An Assessment of the Potential Impacts on Irradiated Nuclear Fuel Transportation Operations of Applying ICRP Publication 60 Recommendations to Transport Regulations[a]

R. B. Pope and J. E. Ratledge
Oak Ridge National Laboratory[b]
Oak Ridge, Tennessee, USA

C. V. Hill and G. C. Loud
Science Applications International Corporation
Oak Ridge, Tennessee, USA

INTRODUCTION AND BACKGROUND

The International Atomic Energy Agency (IAEA) provides the worldwide basis for regulating the transportation of radioactive materials, the current form of which was issued in 1985 and has since been amended (IAEA 1990). This document [denoted here as "Safety Series No. 6"] serves as regulations for activities controlled or funded by the IAEA and as a model for domestic regulations.

The "*General principles for radiation protection*," embodied in paragraphs 201 - 205 of Safety Series No. 6, are patterned after the requirements set forth in the IAEA's companion document on basic safety standards for radiation protection (IAEA 1982) [denoted here as "Safety Series No. 9"]; and these in turn were developed based upon various recommendations made by the International Commission on Radiological Protection (ICRP).

As noted in the Foreword to the 1985 Edition of Safety Series No. 6 (removed in the Foreword of the 1990 amendment), the document:

> "*sets forth a new system of dose limitation, the components of which are: (1) justification of the practice, (2) optimization of protection for sources of exposure, and (3) individual dose limitations.*"

This paper focuses on the third component noted above, that is, upon the requirements to provide individual dose limitations. This need to implement limitations on individual dose commitments resulted in the requirements in paragraph 204 of Safety Series No. 6 dealing with operational radiological protection which, among other things specify that, for occupationally exposed workers, if:

> (i) "*the dose received is likely to be between 5 mSv (500 mrem) and 15 mSv (1500 mrem) per year, periodic (as necessary) environmental monitoring and assessments of radiation exposure levels in work areas (including in* ***conveyances****) shall be conducted; and*"

---

[a] The authors acknowledge the work of A. C. Heitzman and E. O. Rutenkroger of SAIC, Oak Ridge, Tennessee, USA, for assisting in the assessment of worker exposures used in this paper.

[b] Managed by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract DE-AC05-84OR21400.

(ii) *"the dose received is likely to be between 15 mSv (1500 mrem) and 50 mSv (5000 mrem) per year, individual radiation exposure monitoring programmes and special health supervision shall be required."*

Beyond the inclusion of this requirement, the need for including dose limitations resulted in the addition in paragraph 205 of Safety Series No. 6 of design (or planning) limits for calculating segregation distances or dose rates in regularly occupied areas that require, for transport workers, *"a dose level of 5 mSv (500 mrem) per year as the limiting value."* This limit was derived as being a reasonable fraction (1/10th) of that allowed in Safety Series No. 9 for all sources.

DISCUSSION OF POTENTIAL CHANGES IN REQUIREMENTS

The ICRP has now issued new recommendations (ICRP 1990) [denoted here as ICRP 60] which are under consideration by the international community, including the IAEA, for adoption into international regulatory documents, including Safety Series Numbers 6 and 9. These recommendations reduce the individual dose limits and have the potential of significantly impacting the operation of radioactive material transportation systems which have been designed to satisfy the Safety Series No. 9 and Safety Series No. 6 requirements discussed above, or earlier requirements.

Specifically, ICRP 60 recommends a significant reduction in the dose limits, for both workers and members of the public. Table 1 compares the current Safety Series No. 9 occupational limit values with those from ICRP 60.

Table 1. Comparison of Radiation Protection Requirements Currently in IAEA Safety Series No. 9 with the Guidance Provided in ICRP Publication No. 60

Application	1982 Edition, Safety Series No. 9	1990 Recommendations, ICRP Publication 60
Occupational	50 mSv (5000 mrem) per year	20 mSv (2000 mrem) per year, averaged over defined periods of 5 years [with *"the further provision that the effective dose should not exceed 50 mSv in any single year."*]

What follows focuses on this 60% reduction in occupational dose limits as recommended in ICRP 60; speculates on how these might be adopted into Safety Series No. 6; and assesses the impacts these reductions could have (if incorporated into Safety Series No. 6 as postulated) on the operation of an irradiated nuclear fuel (INF) transport system. Evaluation of the consequences on the road carriage of INF in a cask, transported under the **exclusive use** provision of the regulations, will be presented. Specifically, it will focus on the potential impacts on worker controls if the individual dose limits in paragraphs 204 and 205 of Safety Series No. 6 were unilaterally reduced 60% while the radiation dose rate limits which control the design and use of INF casks were to remain as currently structured in Safety Series No. 6. These latter limits are:

(1) 10 mSv/h (1000 mrem/h) at any point on the external surface of the cask [paragraph 469(a) of Safety Series No. 6, and Table IX of Safety Series No. 6 for carriage under exclusive use]

(2) 2 mSv/h (200 mrem/h) at any point on the outer surface of the vehicle, including the upper surface of the load and lower external surface of the vehicle [paragraph 469(b) of Safety Series No. 6];

(3) 0.1 mSv/h (10 mrem/h) at any point 2 m from the vertical planes represented by the outer lateral surfaces of the vehicle [paragraph 469(c) of Safety Series No. 6]; and

(4) 0.02 mSv/h (2 mrem/h) in any normally occupied position, unless persons in these areas are provided with personal monitoring devices [paragraph 470(b) of Safety Series No. 6]

On the basis of the preceding assumptions, ICRP 60 might lead to a requirement in Safety Series No. 6, similar to the current paragraph 204, which could read:

Possible New Para 204 --

> *"204. The nature and extent of the measures to be employed in controlling radiation exposures shall be related to the magnitude and likelihood of the exposures. Administrative requirements applicable to transport workers are set forth in Section V of the Basic Safety Standards for Radiation Protection. For individual occupationally exposed workers, where it is determined that the dose received*
>
> *(a) is most unlikely to exceed 2 mSv (200 mrem) per year, neither special work patterns nor detailed monitoring or assessment or radiation doses shall be required;*
>
> *(b) is likely to be between 2 mSv (200 mrem) and 6 mSv (600 mrem) per year, periodic (as necessary) environmental monitoring and assessments of radiation exposure levels in work areas (including in **conveyances**) shall be conducted; and*
>
> *(ii) is likely to be between 6 mSv (600 mrem) and 20 mSv (2000 mrem) per year, individual radiation exposure monitoring programmes and special health supervision shall be required."*

Similarly, on the basis of the preceding assumptions, ICRP 60 might lead to a requirement in Safety Series No. 6, similar to the portion of the current paragraph 205 that applies to workers. This might read:

Possible New Para 205 --

> *"205. **Radioactive material** shall be segregated sufficiently from transport workers and from members of the public. Different limiting values for dose, only for the purpose of calculating segregation distances or dose rates in regularly occupied areas shall be required:*
>
> *(a) For transport workers, in the determination of segregation distances or dose rates in regularly occupied working areas, a dose level of 2 mSv (200 mrem) per year shall be used as the limiting value. This value, together with hypothetical but realistic mathematical models and parameters, shall be used to determine segregation distances or associated dose rates for transport workers.*

AN ASSESSMENT OF IMPACTS OF POTENTIAL CHANGES

The assessment of the impacts of these potential changes in the regulations on the operation of a specific transportation system was performed. The results are presented below to facilitate discussion, assist those deliberating how to incorporate the recommendations of ICRP 60 into the transportation regulations, and to assist those developing new transportation systems in adapting their designs to better accommodate the changes, should they occur.

Impact of Operating at Maximum Limit in Occupied Area

In order to consider the impacts of these possible changes, a truck-carried INF cask, designed for the maximum radiation level without individual monitoring in the occupied area of the road vehicle (i.e., the tractor), was assessed. Specifically, the current limit established in Safety Series No. 6 [Para 470(b)] for the radiation level "*at any normally occupied position*" is 0.02 mSv/h (2 mrem/h), "*unless the persons occupying such positions are provided with personal monitoring devices.*"

The continuous operation of a fleet of these road-transported casks was initially used as the model for assessing the potential design and operational impacts of applying ICRP 60 occupational individual dose limits.

To serve as a basis for comparison, it was first assumed that transportation operations use continuously employed, two-person teams of drivers; variations on this assumption were then explored to define alternatives to reducing personnel exposure. The cask/trailer/tractor system, operating using a "sleeper" on the tractor, was considered. Here, a single, continuously employed, two-person driver team would operate the cask, with its associated tractor/trailer system, on an essentially continuous basis. The cask would operate from points of origin, after being loaded with INF, to a destination for unloading, followed by return trips with the cask unloaded. The only period of time when the cask and driving team would not be in service would be during the annual maintenance period. During transit of the cask, the operation would include the necessary stops for refueling the tractor and for satisfying necessary driver personal needs and regulatory-mandated, out-of-tractor resting. The driver team would take time off during the cask loading/unloading periods.

Three alternative operating scenarios in which the tractor would not be equipped with a sleeping unit were also assessed. In comparison with the sleeper-equipped option, these would entail:

1. Use of a support vehicle, where additional crew members are carried in the support vehicle that travels with the cask/trailer/tractor unit. This mode of operation would allow almost continuous transit of the cask but would require a much larger operating crew.

2. Use of a stop and rest strategy, where driver teams would stop at preselected areas and rest away from the tractor. During these rests, guards would be provided at the rest areas. This mode of operation would significantly reduce the usage of the casks because of the interruptions during transit, and would therefore require a much larger cask fleet.

3. Use of staged relief driver teams, where preselected driver change points are used and replacement driver teams would be exchanged during the course of transport. This mode of operation would allow for almost continuous transit of the cask but would require a much larger operating crew.

The results of this assessment are shown in Table 2.

The results of this assessment, considering a cask designed to operate at the radiation limit for the road-vehicle-occupied area as established in Safety Series No. 6, show that:

1. for the current Safety Series No. 6 requirements, the application of Paragraph 204 would require actions ranging from individual monitoring (for a sleeper-equipped truck system) to no action being required (for the staged relief driver teams); and

2. for the possible revisions to paragraph 204 noted above, most shipments would need to be made with individual monitoring and only the staged relief driver team operations could be done with the periodic monitoring in the work area.

Table 2. Projected Annual Radiation Exposure of Drivers and Impacts of Applying Different Radiation Protection Standards for Tractor/Trailer Units Carrying INF Casks Operating with Radiation Levels at the Road Vehicle Operating Limit

Operating Scenario	Projected Driver Exposure Per Driver (mSv/y)	Projected Operational Impacts: Applying Series No. 6	Projected Operational Impacts: Applying ICRP 60
Sleeper-Equipped	~17	individual exposure monitoring and special health supervision required [para 204(c)]	individual exposure monitoring and special health supervision required [para 204(c)]
No Sleeper:			
1. Support Vehicle	~8	periodic monitoring of radiation exposure levels potentially required [para 204(b]	individual exposure monitoring and special health supervision required [para 204(c)]
2. Driver Team, Stop and Rest	~8 - 11	periodic monitoring of radiation exposure levels potentially required [para 204(b)]	individual exposure monitoring and special health supervision required [para 204(c)]
3. Staged Relief Driver Teams	~2 - 6	generally, no special work patterns nor detailed monitoring required [para 204(a)]	periodic monitoring of radiation exposure levels potentially required [para 204(b)]

Thus, based upon the simplistic view of operations and design described above, the changing of paragraph 204 of Safety Series No. 6 to reflect ICRP 60 recommendations could have significant impacts on the manner in which INF is shipped. Even more important, this analysis shows that the requirements in both paragraphs 204 and 470(b) need to be considered together when any changes are made to the regulatory requirements. It is also noted that, although the preceding shows that operations could carry on under any of the scenarios considered based upon the requirements in paragraphs 204 and 470(b) of Safety Series No. 6, the requirement in paragraph 205 (for calculating "*dose rates in regularly occupied areas*") is in conflict with this conclusion. The requirement of paragraph 205 would not be satisfied, and operations could potentially be restricted as a result.

The preceding shows that, in considering how to apply the recommendations of ICRP 60 to Safety Series No. 6, close consideration of all the radiation protection requirements must be considered in concert.

Impact of Operating at Lower Limits in Occupied Area

In order to further consider the implications of the ICRP 60 recommendations, the continuous operation of two road-transported cask designs currently under development in the United States (U.S) for the shipment of INF by the U.S. Department of Energy's Office of Civilian Radioactive Waste Management was used. The casks, the General Atomic GA-4 (being designed for carriage of a maximum of 4 pressurized-water reactor assemblies), and the GA-9 (being designed for the carriage of a maximum of 9 boiling-water reactor assemblies) were assumed to be completed and operated as

currently designed. The assumptions concerning operational scenarios described in the previous section were used. The sleeper-equipped option and the three nonsleeper options were all addressed.

Individual driver exposures for these strategies have been projected based upon design predictions of the maximum radiation levels in the driver-occupied area of the tractor that would be used for transporting the cask/trailer system. These values were determined by the cask designer, for the bolted-lid end of the cask, at a distance of approximately 5.8 m. These predicted values were extended analytically to the distance from the bolted-lid end of the cask to the location in the tractor and sleeping unit for each cask configuration. The projected maximum radiation levels used in the analyses are summarized in Table 3.

As previously noted, the current limit established in Safety Series No. 6 [Para 470(b)] for the radiation level "*at any normally occupied position*" is 0.02 mSv/h (2 mrem/h), "*unless the persons occupying such positions are provided with personal monitoring devices.*" All the projected values shown in Table 3 lie within this limit, and under the current limit, personal monitoring devices would not be required.

The projected annual exposures to drivers of these casks are as shown in Table 4. They range from approximately 0.3 mSv/y (30 mrem/y) to 4 mSv/y (400 mrem/y) depending upon the individual scenario assumed.

When radiation exposures to workers (Safety Series No. 6, paragraph 204) are operationally controlled according to regulations, the projected annual exposures place all of the analyzed operating scenarios -- based upon the current regulatory requirements -- in the range where "*neither special work patterns nor detailed monitoring or assessment of radiation doses shall be required.*" In contrast, however, by assuming that the same philosophy of measures for controlling radiation exposure is applied to future revisions of the transportation regulations, and that the limiting values where measures are required are reduced by 60%, the sleeper-equipped tractor operating scenario could result in annual individual exposures requiring at least "*periodic (as necessary) environmental monitoring and assessments of radiation exposure levels*" in the conveyances. It is projected that the no-sleeper options would remain with projected exposures such that no special radiation protection actions would be required.

Table 3. Predicted Maximum Radiation Levels in the Occupied Areas of the Transport Vehicle for the GA-4 and GA-9 Casks

Operating Location	Cask Type	Projected Radiation Exposure Rate (mSv/h)
Sleeper Position	GA-4	0.00394
	GA-9	0.00549
Driver Position	GA-4	0.00241
	GA-9	0.00333

The design-limiting value for transport workers in occupied areas, which is used for defining segregation distances during transport, is currently 5 mSv (500 mrem) per year (Safety Series No. 6, paragraph 205). Under this current limit, all scenarios are within this limit. However, should the limiting value be reduced by 60% to 2 mSv (200 mrem) per year, then only the nonsleeper options for the operation of the truck casks would be acceptable.

These situations are compared, for the present requirements in Safety Series No. 6 and for those which might result from applying ICRP 60, in Table 5.

Table 4. Projected Annual Radiation Exposure of Drivers of Tractor/Trailer Units Carrying GA-4/GA-9 Casks at Their Operational Design Limits

Operating Scenario	Cask Type	Projected Driver Exposure (mSv/y) Per Driver	Total Per Truck	
Sleeper-Equipped	GA-4	2.77	5.54	
	GA-9	3.86	7.72	
No Sleeper:				
a. Support Vehicle	GA-4	1.03	4.12	
	GA-9	1.42	5.68	
b. Driver Team, Stop and Rest	GA-4	1.00 - 1.27	2.00 - 2.54	54
	GA-9	1.38 - 1.75	2.76 - 3.50	50
c. Staged Relief Driver Teams	GA-4	0.30 - 0.73	1.56 - 2.04	04
	GA-9	0.41 - 1.01	2.13 - 2.83	83

SUMMARY AND CONCLUSION

This paper has addressed the possible impacts on future irradiated nuclear cask designs and their operations which could result from implementing the ICRP 60 recommendations into a future edition of Safety Series No. 6. Depending upon the changes that are made in Safety Series No. 6 in response to ICRP 60 recommendations, the operations of such casks could become much more complex and, in some cases, could become impossible.

Most important, however, it has been shown that as consideration is given to changing the transportation regulations in the radiation protection area, the requirements imposed to control radiation exposures must be considered as a group and not individually. In addition, they should probably be assessed against quantitative examples, as was done here. In doing this, the requirements in paragraphs 204, 205, and 470(b), and other radiation protection requirements throughout Safety Series No. 6, must all be considered together and changed in a manner that they do not impose conflicting requirements on package design and operation.

Table 5. Projected Impacts on Operations of Truck Shipments of INF of Applying ICRP 60 Recommendations to Paragraphs 204 and 205 of Safety Series No. 6

Operating Scenario	Cask Type	Projected Operational Impacts	
		1985 Safety Series 6	Applying ICRP 60
Sleeper-Equipped	GA-4 & GA-9	no action (para 204)	environmental monitoring and assessments of radiation exposure levels potentially required [para 204(b)]
		no limitation (para 205)	operations potentially prohibited (para 205)
No Sleeper:			
a. Support Vehicle	GA-4 & GA-9	no action no limitation	no action no limitation
b. Driver Team, Stop and Rest	GA-4 & Ga-9	no action no limitation	no action no limitation
c. Staged Relief Driver Teams	GA-4 & GA-9	no action no limitation	no action no limitation

REFERENCES

International Atomic Energy Agency 1982. *Basic Safety Standards for Radiation Protection*, 1982 Edition, Safety Series No. 9, STI/PUB/607, Vienna, Austria.

International Atomic Energy Agency 1990. *Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990)*, Safety Series No. 6, STI/PUB/866, Vienna Austria.

International Commission on Radiological Protection 1990. *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, United Kingdom.

PACKAGING TECHNOLOGY

Session 41:

THERMAL ACCIDENT-I

Chairman : M. Grenier
Co-Chairman : T. Nakajima
Coordinator : H. Yamakawa