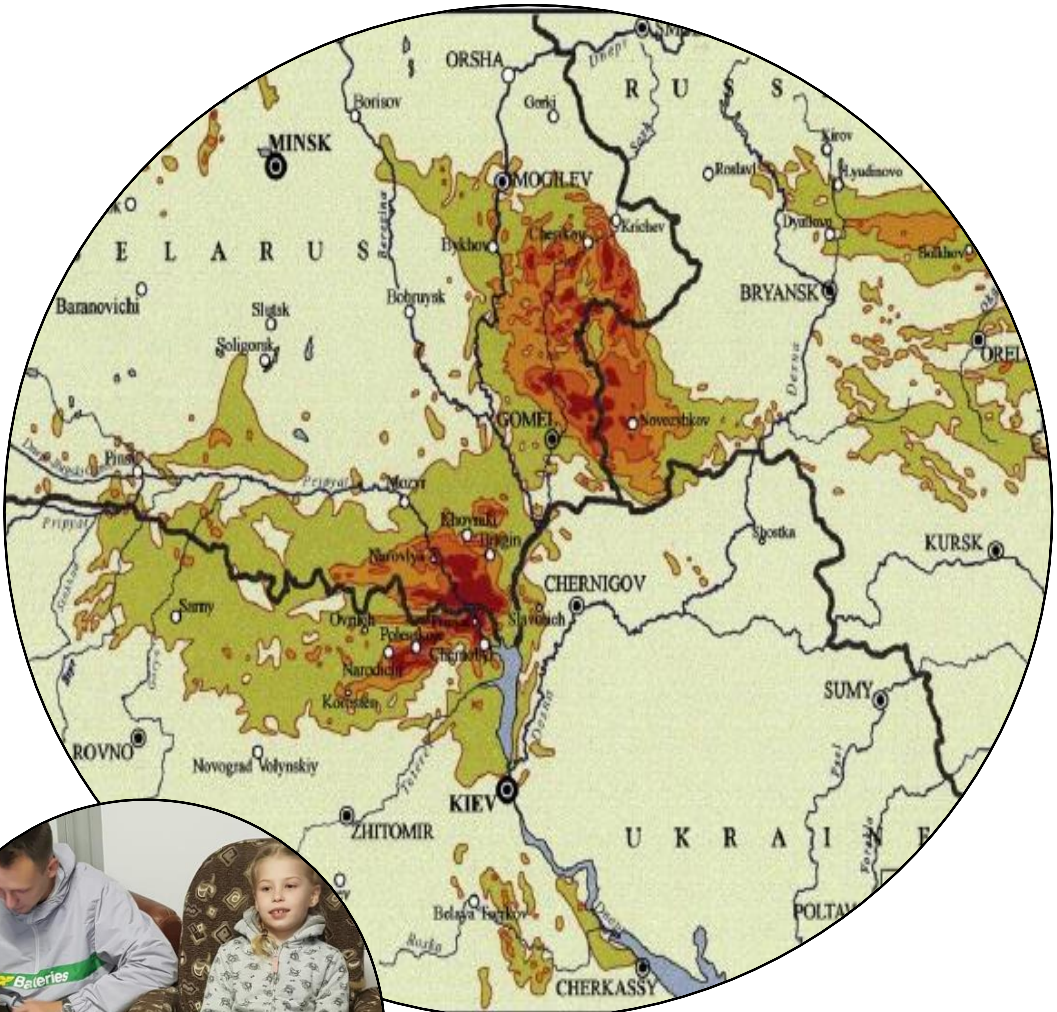


Environmental Sciences bachelor's degree final project

Course 2019-2020

Effects of recuperative holidays on Chernobyl children's ^{137}Cs body burden

Authors:

Irene Alorda Montiel

Jack Turner Cabeza

Tutors:

Jordi Garcia-Orellana

Valentí Rodellas Vila

UAB Universitat Autònoma de Barcelona

Effects of recuperative holidays on Chernobyl children's ^{137}Cs body burden.

Authors:

Irene Alorda Montiel and Jack Turner Cabeza.

Tutors:

Jordi Garcia-Orellana and Valentí Rodellas Vila.

Bellaterra, Barcelona. June 2020.

Universitat Autònoma de Barcelona.

Cover images sources: BELRAD and Saenko et al. (2011).

Recommended citation:

Alorda Montiel, I. and Turner Cabeza, J. (2020). Effects of recuperative holidays on Chernobyl children's ^{137}Cs body burden. Bachelor's degree final project. Universitat Autònoma de Barcelona.

Acknowledgements

This project has been possible thanks to the collaboration of several entities and people. We are especially grateful to our tutors, Jordi Garcia-Orellana and Valentí Rodellas Vila, for giving us the opportunity to choose this study as our bachelor's degree final project, for the support they have brought us during the course, and all the time and effort they have dedicated to this project.

We also want to express our gratitude to all the NGOs that have cooperated with us and given us access to the data during the project's execution, and to the Institute of Radiation Safety-BELRAD for their help.

Finally, we would like to show appreciation to Universitat Autònoma de Barcelona and to the TFG coordinators for allowing us to work on this bachelor's degree final project.

Index

Index of figures and tables

Abstract

The goal of this project is to study the effects recuperative holidays have on the health of children affected by radiation from the Chernobyl nuclear accident. This is accomplished by reviewing data on child ^{137}Cs body burdens, provided by NGOs participating in recuperative holiday programmes in Belarus, and interviews of the same organizations.

A statistical analysis and subsequent modelling of provided data has been conducted, showing consistent reduction in ^{137}Cs body burden during stays away from the contaminated area, and rates of excretion and incorporation. The reduction however is not significant over time, as the original amount of ^{137}Cs in the body is almost re-established within a year following a stay abroad.

The participants improve in social and psychological aspects, and benefit from the establishment of a support network. Therefore, focus from recuperative holiday programmes should prioritize these benefits. Long-term solutions to more permanently reduce body burden should also be developed.

1. Introduction

The Chernobyl accident is the most important nuclear accident in world history, in terms of both social and scientific impact. Since 1986, a great deal of scientific research has been conducted with the purpose of studying the causes and consequences of this nuclear accident. An example of this is the resurgence of radioecological studies after 1986 with the aim of making future predictions on the post-accident situation and creating more knowledge to cope with future nuclear accidents (Beresford et al., 2016). The social influence of the accident at Chernobyl can be perceived in public opinion on nuclear power: the percentage of opponents in most European countries increased significantly after Chernobyl's accident, with the biggest impact found in those countries most affected by radiation the years following the accident (Renn, 1990).

1.1 The accident

On the night of April 26th, 1986, an accident occurred at the Chernobyl nuclear power plant (CNPP), officially named Vladimir Ilyich Lenin Nuclear Power Plant, located in the northern part of Ukraine, less than 15 km away from the frontier with Belarus and less than 150 km from the Russian border. On the morning of the 26th of April, the preparations for a programmed revision for reactor 4 were planned; however, a series of delays and mistaken decisions lead to the two final explosions shortly after 01 h 23 m (Petrangeli, 2006).

Reactor 4 of the plant (Figure 1) was an RBMK class, and these two explosions were caused by an uncontrolled increase in power due to a combination of design flaws and the mistaken decisions already mentioned.

Figure 1: Aerial image of the Chernobyl nuclear power plant after the explotion of Unit 4 (BBC).

The explosion and the subsequent fire produced major release of radionuclides from the reactor that lasted for 10 days (Higley, 2006) and caused radiation exposure to a large amount of population in many European countries around Ukraine. The accident was classified as category 7 (major accident) in the International Nuclear and Radiological Event Scale (INES).

1.2 Radionuclide dispersion

The Chernobyl accident caused a large regional dispersion of radioisotopes. Even though many European countries received radioactive deposition, three former USSR republics, Belarus, Ukraine and Russia were the most affected ones (Higley, 2006). Whilst maps and studies of local deposition have been conducted in Ukrainian territory, Belarus and Russia lack comprehensive local deposition maps. This is somewhat of a paradox, given that 23% of Belarusian territory was polluted whereas Ukraine and Russia had only 4.8% and 0.5% of their territories affected by radionuclide deposition respectively (Alexiévich, 2005).

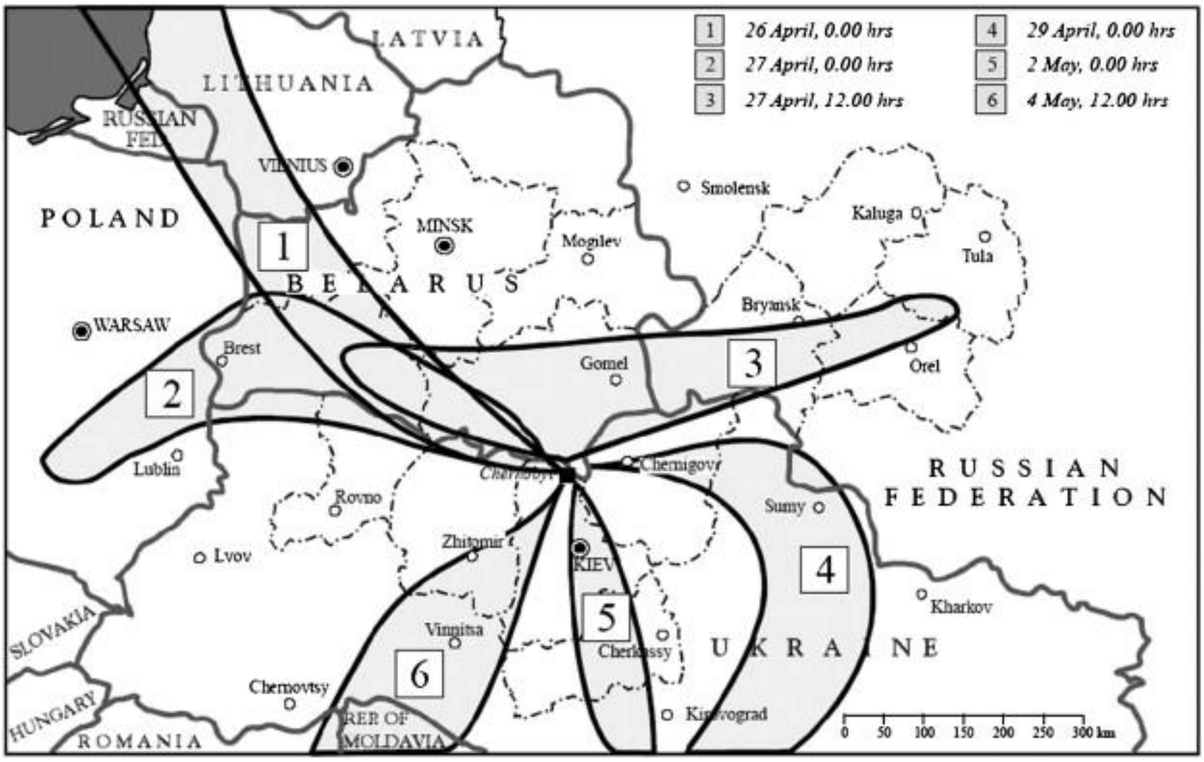


Figure 2: Calculated plume formation according to meteorological conditions for radioactive releases on corresponding dates just after the Chernobyl accident (Saenko et al., 2011).

Meteorological conditions were of great importance for the dispersion and deposition of radioactive isotopes (Figure 2). Overall, all of the Northern hemisphere was affected by Chernobyl radioactive pollution (Pudykiewicz, 1989). Part of the radioactive plume headed to the Scandinavian peninsula, where Forsmark (Sweden) nuclear power plant workers alerted their government of the rising levels of radioactivity outside the nuclear power plant (Svensson, 1988), which then warned the world about the Chernobyl accident.

Some of the most important radioisotopes released due to the explosions were ^{137}Cs, ^{90}Sr, ^{131}I, ^{134}Cs, ^{238}Pu and $^{239+240}Pu$. These radionuclides contributed to the population according to their features: their volatility/solubility and their half-life.

Pu isotopes ($T_{1/2-239}$=2.41×10^4 y; $T_{1/2-240}$=6500 y) remained near the power plant as they corresponded to the fuel component of the radioactive fallout (Kashparov et al., 2003) and due to its low volatility.

I-131 ($T_{1/2}$= 8.02 d) was the most radiologically significant isotope in the early days after the accident due to its short half-life, and its presence was correlated with an increase in child thyroid cancer (Saenko et al., 2011).

Sr-90 ($T_{1/2}$= 28.8 y) is neither volatile nor soluble, it remained in the vicinity of the nuclear power plant and the general public has not been exposed to it.

Cs isotopes (^{134}Cs and ^{137}Cs) are volatile and soluble, favouring their widespread dispersion. Whereas ^{134}Cs has a short half-life ($T_{1/2=}$ 2.1 y), the latter has a half-life of 30.2 years and therefore is still of concern presently. Generally, ^{137}Cs has been the main cause of radioactive exposure derived from the Chernobyl accident. As shown in Figure 3, territories polluted with more than 40 kBq·km^{-2} were found in the Scandinavian peninsula, the Alps, Greece or even the UK, in addition to Eastern Europe.

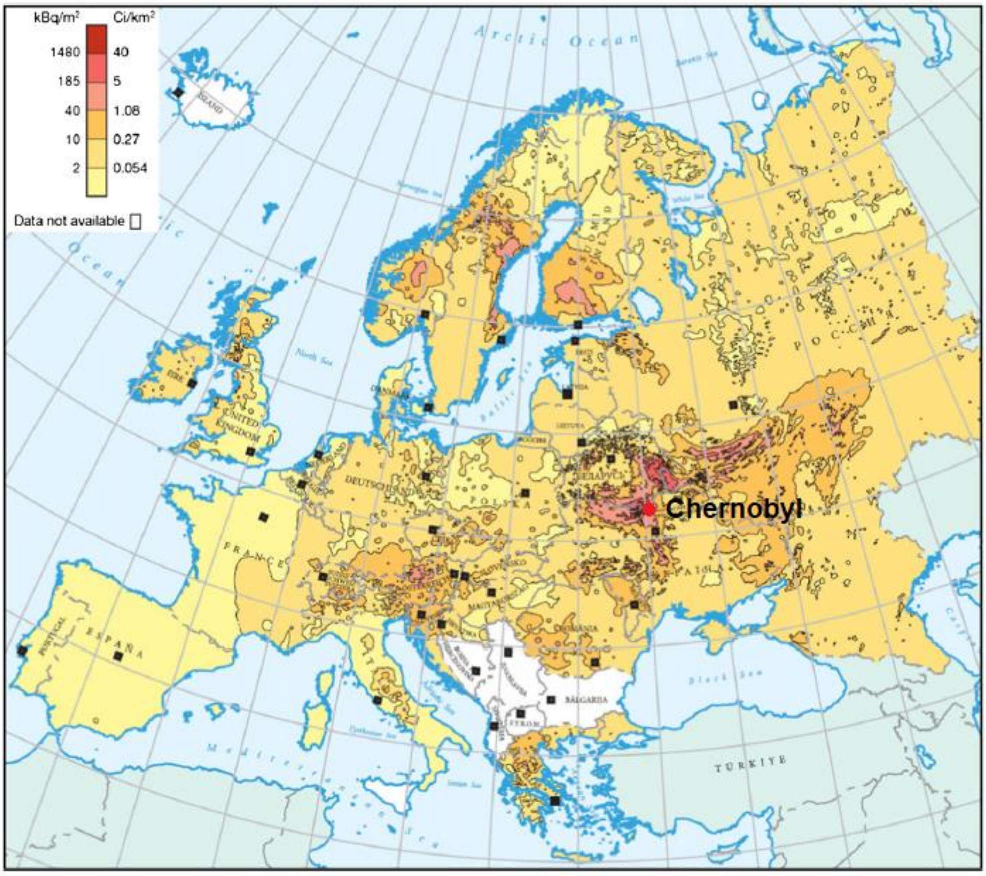


Figure 3: Ground deposition of ^{137}Cs in Europe after the Chernobyl accident (Saenko et al., 2011).

The different distribution of radionuclides can be seen by looking at isotope ratio maps. Figure 4 shows that the $^{137}Cs/^{90}Sr$ activity ratio decreases as proximity to the nuclear power plant increases (except for higher levels northward due to the direction taken by the radioactive plume), therefore meaning that ^{90}Sr is a more relevant isotope in the environment the more we approach Chernobyl's nuclear power plant.

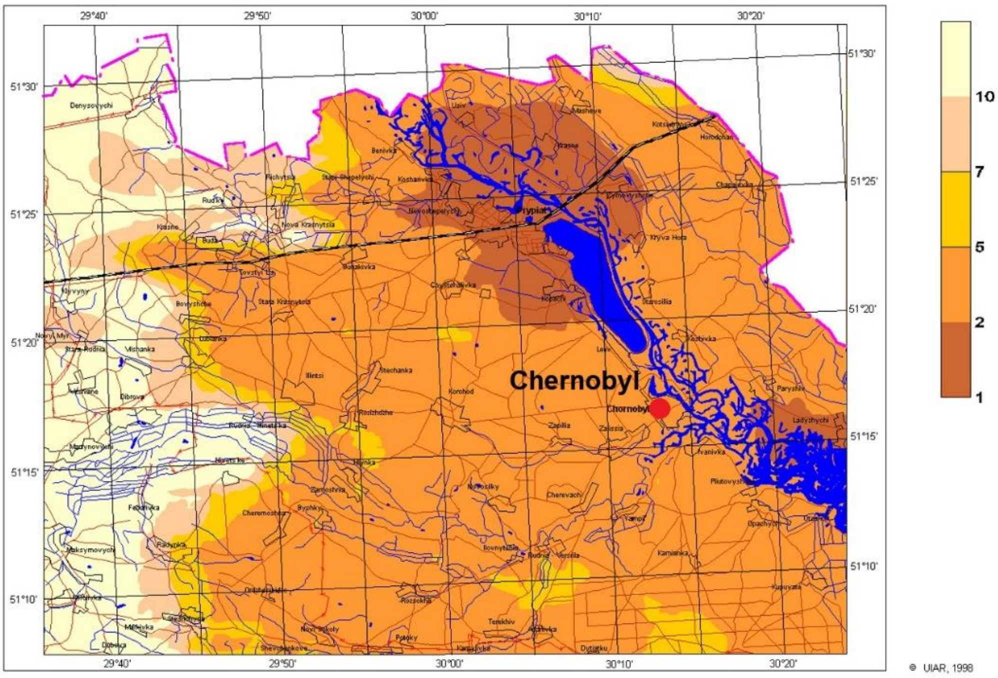


Figure 4: The map of $^{137}Cs/^{90}Sr$ activity ratio in soils of the 30-km Chernobyl zone (in 1997) (Adapted from UIAR, 1988).

1.3 Soil contamination

As previously stated, several radionuclides were released to the environment because of the accident, but ^{137}Cs was the only one that combined a high volatility and solubility as well as a long half-life, and therefore continues to have a great impact on large areas around the nuclear power plant. The most affected areas by the Chernobyl fallout were north-western Ukraine, southern Belarus and Russian border lands (Lestaevel et al., 2010). Figure 5 shows the most contaminated territories from these three countries.

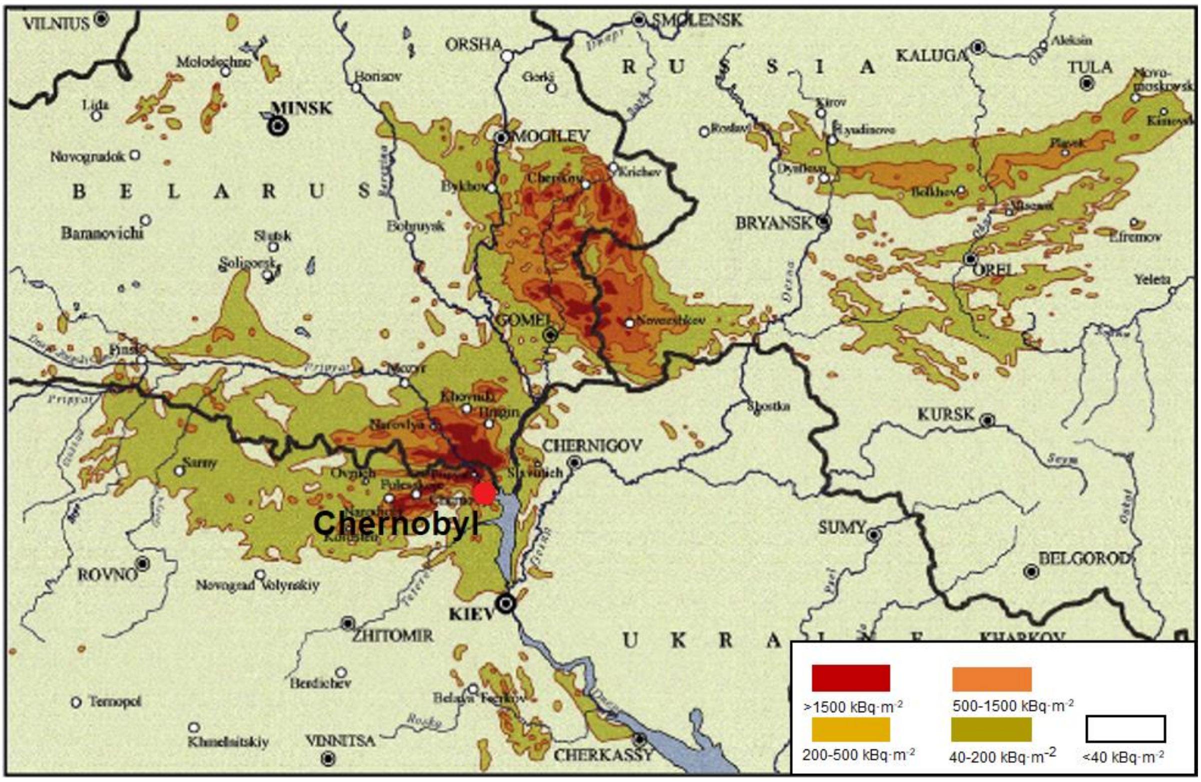


Figure 5: Ground deposition of ^{137}Cs in Ukraine, Belarus and Russia around the accident site (Saenko et al., 2011).

Numerous actions have been conducted in order to reduce ^{137}Cs content in soil and food. The most effective ones have been radical improvement of soil, which combines fertilization and deep ploughing, use of cesium binders in cattle, and forest and consumption restrictions. With current countermeasures, a ·3-5% dose reduction per year was expected (Higley, 2006). During the first 20 years after the accident, the implementation of agricultural countermeasures averted 30–40% of the internal collective dose (except thyroid dose) that would be received by the residents of contaminated areas of Russia, Ukraine and Belarus without the use of corrective measures (Fesenko et al., 2007).

1.3.1 Belarus

As previously stated, Belarus was, in terms of territory, the most affected country by the Chernobyl accident but public concern and resources have been generally directed to Ukraine, where the nuclear power plant was located.

23% of Belarus territory was exposed to a ^{137}Cs contamination of over 37 $kBq \cdot m^{-2}$ (> 1 $Ci \cdot km^{-2}$). About 2 million people, among them 500,000 children, live in this area (Nesterenko et. al, 2004). 80,000 children live in regions contaminated by a ^{137}Cs deposition of more than 185 $kBq \cdot m^{-2}$ (Hill et al., 2007). The most contaminated region of Belarus, next to the Ukranian border, was transformed into the Polesie State Radioecological Reserve, which mainly hosts research activities and wildlife tours. Its extension (2162 km^2) is shown in Figure 6.

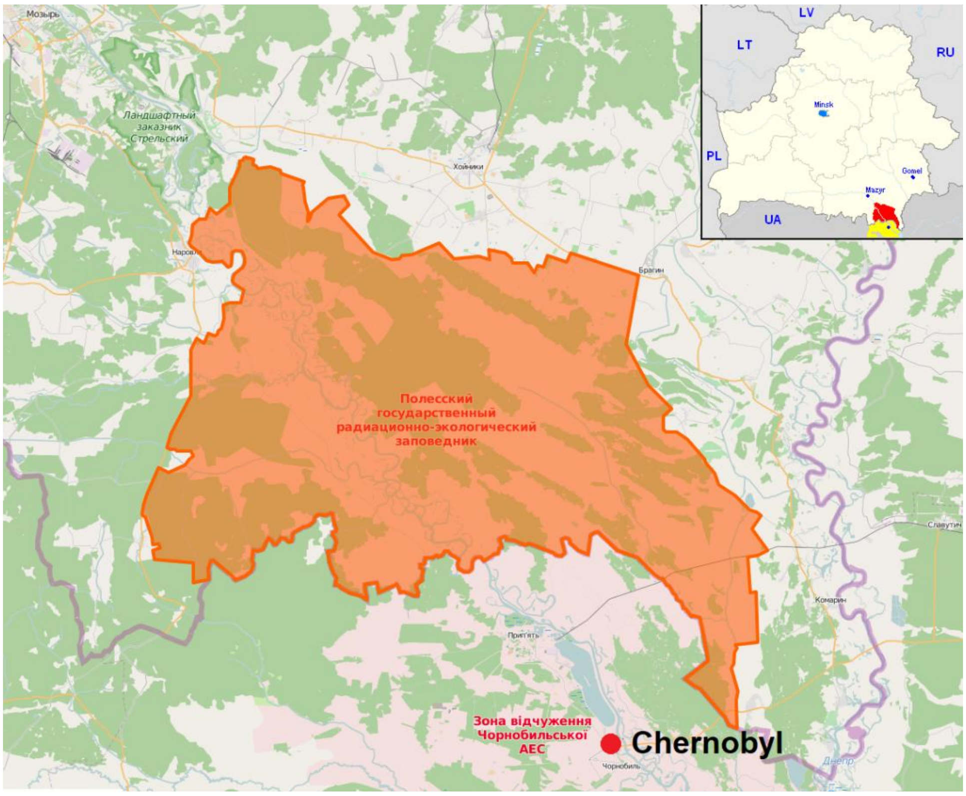


Figure 6: Polesie State Radioecological Reserve extension and location.

Most of the previously described remediation actions were conducted in Belarus. However, as many testimonies depicted in Svetlana Alexiévich's *Voices from Chernobyl: The Oral History of a Nuclear Disaster* show, their general effectiveness was compromised mainly due to the lack of transparency of the Belarus government and the reliance on self-produced food in the poor rural areas surrounding Chernobyl. Since the implementation of the legislation based on the Chernobyl accident, first by the former USSR and after by the Republic of Belarus, there has been several programmes that have combined different actions with the aim to tackle the accident's consequences, the first ones more focused on population relocation, whereas the last ones have evolved towards radiological monitoring and long-term rehabilitation of the communities (Trofimchik, 2004).

1.4 Ingestion and human health effects of ^{137}Cs body burden

In contaminated areas, the population has been exposed to ^{137}Cs primarily through daily ingestion of polluted food. Milk, meat, potatoes and especially wild berries and mushrooms have been noted to be the principal contributors to the ^{137}Cs internal dose (Labunska et al., 2018). Seasonal peaks in whole body radiocesium activity during late summer/autumn have been observed within rural populations in Russia due to a higher mushroom consumption (Beresford, 2016). In Table 1, the average ingestion and ^{137}Cs content of common foodstuffs is shown. Table 1 also exhibits the equivalent amount of ^{137}Cs ingested daily in 2020, which has been calculated considering its half-life and a 4% annual reduction in ^{137}Cs food content due to the remediation measures (Higley, 2006).

Table 1: Usual ^{137}Cs ingestion in Christinovka (Ukraine) in 1998. Data from *Caesium 137: Properties and biological effects resulting of an internal contamination* (Lestaevel et al., 2010).

Type of food	Usual consumption	Average activity in 1998	Daily ingestion in 1998	Average activity in 2020	Daily ingestion in 2020
Unit	kg of fresh food	$Bq \cdot kg^{-1}$ of fresh food	Bq	$Bq \cdot kg^{-1}$ of fresh food	Bq
Milk	1.000	54	54	13	13
Bread	0.400	0.3	0.1	0.07	0.03
Potatoes	0.500	9	4.5	2.2	1.1
Turnip	0.050	3.8	0.2	0.9	0.045
Cabbage	0.050	1.5	0.1	0.4	0.02
Fruit	0.400	4.7	1.9	1.2	0.48
Meat	0.200	20	4.0	4.9	0.98
Fish	0.050	12	0.6	3.0	0.15
Eggs	0.014	2.5	0.04	0.6	0.0084
Wild berries	0.011	2600	28	640	7.04
Mushrooms	0.010	200,000	2000	49,000	490
Total without mushrooms			93		23

Due to its ingestion and once there is a significant body burden of ^{137}Cs, this radionuclide can affect human health. As an alkali metal, ^{137}Cs is a chemical analogue of potassium (K) and therefore it spreads in the body soft tissues once consumed. It has a special affinity for certain organs, including heart muscle, skeletal muscles, liver, spleen and, in children, thyroid, pancreas, kidneys and intestines (Lestaevel et al., 2010). Some health problems that have been detected in exposed children are immunity deficits, sight problems, higher frequency of some cancers, digestive problems and heart and liver-related diseases (Lestaevel et al., 2010). Figure 7 displays ^{137}Cs distribution in the body of a child.

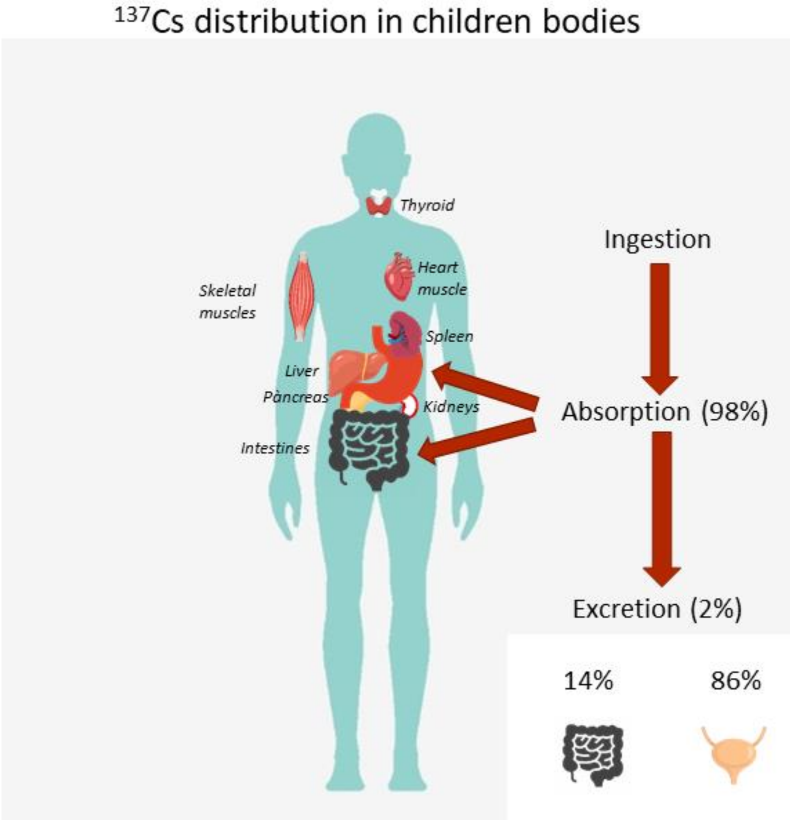


Figure 7: Cs-137 distribution in children bodies. Excretion % from *Caesium 137: Properties and biological effects resulting of an internal contamination* (Lestaevel et al., 2010).

The amount of ^{137}Cs in the human body depends on its biological half-life. This is the time it takes its maximum concentration to decrease to half of it. The biological half-life of Cs in adults is slightly higher than in children, approximately 70 days in women and 100 in men (Lestaevel et. al, 2010; Schwarz and Dunning, 1982; Lindgren et. al, 2015). Accordingly, children are expected to excrete Cs faster than adults.

1.5 Decontamination

^{137}Cs decontamination can be defined as the increase of ^{137}Cs excretion rates by ingesting medically approved substances aimed to do so. It can be achieved by the intake of Prussian blue, an approach which has been mainly studied in connection with the radiological accident in Goiania, Brazil (Hill et al., 2007). Prussian blue is the chemical compound ferric ferrocyanide, which is insoluble and acts in the intestine by exchanging cations with ^{137}Cs and enhancing its excretion with faeces (Lestaevel et al., 2010).

Another means of decontamination that has been studied is apple pectin, a polysaccharide often prescribed as an oral adsorbent for heavy metal intoxication, that is administered to students by numerous schools in Belarus. The adsorbent works by binding heavy metals (including ^{137}Cs) in the intestinal lumen, the complex being then eliminated with the faeces. The reduction of ^{137}Cs uptake happens whether children are eating clean food or not, implying that pectin is still active in the gut when radiologically clean food is provided (Nesterenko et al., 2004).

1.6 Recuperative holidays

In the early 1990s several projects of recuperative holidays for children from Belarus were initiated by several NGOs. These recuperative holidays are stays abroad that aim to temporarily move the children away from a radioactive environment and improve their health (Fairlie, 2016). All NGOs hosting recuperative holidays reported health improvements in children that took part in them, highlighting the benefits of those activities (Chernobyl Children's Project, 2020b).

Children participating in recuperative holidays live with host families in a Western country for 1 to 2 months each year (European Commission, 2003), providing "fresh air and nutrition free from radiation" (Chernobyl Children's Lifeline, 2020a). Some NGOs have used pectin in the first years of the programme, but they state difficulties in encouraging children to consume it regularly, mainly due to its bad flavour. Other NGOs do not report these problems. The cost of these holidays is typically paid by the host family, and the average number of visits is between 2 and 4 per child, and includes children 7 years old and up (Gray, 2017).

Due to the lack of information provided by national authorities, solid scientific evidence on the radiological benefits of recuperative holidays is scarce (Gray, 2017). There is no consensus at this time between those who believe the health benefits related to radioactivity to be significant (Fairlie, 2016), and those who highlight the social benefits of spending time in a wealthier region (Zhukova, 2020).

In this project, we have interacted with several NGOs that offer recuperative holidays. The NGOs that provided us with data on participating children and their Cs body burden, as well as information on their recuperative holidays are:

- *Osona amb els nens,* a Catalan NGO based in Vic (Osona, Catalonia), which has been organizing recuperative holidays since 1996. Most of the analysed data was provided by this NGO.

- *Associació de Collbató per a la Solidaritat,* a Catalan NGO based in Collbató, Baix Llobregat, that has also been organizing recuperative holidays since 2001. This is a participant in the *Federación Pro Infancia Chernobyl,* a federation that includes several NGOs that organizes recuperative holidays in Spain.

- *ACOBI Acogida,* a basque NGO based in Bizkaia that has been participating in this kind of projects since 1997.

Most of the children that participate in the programmes organized by these NGOs come from towns and little villages in rural areas, specially from Gomel region. Gomel is a poor region, as is most of Belarus, and therefore a self-sufficient food supply is rather common. Most families with a backyard have a small kitchen-garden where potatoes and other vegetables are grown. Soil pollution is currently still of concern, as we have previously noted, and self-produced vegetables can be less recommended for consumption due to potentially higher ^{137}Cs contents. However, families with a garden often do not have access to other food due to economic reasons.

2. Objectives

2.1 General

The objective of this bachelor's degree final project is to understand the potential ^{137}Cs body burden reduction in children from Belarus due to their participation in recuperative holidays, as an indicative of the beneficial effects of these programmes on children health. With this aim we will evaluate recuperative holiday programmes' effects on children's ^{137}Cs body burden (total Bq) and specific activity ($Bq\cdot kg^{-1}$). As an additional objective, we aim to analyse the role these programmes play in the improvement of child social and psychological welfare.

2.2 Specific

- To compare the average ^{137}Cs body burden (total Bq) and specific activity ($Bq\cdot kg^{-1}$) before and after recuperative holidays.
- To determine the relation between different parameters and ^{137}Cs body burden.
- To analyse tendencies since the recuperative holidays' projects started.
- To quantify the reduction in annual ^{137}Cs body burden a theoretical participant child would have, in comparison to a non-participant.
- To detect other psychological and social benefits associated to recuperative holidays.
- To compare these children body burden and dose with those received in areas not affected by Chernobyl radiation.

3. Methodology

3.1 Sample

In order to achieve the proposed objectives, we mainly have used the data collected by the Institute of Radiation Safety (BELRAD) of the children participating in the *Osona amb els nens* recuperative holiday programme over a twelve-year period, from 2007 to 2019. Additionally, we also obtained data from Khoiniki district schools and data supplied by *Federación Pro Infancia Chernobyl* from 2019, both collected by BELRAD. BELRAD is an independent non-governmental organization founded in 1990 by Professor Vasily Borisovich Nesterenko, member of the National Academy of Sciences of the Republic of Belarus and Doctor of Technical Sciences (Belrad Institute, 2019).

Information provided consists of name and surname, withheld from publication, year of birth, year of recuperative holidays, and measurements taken at the start and end of holiday period that include weight (kg), expected and actual potassium load (g) and ^{137}Cs specific activity ($Bq \cdot kg^{-1}$). Although the concept of absorbed dose (Sv) should be the one used to assess the damage of radioactivity in the organism, given that the main radionuclide currently contributing to the dose is ^{137}Cs and that the data reported by BELRAD is expressed in terms of activity (Bq), this is the parameter we have chosen to use along the TFG. In *Osona amb els nens* database, data is lacking from the years 2010, 2011 and 2018 due to technical or bureaucratic errors.

Figure 8 shows the age distribution of all studied children, both from *Osona amb els nens* and *Federación Pro Infancia Chernobyl*. As can be seen, the vast majority of children that attended these recuperative holidays were between the ages of 8 and 17, with 9- and 10-year olds being especially prevalent.

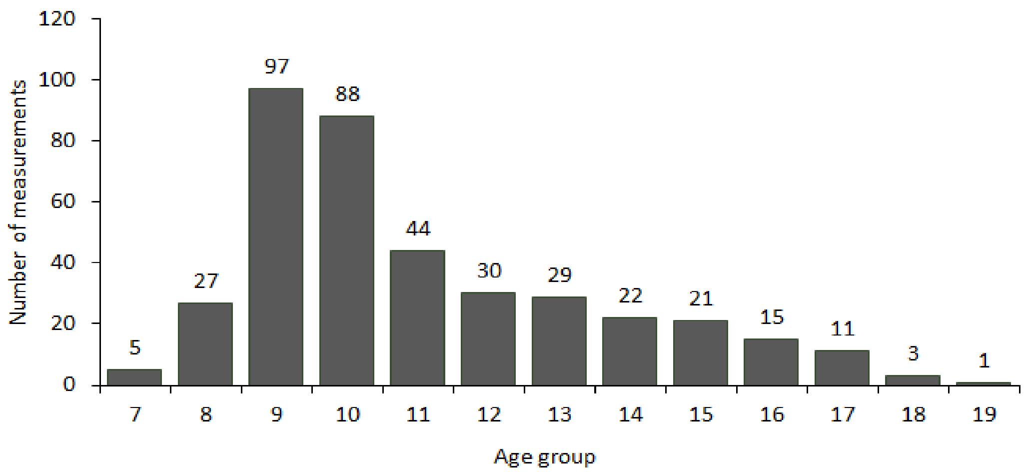


Figure 8: Number of measurements by age group available from *Osona amb els nens* during the 2007 to 2019 period.

Over time, the children participating in recuperative holidays are part of more diverse age groups, as shown in Figure 9. In 2007, there were only children from 7 to 10, whereas in recent years there were older children participating in the programme. This pattern is mainly caused by children that participate in the recuperative holidays in different years.

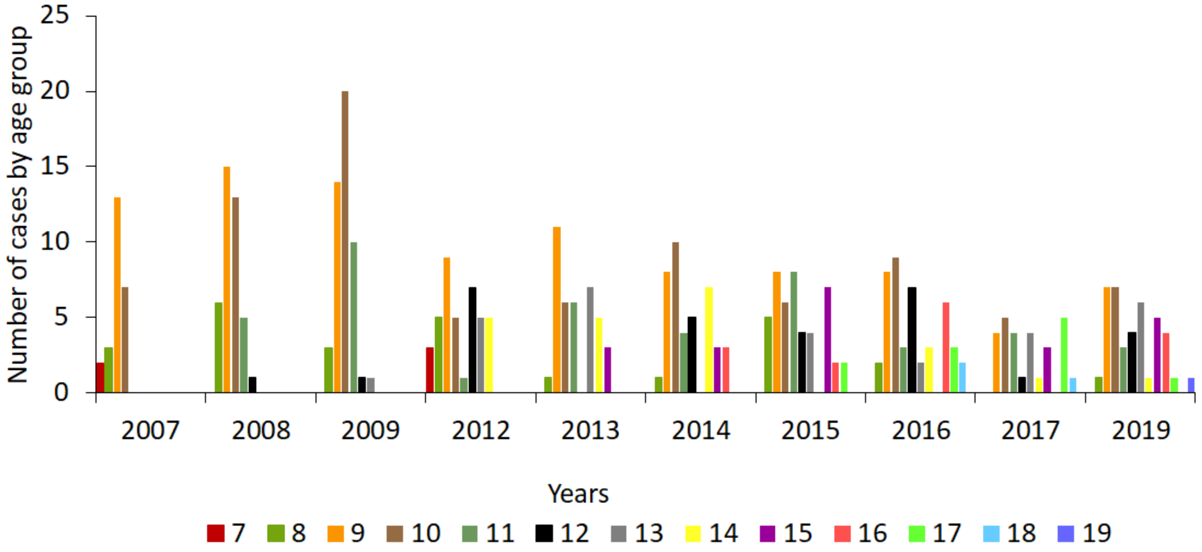


Figure 9: Number of children in each age group every year.

Regarding the gender distribution of the sample, Figure 10 shows how there are more female participants than male ones every year except for 2007. The greatest difference occurred in 2016, when female participants doubled the number of male participants.

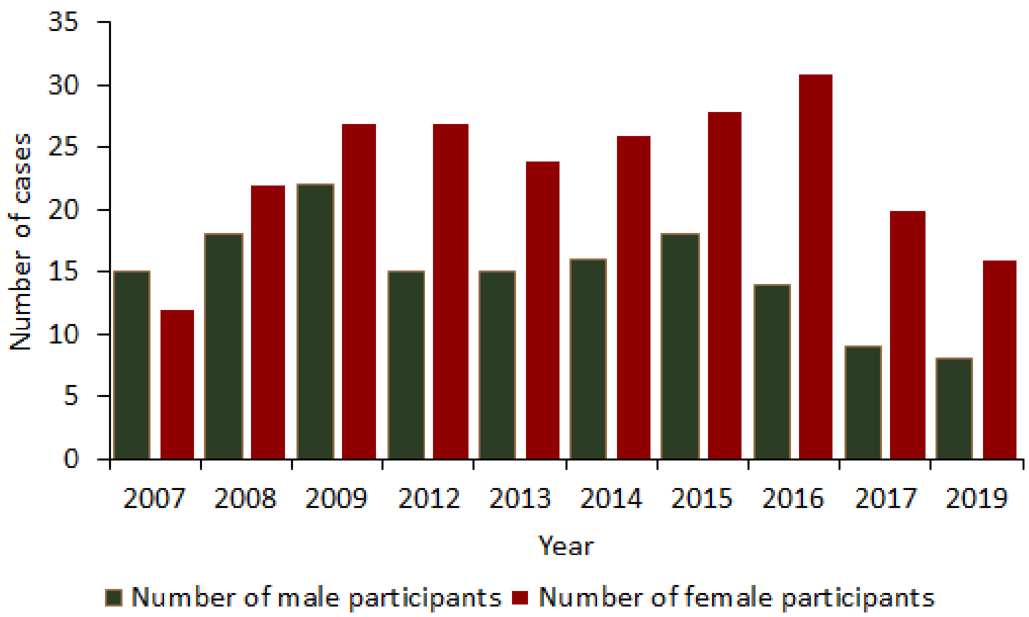


Figure 10: Number of male and female participants each year.

As for the number of visits for each kid, as Figure 11 shows, most children (86 kids) have only participated in the recuperative holidays programme once. 39 children have done so twice, 18 have been here three times and the number generally decreases up to a maximum of 8 visits.

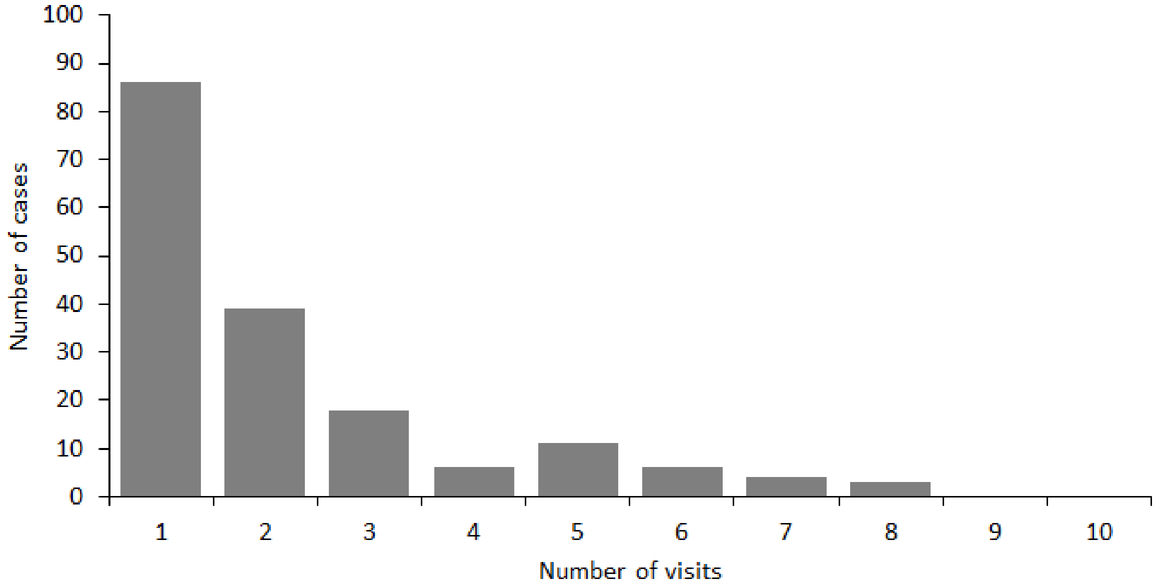


Figure 11: Number of visits children make.

3.2 Body measurements

Every time the children travels, radiation measurements are performed in a room in Minsk airport, right before boarding the plane, usually early in the morning. Measurements are conducted using a chair containing a chair-shaped whole body counter (WBC) with a crystal NaI(Tl) 150x100mm detector situated in the back, connected to a computer (Figure 12), that estimates ^{137}Cs and ^{40}K content values in children's bodies. The minimum detectable activity is around 150 Bq per whole body and the efficiency of the geometric model is determined with annual measurements of phantoms of a child, teenager and adult and an error not greater than 15% is attributed to the measures. When children return to Belarus, the same tests are repeated in order to evaluate the reduction in their ^{137}Cs specific activity.

Figure 12: Chair containing the WBC and body measurements conducted by BELRAD institute in Minsk airport, July 13, 2019 (Osona amb els nens, 2019).

3. 3 Interviews

We interviewed several Spanish NGOs in order to acquire a more detailed knowledge about their functioning and the possible effects recuperative holidays can have on participating children, other than the ^{137}Cs body burden reduction. Three interviews with different NGOs were carried out. Interviews were conducted face to face in the *Osona amb els nens* case and by phone in *Collbató per la Solidaritat* and *ACOBI* cases. Questions regarding several aspects of recuperative holidays were asked (as shown in Annexes).

4. Results and discussion

The importance of recuperative holidays is based upon their supposed effect on children's health from two points of view: the radiological effects due to the decreased body burden of ^{137}Cs, and the social and psychological effects due to a change in lifestyle. In this section we evaluate if recuperative holidays fulfil these claimed effects.

4.1 Interviews

In this section we show the results of various interviews with the responsible NGOs that host recuperative holidays. The questions used for these interviews are displayed in Annexes.

All NGOs report significant reductions in ^{137}Cs body burden each year. They get these results through BELRAD. In the case of *Osona amb els nens*, these reductions tend to be around 40%, as reported. In both their case and in the *Federación Pro Infancia Chernobyl* one, the reduction results are highlighted as an important achievement. *Collbató per a la Solidaritat* did not emphasized that much these reductions and drew attention to other matters.

Osona amb els nens state improving physical and emotional wellbeing for the children as their primary goal, apart from ^{137}Cs body burden reduction, whereas *Collbató per a la Solidaritat* puts their focus on improving long-term socioeconomic conditions for the children and allowing them to relocate to places with lower background radiation. As stated by the *Federación Pro Infancia Chernobyl*, the core aim of their programmes is to reduce the amount of radioactive ions present in the childrens' bodies to diminish the chance of developing illnesses such as cancer (Federación Pro Infancia Chernobyl, 2020).

The Chernobyl accident had different kinds of health consequences. Mental health affections are rather usual in the Gomel region. NGOs note that there is a significant number of children with at least one parent with alcoholism issues and/or children with negligent parents. This is the main reason, in addition to economic hardship suffered by the region, why some families tend to check on these kids during the year, even choosing to support them financially by paying for their studies partially or completely. Their bond with the host families tends to give them stability and role models they often lack.

Regarding physical health issues, NGOs reveal a high prevalence of heart-related diseases and other pathologies, such as vision affectations, among children. Statements of improvements after spending some weeks in Spain have been made, such as better cholesterol levels in blood and amelioration of previous conditions they might have. Additionally, their eating and hygiene habits have been reported to improve and maintain that improvement on returning home, positively impacting their home environment.

NGOs report higher levels of self-esteem, an increase in their interest in learning, and the possibility of spending time in a stable environment that provides them with affection. The creation of meaningful bonds between the host family and the children (especially for those who repeat stays) gives them a new kind of emotional and financial support they lacked before. Additionally, children tend to learn either Catalan or Spanish when they come here and therefore gain all the cognitive benefits associated with learning a new language, as well as the access to a different culture.

4.2 Origin of the children

All children studied lived in Belarus at the time of their recuperative holiday. Amongst the cases where location is reported, the majority come from the region of Gomel, the Belarus region closest to the Chernobyl Power Plant (Figure 13). Though many children also come from other regions, the *Osona amb els nens* programme has their primary focus there. As shown in Table 2, the total number of cases on which hometown information has been obtained is 149, out of a total of 400 cases.

Table 2: Number of cases in each region.

Region	Number of cases
Vitebsk	3
Minsk	11
Gomel	107
Grodno	6
Mogilev	4
Brest	2

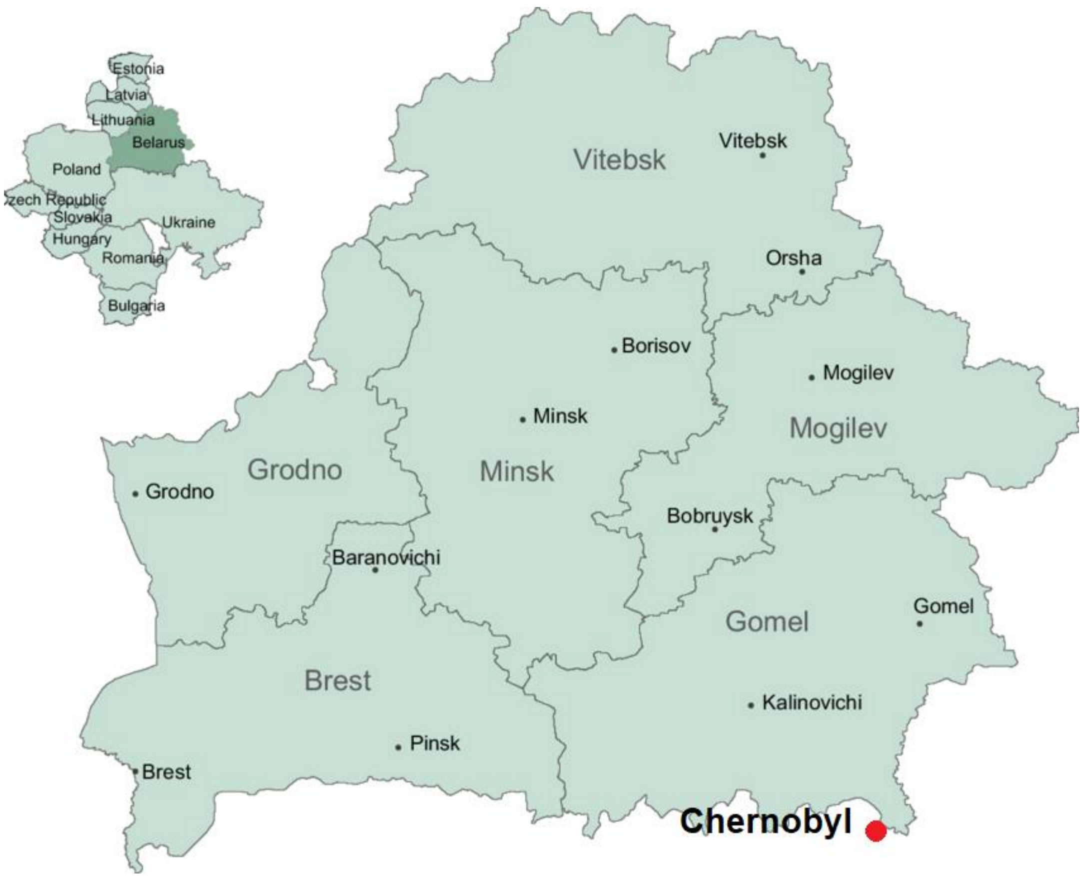


Figure 13: Regions of Belarus in relation to Chernobyl nuclear power plant (Gerasimov and Karjalainen, 2010)

4.3 Variation by year

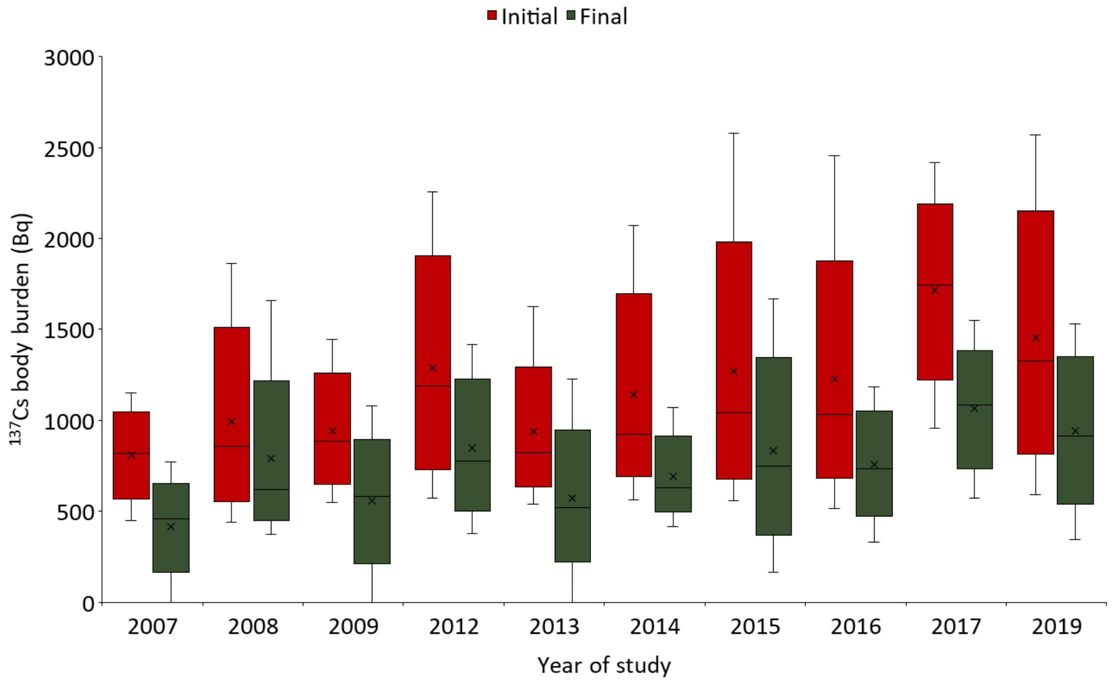


Figure 14: Annual initial and final ^{137}Cs body burden.

The ^{137}Cs body burden before and after the recuperative holidays (hereinafter referred to as Initial and Final body burden, respectively) is shown in Figure 14. Whilst there is a large variability on the measurements results, there is a consistent body burden reduction during the recuperative holidays. According to the results, 2017 was one of the most successful years in these terms.

Initial average body burden seems to increase progressively each year, from values near to 800 Bq in 2007 to values around 1700 Bq in 2017. This might be related to the variation in participants' age, as shown in Figure 9, given that many of them repeat stays, so in recent years we tend to have a more variable distribution in terms of age. Therefore, the participation of older children might have raised the average body burden. Variation in final average body burden is smaller, from approximately 500 Bq up to values of 1000 Bq.

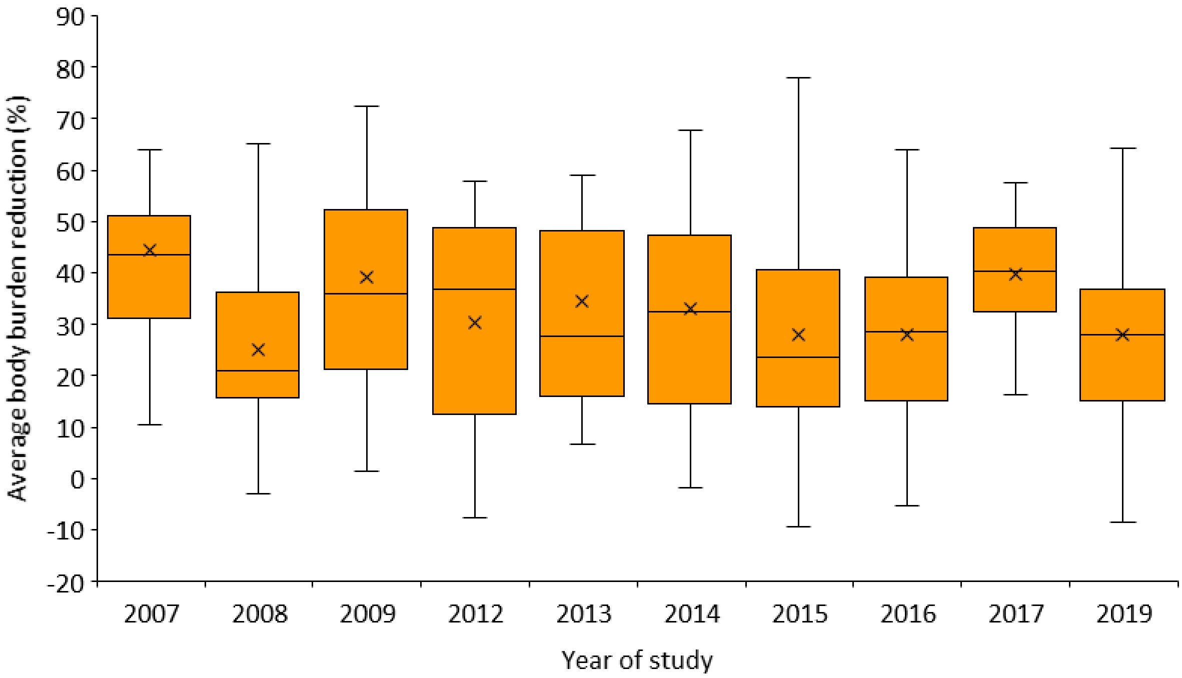


Figure 15: Average ^{137}Cs body burden reduction in percentage during the recuperative holidays for each studied year.

Figure 15 shows the percentage of reduction in ^{137}Cs body burden according to each year. Values of reductions range mainly between 15% and 50%. The overall average body burden reduction is 33 %, with the highest recorded being 44% in 2007 and the lowest, being 25%, in 2008. Some years, such as 2015, show higher levels of dispersion. This reduction trend is consistent during the years and therefore it suggests that the variation between initial and final body burden results is reliable. The differences between average body burden reductions(%) may be caused by a variety of factors such as measurement errors, disparity in food consumption or group changes like age variability.

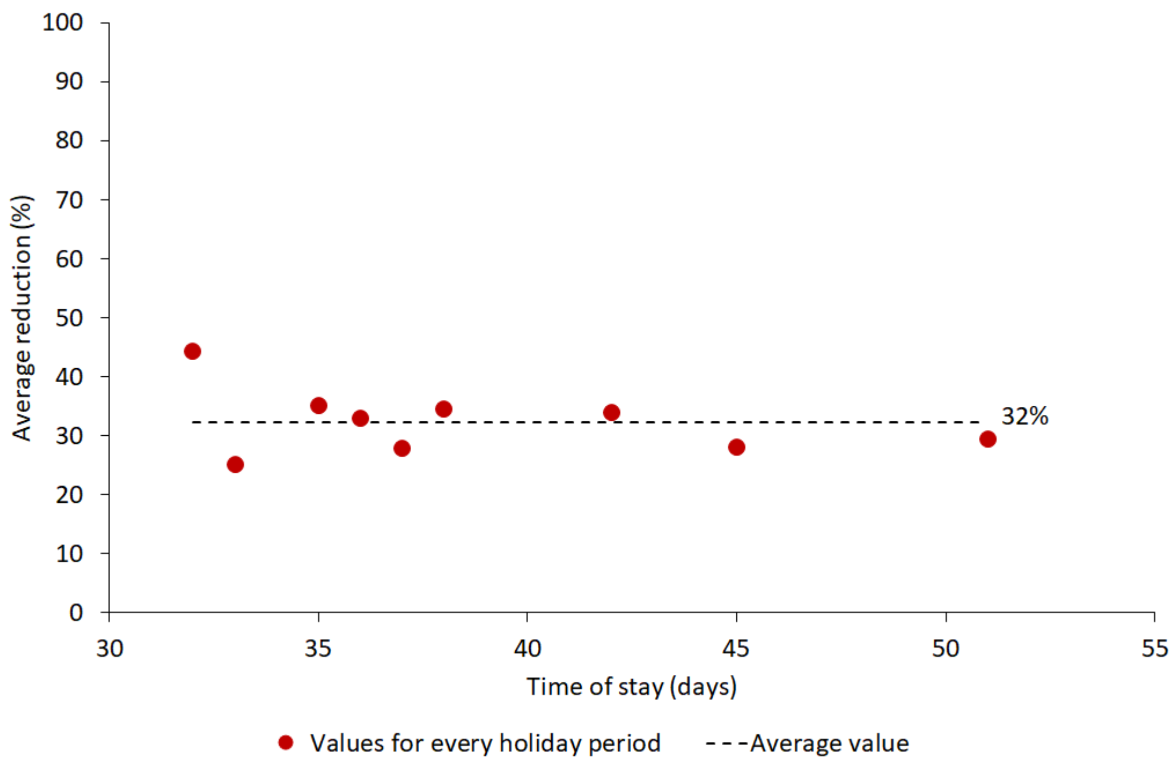


Figure 16: Average decrease in body burden by the duration of the recuperative holiday.

In Figure 16, the same average reduction is shown, but this time by the recuperative holidays' length. The maximum length was 51 days, offered by an NGO in the *Federación Pro Infancia Chernobyl* in 2019 while the shortest, of 32 days, corresponds to *Osona amb els Nens* in 2007. The largest percentile decrease took place during this short stay, while the largest average reduction in total Bq was during a 42-day trip in 2019. The average value is 32.4% and the standard deviation of the sample is 5.65%.

There is no significant observed correlation between the length of the stay and the associated reduction in body burden. As mentioned, the highest percentile average body burden reduction (47%) corresponds to a 32-day stay, whilst a 51-day stay lead to a 30 % reduction. These results make us infer that short-length stays are as efficient in reducing children's' body burden as long-length stays. The highest reduction, 47%, occurred in 2007, when only children from 7 to 10 years old was participating in the holidays, and this high percentages could be related to the more rapid excretion of ^{137}Cs body burden in children.

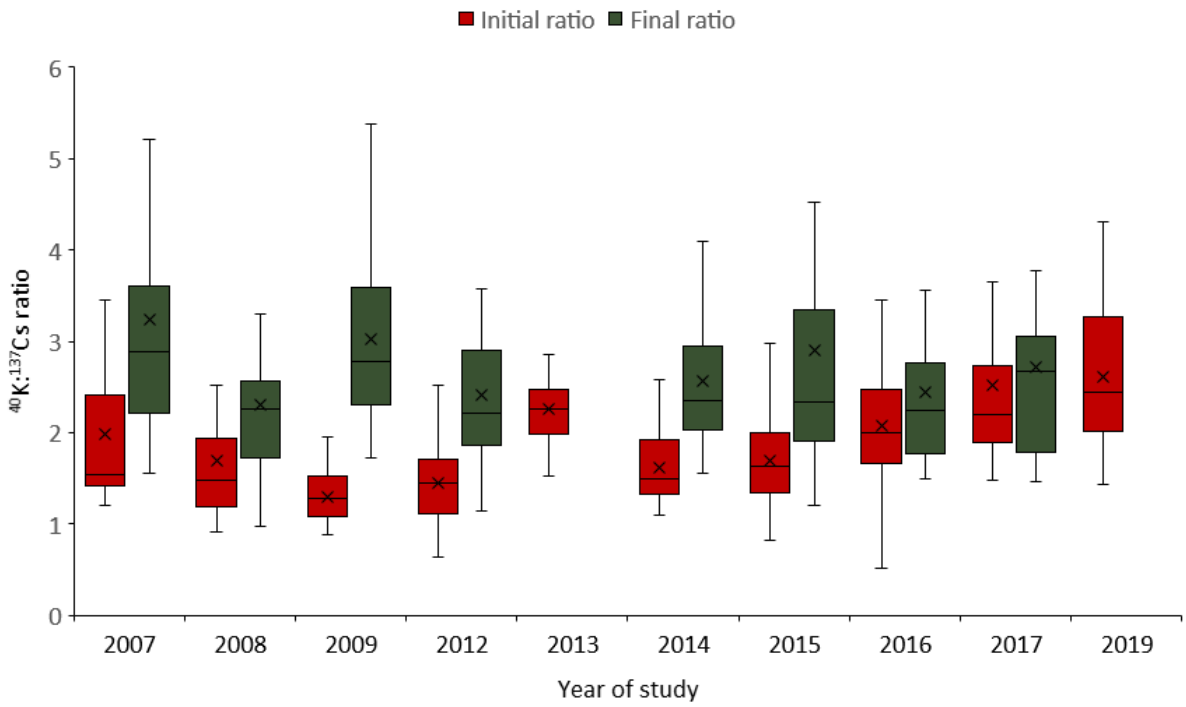


Figure 17: Initial and final potassium-cesium body burden ratio by year of study.

The initial and final ^{40}K:^{137}Cs ratio can be seen in Figure 17. We use this ratio because potassium and its radioactive isotope, ^{40}K has a similar chemical and biological behaviour as ^{137}Cs. However, ^{40}K has no relation with Chernobyl fallout and is ingested in all locations, whereas ^{137}Cs is only incorporated by the kids in Belarus (or in other areas affected by the nuclear accident). Thus, we expect to see a lower ratio before travelling to Spain and a higher when they return from their recuperative holidays. There is no data for the final potassium measurements corresponding to 2013 and 2019 and therefore we cannot show the ratio for these measurements. There is a consistent increase in the ^{40}K:^{137}Cs ratio for each year during the recuperative holidays. This tendency implies that children do ingest ^{40}K but do not incorporate ^{137}Cs when they are abroad.

4.4 Variation by gender

As displayed in Figure 18, the highest reduction value was found in male participants, and it corresponds to the year 2009, with an almost a 50% reduction in ^{137}Cs body burden. The lowest value is one that belongs to 2015, a 20% reduction in males, too. The highest reduction value for females happened in 2007, with a 45% reduction, whereas the lowest corresponds to 2016, with a reduction lower than 30%. Male body burden reduction fluctuates more than that of females. As also depicted in this Figure 10, a higher number of females attend these programmes compared to the number of males and therefore statistical error for males is more significant.

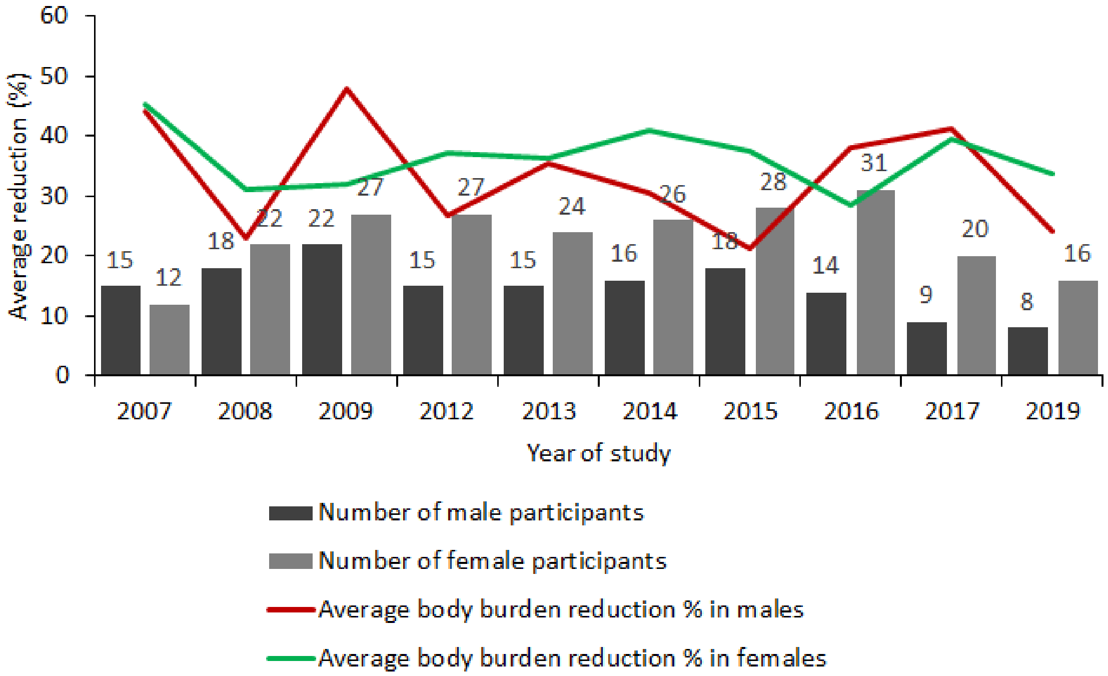


Figure 18: Annual variation between sexes of the number of participants average ^{137}Cs body burden reduction.

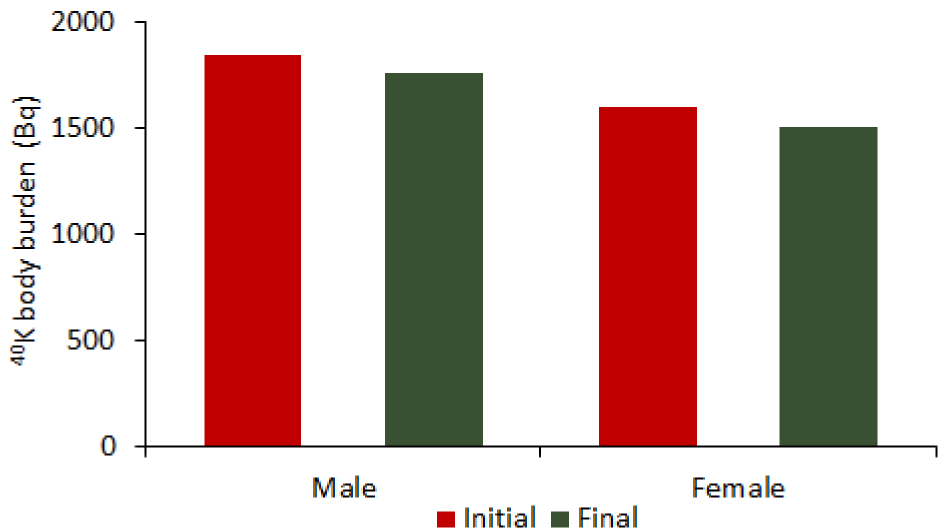


Figure 19: Initial and final ^{40}K body burdens by gender.

The ^{40}K body burden (Figure 19) describes the total amount of radioactive potassium that is contained in a body. The highest value belongs to initial values for males and the lowest is final values for females.

The ^{40}K body burden is slightly higher in males than in females, probably because males tend to weigh more than females and therefore to accumulate more potassium in their organism. Both genders present a greater ^{40}K load before the recuperative holidays than after, however this is a small variation, and it confirms what had been already discussed, that ^{40}K is lost during the periods spent abroad.

4.5 Variation by age

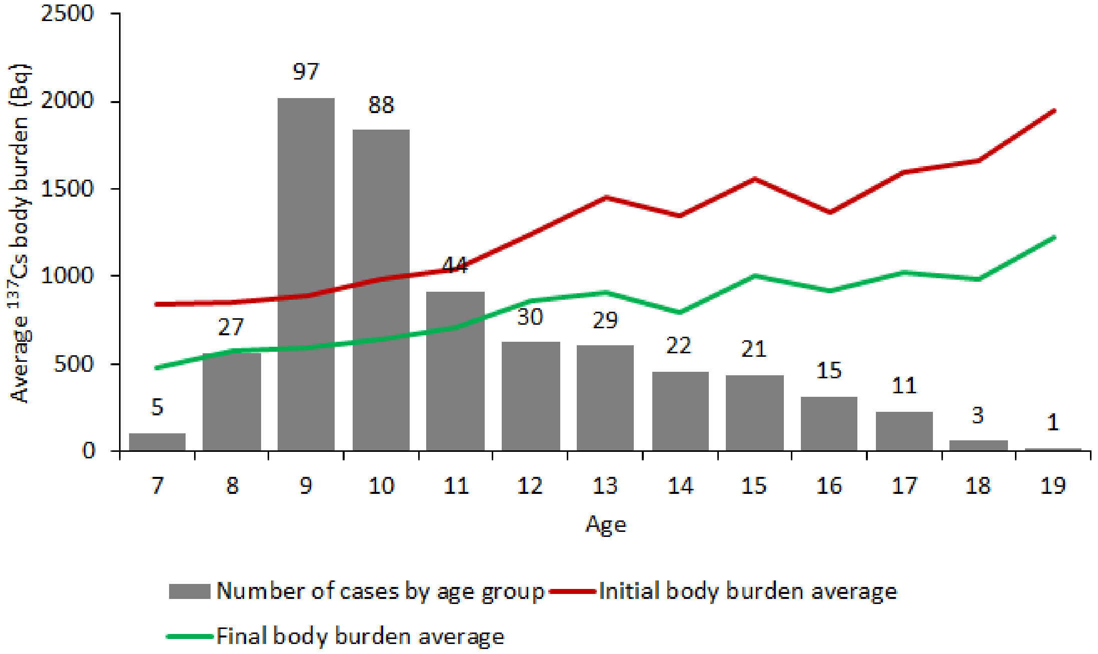


Figure 20: Initial and final average ^{137}Cs body burden (in Bq) by age group and number of cases in each group.

Figure 20 shows how as age group increases, so does the average body burden, both initial and final. Minimum values for initial body burden are found in 7 years old kids, and they are lower than 1000 Bq. These values increase to be nearly 2000 Bq in the case of the 19-year old. Minimum values for final body burden are around 500 Bq and grow up to 1200 Bq. There are few adolescents from older groups and therefore they are not considered statistically significant.

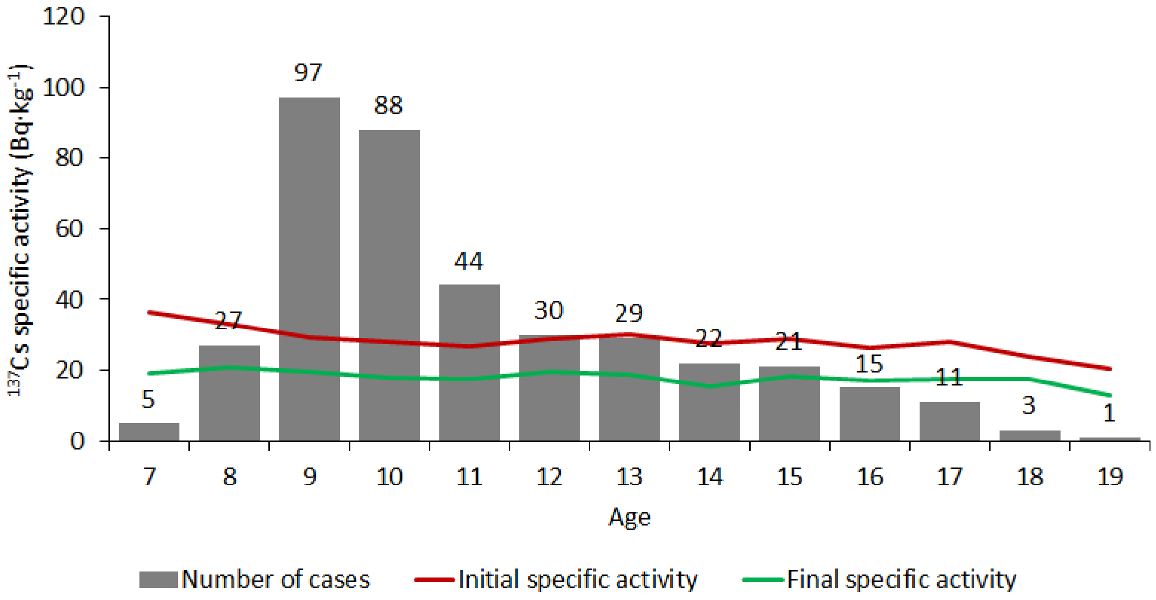


Figure 21: Initial and final specific activity by age group and number of cases in each group.

As can be seen in Figure 21, specific activity for ${}^{137}Cs$ does not show the same behaviour as body burden. It does not increase with age and remains constant. We have found the average initial values to be around 20-37 $Bq \cdot kg^{-1}$ and the final average ones around 12-20 $Bq \cdot kg^{-1}$. Accordingly, we can assume that there is an equilibrium value of ${}^{137}Cs$ body burden that is reached by children where they do not gain more $Bq \cdot kg^{-1}$ and that body burden only increases when weight does.

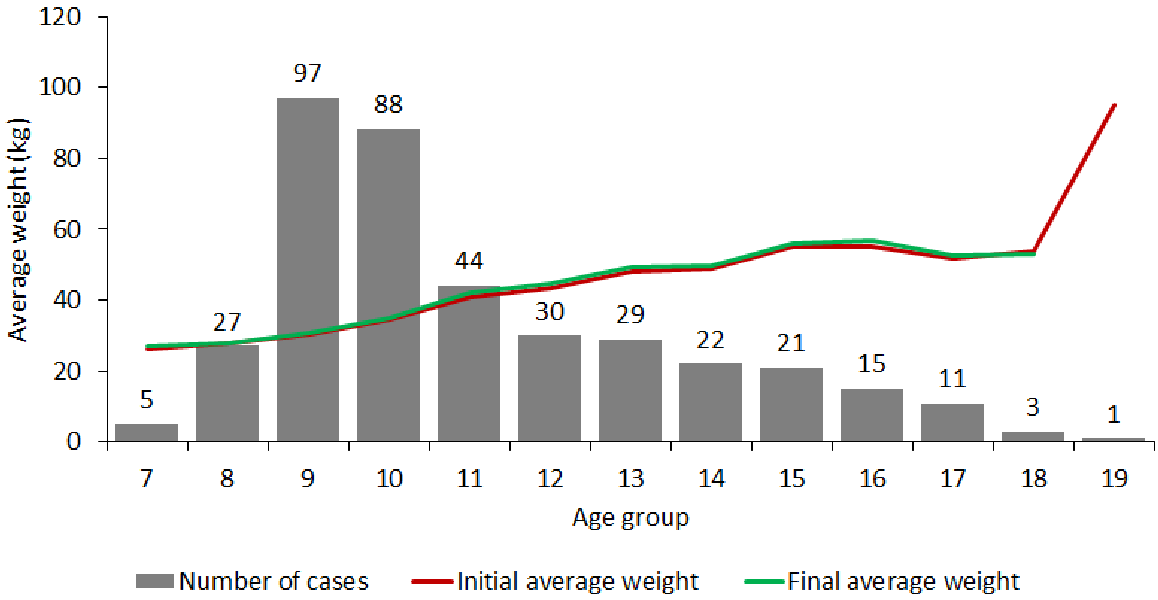


Figure 22: Initial and final weight by age group and number of cases in each group.

Figure 22 displays age and weight and the relationship between these two variables. There is a positive correlation between them and as can be seen, there is a nearly non-existent difference between the initial and final weights. Therefore, weight and age could be used as interchangeable variables and weight gain or loss does not play an important role in the studied processes.

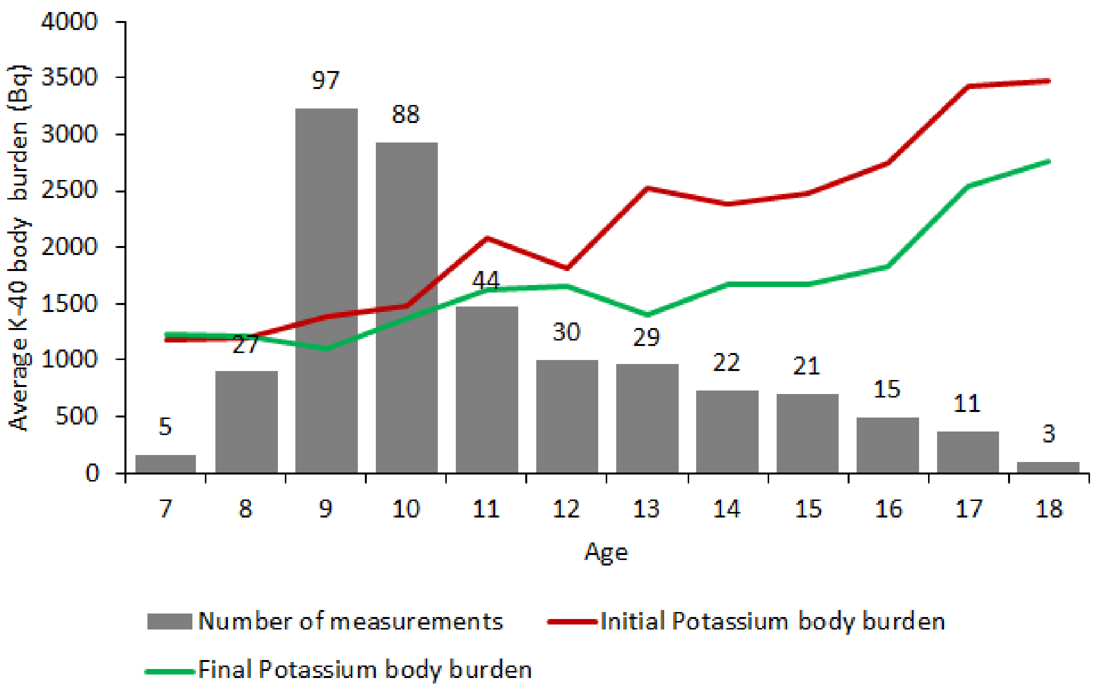


Figure 23: Initial and final ^{40}K body burdens according to age group.

In Figure 23, a positive correlation between age and average potassium body burden can be seen. There are some fluctuations in this tendency as there is a smaller number of cases for older children and teenagers. Generally, the average final ^{40}K load is lower than the average initial ^{40}K load, as we had already seen in Figure 19. During the recuperative holidays period this might imply a loss of this isotope, which was not expected as ^{40}K is ingested everywhere. This could be related to changes on the alimentation during the holidays and, thus, on the ingestion of potassium sources (e.g. differences on the purity of the salt consumed, different fruit and vegetable consumption, etc.).

4.6 Variation by weight

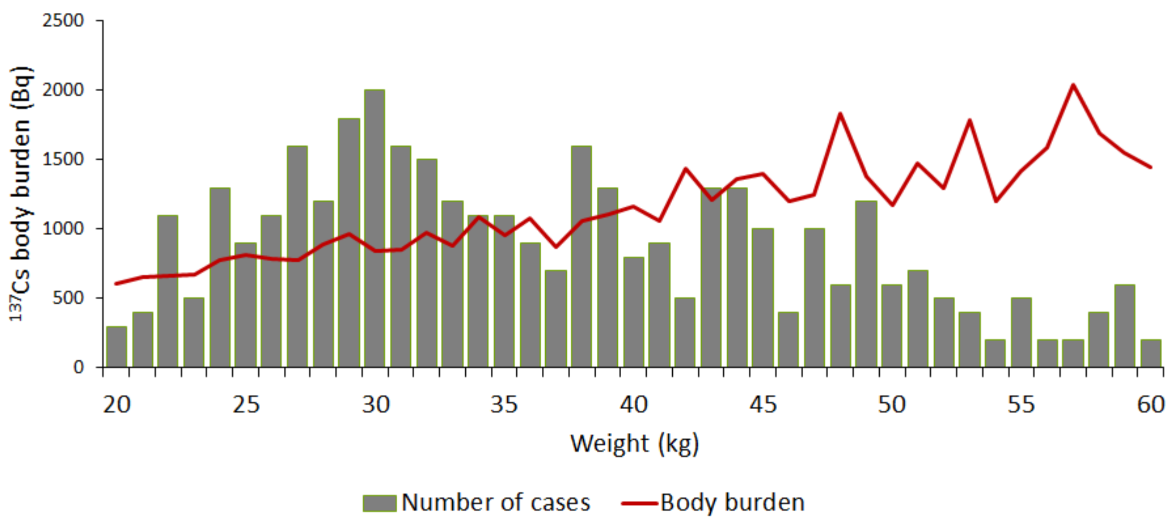


Figure 24: Body burden of ^{137}Cs (Bq) by weight group (kg) with number of cases per group.

In Figure 24, ^{137}Cs body burden is displayed by weight groups. We consider reliable data that that corresponds to weight groups from 22 kg up to 50 kg. Higher values have samples too small to be considered representative.

Weight has a direct correlation with the average body burden in highly reliable values (those with a significant statistical sample). As already discussed in Figure 21, the ^{137}Cs body burden could be expected to stabilize at a maximum body burden for adult average weights.

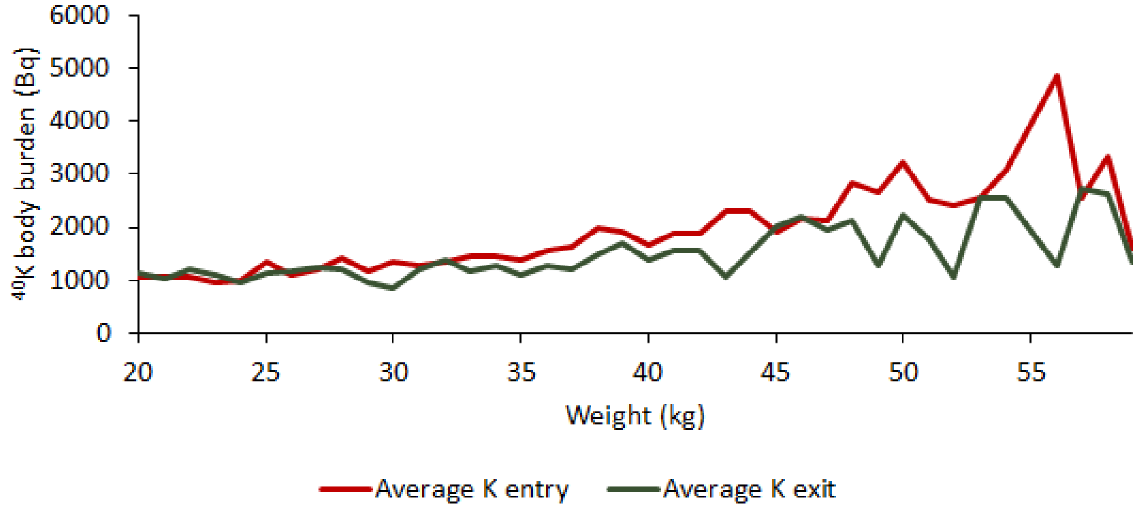


Figure 25: Initial and final ^{40}K body burden according to weight group.

As weight increases, so does the ^{40}K body burden (Figure 25), as was expected. Extreme values, as with the previous graph, are underrepresented and do not account for statistically significant data. Therefore, potassium can be conceived as a weight tracer, although changes in the ^{40}K body burden are greater than weight changes when comparing initial and final values.

4.7 Variation between programmes

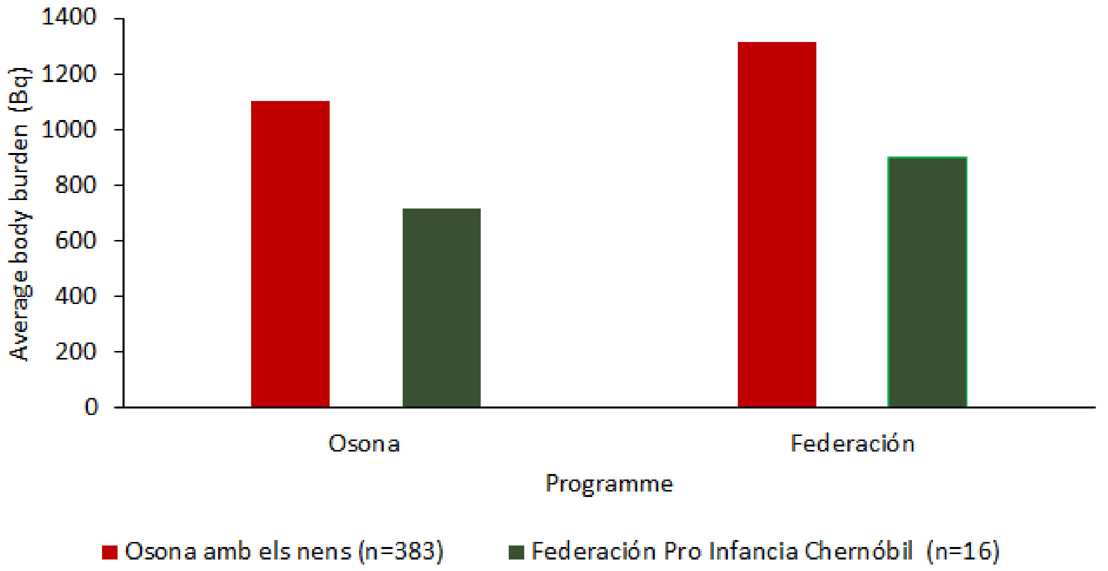


Figure 26: Initial and final ^{137}Cs body burden averages in both studied recuperative holiday programmes.

The body burden of initial and final ^{137}Cs average values according to the programme the children attended is shown in Figure 26. Nevertheless, these values are not equally representative because the Osona programme accounts for the 96.25% of the studied cases. The results show similar reduction values between both programs with average values of 35% in the case of *Osona amb els nens* and a 31% reduction in the case of *Federación Pro Infancia Chernobyl*.

4.8 Specific cases

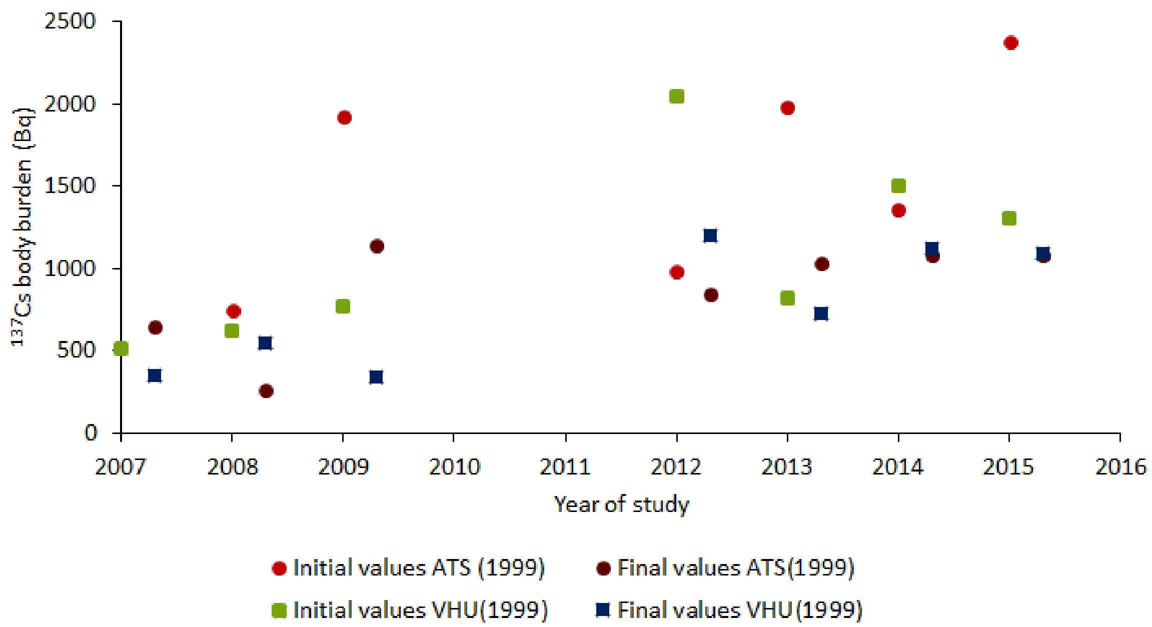


Figure 27: ^{137}Cs body burden for two children who participated in the programme for several years.

In Figure 27, it is possible to see the evolution of the ^{137}Cs body burden for two kids that have participated of the recuperative holidays' programmes for many years. Generally, the body burden decreases after spending these periods abroad and increases when the kids go back to their hometowns. As can be seen, there are some years when the kids' body burden tends to grow greatly, whereas there are others when their levels make much more slight changes. Overall, the great variability that can be observed in individual results can be linked to a multiplicity of factors: diet, habits, measurements, etc. and illustrates how complex this dynamic is.

4.9 Models

From the results of the ^{137}Cs body burdens analysed from BELRAD and after evaluating the role that different factors play on the variation of the ^{137}Cs body burden, it can be observed how the values for the children who participate in the recuperative holidays programmes make significant reductions whatever the program, age or gender.

The objective of this work is to understand the potential ^{137}Cs reduction in children's bodies as a consequence of their participation in recuperative holiday programmes, as an indicative of the radiological beneficial effects of these programmes on children health. Due to the lack of available data regarding incorporation and excretion, we are using theoretical models to derive these parameters from the ^{137}Cs body burden data obtained from the NGOs, considering the amount of time they spend at each place and thus obtaining the excretion and incorporation rates.

In order to calculate the rate of ^{137}Cs variation during the period children spend in Belarus (ingesting ^{137}Cs) and the period they spend in their recuperative holidays' location, we have applied a simple model that considers incorporation and excretion rates. We used two box models, modified versions of Single-Compartment Systems with Constant Input Rates models (Whicker & Schultz, 1982). These models allow to calculate different parameters that take part in ^{137}Cs metabolism in children's bodies. By applying Model I, it will be possible to obtain the rate of excretion (the property that describes the decrease rate of the ^{137}Cs body concentration), and afterwards, the biological half-life, which is the time it takes to reduce from a certain body burden of ^{137}Cs to half this amount. Then, by applying Model II, the incorporation rate during the period children spend in Belarus (the radioactive activity that is being incorporated every day) can be estimated.

4.9.1 Model I: Periods in host location

During the periods the children spend in host locations and are away from contaminated soil and food sources, they reduce drastically the incorporation of ^{137}Cs to their organisms. Thus, we can assume a negligible ^{137}Cs incorporation rate during holiday periods. Without incorporation, children's body burden of ^{137}Cs (q, in Bq) is expected to decrease at a rate (k, in d^{-1}) governed by the biological half-life of ^{137}Cs (notice that the radioactive half-life of ^{137}Cs is 30 years, so it plays a minor role on the decrease of concentrations observed during the 1-2 month holiday periods). Taking this into account, we apply a model of only excretion to these periods.

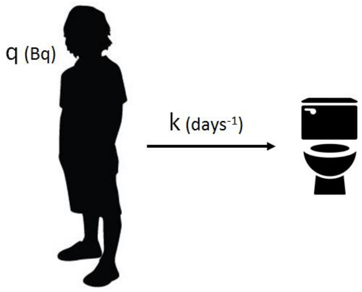


Figure 28: Excretion-only period representation.

Where q is ^{137}Cs body burden and k the rate of excretion. The ^{137}Cs body burden will change according to $\frac{dq}{dt} = -k \cdot q$, and therefore:

$$q = q_0 \cdot e^{-k \cdot t}$$

$$k = -\frac{ln\frac{q_f}{q_0}}{t_f}$$

We take q_0 to be the total ^{137}Cs body burden (Bq) at the start of the recuperative holiday period, q_f to be the ^{137}Cs body burden (Bq) at the end of the stay. Time (t) is represented in days, considered year to year, since the values vary as Table 3 shows. (t_f) represents the date of the end of the recuperative holiday programme.

Table 3: Length of stay per year.

	Year	Length of stay
Osona	2007	32
	2008	33
	2009	35
	2012	35
	2013	38
	2014	36
	2015	46
	2016	37
	2017	42
	2019	42
Federación	2019	51

The rates were calculated by determining each case's rate of excretion and the average of those values each year. The average rate of excretion for all years is 0.011 d^{-1} (Figure 29), with the lowest (0.0079 d^{-1}) taking place during the 2019 holiday, and the highest (0.016 d^{-1}) during the 2007 holiday. The standard deviation is 0.0025 d^{-1}.

The highest value corresponds to 2007, a year when most children attending recuperative holidays were younger than 10 years old and therefore tended to excrete more rapidly their ^{137}Cs body burden, because as previously stated, children have a shorter biological half-life compared to that of adults. The rest of the years have children from more different ages, as can be seen in Figure 9, and therefore these excretion rate values are lower.

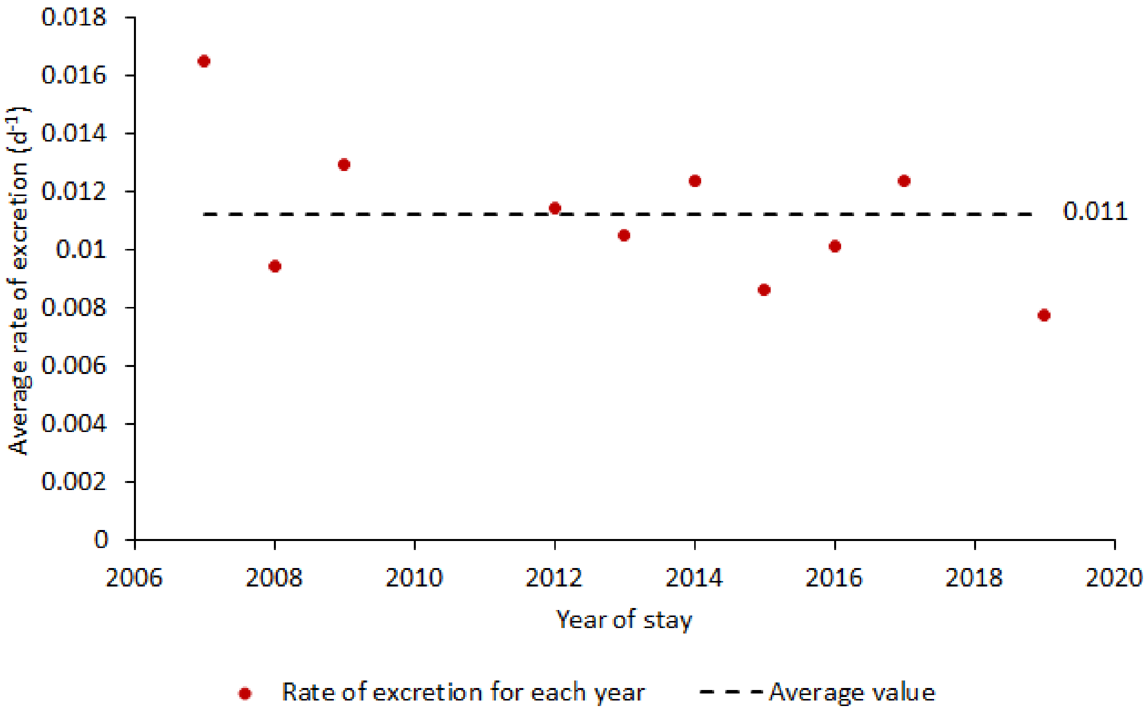


Figure 29: Rate of excretion (k) during the holiday period (d^{-1}).

From the rate of excretion, we can calculate the half-life in a child's body: $T_{\frac{1}{2}} = \frac{\ln 2}{k}$, as shown in Figure 30**.** The average biological half-life is 65 days considering all participants and the different periods analysed, whereas its standard deviation is 14 days.

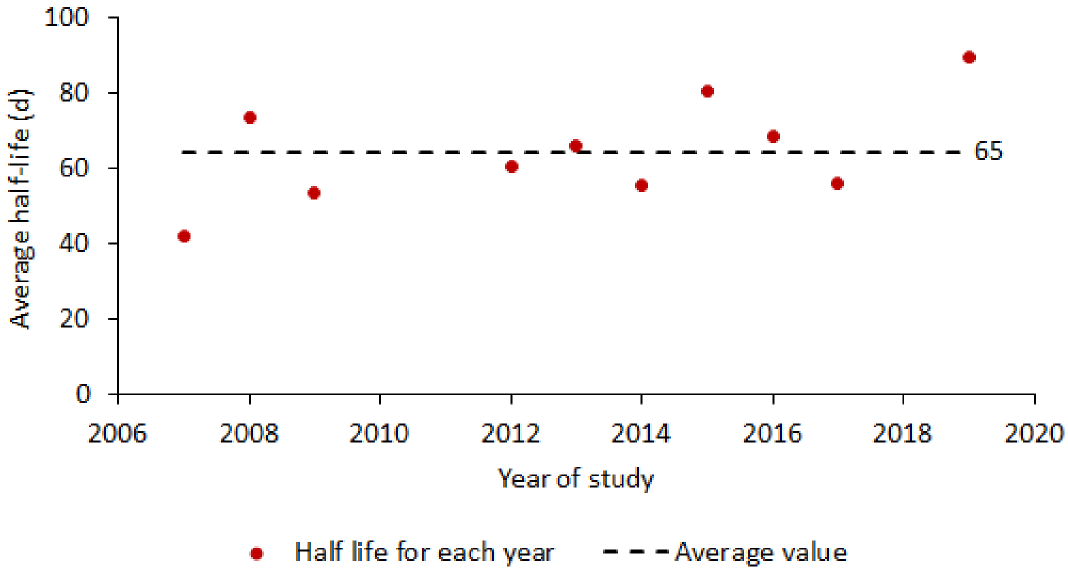


Figure 30: Average biological half-life in days per year.

According to Lestaevel et. al. (2010), the biological half-life for children is 34 days. Karches et al. (1969) found a half-life of 46 days by studying a group of children and teenagers aged from 6 to 16 years old. As previously stated, most of our values are in the 50-80 days range and therefore are closer to those obtained by Karches et. al (1969) than to those stated by Lestaevel et. al. (2010).

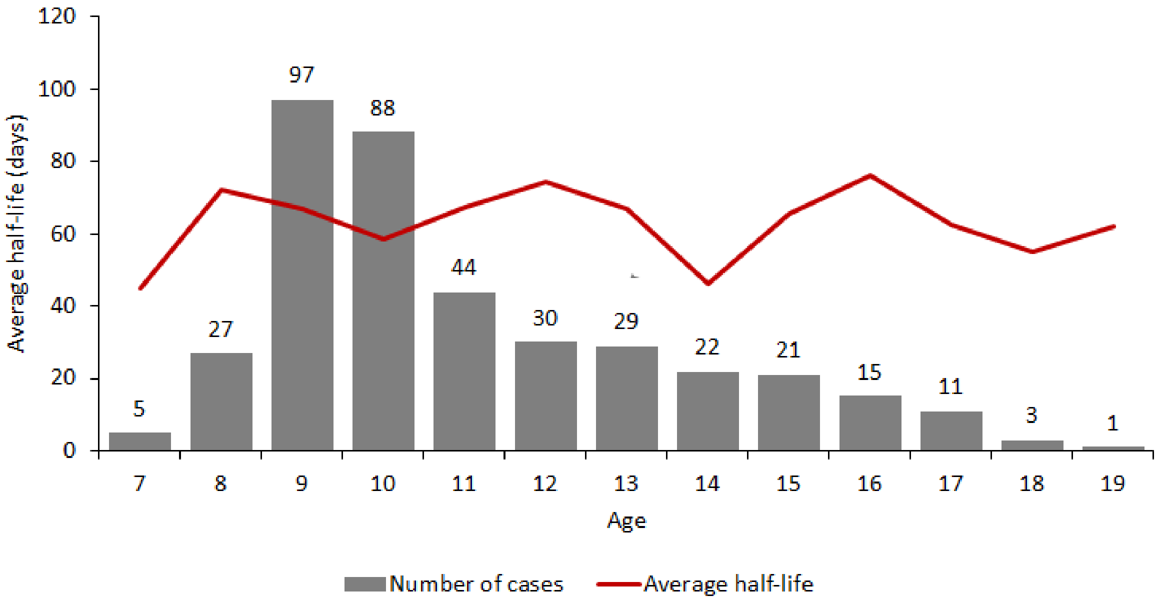


Figure 31: Average biological half-life by age group, showing number of participants in each.

Figures 31 and 32 show potential correlations between variations in half-life duration and age for the first one and weight for the latter. In Figure 31, average half-life ranges from approximately 45 days for 7-year olds up to 75 days for 16-year olds, but these values remain much more constant that we would have expected, given that the biological half-life should change with age, as we know from previous research. However, several age groups are underrepresented as we have less than 20 cases per each. In Figure 32, values for the average half-life show no correlation with the weight of the participants. Most results are comprised between 50 and 100 days. The average value for all the participants is 72 d and the standard deviation is 40.1 d.

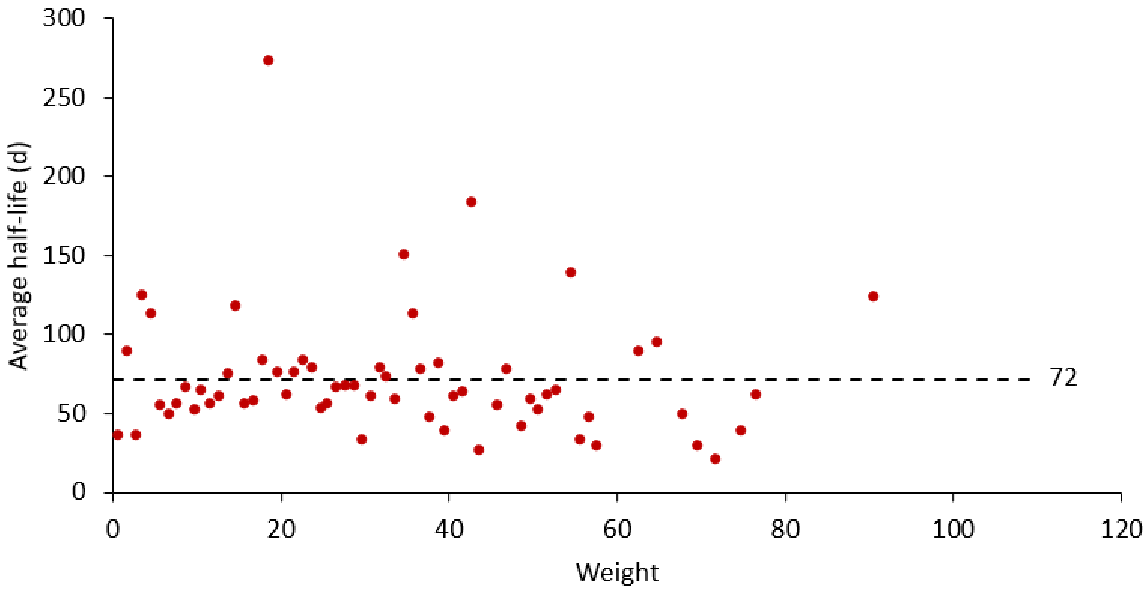


Figure 32: Average biological half-life by weight group.

4.9.2 Model II: Periods in Belarus

When children are in Belarus, they are in contact with contaminated food sources, and thus they are continuously incorporating and excreting ^{137}Cs. Now that the excretion rate (k) has been calculated (Model I), the rate of incorporation (R) can be found.

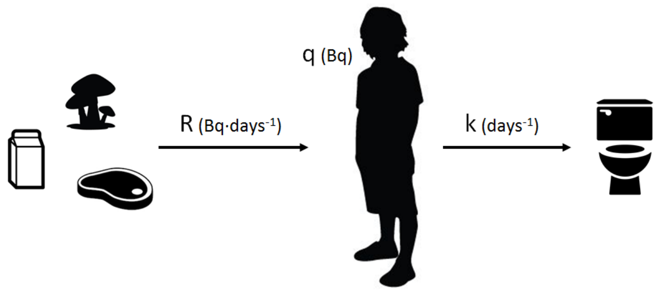


Figure 33: Excretion and incorporation period representation.

In equilibrium, rate of incorporation (R) equals excretion rate (k), $R = k \cdot q$. Considering equilibrium is reached once 5-7 half-life periods have passed (estimated half-life ranging from 50 to 80 days), we assume that the ^{137}Cs body burden corresponds to the equilibrium value when children have lived in Belarus for a year. We thus assume that the ^{137}Cs body burden measured just before the children moves to the host location (initial body burden) is representative of this equilibrium value (q).

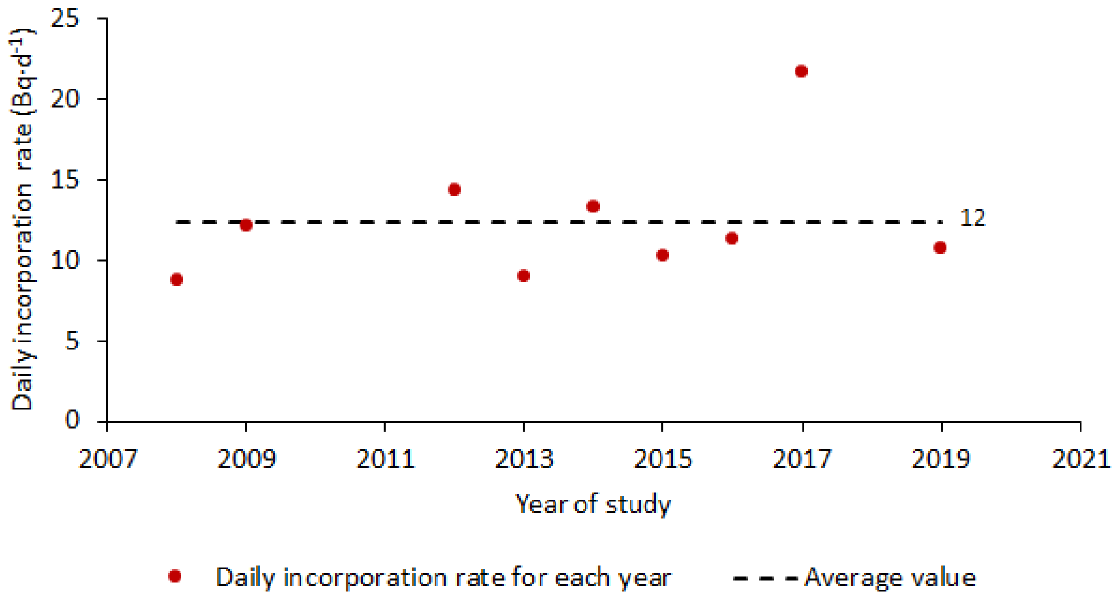
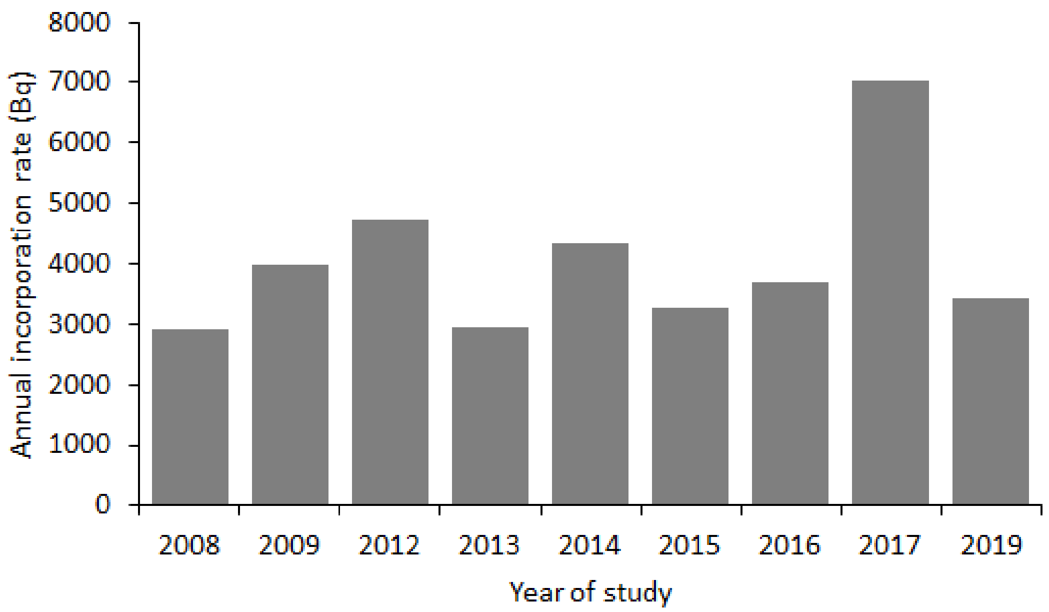


Figure 34: Average rate of ^{137}Cs incorporation during standard living conditions.

By applying the second model, the average amount of ^{137}Cs incorporated daily in equivalent Bq is found (Figure 34). Its value ranges from 8 to 21 Bq·d^{-1}. This theoretical value is considerably similar to the calculated ^{137}Cs ingestion for 2020 (23 Bq·d^{-1}; Table 1), which considers the foodstuff list, the annual reduction factor due to remediation actions and the ^{137}Cs decay. We thus consider that the theoretical values obtained through the model are reasonable. The average value for all years is 12 Bq·d^{-1} and the standard deviation is 4 Bq·d^{-1}.



.

Figure 35: Annual incorporation rate per year of study.

Figure 35 shows the total quantity of ^{137}Cs (Bq) that is incorporated every year. Values range from 3000 Bq in 2008 up to nearly 5000 Bq in 2012. Year 2017 is the one that presents higher values, those being close to 7000 Bq. It should be noted that the excretion rate is not being considered in this graphic and therefore this only shows the amount of ^{137}Cs being ingested by the organism, and not the dynamics of this ^{137}Cs. Consequently, these are not quantities we can found in any of the children's' bodies.

4.9.3 Model analysis

The results of applying Single-Compartment Systems with Constant Input Rates have informed us of the average rate of Cs excretion (k), the average incorporation rate (R) and the average yearly biological half-life and their relationships with variables such as weight and age.

The average biological half-life is relatively constant, with a tendency to grow in more recent years. As mentioned before, we believe this is due to the fact contemporary groups are more diverse and include older children than in the earlier years of the programmes.

As previously mentioned, the biological half-life of ^{137}Cs in adults is higher than in children, approximately 70 days in women and 100 in men (Lestaevel et. al, 2010; Schwarz and Dunning, 1982; Lindgren et. al, 2015). Therefore, as the group's average age increases, so should the average biological half-life of that group. We do not see that confirmed in our results, as shown in Figure 31.

There is no apparent correlation between the weight of the subject and their biological half-life (Figure 32). We assume the most important feature influencing someone's biological half-life to be metabolism characteristics, or other factors other than weight.

Additionally, using the information on the rate of incorporation and excretion from both models, we simulated the body burden of a hypothetical child during several years, to analyse the evolution over time.

The obtained biological half-life values by age did not match the expected tendency (the older a person is, the greater biological half-life) and therefore we assumed a linear degrowth for the excretion rate from the values corresponding to 8-year-old children to adult values.

To build Figure 36 model, we have started with the body burden of a seven-year-old kid (average value from our data) and we have applied a degrowing rate of excretion (k) and a growing rate of incorporation (R).

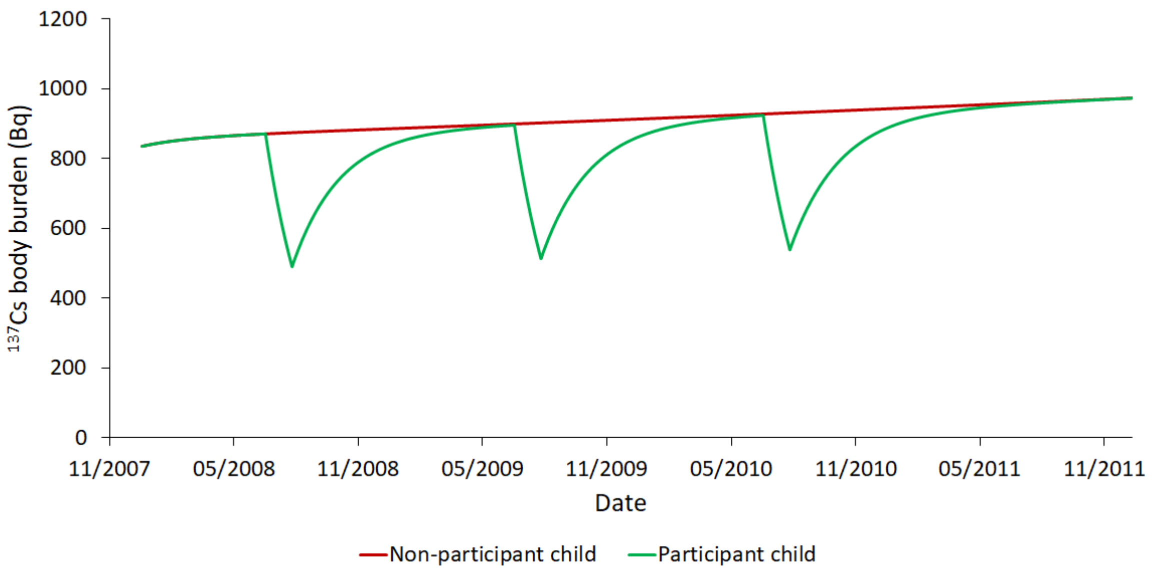


Figure 36: Plot of annual body burden in two theoretical case studies, between the ages of 7 and 11 years of age. In red, a child that does not participate in the programme. In green, a child that moves to a host location once a year during the average duration of 38 days for 3 years.

The body burden over time of two hypothetical cases is shown in Figure 36. Both are assumed initially to be seven-year-old children, and to grow up until they are 11 years old.

In red we simulate a child who does not participate in recuperative holidays, remaining in a contaminated area yearlong with a ^{137}Cs body burden that grows steadily, according to their growth, and as we have seen in Figure 20.

In green we represent a child that starts participating in these programmes at eight years of age, spending 38 days a year in a non-contaminated host location. Once the child moves to the host location, their body burden drops quickly at the excretion rate (k). The lowest recorded measurement is thus taken on the last day before the return to Belarus. Once back in Belarus, their body burden increases at the incorporation rate (R) due to the ingestion of ^{137}Cs, nearing their original state after ~1 year. As shown in Model I and II, this develops in a logarithmic way, so while the return to the expected body burden may take longer than a year, the majority of it is reincorporated quickly.

By comparing the annual body burden of the two theoretical children, a child that participates in the recreational holidays can expect a 11 % annual reduction in their ^{137}Cs body burden during the year they participate in the programme, the reduction the following year is 1.1 % if they no longer participate. Notice, however, that the body burden is rapidly recovered once children return to Belarus, where 95 days after their return 75% of the body burden reduced during the programme is recovered. This implies that the radiological benefits related to the reduction of the body burden will not last longer than a few months if the child does not participate again in the programmes.

4.10 Body burden and dose comparison

In this section, we are going to compare the studied children's ^{137}Cs body burden and dose to that of people from non-contaminated areas and people from areas with naturally occurring high background radiation.

The average body burden in 70 kg adults living in non-contaminated zones is 8000 Bq, mainly from ^{40}K and ^{14}C. Assuming isotope ratios and specific activities are equal in children, the expected body burden for a 40 kg child who is not exposed to contaminated areas is 4600 Bq (UNSCEAR, 1982). Given the average ^{137}Cs body burden of 1100 Bq in children who have grown up in affected areas, this represents an additional dose of 24% over their homologues.

To better ascertain the significance of the amount of radiation received from ^{137}Cs by children living in contaminated areas of Belarus, the body burden is converted into effective dose (Sv), as this also accounts for the behaviour of the isotope and the type of disintegration (Encyclopaedia Britannica, 2011), as well as the effect on different tissues of the humand body.

To calculate the effective dose (Sv) received by these cases from the activity (Bq), the effective dose equivalent factor of ingested ^{137}Cs for children of the same age is applied: $1.0 \cdot 10^{-8}$ $Sv \cdot Bq^{-1}$ (ICRP, 2012). Children who do not attend recuperative holiday programmes receive an effective dose of 4.14 mSv annually from ^{137}Cs alone. Participants have a yearly reduction of 0.44 mSv from this amount.

The average annual human dose from background radiation is 2.4 mSv (UNSCEAR, 2008), but this is greatly variable across the world: while some areas have naturally occurring higher background doses, others present much lower values. For example, in Ramsar, Iran, there have been detected doses as high as the 260 $mSv \cdot yr^{-1}$, and the average dose reported in residents is 6 $mSv \cdot yr^{-1}$ (Ghiassi-nejad et. al., 2002). Assuming that Chernobyl affected children from Belarus receive an annual dose of 2.4 mSv apart from the 4.14 mSv from the ^{137}Cs alone, their total effective dose would be greater than that of the average Ramsar inhabitant, more than 6.5 $mSv \cdot yr^{-1}$.

5. Conclusions

The main purpose of this study was to further scientific knowledge concerning ^{137}Cs body burden reduction in Belarusian children, in order to understand the benefits provided by recuperative holiday programmes.

The principal stated goal of recuperative holidays is to reduce the amount of radiation the children are exposed to. Our study shows this decrease is minor and only accounts for the 11% of the total isotope incorporation a child would have in a year. This decrease has also limited permanence, given that 95 days after their return, 75% of their body burden has already been recovered. For this reason, ^{137}Cs body burden reduction is not as relevant as it seemed as an achievement of these programmes.

Children from Chernobyl affected areas have relatively higher radioactive body burdens than their counterparts and are exposed to effective doses (more than 6.5 $mSv \cdot yr^{-1}$) greater than people living in naturally high background dose. This value, while significant when compared with the average for non-contaminated areas, is comparable to that of locations with high naturally occurring radiation. Further research on the similarities between these two situations could help improve our understanding of them.

The information acquired through the interviews showed how child social and psychological welfare is improved thanks to the participation in recuperative holiday programmes. Social and financial support, as well as meaningful bonds, are developed and contribute to a better environment for the children. The formation of an external support network also helps the children to build a more structured life beyond the duration of the programme.

Some health improvements have been noted by the recuperative holidays' organizers, such as ameliorations in pre-existing conditions in some children. Despite these statements, evidence supporting them needs to be collected.

As some associations state, they focus on making a better life for the children beyond these programmes and develop support structures to further that goal. Due to the limited body burden reduction that has been calculated (11%), alternatives such as long-term re-location or a permanent change in diet could be more efficient ways to reduce children's exposure. Both measures could permanently reduce the intake of ^{137}Cs by the kids and therefore their body burden, and consequently be better at fulfilling the radiologically related goals stated by the programme organizers. Shifting the focus from ^{137}Cs body burden reduction to the social and psychological benefits of recuperative holidays would make much more sense according to the effectiveness in fulfilling each of these goals.

6. Limitations and future research

To conclude this project, we explore its limitations and the potential improvements and future research that would expand knowledge in this field, in order to achieve a more complete and exhaustive analysis of recuperative holidays programmes.

Our database was limited in sources, with insufficient information to describe general patterns for Belarusian children, and to accurately determine errors. Further sources of data would contribute to solidifying the database, reducing errors and increasing statistical significance. More information on the accuracy of the measurements would be helpful in assessing errors.

Specifically, more information on the place of residence of children would help in identifying correlations between ground contamination and incorporated body burden. This is rather complicated by the limited information on the current state of radiological contamination in the area.

With further study of contaminated areas and food supply, vulnerable populations could be identified, and adequate measures addressed to reduce ^{137}Cs exposure could be implemented.

Extensive research on the psychological and social benefits of recuperative holidays is essential to understand the scope of this kind of programmes.

7. Bibliography

Aarkrog, A. (1971). Prediction models for strontium-90 and caesium-137 levels in the human food chain. Health Physics, 20(3), 297–311. https://doi.org/10.1097/00004032-197103000-00007

Alexiévich, S. (2005), *Voces de Chernóbil. Crónica del futuro*, Barcelona. Debolsillo.

Alinaghizadeh, H., Wålinder, R., Vingård, E., & Tondel, M. (2016). Total cancer incidence in relation to 137Cs fallout in the most contaminated counties in Sweden after the Chernobyl nuclear power plant accident: A register-based study. BMJ Open, 6(12). https://doi.org/10.1136/bmjopen-2016-011924

Balonov, M., & Bouville, A. (2011). Radiation Exposures Due to the Chernobyl Accident. In Encyclopedia of Environmental Health. https://doi.org/10.1016/B978-0-444-52272-6.00086-6

Balonov, M. I. (1997). Health impacts of large releases of radionuclides. Internal exposure of populations to long-lived radionuclides released into the environment. Ciba Foundation Symposium, 203.

BELRAD Institute (2019). Retrieved 10 June 2020, from http://www.belrad-institute.org/En/doku.php

Beresford, N. A., Fesenko, S., Konoplev, A., Skuterud, L., Smith, J. T., & Voigt, G. (2016). Thirty years after the Chernobyl accident: What lessons have we learnt? Journal of Environmental Radioactivity, 157, 77–89. https://doi.org/https://doi.org/10.1016/j.jenvrad.2016.02.003

Bandazhevskaya, G. S., Nesterenko, V. B., Babenko, V. I., Babenko, I. V., Yerkovich, T. V., & Bandazhevsky, Y. I. (2004). Relationship between caesium (137Cs) load, cardiovascular symptoms, and source of food in "Chernobyl" children - Preliminary observations after intake of oral apple pectin. Swiss Medical Weekly, 134(49–50), 725–729.

Bhat, R., & Gómez-López, V. M. (2014). Radionuclides in Food: Past, Present and Future. In Practical Food Safety: Contemporary Issues and Future Directions (Vol. 9781118474). https://doi.org/10.1002/9781118474563.ch15

Cahill, D. F., & Wheeler, J. K. (1968). THE BIOLOGICAL HALF-LIFE OF CESIUM-137 IN CHILDREN DETERMINED BY URINARY ASSAY (Vol. 14). Health Physics Pergamon Press.

Chernobyl Children's Lifeline (2020). About Us. Retreived 12 May 2020, from https://www.ccll.org.uk/about_us

Chernobyl Children's Lifeline (2020). Recuperative holidays. Retreived 10 June 2020, from https://www.chernobyl-children.org.uk/recuperative-holidays

Devita, R., Grollino, M. G., Padovani, L., Tarroni, G., Olivieri, A., Sorcini, M., … Crescenzi, G. S. (2000). Health Status and Internal Radiocontamination Assessment in Children Exposed to the Fallout of the Chernobyl Accident. Archives of Environmental Health, 55(3), 181–186. https://doi.org/10.1080/00039890009603404

Donath, A. (1996). The whole-body incorporation of radioactive caesium in Switzerland during the last 30 years: A survey of young persons in Geneva and some measurements of Belarusian and Ukrainian children. World Health Statistics Quarterly, 49(1), 32–34.

Dubrova, Y. E., Nesterov, V. N., Krouchinsky, N. G., Ostapenko, V. A., Vergnaud, G., Giraudeau, F., … Jeffreys, A. J. (1997). Further evidence for elevated human minisatellite mutation rate in Belarus eight years after the Chernobyl accident. Mutation Research - Fundamental and Molecular Mechanisms of Mutagenesis, 381(2), 267–278. https://doi.org/10.1016/S0027-5107(97)00212-1

Encyclopaedia Britannica. Sievert (2011). Encyclopædia Britannica. Encyclopædia Britannica, inc. March 23, 2011. https://www.britannica.com/technology/sievert. Accessed June 12, 2020

European Commission (2003) Assistance Through Temporary Children's Holidays: Guidelines and Intervention Models – REMATCH (Ref.: 2002-102-YC). Brussels: European Commission.

Fairlie, Ian. Chernobyl's health impacts. Chain Reaction (2016). No. 126, Apr 2016: 22. https://search.informit.com.au/browseJournalTitle;res=IELHSS;issn=0312-1372 ISSN: 0312-1372.

Federación Pro Infancia Chernobyl (2020). Conócenos. Retrieved 10 June 2020, from https://proinfanciachernobyl.org/contact/

Fesenko, S. V., Alexakhin, R.M., Balonov, M.I., Bogdevich, I.M., Howard, B.J., Kashparov, V.A., Sanzharova, N.I., Panov, A.V., Voigt, G. & Yu Zhuchenka. An extended critical review of twenty years of countermeasures used in agriculture after the Chernobyl accident. Sci. Total Environ., 383 (2007), pp. 1-24. http://dx.doi.org/10.1016/j.scitotenv.2007.05.011

Gerasimov, Y., & Karjalainen, T. (2010). Atlas of the forest sector in Belarus Working Papers of the Finnish Forest Research Institute.

Ghiassi-nejad, M & Mortazavi, SMJ & Cameron, J & Niroomand-Rad, Azam & Karam, P.. (2002). Very high background radiation areas of Ramsar, Iran: Preliminary biological studies. Health physics. 82. 87-93. 10.1097/00004032-200201000-00011.

Gray, Colette. (2017). Crossing cultural barriers: children's views on the recuperative holiday experience, European Early Childhood Education Research Journal, 25:2, 321-339, DOI: 10.1080/1350293X.2017.1292652

Harrison, J. D., Smith, T. J., & Phipps, A. W. (2003). Infant doses from the transfer of radionuclides in mothers' milk. Radiation Protection Dosimetry, 105(1–4), 251–256.

Higley, K. (2006). Environmental consequences of the Chernobyl accident and their remediation:twenty years of experience. Report of the Chernobyl forum expert group 'Environment'. Radiation Protection Dosimetry, 121(4), pp.476-477.

Hill, P., Schläger, M., Vogel, V., Hille, R., Nesterenko, A. V., & Nesterenko, V. B. (2007). Studies on the current 137Cs body burden of children in Belarus - Can the dose be further reduced? Radiation Protection Dosimetry, 125(1–4), 523–526. https://doi.org/10.1093/rpd/ncm153

ICRP, 2012. Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.). https://doi.org/10.1016/j.icrp.2006.06.001

Kalef-Ezra, J. A., & Yasumura, S. (1997). Doses and risk estimates to the human conceptus due to internal prenatal exposure to radioactive caesium. Radiation Protection Dosimetry, 69(3), 205–210. https://doi.org/10.1093/oxfordjournals.rpd.a031905

Karches, G. J., Wheeler, J. K., Helgeson, G. L., & Kahn, B. (1969). Cesium-137 body burdens and biological half-life in children at Tampa, Florida, and Lake Bluff, Illinois. *Health physics*, *16*(3), 301–313. https://doi.org/10.1097/00004032-196903000-00006

Kashparov, Valery. (2003). Kashparov V.A. Hot Particles at Chernobyl //Environmental Science and Pollution Research, v.10 Special (1), 2003, pp.21-30.. Environmental Science and Pollution Research. 10. 21-30.

Konstantinov, I. O., Korelina, N. F., Lebedev, O. V., & Novikova, O. V. (2007). Age specific formation of doses in children exposed to radioactive caesium following the accident in the Chernobyl Nuclear Power Plant. Radiatsionnaia Biologiia, Radioecologiia / Rossiĭskaia Akademiia Nauk, 47(6), 741–745.

Labunska, I., Kashparov, V., Levchuk, S., Santillo, D., Johnston, P., Polishchuk, S., … Khomutinin, Y. (2018). Current radiological situation in areas of Ukraine contaminated by the Chernobyl accident: Part 1. Human dietary exposure to Caesium-137 and possible mitigation measures. Environment International, 117, 250–259. https://doi.org/10.1016/j.envint.2018.04.053

Leggett, R. W., Williams, L. R., Melo, D. R., & Lipsztein, J. L. (2003, December 30). A physiologically based biokinetic model for cesium in the human body. Science of the Total Environment, Vol. 317, pp. 235–255. https://doi.org/10.1016/S0048-9697(03)00333-4

Lestaevel, P., Racine, R., Bensoussan, H., Rouas, C., Gueguen, Y., Dublineau, I., … Souidi, M. (2010, February). Césium 137 : Propriétés et effets biologiques après contamination interne. Medecine Nucleaire, Vol. 34, pp. 108–118. https://doi.org/10.1016/j.mednuc.2009.12.003

Lindgren, A., Stepanova, E., Vdovenko, V., McMahon, D., Litvinetz, O., Leonovich, E., & Karmaus, W. (2015). Individual whole-body concentration of 137Cesium is associated with decreased blood counts in children in the Chernobyl-contaminated areas, Ukraine, 2008–2010. Journal of Exposure Science & Environmental Epidemiology, 25(3), 334–342. https://doi.org/10.1038/jes.2013.60

Luccioni, C., Kornevich, O., Rozhko, A., Averin, V., Kanada, S., Yauseyenka, V., … Tretiakova, J. (2016). Health check-ups of children living in a Belarus district contaminated after the Chernobyl accident. Radioprotection, 51(2), 91–99. https://doi.org/10.1051/radiopro/2016020

Martínez Gasol, C. (2020). Other forms of LCA:Carbon footprint of products and organizations (PPT).

McMahon, D. M., Vdovenko, V. Y., Karmaus, W., Kondrashova, V., Svendsen, E., Litvinetz, O. M., & Stepanova, Y. I. (2014). Effects of long-Term low-level radiation exposure after the Chernobyl catastrophe on immunoglobulins in children residing in contaminated areas: Prospective and cross-sectional studies. Environmental Health: A Global Access Science Source, 13(1). https://doi.org/10.1186/1476-069X-13-36

Melo, D. R., Lipsztein, J. L., Oliveira, C. A. N., Lundgren, D. L., Muggenburg, B. A., & Guilmette, R. A. (1998). Prussian blue decorporation of 137Cs in humans and beagle dogs. Radiation Protection Dosimetry, 79(1–4), 473–476. https://doi.org/10.1093/oxfordjournals.rpd.a032453

Michel, R., Daraoui, A., Gorny, M., Jakob, D., Sachse, R., Romantschuk, L. D., … Synal, H.-A. (2015). Retrospective dosimetry of Iodine-131 exposures using Iodine-129 and Caesium-137 inventories in soils - A critical evaluation of the consequences of the Chernobyl accident in parts of Northern Ukraine. Journal of Environmental Radioactivity, 150, 20–35. https://doi.org/10.1016/j.jenvrad.2015.07.023

Nesterenko, A. V, Nesterenko, V. B., & Yablokov, A. V. (2004). 2. Chernobyl's Radioactive Contamination of Food and People.

Nesterenko, V. B., & Nesterenko, A. V. (2009). Decorporation of Chernobyl radionuclides. Annals of the New York Academy of Sciences, Vol. 1181, pp. 303–310. https://doi.org/10.1111/j.1749-6632.2009.04838.x

Nesterenko, V.B.; Devojno, A.N.; Babenko, V.I. (1997). Radiation monitoring of the inhabitants and the foods in the Chernobyl zone of Belarus.

Petrangeli., G. (2006). Nuclear Safety. ISBN: 978-0-7506-6723-4. DOI: https://doi.org/10.1016/B978-0-7506-6723-4.X5000-1

Pudykiewicz, J. (1988). Simulation of the Chernobyl dispersion with a 3-D hemispheric tracer model. Tellus 41B, 391–412. Renn, O. (1990). Risk perception and risk management :a review. Pt. 1, Risk perception. 10.18419/opus-7299.

Rosoff, B., Cohn, S. H., & Spencer, H. (1963). I. Cesium-137 Metabolism in Man. In Source: Radiation Research (Vol. 19).

Rundo, J., & Turner, F. M. (1992). On the biological half-life of caesium in pregnant women and in infants. Radiation Protection Dosimetry, 41(2–4), 211–216.

Saenko, V., Ivanov, V., Tsyb, A., Bogdanova, T., Tronko, M., Demidchik, Y. U., & Yamashita, S. (2011). The Chernobyl Accident and its Consequences. Clinical Oncology, 23(4), 234–243. https://doi.org/10.1016/j.clon.2011.01.502

Schwarz, G., & Dunning, D. E., Jr (1982). Imprecision in estimates of dose from ingested 137Cs due to variability in human biological characteristics. *Health physics*, *43*(5), 631–645. https://doi.org/10.1097/00004032-198211000-00001

Sesana, L., & Zaninelli, M. L. (1996). Radiocaesium levels in children from Belarus. Radiation Protection Dosimetry, 64(4), 313–318. https://doi.org/10.1093/oxfordjournals.rpd.a031590

Spatial Data Download | DIVA-GIS. Diva-gis.org. (2020). Retrieved 10 May 2020, from http://www.diva-gis.org/datadown.

Svendsen, E. R., Kolpakov, I. E., Stepanova, Y. I., Vdovenko, V. Y., Naboka, M. V., Mousseau, T. A., Karmaus, W. J. J. (2010). ^{137}Cesium exposure and spirometry measures in Ukrainian children affected by the Chernobyl nuclear incident. Environmental Health Perspectives, 118(5), 720–725. https://doi.org/10.1289/ehp.0901412

Svensson, H. (1988). The Chernobyl accident-Impact on Western Europe. Radiotherapy and Oncology, volume 12, issue 1, P1-P13.

Tarroni, G., Castellani, C. M., Melandri, C., Battisti, P., Rampa, E., Ticconi, R., … Crescenzi, G. S. (1992). Evaluation of 137Cs internal contamination in children by means of whole body counter measurements. Radiation Protection Dosimetry, 41(2–4), 223–227.

Thornberg, C., Vesanen, R., Wallström, E., Zvonova, I., Jesko, T., Balonov, M., & Mattsson, S. (2005). External and internal irradiation of a Rural Bryansk (Russia) population from 1990 to 2000, following high deposition of radioactive caesium from the chernobyl accident. Radiation and Environmental Biophysics, 44(2), 97–106. https://doi.org/10.1007/s00411-005-0007-2

Trofimchik, Z. (2004). *Belarus: towards a new post-chernobyl rehabilitation strategy. Radiation Protection Dosimetry, 109(1-2), 141–145.* https://doi.org/10.1093/rpd/nch269

Ukranian Institute of Agricultural Radiology (UIAR) (1988). Spatial datasets of radionuclide contamination in the Ukrainian Chernobyl Exclusion Zone. Earth System Science Data. 10. 339-353. 10.5194/essd-10-339-2018.

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation (2008). Sources and effects of ionizing radiation. New York: United Nations (2010). p. 4. ISBN 978-92-1-142274-0.

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation (1982). Ionizing radiation: Sources and biological effects. New York: United Nations, updated 2016. http://www.unscear.org/docs/publications/1982/UNSCEAR_1982_Report.pdf

Vohra, K. G., Bhatnagar, V. S., Mishra, U. C., & Ragupathy, S. (1961). Measurement of caesium-137 in milk. Health Physics, 6(2), 142–148. https://doi.org/10.1097/00004032-196109000-00007

Whicker, F. W & Schultz, V. (1982). *Radioecology: Nuclear Energy and the Environment Volume II*. CRC Press.

Zhukova, E. (2020). Private humanitarian responses to disaster vulnerabilities: The Chernobyl children from Belarus in Italy. Childhood, 27(2), 238–253. https://doi.org/10.1177/0907568220901747

8. Annexes

8.1 Interview questions

8.1.1 Catalan

- Qui sou i a què us dediqueu ?
- Com vau poder començar la vostra activitat?
- Quins són els vostres contactes de referència a Bielorússia ?
- D'on provenen els infants i adolescents que acolliu ?
- Quants n'acolliu cada any i durant quants anys heu dut a terme el projecte ?
- Quant temps passen amb vosaltres ?
- Quins són els efectes en la salut dels infants i adolescents participants del projecte dels quals teniu coneixement ?
- Quins altres efectes (ex: socials, psicològics) heu pogut detectar o us han estat explicats?
- En alguna ocasió els participants han seguit algun tractament mèdic amb l'objectiu de reduir la seva càrrega corporal de cesi (ex: la ingesta de pectina)?
- Qui i com realitza les mesures de la càrrega corporal de ^{137}Cs als participants ?

8.1.2 Spanish

- ¿Quiénes sois y a qué os dedicáis?
- ¿Cómo pudisteis empezar vuestra actividad?
- ¿Quiénes son vuestros contactos de referencia en Bielorrusia?
- ¿De dónde provienen los niños y adolescentes que acogéis?
- ¿Cuántos acogéis cada año y durante cuántos años ha durado el proyecto?
- ¿Cuánto tiempo pasan con vosotros?
- ¿Cuáles son los efectos en la salud de los niños y adolescentes participantes del proyecto de los cuales tenéis conocimiento?
- ¿Qué otros efectos (ejemplo: sociales, psicológicos) habéis podido detectar o os han sido explicados?
- ¿En alguna ocasión los participantes han seguido algún tratamiento médico con el objetivo de reducir su carga corporal de cesio (ejemplo: la ingesta de pectina)?

8.2 Planification

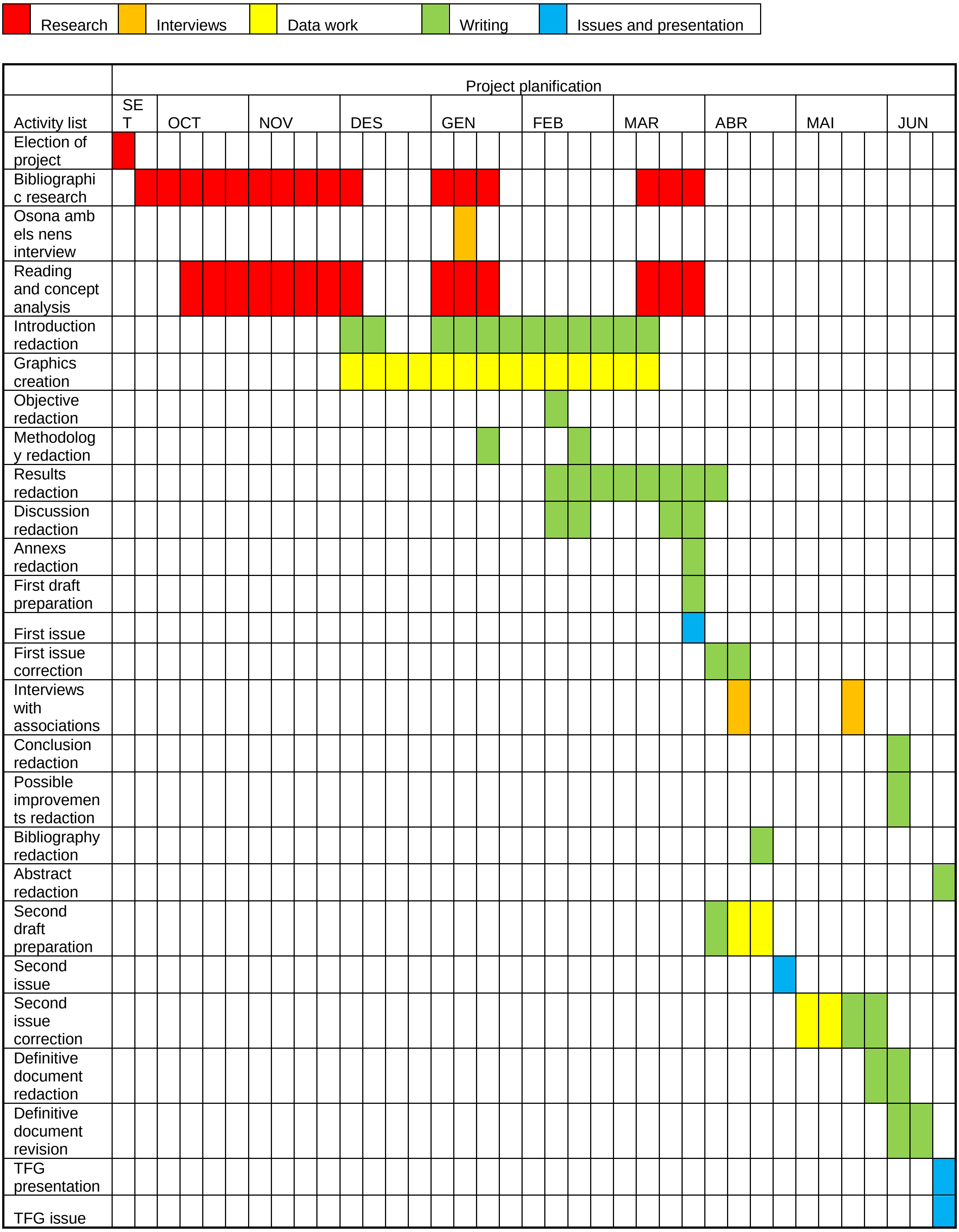


Figure 37: Gantt diagram.

8.3 Budget

DIRECT COSTS						
Concept		Amount	Unitary cost	People	Amortization	Cost
HUMAN RESOURCES						
Project redaction cost[1]		300h	20 €	2		12,000 €
TRIPS						
Trip cost	Train	40 trips	2.40 €	1		96 €
	Bus	40 trips	2.10 €	1		84 €
	Car	123,6 km	6.60 €			816 €
MATERIAL RESOURCES						
Non-perishable material	PCs	2	700 €		Lifetime of 120 months, 6 months for amortization	70 €
Perishable material	Office material	2	10 €			20 €
	Colour printout	200 pages	0.40 €			88 €
	Binding	2	4.00 €			8 €
	CDs	5	0.50 €			3.50 €
Subtotal						13.185,5 €
Light/gas/electricity/rent (20% of subtotal)						2,637.10 €
Reserve fund (10% of subtotal)						1.318,55 €
IVA (21%)						2,768.96 €
Total						19,910.11 €

The real budget has been equal to the predicted one except for the project redaction cost and the printing costs.

Car	Fuel type	Fuel price (€/L)	Average fuel consumption (L/100km)	Trip cost (€/km)
Seat Ateca	Gasoline	1.12	5.5	0.0616

1 The Col·legi d'Ambientòlegs de Catalunya estimates that the cost per hour of an environmental scientist work without professional responsibilities ranges from 20 to 40 €/h.
2 Fuel price according to Dieselogasolina.com

8.4 Carbon footprint

In this section, we aim to determine the environmental impact of our project in terms of contribution to global warming. To do so, it is necessary to calculate the carbon footprint of the project. The carbon footprint describes the total amount of CO_2 and other greenhouse gas (GHG) emissions caused directly or indirectly by an individual, organization, event or product throughout their whole life cycle (Sostenipra, 2020). Our main source of information has been the *Guia pràctica de càlcul d'emissions de GEH*, published by the Oficina Catalana del Canvi Climàtic (OCCC). We will express our calculations in equivalent CO_2 kg, which comprises the six global warming gases as stated by the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6). Most of our trips have been made in order to meet to work on the project. We have mainly travelled by train and bus and therefore we have saved some emissions that could have been generated if we had travelled by car.

We also travelled by car to Vic to interview *Osona amb els nens*.

Table 4: Calculations on emissions due to transport.

Vehicle	Fuel	Model	Emission factor (g $CO_2 \cdot km^{-1}$)	Distance (km)	Trips	Produced emissions (equivalent CO_2 kg)
Car	Gasoline	Seat Ateca	119	123.6	1	14,708.4
FGC	Electricity	FGC	34.32	6	40	8,236.8
Bus	Biodiesel		72.22	16.2	40	46,798.56
Total						69,743.76

Energy consumption was mainly due to to the functioning of our computers and lighting. Green energy providers have 0 emission factors. For lightning we have assumed 150 W of power.

Table 5: Calculations on emissions due to energy consumption.

Tool	Emission factor (g CO_2·kWh)	Hours of use	Power (W)	Produced emissions (equivalent CO_2 kg)
Laptop 1	0	300	90	0
Laptop 2	0	300	125	0
Lighting	0	600	150	0
Total				0

Printing emissions have been calculated based on the paper production factor emission by the Ministry for the Ecological Transition.

Table 6: Calculations on emissions due to printing.

Concept	Emission factor (g CO_2·page)	Pages	Produced emissions (equivalent CO_2 kg)
Printed TFG copies	3	200	0.6
Total			0.6

Total= 55,05 + 0 + 0,6 equivalent CO_2 kg= **55.65 equivalent CO_2 kg**