Historical Background of the Development of Various Requirements in the International Regulations for the Safe Packaging and Transport of Radioactive Material

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ABSTRACT

Questions are frequently asked regarding the source of some of the package test requirements in the Transport Regulations, the philosophy behind them and the basis for selecting them. This paper summarizes the results of a review of early historical documents and elaborates on the early philosophy behind the regulatory requirements. To the extent possible, the paper compares the early philosophy with the current structure of the Transport Regulations in key topic areas with a focus on the test requirements for packages that are designed to withstand accident conditions of transport.

1. INTRODUCTION

Efforts to develop an internationally-accepted, standardized set of recommended requirements for the packaging and transport of radioactive material began shortly after the formation of the International Atomic Energy Agency (IAEA) in the late 1950's. Those efforts have resulted in today's IAEA Regulations for the Safe Transport of Radioactive Material (the Transport Regulations) [1]. The current edition of the Transport Regulations, and it predecessor editions, have served and continue to serve as the primary basis for harmonized transport regulations at the international modal level and within many countries. For example, in the latest edition of the United Nations Recommendations on the Transport of Dangerous Goods — Model Regulations [2] all of the regulatory requirements in the Transport Regulations have now been incorporated into that document. This then serves as the model for each of the international modal regulatory documents issued by such organizations as the International Maritime Organization (IMO) for maritime (sea) transport, the International Civil Aviation Organization (ICAO) for air transport, the Universal Postal Union for transport by post, and the United National Economic Commission for Europe (UNECE) and other international organizations for land transport modes (road, rail and inland waterway) transport within Europe and other regions of the world. Thus, the IAEA regulatory requirements have now generally been harmonized throughout the international regulatory system.

Questions are frequently asked regarding the source of some of the requirements in the Transport Regulations – specifically the package test requirements – and the associated philosophy behind them and the basis for selecting them. Of particular interest has been the accident-simulating test requirements including the 9-m drop test, the 800 ^{o}C thermal test, and the water immersion test. The advisory material issued by the IAEA to support the Transport Regulations [3] provides some insight into these questions. However, a number of early historical documents are available that deal with the initial development of the international regulations; they provide further insights into the philosophy behind the early regulatory requirements.

This paper documents and summarizes a review of these early historical documents and elaborates on the early philosophy that has led us to the current set of regulatory test requirements. To the extent possible, the paper compares the early philosophy with the current structure of the Transport Regulations in key topic areas with a focus on the test requirements for packages that are designed to withstand accident conditions of transport.

2. BACKGROUND

In 1957, the Preparatory Commission of the International Atomic Energy Agency [4] elaborated that the "*Agency might obtain information on the work which has been done in, and consider the formulation of regulations governing, (i) the transport of radioactive materials, (ii) the transport of radioactive waste to burial grounds, …*". It then discussed the manner in which the Agency might staff and organize this effort, including noting that an advisory panel might be appointed, "*which might later be transformed into a standing committee.*" It further noted that the "*Agency should take measures for preparation and distribution, in consultation with other international* *organizations concerned, problems related to the international transport of radioisotopes, particularly of short-lived radioisotopes.*" In a following action, in 1959 the United Nations Economic and Social Council (ECOSOC) passed a resolution [5] that, *inter alia*, noted the progress made by the "*new Committee of Experts on the Transport of Dangerous Goods*", requested the "*Secretary General, in light of the relevant recommendations contained in the report of the Committee of Experts*", to continue the Committee of Experts, to explore "*the possibility of finding mutually acceptable performance tests for outer packages for certain classes or groups of dangerous substances*", and – significantly – to "*inform the International Atomic Energy Agency of the desire of the Council that the Agency be entrusted with the drafting of recommendations on the transport of radio-active substances, provided that they are consistent with the framework and general principles of recommendations of the Committee of Experts on the Transport of Dangerous Goods of the United Nations, and that they are established in consultation with the United Nations and the specialized agencies concerned*."

It is noteworthy that these recommendations were acted upon and continue to be acted upon. The IAEA:

- formulated and periodically updates regulations governing the transport of radioactive material;
- formed a committee, which it transformed in the late 1970s into a standing committee for transport safety (initially identified as the Standing Advisory Group on the Safe Transport of Radioactive Material (SAGSTRAM)., which was later transitioned into the Transport Safety Standards Advisory Committee (TRANSSAC) and more recently renamed the Transport Safety Standards Committee (TRANSSC);
- developed performance tests for packages for radioactive materials (Class 7 radioactive material, one of the nine classes of dangerous goods as defined by the United Nations Committee of Experts); and
- worked and continues to work, in undertaking these tasks, in consultation with other concerned UN bodies, other international bodies and its own Member States.

3. EARLY HISTORY OF REGULATORY DEVELOPMENT

In a paper issued in the 1960s, Thurber George [6] discussed the development of the United States Interstate Commerce Commission (ICC) regulations, which were one of the precursors to the international regulations. The U.S. Bureau of Explosives (BoE) was formed in about 1906, with an initial view to establishing some rules for assuring a higher level of safety in the rail transport of explosive materials. With time, the rules were expanded and other dangerous articles were added. Ultimately, through an act of the U.S. Congress, the ICC was empowered to write and enforce regulations for the transport of dangerous articles. Initially, these regulations were based on the BoE rules, and were then expanded to cover more materials and address new problems as they were identified. As the use of radioactive materials expanded, the ICC initiated work in about 1944 on establishing regulations for the transport of radioactive materials. It worked with interested parties including the BoE and issued regulations in about 1946. His paper includes two example permits, each only two-pages in length, one for spent nuclear fuel (SNF) elements– issued in 1959 – and one for radioactive materials – issued in 1962. With regard to the package design requirements in these early permits, for example, for SNF the issues that were addressed included, inter alia:

- describing the packaging as a "container" although it didn't explicitly establish quantified containment requirements;
- establishing simple requirements for managing heat generated;
- specifying requirements on structural element thicknesses (i.e., specifying how to design a package not what requirements must be satisfied);
- defining that shielding "*must be supported in outer container so that it cannot change position or open under any ordinary conditions, and must be capable of maintaining its efficiency under severe fire conditions*";
- specifying that the container for the shielding "*must be of metal with welded joints and closure must be secured by positive fastening device capable of withstanding severe impacts without failure*"; and
- specifying that it "*must be designed and maintained so as to provide against criticality in the presence of other shipping containers of fissionable materials during transportation.*"

Thus, in view of the underlying objective specified in paragraph 104 of the current Transport Regulations [1], i.e.:

> *"104. The objective of these Regulations is to protect persons, property and the environment from the effects of radiation during the transport of radioactive material. This protection is achieved by requiring:*
> *(a) containment of the radioactive contents;*
> *(b) control of external radiation levels;*
> *(c) prevention of criticality; and*
> *(d) prevention of damage caused by heat"*

it is illuminating that all four of the parameters currently deemed needed to provide protection (containment, radiation control, prevention of criticality, and managing heat) were covered in this very brief U.S. domestic permit issued almost five decades ago, and well before international regulations were first issued.

In a companion paper, Lester Rogers [7] discussed – from the perspective of the United States, its early activities in developing transport regulations. He noted that radioactive material transport regulations were issued by the ICC in January 1948 (as 49 CFR 71-78). Additional regulatory actions followed by different regulatory bodies resulting in five different agencies issuing regulatory documents. These actions were taken as a result of concerns that controls in this area needed to be codified. He quoted Roy Gibson of the United Kingdom as follows:

> "*We can no longer expect competent authorities, port authorities and others to be content that a shipment is safe because we in the industry are satisfied that it is safe – safety not only has to be achieved but must be seen to be achieved*."

In 1957, a U.S. domestic interagency committee was formed to coordinate the Federal Agency activities in this area. Rogers noted that the IAEA convened two panels shortly thereafter (in 1959) to develop international transport regulations, which was in response to the ECOSOC guidance noted earlier [5]. These two panels drew heavily from the concepts contained in the then-existing U.S. ICC regulations and upon experience gained during the previous 15-years in thousands of shipments in both national and international transport. The result of these initial efforts was the IAEA 1961 Edition of the Transport Regulations [8]. With regard to package test standards established in this first edition of the Transport Regulations, Mr. Rogers summarized it as follows:

> "*The Type A package must be leakproof, securely closed by a positive fastening device, shielded adequately to prevent an external dose rate in excess of the values prescribed in the regulations and must prevent loss or dispersal of radioactive contents and retain shielding efficiency under conditions normally incident to transport (such as minor drops and spills) and under minor accident conditions*."
>
> "*The Type B package must be designed so as to maintain its integrity under conditions normally incident to transport without loss or dispersal of radioactive contents and the package must retain shielding efficiency under conditions normally incident to transport and in the most severe accident which is considered credible for the mode of transport involved.*"

From the preceding it is noteworthy – considering the requirements that exist today [1] – that:

1. both the test criteria described generically and the acceptance criteria for Type A packages has not changed significantly since first conceived although the specification of "*conditions normally incident to transport*" have since been quantified;
2. the accident test criteria for Type B packages was then specified qualitatively as essentially the "*maximum credible conditions*", which – as will be shown below – were very quickly quantified in later editions of the Transport Regulations; and
3. the acceptance requirements for Type B packages following exposure to both the test conditions "*normally incident to transport and in the most severe accident*" were only specified qualitatively and which were also very quickly quantified in later editions of the Transport Regulations.

In a 1962 document [9], Gibson and Messenger also elaborated on the development of the package design standards, noting that the

> "*I.A.E.A. regulations confine themselves to specifying the objects to be attained by the packaging standards. They <u>state</u> what is to be achieved, but only <u>suggest</u> how it is to be achieved. Thus the designer is allowed the greatest possible freedom to develop new techniques for improving both safety and economy. …. The packaging standards are in fact defined in terms of transport conditions of differing severity under which the four radioactivity hazards must be so controlled as to afford the same high degree of safety."*

Also, in their discussion of the development of the transport regulations in the United Kingdom, Gibson and Messenger [9] discussed how these domestic regulations related to the emerging IAEA Transport Regulations [4]. One topic they introduced was the need to be specific about the use of terminology in the Transport Regulations. They introduced terms such as "packaging" and "package", and noted that the

> "*indiscriminate use of these terms in the past, both in regulations and in U.K.A.E.A. domestic documents, has led to difficulties of interpretation and to some confusion. Transport regulations should be primarily concerned with complete packages, loads and consignments, and only to a minor extent with the constituent containers and packaging details. There is a need, we believe, for definitions of these terms to be embodied in regulations.*

"*We realize that this represents a council of perfection ….. but we feel that regulations, and papers about regulations, should at least embody an explanation of the terms they employ.*"

It is noteworthy that essentially all of these concepts were implemented into the Transport Regulations and have survived the test of time and exist in the Regulations today. The remainder of this paper will focus only on the testing requirements for Type B packages and the changes that have been made to those requirements over the years.

4. ADDING SPECIFICITY TO THE TRANSPORT REGULATORY TEST REQUIREMENTS

The steps taken immediately following the issuance of the first international transport regulations [8] to elaborate on the international test and acceptance requirements for packages containing radioactive material were documented in 1962 by Gibson and Messenger [9] and in 1963 by Messenger and Fairbairn [10]. They indicated that the "*requirement for the packaging to be able to withstand the 'maximum credible accident' is novel in the transport field; it has not been applied as a mandatory requirement to the carriage of non-radioactive dangerous goods, some of which, for example, cyanides, may be far more hazardous than many radioactive materials*"[10]. This statement still holds true today – none of the packages of other classes of dangerous goods are required to withstand 'maximum credible accident' environments. In addition, it is noteworthy that the package test requirements for Type B radioactive materials are more demanding than any of the package category tests specified for Classes 1 -6, 8 and 9 in the UN Recommendations [2].

Messenger and Fairbairn further elaborated on the situation as perceived in 1963 as follows:

"*In the absence of a reasonable borderline between 'credible' and 'incredible' accidents, some accident can always be postulated sufficiently severe or elaborate to defeat any packaging design. No accident, however extraordinary, can be ruled out as completely impossible. In fact many major accidents that have occurred had been thought incredible. On the other hand, no transport package can be designed to withstand every conceivable accident including combinations of both natural and man-made forces. Indeed, if such a package could be constructed, it would not be transportable.*"

This quote is provided to illustrate the thinking and the wisdom of those involved in working to establish reasonable yet meaningful test requirements for the Type B radioactive material packages. Having established their philosophy, they then elaborated on considerations underlying their proposed quantitative tests. These considerations included:

- mishandling and tampering,
- impacts due to large drops when loading or to collision during transport,
- fire and damage by fire-fighting materials,
- immersion in water, and
- 'smothering' by debris or by other goods as a result of one of the above;

where it was judged that "*impact and fire are the most likely to cause serious immediate damage*".

With regard to their concern about mishandling, tampering and a possible requirement for tamper-indicating seals, they noted that it "*is almost impossible to devise tests to represent such possibilities*", and therefore noted that such seals "*cannot prevent wilful interference, but they constitute a deterrent and, if tampering has occurred, [provide] a telltale that warns those concerned to handle or open the package under precautions*". With regard to 'smothering', they noted that this would only be of concern for large packages with contents generating significant quantities of heat, and that appropriate analyses for the "smothering" phenomenon should be undertaken as part of a package design.

Following detailed analysis of each of the five phenomenon they had listed, Messenger and Fairbairn [8] then "*proposed that, for the practical purposes of approval of design of Type B packagings, …the postulated 'maximum credible accident' shall be regarded as compromising:-*

(i) Head-on collision at 30 m.p.h. (or 30 ft free fall, which is equivalent) with a rigid structure, followed by –

(ii) Exposure for 30 minutes to a liquid fuel fire, the mean effective temperature of which is 800 ^{o}C, with no quenching after such exposure until the temperature of the interior as measured during test …has started to fall, followed by –

(iii) Immersion in water, provided that ingress of water to the package constitutes a hazard.

One year later, in a document issued by Appleton and Servant [11], the results of deliberations at the IAEA leading to the 1964 edition of the IAEA Transport regulations [12] were documented. The experts used the information provided by Messenger and Fairbairn [8]. During these discussions three important aims were kept in mind as the detailed standards were developed. These were that:

- an adequate standard of containment and shielding needed to be maintained,
- no reduction in standards below those already being attained should result, and
- there should be no restriction on the initiative of the designer of packaging in choosing new materials or employing new methods.

Appleton and Servant further noted that:

> "*…the effects of the transport environment on packages under either normal or accident conditions, were complex and that no series of tests could simulate those conditions accurately. The aim* [therefore] *would be to produce tests of a severity which would provide for packages of an adequate standard without attempting to cover every detailed effect. This would also have the result of reducing to a minimum the number of tests required, with a consequential saving in the expenditure of time and money on testing.*"

They went on to state that:

> "*The packaging standards …. were to be so developed that alternative calculative methods could be derived in order to avoid actual testing. This is of importance in particular for specimens of type B packaging which may be very expensive.*"

It is fair to say that the principles elaborated by Messenger and Fairbairn and by Appleton and Servant have continued in all later revisions of the Transport Regulations.

The following summarizes the arguments, first of Messenger and Fairbairn [8] for the two environments they felt were most significant (mechanical and thermal), and for immersion, and then elaborates on how these were adapted into the Transport Regulations using information from various sources, e.g. Appleton and Servant [11], Fairbairn and George [13], and Bader [14].

4.1. The Mechanical Tests

With regard to mechanical impacts, Messenger and Fairbairn [8] used then-available data on impacts. Heights, frequencies and probabilities of the potential for drops from cranes especially in seaports as well as those for collisions and other mechanical accidents (derailments, falls, impacts with stationary structures, aircraft –to-ground crashes, impacts with other vehicles, etc.) were all considered. In addition, the modifying factors that were needed to establish realistic environments were considered. For example, they recognized for collisions between vehicles that "*it is misleading to add their speeds*" because "*the additional kinetic energy would be absorbed by damage to the second vehicle.*" They therefore concluded that: "*collisions between vehicles may be regarded as no more severe than collisions at similar speeds with permanent structures.*" Other modifying factors considered included (a) a propensity for such heavy vehicles to adhere to statutory speed limits, (b) the potential for braking of vehicles before impact, (c) noting that many impacts will not be "head-on", but rather will involve only a glancing blow, and (d) the ameliorating effects of the crushing of the carrying vehicle structure before impact of the package into some more solid structure.

In establishing the recommended impact test requirements, they took note of the requirement then imposed by the U.S. Atomic Energy Commission that required a flask carrying irradiated nuclear fuel to be able to withstand a fall of 15-ft (5.47-m) fall onto an "unyielding horizontal flat surface" whereas some packages used for transporting military stores in the UK were then required to withstand a 40-ft (12.2-m) fall onto a steel plate wet-floated onto 18-inch (0.46-m) thick concrete. At that time, fire-resistant safes were required to be dropped from heights ranging from 12-ft (3.6-m) to 30-ft (9-m) onto "rubble". Another test configuration that was then being used by the United Kingdom Atomic Energy Authority was a 30-ft (9-m) drop onto a rigidly mounted 1-ft (.3-m) steel box beam. At this point in time, Messenger and Fairbairn recommended the 9-m drop onto a rigidly mounted box beam.

Elaborating on the discussion relative to the mechanical tests, Appleton and Servant [11] stated that the "*impact effects are considered to be of two kinds, structural shock and shear respectively. Instead of merely striking a flat surface a package might fall from a height onto a protruding object such as a small package or post, in collision it might be struck by a relatively small projectile or whilst being carried on a vehicle might hit a bridge abutment at an acute angle*." They also stipulated that: "*those effects* [of structural shock accompanied by shear] *could be obtained by dropping a sample package through a suitable height onto appropriate targets.*"

They indicated that, after discussing the alternatives, the experts agreed to adopt a two-drop test concept that was proposed by the USA: first a drop from 30-ft (9-m) onto a flat target, and second a drop from 3-ft (0.9-m) onto a pedestal target. The alternative, the single UK-proposed drop onto a rigid box beam was not accepted due to both testing and analytical complexities. Fairbairn and George [13] indicate that the choice of the 30-ft (9-m) drop test height resulted "*from practical judgement, first that in the course of transport Type B packages are unlikely to suffer higher drops on to very hard targets such as dock wharves, and second that a part of the impact during collisions at high speeds will be absorbed by the vehicles.*"

For the first mechanical test, it was therefore agreed that the drop height should be 30-ft (9-m), and that the target for this test was to be a flat, horizontal surface. They note that "*the target mass could be related to the falling package in order to provide the same relative structural shock*".

Considerable attention was paid in specifying the target for the 9-m drop test to ensure "*minimum loss of energy of the falling package due to mass movement or damage to the target surface.*" More to the point, it was agreed during these deliberations that "*the target shall be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the package would not significantly increase the damage to the package*". This is the text that has continued to serve as the basis for defining the target to this day (e.g. see para. 717 of TS-R-1 [1]).

For the target to be used for the mechanical tests, the experts then agreed upon an example of this "unyielding" target [11, 13], which is essentially the basis for the current example provided in para. 717.2 of TS-G-1.1 [3]. Fairbairn and George [13] described the example target as comprising "*a concrete block of mass at least ten times that of the sample package, faced by a mild steel plate at least 1.25 cm thick in intimate contact with it, the whole being set on firm soil.*" They then elaborated on this, discussing for example the dimensions of packages and target, using the American Standards Materials Handbook [15].

The example target described by Fairbairn and George in 1966 is essentially that provided today 9in para. 717.2 of the IAEA guidance [3]), although the steel thickness has been increased to 4 cm based upon experience. Furthermore, even in the early years, it was noted that the final judgment with regard to the adequacy of the target would be with the competent authority responsible for approving the specific Type B package design [13].

For the second mechanical test, (what was then called the pedestal test) the target surface specified for the 9-m drop test was to be used as the foundation for the pedestal bar. In preparation for issuing the 1964 edition of the transport regulations [12], it was agreed that the test would consist of a drop from a height of 3-ft (0.91-m) onto the end of a 6-in (15-cm) diameter mild steel bar or punch with edges rounded off to a radius not exceeding 6 mm, which was intended to evaluate the package integrity for the effects of shear in an accident [13]. They noted that the "*use of a 6 mm, as opposed to say 0.6 mm radius may be criticized as unduly blunting the punch; on the other hand, it must be recognized that if no radius were allowed this shear test would be very severe indeed, particularly for very heavy packaging.*"

The test today is essentially as specified in the 1960s, although the drop height has been rounded from 0.91-m to 1-m (see para. 727(b) in TS-R-1 [1]).

4.2. The Thermal Test

In considering potential fire environments, Messenger and Fairbairn [8] considered the frequencies, probabilities and many other factors that can work together in defining the environment a package might experience in a severe accident. These included:

- types of fuel, quantities of fuel, rate of spillage of fuel, and dispersal of spilled fuel;
- possible ranges of temperatures in a fire, and associated effects of size of fuel source and effects of oxygen supply (wind);
- duration of fires; and
- size and mass of the package.

They recognized that the maximum temperatures achieved in a fire are typically the result of a "*local 'torching'*", which would not provide a significant threat to large packages. Further, they noted that melting of materials could be a reasonable indicator of effective or average flame temperatures, for which it was shown that large fires in rail accidents had resulted in the following:

- zinc (with melting point of 419 ^{o}C) was melted,
- aluminum (with melting point of 660 ^{o}C) was partially melted,
- glass (with melting point of about 1000 ^{o}C) sagged but was not melted, and
- steel (with melting point of 1500 ^{o}C) was not melted.

After consideration of the data presented, and tests (both open fire and oven environments) that were then being used and noting that some of these test precluded any intervention (i.e. quenching of combustion of burning packaging elements) following thermal exposure until package temperatures had begun to drop, they recommended exposure "*to a furnace temperature of 800 ^{o}C for 30 minutes with no quenching until after the temperature of the interior has started to fall*".

In elaborating on the discussion relative to the thermal test, Appleton and Servant [11] stated that there "*was considerable discussion on the kind of fire to which a package might be exposed. The majority opinion was in respect of a large conflagration as might occur when a tank or petrol or kerosene spilled and took fire, but reference was also made to 'torching' flames from a ruptured compressed gas tank vehicle. Temperatures in the order of 1000 ^{o}C were considered relevant.*" They further noted that reported tests in open fires provided thermal environments very similar to those attained in hot wall, 800 ^{o}C oven tests.

It was further noted [11, 13] that the basis for the average temperature was initially established using work of various individuals, including that of Bader [14] where, following the detailed analysis of a number of open pool fire tests and consideration of work of others, he concluded that "*an <u>exact</u> prediction of temperatures expected in a particular fire <u>cannot</u> be made. Examination [of data] which shows the wide range of fire environments measured in 'similar' fires, indicates the difficulty one would have in predicting the temperatures expected in a given fire. On the other hand, the range of fire temperatures to be expected can be stated with some certainty, and over a large number of tests, the fire temperatures will produce an average. This average turns out to be approximately 1850 ^{o}F*". The average temperature of *1850 ^{o}F proposed by Bader equates to 1010* ^{o}C.

The average fire temperature of *1010* ^{o}C is, of course, higher than the 800^{o}C that was ultimately used in the early Regulations, and continues to be used today. Fairbairn and George [13] stated that severe transport fires "*seldom last more than half an hour, …., and information on the temperatures attained suggests that although flame temperatures of liquids such as petrol can be about 1000 ^{o}C, such peak temperatures are reached only very locally by metallic material involved in the fire*".

Following much deliberation, the experts felt it necessary to consider all factors in establishing the thermal test condition, not just the maximum average attainable temperature in "perfect" fire situation. They considered the ramifications of accounting for multiple, "real life" parameters, including *inter alia* radiant, conductive and convective heat inputs and exposure scenarios, which require specification of:

- an effective source (i.e. flame) temperature and effective flame thickness where, for pool fuel fires, this requires consideration of such parameters as:
  - fuel type,
  - size of package,
  - mass of package,
  - size of pool (too small, the flame is not luminous, too large and the flame suffers from oxygen starvation),
  - location of package above the pool, and
  - wind effects;
- emissivity coefficient of the heat source (i.e. the flame and its luminousity);
- absorption coefficient of the package surface;
- duration of exposure;
- support of the package at specified height; and
- whether the package should be cooled following termination of heat source exposure.

These deliberations resulted in inclusion of the statement in the Regulations that "*any thermal test shall be considered as satisfactory provided that….*", where the parameters for satisfying the test were then specified in terms of:

- source temperature (800 ^{o}C),
- duration of test (30-minutes),
- source emissivity (0.9),
- package surface absorptivity (0.8),
- flame thickness – not less than 0.7-m (2-ft) and not more than 3-m (10-ft),
- the flame must surround the package during the entire test, and
- no intervention after exposure to the thermal source until the inner components of the package began to cool.

Fairbairn and George discussed the positioning of the package so that its lower surface would be 1-m above the surface of the burning fuel, and that the package should be supported "*such that it does not prevent direct exposure of any significant area of the package to the heat generated*"; with a view to ensuring maximum damage to the test package [13]. With minor changes in wording this is essentially the test that exists in para. 728 of TS-R-1 [1] today; and much of the discussion contained in Appleton and Servant has been included in the advisory material on this test contained in TS-G-1.1 [3].

They further discussed the fire duration, noting that"*…when the actual heat input to the interior of the package is examined it can be shown, particularly for large packages, that a test involving a 30 min period of exposure to heat input, and a subsequent natural cooling period until the innermost temperature has started to fall before any artificial cooling is applied, might well be more severe in its effect on the package than one in which heat is applied for 60 min according to a specified time/temperature curve with artificial cooling applied immediately afterwards.*" [13].

4.3. The Immersion Test

With regard to immersion, Messenger and Fairbairn [8] noted that, "*the majority of Type B packages are so designed that the entry of water into the actual containment vessel is incredible provided that they are properly closed; in many cases no significant hazard would result if water did in fact enter*." At this time they proposed an immersion depth of at least 3 ft (0.9-m) head of water on all joints for 24-hours. The general water immersion test for Type B packages has since been changed to requiring immersion to a depth of 15-m for a period of not less that 8 hours "in the attitude which shall lead to maximum damage" (see para. 729 of TS-R-1 [1]).

4.4. The Consecutive Nature of Accident-simulating Tests and the Concept of Maximum Damage

Appleton and Servant [11] note that the mechanical and thermal tests are to be applied consecutively. Fairbairn and George [13], in discussing the mechanical tests also noted that the two tests (i.e. the 30-ft drop onto an unyielding target and the 3-ft drop onto a 6-in punch mounted on the unyielding target) were to be done consecutively. This feature has been retained over the years in the Regulations, with the specimen being "*subjected to the cumulative effects of*" the mechanical tests and the thermal test, "*in that order*" (see para. 726 of TS-R-1 [1]), although it now has been extended such that the "*order in which the specimen is subjected to the drops shall be such that, on completion of the mechanical test, the specimen shall have suffered such damage as will lead to the maximum damage in the thermal test which follows*" (see para. 727 of TS-R-1 [1]).

The concept of testing in a sequence so as to have maximum damage in the following fire test also has been carried forward to testing in the orientation of the package in the mechanical and pressure tests. As early as 1973, the Regulations specified that each mechanical test would have the package drop onto the target "*so as to suffer maximum damage*". This concept is also retained in today's Regulations.

4. **THE REGULATORY ACCIDENT TEST STANDARDS TODAY**

The preceding has outlined the basis established decades ago for the regulatory tests used to demonstrate the ability of packages to withstand accident conditions of transport. Changes have occurred since the 1960s in these standards as technology and the transport environment have changed; however, the basic philosophy and – to a great extent – the specific requirements have remained unchanged. Some changes have been made. In the 1985 edition of the IAEA Regulations, a dynamic crush test was added for low density light weight Type B packages (which replaced the 9-m drop test for those packages); and a deep water (200-m) immersion test was added for some irradiated nuclear fuel (INF) Type B packages (which was later extended in the 1996 edition of the IAEA

Regulations [1] to larger quantities of any radionuclide in a Type B Package). In addition, in the 1996 edition of the Regulations [1], requirements were established for a Type C package for transport by air, which extends the impact and thermal testing requirements beyond those for Type B packages.

However, the concepts of (a) the 9-m drop onto a flat, horizontal target; (b) the 1-m drop onto a pedestal bar (i.e., a punch); followed by (c) the exposure to a 30-min, 800 ^{o}C thermal environment; all coupled with (d) the application of an unyielding target for the drop tests, consecutive testing of a single package, and application of the most damaging conditions – all remain for most Type B and fissile material packages.

Since the test requirements were issued in the 1964 Regulations [12], experience in transporting radioactive material in Type B packages, along with extensive analytical and experimental evaluations of these test requirements against simulated and actual accident conditions have continued to bear out that these test criteria provide for very robust, accident resisting packages. In conclusion, those involved in the early development of the test standards for demonstrating the ability of radioactive material packages to withstand accident environments made decisions that have withstood the test of time, in terms of real life experience in transport, and of experimental and analytical studies.

6. REFERENCES

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