagus	5				0.07
	Roof or vicinity of reactor, 4-7 month	5				0.31
	Roof or vicinity of reactor, 0-3 month	5				0.27
	10-30 km or beyond 30 km zone	11				0.15
	Pooled data	26				0.19
Schevchenko, Burkart et al, 1996; 1986 liquidators	CAPS staff (1986-1987)	83			0.322	
	Physicians	37			0.150	
	Dosimetrists	23			0.267	
	Drivers	60			0.178	
	Sarcophagus builders	71			0.244	
	Pooled data	274			0.242	
Sevan'kaev, Lloyd et al, 1995; 1986 liquidators		601			0.2	
Sevan'kaev, Lloyd et al, 1995; 1987 liquidators		175			0.15	
Vorobtsova et al, 1994; 1986-1987 liquidators		161			0.2	
RNMDR[3]; 1987 liquidators		48 077	43	0.089		

[1] Unstable chromosome aberration test (Qdr)
[2] Stable chromosome aberration test (FISH)
[3] Russian National Medical and Dosimetric Registry, documented doses

Table 3 Comparison of dosimetry data from the Russian National Medical and Dosimetric Registry and results of biodosimetry: liquidators 1988-1989

Source	Number of people	Mean age, in 1996	Physical dosimetry, Gy	Biodosimetry[1], Gy
RNMDR[2], 1988 liquidators	18 208	43	0.033	
Sevan'kaev, Lloyd et al, 1995; 1988 liquidators	60			0.15
RNMDR[2], 1989 liquidators	5 475	43	0.032	
Sevan'kaev, Lloyd et al, 1995; 1989 liquidators	16			0

[1] Unstable chromosome aberration test (Qdr)
[2] Russian National Medical and Dosimetric Registry, documented doses

Table 4 Comparison of dosimetry data from the Russian National Medical and Dosimetric Registry and results of biodosimetry: liquidators 1986-1989

Source		Number of people	Mean age, in 1996	Physical dosimetry, Gy	Biodosimetry, Gy	
					St.Ch.A.[1]	GPA[2]
RNMDR[3], 1986-1989 liquidators		118 335	43	0.105		
Snigiryova, Bauchinger et al, 1997; 1986-1989 liquidators	Working 1986-1995	17	51		0.39	
	With documented doses	34	45	0.26	0.27	
	Without documented doses	17	45		0.27	
	Pooled data 1986-1995	52	44		0.27	
Bigbee, Tekkel et al, 1996; 1986-1989 liquidators		782				0.04-0.08

[1] Stable chromosome aberration test (FISH)
[2] Glycophorin A somatic cell mutation assay
[3] Russian National Medical and Dosimetric Registry, documented doses

Table 5 Dose estimates of "sarcophagus workers" (Sevan'kaev, 1995)

	Year of birth	Date of start work at Chernobyl	Total physical Dose, Gy[1]	Sampling	Results of retrospective biodosimetry (Gy)	
					Qdr[2]	ESR[3]
1	1958	Sept 1988	11.6	1992	13.1	-
				1993	12.2	-
				1994	12.6	-
2	1947	May 1986	17.1	1992	8.4	9.3
				1994	8.0	-
3	1933	Sept 1986	3.6	1991	4.1	3.7
				Sept 1992	3.3	-
				Oct 1992	6.0	-
				1993	4.7	-
4	1955	Aug 1986	2.0	1991	2.7	-
				1992	5.5	-
5	1956	Sept 1989	1.5	1991	1.0	-
6	1946	Aug 1989	0.9	1991	0.5	-

[1] Estimated with quartz fibre electrometers
[2] Unstable chromosome aberration test
[3] Tooth electron spin resonance retrospective dosimetry

Table 6 A comparison of morbidity rates per 100 000 persons on general classes of diseases for the population of Russia as a whole and liquidators in 1993, RNMDR (Ivanov, 1996)

Classes of diseases	Population of Russia	Liquidators	Ratio observed/expected
Neoplasms	788	747	0.9
Malignant neoplasms	140	233	1.6
Diseases of the endocrine system	327	6 036	18.4
Diseases of blood and blood-forming organs	94	339	3.6
Mental disorders	599	5 743	9.6
Diseases of the circulatory system	1 472	6 306	4.3
Diseases of the digestive system	2 635	9 739	3.7
All classes of diseases	50 785	75 606	1.5

Table 7 Dynamics of disability rates of liquidators per 1 000 persons in dose groups in 1990-1993, RNMDR (Ivanov, 1996)

Year of observation	0-5 cGy	5-20 cGy	over 20 cGy
1990	6.0	10.3	17.2
1991	12.5	21.4	31.1
1992	28.6	50.1	57.6
1993	43.5	74.0	87.4