Type B Activity Limits for Air Transport – (An Examination of Special Form and non-Special Form Limits)

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Summary:

This paper examines the application of the "Q system" with respect to the maximum limits of activity permitted in Type B (Type B(U) or Type B(M)) packages when transported by air. In particular, estimation is made of the radiological consequences to determine if there is a difference depending on whether the material is in special form or not. An estimate is also made of the radiological consequences of an air accident involving low dispersible radioactive material (LDRM) in the reference Type B package.

Background

In the 1996 edition of the IAEA "Regulations for the Safe Transport of Radioactive Material" Type B packages had a ceiling activity imposed for the first time on the permissible contents when used for transport by air.

> "416. *Type B(U)* and *Type B(M) packages*, if transported by air, shall meet the requirements of para. 415 and shall not contain activities greater than the following:
>
> (a) for *low dispersible radioactive material* — as authorized for the *package design* as specified in the certificate of approval,
> (b) for *special form radioactive material* — 3000 A_1 or 100 000 A_2, whichever is the lower; or
> (c) for all other *radioactive material* — 3000 A_2."

As can be seen, with paragraph 416 of the IAEA regulations there is now a three tier limit on the maximum amount of radioactive material allowed in Type B packaging when used for the air transport of that material. For non-Special Form Radioactive Material (non-SFRM), the limit is 3000 A_2. For Special Form Radioactive Material (SFRM), the limit is 3000 A_1 or 10^5 A_2, whichever is lower. For Low Dispersible Radioactive Material (LDRM), there is no limit except as authorized by the approval certificate. For larger quantities of radioactive material to be transported by air, a Type C packaging is required.

IAEA-TECDOC-702[i], which forms the basis of the maximum activity limits on Type B packages transported by air, indicates that the exemption levels for Type C packages were determined using "… risk analysis techniques based on limited tests carried out on a representative Type B packaging …"[ii]. This work with the "representative Type B packaging" appears to only deal with non-SFRM as the release fractions are indicated as multiples of A_2. The TECDOC goes on to indicate that "… it follows from the Q system that 3000 A_1 …"[iii] be the limit for SFRM. The TECDOC then goes on further to explain the recommendation for the additional limit of 10^5 A_2 for SFRM.

The IAEA radioactive material transport regulations currently undergo a review and possible revision every two years. In the two-year cycle that started in 2002, it had been proposed to increase the multiple for SFRM ten-fold to 30,000 A_1. After initial deliberations, the proposal was limited to just cobalt-60 (Co-60) in special form with the proviso that the radiological implications of increasing the limit for Co-60 SFRM to 30,000 A_1 would be examined and the increase shown to be justifiable before it would be accepted at the final review in that two-year cycle. At the final meeting of that cycle in Bonn, Germany, the proponent of the proposal provided economic and social reasons to permit the higher limit; however, a technical justification based on radiological hazard was not presented.

The maximum activity limit allowed in Type B packages transported by air of 3000 A_1 or 3000 A_2 depending on the form of the material appears on the surface to be equivalent; however, it is clear that this seeming equivalency needs to be explored to determine if it can withstand scrutiny. Underlying this appearance is the Q system and the bald statement that "it follows from the Q system", which was used to set the same numerical multiple of 3000 for SFRM.

Given the apparent economic and social need, it remains to be determined if a higher limit for SFRM, or the particular case for Co-60, can be justified from a radiological perspective. This paper attempts to estimate the radiological consequences of an aircraft transport accident involving 3000 A_1 (material in special form) in the reference Type B package and the radiological consequences of an aircraft transport accident involving 3000 A_2 (material not in special form) in the same package and answer whether the consequences are the same given all other circumstances being equal.

Q System

According to IAEA TS-G-1.1[iv], "The Q system defines the 'quantity' limits in terms of A_1 and A_2 values , of a radionuclide that is allowed in a Type A package." The Q system limits are derived using a dose reference level of 50 or 500 mSv, a set of exposure pathways and assumptions about the effects of an accident on a Type A package. There are 5 major exposure pathways;

Q_A – external dose due to photons;
Q_B – external dose due to beta emitters;
Q_C – Internal dose via inhalation;
Q_D – Skin contamination and ingestion doses; and
Q_F – submersion dose due to gaseous isotopes.

The A_2 is the smallest value resulting from consideration of the dose pathways; The A_1 is the smallest value resulting from consideration of Q_A and Q_B since the special form material is not very dispersible. Key points to keep in mind about the Q system are:

Table I – Dose pathway assumptions for Q System

Dose pathway	Key assumptions	Reference dose
Q_A	• complete loss of shielding • point source • distance of 1m • 30 minute exposure time	50 mSv
Q_B	• shielding factor of 3 • distance of 1m • 30 minute exposure time	500 mSv
Q_C	• release fraction between 0.01 and 0.001 • uptake ranges between 0.001 and 0.0001 • net factor used is 0.000001 • distance of 1m • exposure time 30 minutes for indoor • dispersion estimate for external exposures	50 mSv
Q_D	• release fraction of 0.01 • area equals 1 m^2 • 10% of released fraction ends up on skin • exposure time 5 hours	500 mSv

Dose pathway	Key assumptions	Reference dose
Q_F	• indoors • applies to gaseous contents only • 100% release • 300 m^2 dilution volume (room) • four air changes per hour • exposure time 30 minutes • submersion in semi-infinite cloud	50 or 500 mSv

IAEA-TECDOC 702

IAEA-TECDOC-702 is the basis for the limits on permissible radioactivity in Type B packages used for air transport (Type C exemption level). It uses an extension of the Q system, taking into consideration the effects of an air accident on a “reference” Type B package. Initial considerations in drafting the TECDOC focused on material with low A_2 values (plutonium like materials) that could present a significant hazard if released in large quantities; however, the TECDOC also made recommendations for SFRM and allowed for a “non-dispersible form” which has become known as Low Dispersible Radioactive Material (LDRM).

As noted earlier, release limits for normal form in an air accident were estimated using a reference Type B package. This package is assumed to lose between 0.3 and 3 percent of its contents in an aircraft accident at impact speeds somewhat above 85 m/s. With a content of 3000 A_2, releases between 100 A_2 and 10 A_2 are estimated. This sets an implicit reference dose level which corresponds to the release of this quantity of radioactive material.

Special form radioactive material is assumed to also provide a reduction factor on release similar to that provided by the packaging. No studies were presented to support this factor. For the purpose of this paper, this assumption is retained.

Reference Type B packaging

The model FS-47 is the reference Type B packaging used in the risk analysis work done by Hubert (et al) and consequently the FS-47 is the reference package for the TECDOC. Its anticipated behaviour in an air accident is used to set the Type C exemption level. The packaging Is used to transport plutonium materials. A one-half scale model was subject to impact onto an essentially unyielding target at speeds around 134 m/s. A model was also subjected an extended duration fire (1.5 hour) and extreme pressure tests (up to 3400 Bar). From the report of the impact test, the model sustained serious damage, losing leaktightness, but there was not a gross failure of the structure that would result in the complete ejection of the package contents.

Type C package design requirements

In order to qualify as a Type C package, a design must meet the regulatory criteria after being subjected to two test sequences. It is not necessary to subject the same specimen to both test sequences.

> “734. Specimens shall be subjected to the effects of each of the following test sequences in the orders specified:
>
> (a) the tests specified in paras 727(a), 727(c), 735 and 736; and
> (b) the test specified in para. 737.
> Separate specimens are allowed to be used for each of the sequences (a) and (b).”

The test sequence in 734(a) is an enhanced Type B sequence, with the differences being

- a specified test order,
- a puncture/tear test that replaces the drop II mechanical test (drop onto bar),
- the requirement to do both drop I and III mechanical test rather than either one or the other, and

- an increased fire duration of 60 minutes vs. 30 minutes.
- a less stringent immersion test (0.9m vs. 15 m)

The test sequence in 734(b) simulates the effect of a high speed impact, particular to the risk in an air transport accident environment.

Type B packages should perform reasonably well when subjected to 734(a) sequence unless they are susceptible to crushing (test in 727(c)) or have shielding or other material that degrade significantly due to the enhanced heat input. With respect to the enhanced thermal test of 736, the effect on SFRM is not expected to be significant. The puncture/tear test may result in deep penetration of the package, possibly breaching containment or SFRM, but it is also very likely that the probe will "seal" the damage area of the package as it may be difficult to remove the probe from the package test specimen if it penetrates deeply.

With respect to the test sequence in 734(b), the tests on the reference Type B package at higher speeds indicates that there is not a gross disintegration of the packaging. It would be reasonable to assume that some residual shielding would also remain following this test at the lower speed of 90 m/s.

Dose estimates

The expected doses from an air accident require summation of the doses from each of the five pathways used in the Q system. At any given distance from the accident scene, an individual could be exposed to the combined effects of external radiation from the radioactive material that remains in the wreckage of the package, as well as the dose arising from the released material that may be inhaled, ingested and give rise to an additional external dose due to an assumed cloud of released material. In reality, much of the released material may not be of a suitable size to be inhaled and larger particles may settle quickly reducing the radioactivity in the passing cloud. The estimates make conservative assumptions of the behaviour of the released material along the lines of the Q system. Each dose pathway and the assumptions used to estimate the dose are detailed as follows:

Table II - Dose pathway assumptions for air accident analysis

Dose pathway	Key assumptions	Reference dose
External dose due to photons, air accident	• retention of one-tenth value layer of shielding material (approx. 5 cm of steel) • not a point source – self shielding of 30%	Estimated at various distances from package remains
External dose due to beta emitters, air accident	• sufficient shielding remains to make this a dose pathway of limited significance	No contribution to exposure
Internal dose via inhalation, air accident	• release fraction 0.03 for package release fraction 0.03 for SFRM into package • dispersion estimate for external exposures using Q system assumptions for out-of doors exposures	Estimated at various distances from package remains
Skin contamination and ingestion dose pathway, air accident	• release fraction same as for internal dose	Estimated at various distances from package remains
Submersion dose, air accident	• submersion in cloud based on external dose from released material	Estimated at various distances from package remains

Results

Preliminary values for doses were estimated using the above assumptions. These are presented in Figure 1. Some of the assumptions were varied in the analysis to determine the sensitivity of the results to various assumed conditions. The effect of these sensitivity calculations are presented in a general way below.

The assumed residual-shielding and self-shielding effects do not affect the results significantly because of the large doses estimated from the other pathways. Due to the simplification of using a straight attenuation factor rather than calculating the effectiveness of, say 5 cm of steel, residual shielding, the external dose pathway results are likely conservative for weak gamma emitters.

The dose from the release fraction appears to be the most significant contribution to the total estimated dose at the levels assumed in the analysis. Small changes in the release fraction affect the estimated dose. This is due to the assumed triple effectiveness of released material, as it can give rise to inhalation, skin contamination/ingestion as well as submersion doses that are not limited to gaseous isotopes.

The results need to be used with caution as the dose estimates are based on some assumptions. Most of these assumptions have their base either in the Q system or in the assumptions used in IAEA TECDOC-702. Nonetheless, they remain assumptions that need to be validated.

Where the results are clearly different by at least an order of magnitude, refinement of the assumptions may only, in the most dramatic cases, serve to reduce the difference, rather than eliminating it. On this basis the following may also be said:

- The maximum doses from SFRM are in the same range as for non-SFRM; however, the average doses for SFRM when looking at all the isotopes listed in Table 1 of TS-R-1 would be significantly lower than the average for non-SFRM. This implies that for many isotopes SFRM does provide a significant reduction in estimated doses.

- In the particular case of Co-60, the doses from 3000 A_1 are estimated to be similar to that from LDRM, which are significantly less than the average SFRM estimated doses. If the release fraction from Co-60 SFRM were to be demonstrated lower than the assumed 0.03, there would be a large reduction in the estimated dose for Co-60, as the external dose component from the package wreckage is significantly lower than that for the average for LDRM. (see figure 1)

Discussion

Following this initial estimation of doses, it appears that for the worst case isotopes, it does follow from the Q system that the limit for SFRM should be 3000 A_1. For a large number of radioisotopes, special form does provide a lower exposure risk. In the particular case of Co-60 in special form, it may be possible to technically justify a higher multiple of A_1. Before such an increase is effected, the results, methodology and assumptions used in the analysis should be independently validated. In addition, further work to refine the assumptions would increase confidence in the results.

Further work

Work on the following issues would allow validation of some of the assumptions made and increase confidence in these preliminary results.

- Detailed modeling of plume,
- Collective dose estimation considering various population densities.
- Behaviour in a high speed impact of package designs that have significant biological shielding mass (e.g. lead).

- Estimation of the effect of the additional 30 minute thermal test duration on fusible shielding materials used in packages that have significant biological shielding requirements (e.g. lead).
- Choice and assessment of a “reference” special form radioactive material to validate the release fraction assumed in TECDOC.
- Refined dose estimates taking into account residual shielding material.
- Consensus on assumptions.
- Beta dose factors for various distances need to be tabulated.
- Independent validation of dose estimates.

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Key to figure 1

NF = material in normal form (i.e. non-SFRM)
SF = Special Form Radioactive Material (SFRM)
LD = Low Dispersible Radioactive Material (LDRM)
avg = average of values for all radioisotopes
max = max value for all isotopes
all = value from pathways as assumed in table II
ext = external dose pathway due to photons only
QS = Q system assumption of release which is used to infer the Q system uptake factor
Shielding = assumption of residual shielding of packaging or debris and self-shielding effects

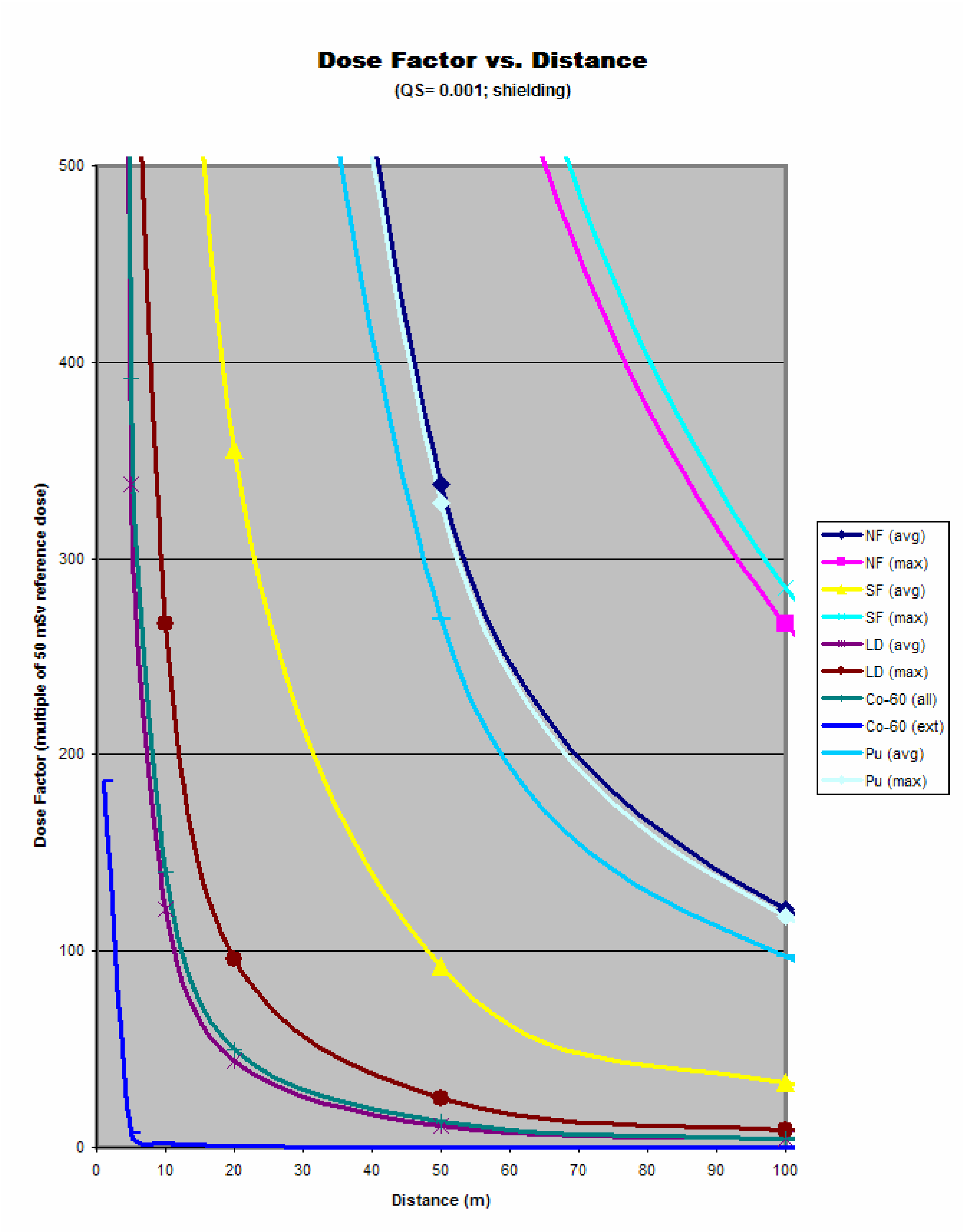

Figure 1 – Relationship of "Dose Factor" with distance from crashed package

Endnotes:

[i] IAEA-TECDOC-702, "The air transport of radioactive material in large quantities or with high activity", IAEA, Vienna, 1993.
[ii] Ibid, 30.
[iii] Ibid, 30.
[iv] "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material", Safety Guide No. TS-G-1.1 (ST-2), IAEA, Vienna, 2002.