CHAPTER 6

OBSERVATIONS AND CONCLUSIONS

The present document is an assessment (or evaluation) of the risks of transporting spent nuclear fuel, updating the assessment performed for NUREG-0170, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*. Both NUREG-0170 and this document provide a technical basis for the regulations of 10 CFR Part 71.

Comment [MF1]: Which is it?

Deleted: *the 1977*

Formatted: Font: Italic

Comment [MF2]: What about NUREG/CR-6672 and Modal study?

Regulations and regulatory compliance analyses are different from risk assessments. A regulation must be conservative, because its purpose is to ensure safety, and 10 CFR Part 71, which regulates transportation, requires a conservative estimate (i.e., over-estimate) of the damage to a cask in an accident and the radiation emitted from the cask during routine transportation. The original technical basis for 10 CFR Part 71, NUREG-0170, was also conservative, but for a different reason: only limited data were available to perform the required assessment, so NUREG-0170 deliberately used conservative parameter estimates. The NRC's conclusion was that NUREG-0170 showed transportation of radioactive materials to be safe enough, even with conservative assumptions, to support the regulation.

When an assessment is used to inform regulations, the assessment should be as realistic as possible so as to provide information needed to confirm, or to revise, the regulations it informs. Realistic assessment depends on the data availability and accurate and precise modeling techniques that have become increasingly available in the years since 1977. Consequently, the Modal Study and NUREG/CR-6672 made good progress in assessing transportation risks more realistically than NUREG-170. As a result, both the calculated consequences and risks of radioactive materials transportation decreased. The decrease in risk means that the regulations provide a greater level of safety than previously recognized.

Deleted: However, assessments are not regulations; they serve a different purpose. An

The present study is a more accurate analysis than the previous analyses. Certified spent fuel cask types are analyzed, rather than generic designs. Recent (2005 or later) accident frequency data and population data are used in the analyses, and the modeling techniques have also been upgraded. This study, the Spent Fuel Transportation Risk Assessment, is another step in building a complete picture of spent nuclear fuel transportation safety, and an addition to the technical basis for 10 CFR Part 71 and represents the current state-of-the-art for such analyses. The results of this study are compared with preceding risk assessments in the figures that follow.

Deleted: closer to a "real world"

6.1 Routine Transportation

Figure 6-1 and Figure 6-2 show results of routine truck and rail transportation of a single shipment of spent nuclear fuel; Figure 6-1 plots average collective radiation dose (person-Sv) from truck transportation and Figure 6-2 from rail transportation. These average doses include the doses to the population along the route, doses to occupants of vehicles sharing the route, doses at stops, and doses to vehicle crew.

Deleted: Figure 6-1

Deleted: Figure 6-2

Deleted: Figure 6-1

Deleted: Figure 6-2

Collective doses from routine transportation depend directly on the population along the route and the number of other vehicles that share the route, and inversely on the vehicle speed. Doses to occupants of vehicles that share the route depend inversely on the square of the vehicle speed.

H-6

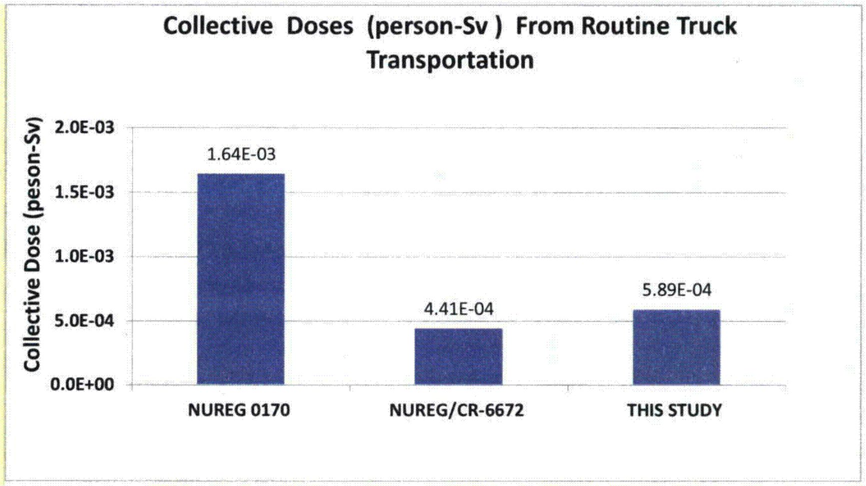

Figure 6-1. Collective doses (person-Sv) from routine truck transportation.

Comment [s3]: Needs to be hyphen between NUREG and 0170. Also, the y-axis label to Figure 6-1 should be person-Sv, not peson-Sv

The NUREG-0170 results for truck transportation were based on a single long route, constant values of rural, suburban, and urban population densities, on different and conservative vehicle speeds on rural, urban, and suburban roads, on a fixed rate of vehicle stops, and on 1975 estimates of vehicle density (vehicles per hour), all of which led to conservative results. NUREG/CR-6672 used more realistic distributed route lengths, population densities, vehicle occupancy and density, vehicle dose rate, and stop times and used the means of the distributions as parameters. As Figure 6-1 shows, the conservatism was decreased considerably.

The collective average dose in the present study is larger than the NUREG/CR-6672 result because present populations are generally larger, particularly along rural routes, and the vehicle densities are much larger (see Chapter 2). These increases were offset to some extent by the 20 percent greater vehicle speeds used in the present study.

Figure 6-2 and 6-3 show the difference between the present study's calculation of average collective dose to the public and doses to rail and yard crew, and NUREG/CR-6672 for rail casks.

Deleted: Figure 6-2

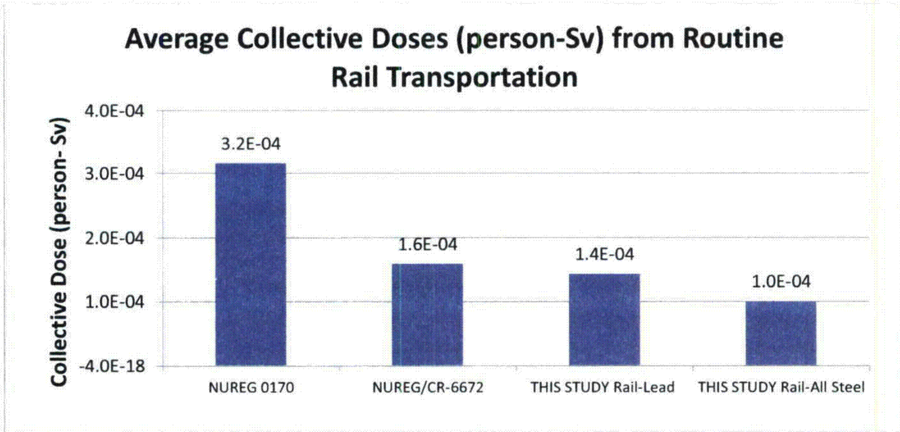

Figure 6-2. Collective doses (person-Sv) from routine rail transportation

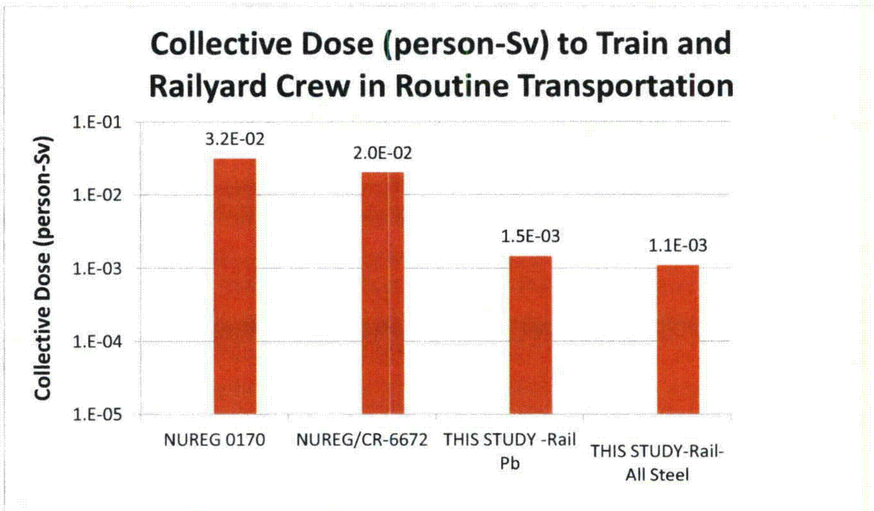

Figure 6-3. Collective dose (person-sv) to train and railyard crew in routine transportation

The difference in dose between the Rail-Lead cask and the Rail-Steel cask occurs because the latter cask has a smaller TI (Chapter 2). The differences in crew doses between the studies reflect the considerable difference between the methods used in the different studies.

The differences in the collective doses from routine transportation between the cited studies are not the result of differences in external radiation from the spent fuel casks. The 1975 version of 10 CFR Part 71[1] specified the same limit on external radiation (the transport index) as Part 71 specifies today. The differences in results are due primarily to vehicle speed, population and vehicle densities, and differences in calculating crew and yard doses. These differences are summarized below:

- Differences in vehicle speed. The faster the cask moves past a receptor, the less that receptor is exposed. NUREG-0170 and NUREG/CR 6672 used 80 kph for all truck routes and 64 kph on rural rail routes, 40 kph on suburban rail routes, and 24 kph on urban rail routes. The truck speeds used in this study are 108 kph on rural routes, 102 kph on suburban routes, and 97 kph on urban routes and the rail speed is 40 kph on rural and suburban routes and24 kph on urban routes. Faster highway vehicle speeds results in lower individual doses from truck transportation. The present speeds are based upon reported speed distributions for trucks and trains instead of the estimated values used in the previous studies.
- Differences in populations along the routes. NUREG-0170 used six persons per km^2 for rural populations, 719 per km^2 for suburban routes, and 3861 per km^2 for urban routes. NUREG/CR-6672 used 1990 census data provided by the code TRAGIS and used the mean values of Gaussian distributions of population densities on 200 routes in the United States. This study uses 2000 census data, updated to 2009, for the rural, suburban, and urban truck and rail route segments in each state traversed in each of the sixteen routes studied.
- Differences in vehicles per hour on highways. NUREG-0170 and NUREG/CR-6672 both used the 1975 values of 470 vehicles per hour on rural routes, 780, on suburban routes, and 2800 on urban routes. This study used 2002 state vehicle density data for each state traversed. The national average vehicle density is 1119 vehicles per hour on rural routes, 2464, on suburban routes, and 5384, on urban routes. This very large difference in vehicle density probably explains the differences in truck doses between NUREG/CR-6672 and this study.
- Differences in calculating doses to rail crew. NUREG-0170 calculated doses to rail and railyard crew by estimating the distance between the container carrying radioactive material and the crew member. NUREG/CR-6672 used the Wooden (1986) calculation of doses to railyard workers, and did not calculate a dose to the crew on the train. This study calculated all doses using the formulations in RADTRAN 6, calculated an in-transit crew dose, used an updated value for the time of a classification stop (27 hours instead of 30 hours), and used in-transit stop times from TRAGIS rather than the stop dose formula, pegged to total trip length, used in NUREG/CR-6672. The in-transit crew dose calculated in this study was small enough that it contributed a negligible amount to these doses.

Dose to the maximally exposed individual is a better indication of the radiological effect of routine transportation than collective dose. The dose to the maximally exposed individual is

Deleted: Web

Comment [MF4]: TRAGIS superseded the legacy HIGHWAY and INTERLINE routing codes about 2000. Was TRAGIS used to develop the 200 routes discussed in this bullet or were the legacy HIGHWAY and INTERLINE codes used? Also, it is stated in this bullet that this study uses 2009 census data. With most of the truck route population data matching the output from the TRAGIS model, it is questionable whether 2009 census data was used. Population data in the TRAGIS model is based on the 2000 Census. Chapter 2 states that 2008 census data was used.

Comment [MF5]: What is a truck dose? Is it the dose a truck receives?

Deleted: Web

[1] A copy is provided in NUREG-0170.

shown in Figure 6-4 for NUREG-0170 and for the three cask types of this study. NUREG/CR-6672 did not calculate this dose for routine transportation.

Deleted: Figure 6-4

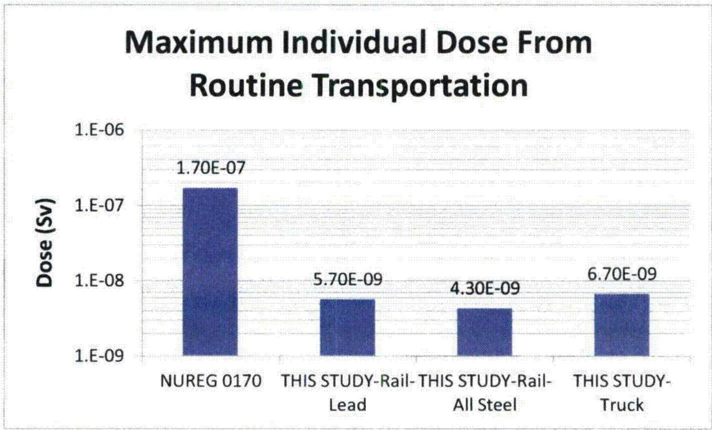

Figure 6-4. Maximum individual dose (Sv) from routine transportation.

6.2 Transportation Accidents

Radiological accident risk is expressed in units of "dose risk" that include the probability of an accident and the conditional probability of certain types of accidents. The units used are dose units (Sv) because probability is a unitless number. NUREG-0170, NUREG/CR-6672, and this study all used the version of RADTRAN available at the time of the study to calculate dose risk, but the input parameters differed widely. In addition, improvements in RADTRAN and in other modeling codes described in earlier chapters resulted in a more accurate analysis of cask behavior in an accident.

The results shown in Figure 6-5 and 6-6 for this study are averages over the 16 routes studied. As was discussed in Chapters 3, 4, and 5, a lead-shielded rail cask, the Rail-Lead cask in this study, is the only cask type of the three studied that can either release radioactive material or can lose lead gamma shielding in a rail or highway accident.

Deleted: Figure 6-5

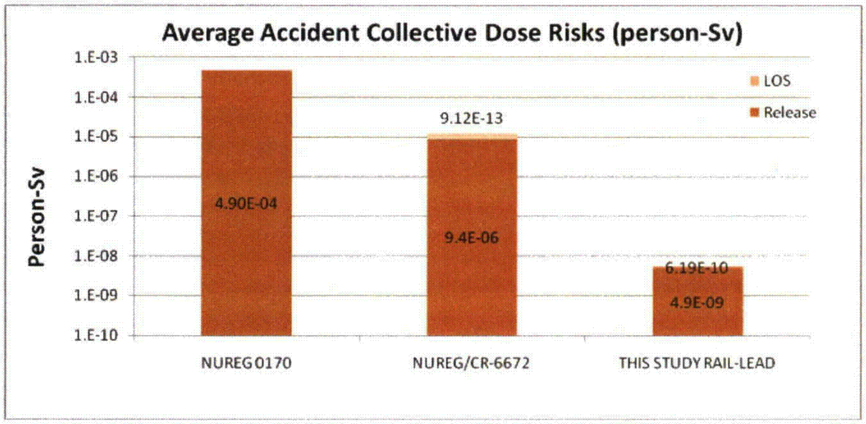

Figure 6-5. Accident collective dose risks from release and LOS accidents. The LOS bar representing the NUREG/CR-6672 collective dose is not to scale.

Unlike the results for routine transportation, the results shown in Figure 6-5 depend on different amounts of radioactive material released and different amounts of lead shielding lost. NUREG-0170 used a scheme of eight different accident scenarios, four of which postulated release of the entire releasable contents of the cask, two of which postulated no release, one postulated a ten percent release, and one, a one percent release. The range of conditional probabilities was from 1 x 10^{-5} for the most severe (100 percent release) accident to 80 percent for the two no-release accident scenarios. The NUREG-0170 "universe" of accidents and their consequences was based primarily on engineering judgment and was clearly conservative.

NUREG/CR-6672 analyzed the structural and thermal behavior of four generic cask designs—two truck and two rail casks—in great detail, and analyzed the behavior of the five groups that best describe the physical and chemical nature of the radioactive materials potentially released from the spent fuel through the casks. These five groups are: particulate matter, semi-volatile substances, ruthenium, gas, and Chalk River Unidentified Deposits (CRUD). The spent fuels considered were high burnup and low burnup PWR and BWR fuel. This analysis resulted in 19 truck accident scenarios and 21 rail accident scenarios, each with an attendant possibility, including a no-release scenario with better than 99.99 percent probability.

The present study followed the analytical outline of the NUREG/CR-6672 analysis, but analyzed the structural and thermal behavior of three certified cask designs loaded with the fuel that the cask is certified to transport. Instead of the 19 truck scenarios and 21 rail scenarios that included potential releases of radioactive material, the current study resulted in only seven rail scenarios that included releases, as described in Chapters 3 and 5. The only parts of the cask structure that could be damaged enough to allow a release are the seals. Release could take place through the seals only if the seals fail and if the cask is carrying uncanistered fuel. No potential truck accident scenario resulted in seal failure, nor did any fire scenario. In the present study, only the Rail-Lead cask response to accident conditions resulted in a release. A comparison of the

Deleted:

Deleted: accidental

collective dose risks from potential releases in this study to both NUREG-0170 and NUREG/CR-6672, is appropriate, since the latter two studies considered only potential releases. The collective dose risks decrease with each succeeding study as expected, since the overall conditional probability of release and the quantity of material potentially released decreases with each successive study.

The collective dose risk from a release depends on dispersion of the released material, which then either remains suspended in the air, producing cloudshine, or is deposited on the ground, producing groundshine, or is inhaled. All three studies used the same basic Gaussian dispersion model in RADTRAN, although the RADTRAN 6 model is much more flexible than the previous versions and can model elevated releases. NUREG-0170 calculated only doses from inhaled and resuspended material. NUREG/CR-6672 included groundshine and cloudshine as well as inhaled material, but overestimated the dose from inhaled resuspended material. The combination of improved assessment of cask damage and improved dispersion modeling has resulted in the decrease in collective dose risk from releases shown in Figure 6-5.

Frequently, public interest in the transportation of spent fuel focuses on the consequences of possible accidents (without regard to their likelihood). The average estimated consequences (collective doses) from potential accidents involving release for the present study is 2 person-Sv. This consequence is orders of magnitude less than the 110 person-Sv in NUREG-0170 and 9000 person-Sv estimated from Figure 8.27 in NUREG/CR-6672.

NUREG-0170 did not consider loss of spent fuel cask lead shielding, which can result in a significant increase in the dose from gamma radiation being emitted by the cask contents. NUREG/CR-6672 analyzed 10 accident scenarios in which the lead gamma shield could be compromised and calculated a fractional shield loss for each. An accident dose risk was calculated for each potential fractional shield loss. The present study followed the same general calculation scheme, but with a more sophisticated model of gamma radiation from the damaged shield and with 18 potential accident scenarios instead of 10. Much of the difference between the NUREG/CR-6672 dose risks from shield loss and this study is the inclusion of accident scenarios that have a higher conditional probability than any such scenarios in NUREG/CR-6672. The consequence of loss of lead shielding estimated in NUREG/CR-6672 Table 8.13 is 41,200 person-Sv, about 100 times the 690 person-Sv estimated in this study. Lead shield loss clearly affects only casks that have a lead gamma shield; casks using DU or thicker steel shielding would not be affected.

More than 99.999 percent of potential accident scenarios do not affect the cask at all and would not result in either release of radioactive material nor increased dose from loss of lead shielding. However, these accidents would result in an increased dose from the cask external radiation to the population near the accident, because the cask remains at the location of the accident until it can be moved. A nominal ten hours was assumed for this delay in this study. The resulting collective dose risk from this accident is shown in Figure 6-5 for all three cask types studied. Even including this additional consequence type, the collective dose risk from this study is less than that reported in either NUREG-0170 or NUREG/CR-6672.

Comment [s6]: Should this reference Figure 6-9 instead?

In conclusion, the three studies reviewed here show that the NRC regulation of transportation casks ensures safety and health. The use of data in place of engineering judgment shows that accidents severe enough to cause loss of shielding or release of radioactive material are improbable and the consequences of such unlikely accidents are serious but not dire. Moreover, these consequences depend on the size of the population exposed rather than on the radiation or radioactive material released. The consequences (doses) to the maximally exposed individual, 1.6 Sv from a release and 1.1 Sv from loss of lead shielding, are chronic rather than acute doses.

Comment [s7]: Where is the 1.1 Sv dose from LOS previously mentioned in Chapters 1-5? I do not understand how it was obtained based on Fig 5-2 - perhaps it has to do with assumed time of exposure, but not clear. And is this worker exposure? I'm assuming so since App. V.3.1.1 on p. 451 gives a dose of 1.33 mSv as max dose to public from LOS event. (CParks)

The most significant consequence of an accident, in addition to any non-radiological consequence of the accident itself, is the external dose from a cask immobilized at the accident location. Average collective doses from this type of accident for the 16 routes studied are shown in Figure 6-9. The most significant parameters contributing to this dose are the accident frequency and the length of time that the cask sits at the accident location. Even in this case, the significant parameter in the radiological effect of the accident is not the amount or rate of radiation released, but the exposure time.

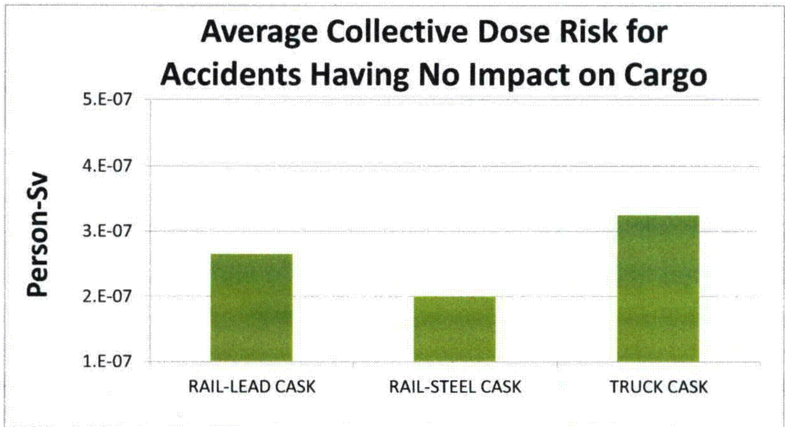

Figure 6-9. Average collective dose from accidents that have no impact on the cargo.

This study demonstrates that risks of transporting spent nuclear fuel are extremely small, and are essentially a tiny fraction of background radiation dose.

- Radiological risks to the public from routine transportation of spent fuel are very small for all shipments.
- When spent fuel is transported in a canister inside a rail cask, the cask is not expected to release radioactive material in an accident, even if the accident involves a fire.
- When spent fuel is transported in a truck cask, the cask is not expected to release radioactive material in an accident, even if the accident involves a fire.

- When spent fuel is transported in a rail cask without an inner canister, only extremely severe and rare accidents can lead to any release of radioactive material—approximately one accident in 100,000.

- Even this extremely rare accident results in a relatively low dose consequence.

- An accidental fire that burns hot enough for long enough, and is close enough to either a truck or rail cask to cause damage is highly unlikely – the probability that this situation occurs is less than one in ten billion, and the accident would not result in any release of radioactive material, only a loss of shielding both for gammas and neutrons.

- The regulation of spent fuel transportation guarantees that such transportation will have no adverse impact on people or the environment. The regulation is effective and accomplishes its purpose.

Public perception of radiological risk of transportation may have been distorted by an emphasis on the number of people exposed to a shipment and by failing to recognize that those same people are exposed to background radiation, which is continuous and which delivers a much larger dose. Transportation risk depends more on artifacts of calculation, parameter selection (like the number of people along a route) and assumptions than on the amount of radiation emitted. The conservative estimates of NUREG-0170 may have inadvertently contributed to this misperception The more realistic and less conservative the analysis, the greater the likelihood of redirecting public perception to the more realistic result that spent fuel transportation is so well regulated that it carries almost no risk.

In the nearly 40 years since the NRC published NUREG-0170, there have three reconfirmations of the results—that regulations for spent fuel transport adequately protect the public. Each of these subsequent studies has utilized more sophisticated analysis techniques and improved data to obtain an improved estimate of the risks of transporting spent fuel, and each time the reported risks have been less. While this study has used improved analysis techniques in place of conservative estimates, it still retains conservatism. Some of these conservatisms are:

- Assuming the casks will transport the worst-case fuel they are certified for.
- Neglecting the protection provided by the trailer or railcar that is carrying the cask.
- Assuming the fire accidents happen after the cask has been exposed to extreme normal conditions of transportation temperature.
- Not taking credit for operational controls, such as speed restrictions for trains transporting spent fuel.
- Hard rock surfaces are assumed to be unyielding, but would have to be able to withstand a force of more than 146 MN (33,000,000 pounds) in order to cause a release from any of the casks studied.

Comment [s8]: 1.. Please add the word accidents or shipments as appropriate. Is it 1 accident in 100,000 accidents or 1 accident in 100,000 shipments? It is not clear to me which is the case.

Comment [s9]: The ending phrase "relative low dose consequence" needs to have more detail. This is a *Conclusions* section and it is important to not have the appearance of "sweeping things under the rug." I would not call 1.6 Sv a relatively low dose, yes it is low consequence because of its low probability, but state the dose and why it is low consequence, don't use vague concepts to get your point across.

Comment [MF10]: This seems too strong. It is not clear that it will have no adverse impact. To make this statement the study would have to present copious amounts of information about the maximally exposed individual.

Comment [MF11]: This paragraph is very well written!

Comment [MF12]: This information should come earlier – either at the beginning of the chapter or at least above the previous paragraph. The previous paragraph should be the final statement.