The Classification Systems for Surface Lining Materials used in Buildings in Europe and Japan

- a Summary and Comparison

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Abstract

This report summarizes the classification systems for surface lining materials in Europe and Japan. There is also a part including a discussion on differences, similarities and possible ways to link the two different systems together.

In June 1994, an important agreement was made between the member countries in the European Community. The agreement stated that all member countries should have the same test procedures and the same classification system for surface lining materials used in buildings. In September 1998, the final decision was taken. The classification system will be based on the FIre Growth RAte (FIGRA) index, which is calculated using the parameters from the main test method, the Single Burning Item (SBI) test. This FIGRA index has been shown to correlate well with the FIGRA index calculated for the reference scenario, the Room/Corner test (ISO 9705). In addition to the SBI test also the Non-combustibility test (ISO 1182), the Gross calorific value test (ISO 1716) and the Ignitability test (ISO 11925-2) are used for the classification. In total 10 different parameters will be used to specify the seven Euroclasses (A1, A2, B, C, D, E and F). Materials in Euroclass A1 to B do not reach flashover during the Room/Corner test while materials in Euroclass C reach flashover after 10 minutes of testing and materials in Euroclass D to F reach flashover during the first 10 minutes of testing.

Today the classification system in Japan is based on five different test methods that are not ISO standards. By using these five test methods the materials are divided into three classes. These classes represent the non-combustible, quasi non-combustible and the fire retardant materials. The test methods and classification system today do not allow a performance based approach. Therefore, there is ongoing work with the aim to develop new regulations, test methods and a new classification system, which will allow this. Today there are only two final decisions taken. The first states that the classification will be based on the heat release in the Room/Corner test, which will be the reference scenario, and that the main test procedure will be the Cone Calorimeter test (ISO 5660). The second states that the regulations will allow three different routes for design, route A, B and C. Route A will be a prescriptive approach which will use the classification given by law, while route B and C will allow a performance based approach. For the prescriptive approach there are a number of proposal for class limits, but the most probable proposal includes three different classes. Materials in Class 1 do not reach flashover in the Room/Corner test while materials in Class 2 reach flashover after 10 minutes of testing and materials in Class 3 reach flashover during the first 10 minutes of testing.

To open the possibilities for trade with surface lining materials, between Europe and Japan, a comparison and a first attempt to link the two systems together has been made. The conclusion from this work is that there is a strong direct link between the Euroclasses and the proposed Japanese system based on the heat release in the Room/Corner test, but it is difficult to find a complete link when all parameters are considered, even with the use of calculation models. The only way to use materials from Japan in Europe, and vice versa, might be through a performance based approach with performance based design criterion or through a political solution. Therefore, it was also found strange that there is no test method, such as the Cone Calorimeter, that

provides input data to state-of-the-art fire models included among the test methods that will be used in Europe.

Acknowledgements

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1. Introduction

As human civilization developed, so did standardization in various areas. The earliest more organized examples of standardization are alphabets and notes. Early, standardization of measures was formed to make trade possible between countries and areas. When the industrialization took place in the beginning of the 20th century, the standardization increased considerably. In 1926, the ISA was formed and was the precursor to ISO (International Organization for Standardization) which was formed 20 years later. Today, the international trade relies on international harmonization and much effort is made to reduce the number of technical barriers and to use international standards.

Concerning fire technology and testing, classifying and certifying of lining materials used in buildings almost every country has had their own philosophies and backgrounds. The classification systems were often generated by a reaction to one or a series of dramatic fires in the country and therefore different directions and solutions were chosen from one country to another. But, as in almost all areas, the fire protection area has been a target for changes.

The last decade has meant large changes within Europe concerning harmonization and standards. September 9, 1994, the European Community (EC) took a large step towards harmonization of testing, classification and certification of building materials due to their reaction to fire within Europe. The decision that was taken states that the reaction to fire of construction products will be classified using Euroclasses. The final decision was taken in September 1998 and states that this classification system will mainly be based on international standards. Also in Japan there are a lot of changes within the classification system of building products. Work has been done to review the Building Standard Law and a new classification system based on new test methods and a performance based building fire safety system is under development. In June year 2000 the new system will start to be used in practice. The same effort, as in Europe and Japan, will be made and enhanced in the North American Free Trade Association (NAFTA) countries.

The development is natural and also very important for the international harmonization, but some questions arise from a fire safety engineering point of view. For example, are the classification systems and test methods designed to be used only for classification or will it be possible to use them for performance based design and an engineering approach? Even though the classification systems in Europe and Japan are mainly based on international standards, it might be difficult to link them together in an easy way and obtain international harmonization and trade. The development towards using international standards is a step in the right direction for the international harmonization, but is it useful from a fire safety engineering point of view?

This report is written for mainly two target groups. One is students or others with the same background as the authors. The other is people who are interested in the development of the Japanese and European classification systems and are interested in the discussion on how to link the two systems together.

The report is principally based on literature studies and lectures given by Prof. Y. Hasemi, Waseda University, Mr. M. Yoshida, Department of Fire Safety (BRI) and Mr. W. Takahashi.

1.1 Objective and goal of the report

This report is a part of the course "Fire Safety Engineering design and risk evaluation", VBR 130, at the Department of Fire Safety Engineering, Institute of Technology, Lund University. With the report the students are supposed to practice their skills in fire safety engineering, and independently analyze and present an extensive problem in a scientific way.

The goal of the report is to summarize today's situation on the classification systems in Europe and Japan. The report will also discuss differences, similarities and possibilities towards linking the classification systems in Europe and Japan together and thereby open possibilities for trade in the building industry. There will also be a discussion from a fire safety engineering point of view.

1.2 Limitations

The report will only examine surface lining materials, excluding floorings and the report is principally based on literature studies and lectures. The authors have not carried out any tests themselves. Finding relevant literature has been difficult for two reasons. The first reason is that the decision on the European system has very recently been made (end of September 1998) and the second is that the Japanese system still is under development. Due to the lack of literature in English describing the Japanese system most of the information has been earned from lectures.

1.3 Overview of the report

The report is divided into three different parts. The first includes chapter 2 and 3, where a historical overview of the European situation first is given and then a summary of the classification system that will be used within Europe is presented.

Chapters 4, 5 and 6 describes the situation in Japan, the classification system today and the new proposed system.

The last part is a discussion on similarities and differences between the two systems and a discussion on the possibilities to link them together. In this part there will also be a discussion on how the systems can be used for fire safety engineering practice and for performance based design. Figure 1.1 is a sketch of the overview of this report.

Part 1.

Chapter 2. Historical overview of the situation in Europe

Chapter 3. The Euroclasses

Part 2.
Chapter 4. Introduction to the situation in Japan

Chapter 5. The Japanese classification system today

Chapter 6. Proposal for a new Japanese classification system

Part 3.

Chapter 7. Possibilities to a direct link between the systems

Chapter 8. Alternative ways to link the systems

Chapter 9. Conclusions and discussion

Figure 1.1 Overview of the report

2. Historical overview of the situation in Europe

This chapter contains a historical overview of reaction to fire testing of products in Europe. First, the background of the European Community (EC) will be described and after that there is a brief introduction to the standardization work in Europe. The chapter will also give an introduction to the differences in how the European countries tested and classed products before the decision of harmonization was taken.

2.1 Background to European and International standardization

The EC has its roots in the postwar Europe. In the, at that time, lacerated Europe there were thoughts of promoting economic recovery and political stability, in order to reduce the possibility for future wars. On April 18, 1951 one major step was made for a united Europe. That day six countries (Belgium, Luxembourg, The Netherlands, UK, Germany and France) agreed on trying to integrate their economies and formed the European Coal and Steel Community (ECSC). In Rome, Italy, about six years later another two treaties were signed. One created the European Atomic Energy Community and the other established a European Economic Community. These two treaties formed with ECSC the European Communities, which today is known as EC.

The first immediate objective within the EC was to form a Europe where goods, persons, services and capital freely could move across the borders without any obstacles from authorities or customs. If these so called "four freedoms" could be realized it was necessary to harmonize the member states economic policies and the common rules and principles in areas such as agriculture, transport, antirust law and external trade. /1/

In order to do this, the member states had to agree on standards and technical regulations. The number of standards and regulations was in 1990 over 100 000 /1/ and today this figure is probably far exceeded. A directive on construction products (CPD) was published in 1989 and was adopted by all member states and therefore becoming national law. The base for the standards is the so called essential requirements, given in the CPD. Six essential requirement are fixed in the directive, concerning: "mechanical resistance and stability", "safety in case of fire", "hygiene, health and environment", "safety in use", "protection against noise" and "energy economy and heat retention". In order to develop and to get a more detailed definition of the essential requirements for European technical standards, the EC contracted several European standards-setting organizations, among others the Committee for European Standardization (CEN).

The CEN consists of the national standards organizations within the EC and European Free Trade Association (EFTA) and its associates. CEN has also a close co-operation with national organizations in countries, which may become members of the EC and EFTA and corresponding organizations outside Europe.

The work within CEN is carried out by a number of Technical Committees (TC), each responsible for a certain area such as mechanical engineering, food or chemistry. For fire safety there is a TC composed of industry officials, producers and users, CEN

TC127 "Fire Safety in buildings". CEN's work leads to proposals for new European standards, prENs, which hopefully end up in new European standard, ENs.

For fire safety, each nation preserves the right to set the levels of safety. An important aspect of standardization within Europe is that final decision on CEN standards is taken by a majority vote of the member states, irrespective of whether an individual member state votes against them. Each state has a legal duty to follow the agreed-upon standard and in a situation where the existing national and new CEN standard conflict then it is the national standard which must be withdrawn.

In general, the standards used in Europe will be similar to those of the International Organization of Standards (ISO). This was formally agreed in 1991 and is known as the Vienna agreement /2/. ISO was established short after World War II in London, 1947, and is a non-governmental organization that consists of national standard bodies. Today, some 130 countries take part in ISO's work. The organization works for international agreements and standards, published as international standards. Over 200 technical committees carry out the technical work in the ISO organization. For fire safety there are specially two that are of interest: TC21 "Equipment for Fire Protection and Fire Fighting" and TC92 "Fire Safety". In addition, there are several other committees that also include fire in their work, for an example TC61 "Plastics" and TC136 "Furniture". The TCs are served by sub-committees (SC), each with its own Working Group (WG) structure. Each of the SC has a secretariat assigned to a member body e.g. ANSI (American National Standards Institute), JISC (Japanese Industrial Organization for Standardization) and SIS (Swedish Standards Institution).

2.2 Testing, classification and certification of surface lining materials used in buildings.

September 9, 1994, EC took a large step towards harmonization of testing, classification and certification of surface lining materials used in buildings within Europe. The decision /3/ that was taken states that construction products' reaction to fire will be classified with a Euroclass-system in six different classes, A to F. The classification will be done by four different tests: the Non-combustibility test, the Ignitability test, the Gross calorific value test and the Single Burning Item test. These four test methods will be described in Section 3.3. The parameters that will be used for the classification are:

- Heat release rate
- Flame spread
- Smoke production
- Flaming droplets/particles
- Gross calorific potential
- Ignitability
- Combustibility.

Before 1994 there was not much in common between the European countries way of testing, classifying and certifying building products. Each country had their own philosophy and background and the classification system was often generated by a

reaction to one or a series of dramatic fires. This led to difficulties concerning trade. One building product may show good results in German tests and be considered as a "fire safe" product. At the same time, the same product may show poor results from tests in UK and is said to be dangerous when used in buildings. An example of these differences is shown in Figure 2.1. The figure shows the result of six different European laboratories, in Western Germany, Belgium, Denmark, France, The Netherlands and United Kingdom, when the same material was subjected to the national fire tests. The reader should especially note the large differences in the results for materials no. 7, 8 and 18.
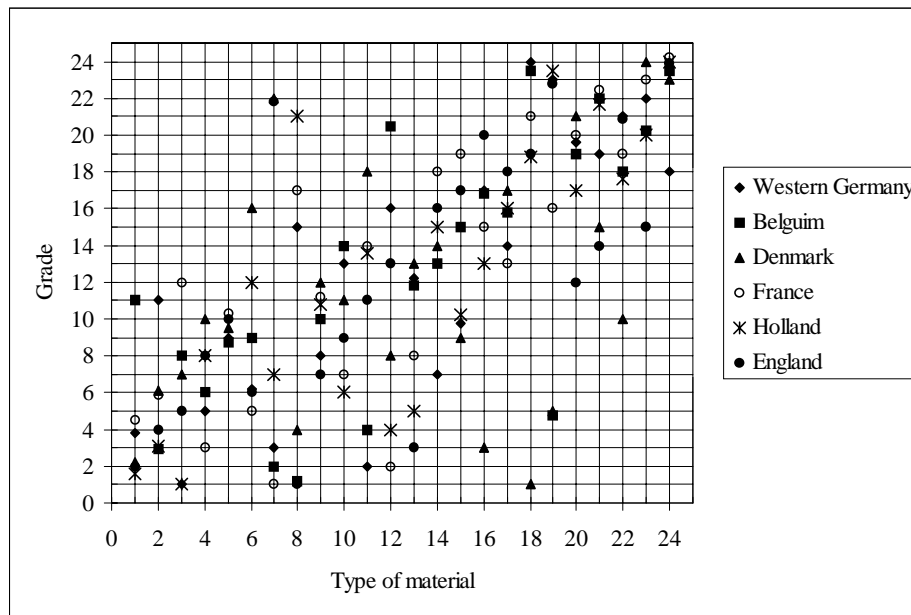
Figure 2.1 The same materials tested in six different European fire test laboratories (after /4/). A high grade indicates good performance in test

In the Construction Products Directive (CPD), described in Section 2.1, the second essential requirement regards fire. The CPD is adopted by all member states and therefore becomes national law. In order to harmonize the evaluation systems within EC the EC Pre-normative Research program started in 1991, designed to develop a sound scientific basis for test methods needed to evaluate the fire performance of all the materials included in the CPD. In the end of 1980 and in the beginning of 1990 some other research programs, for example the EURIFIC and CHARLEMANGE program, were carried out in order to offer one or more solutions to the problem of classification of materials.

EUREFIC program
Laboratories in Denmark, Norway, Finland and Sweden launched this program. The objective of the program was to show that modern testing techniques could be used for evaluating the fire behavior of building materials. The program resulted in about 70 titles of scientific reports and papers. These reports include instructions on how to obtain the test data, computer codes on prediction models etc. from the appropriate laboratories. A bench-scale test called the Cone Calorimeter (ISO 5660) and a full-scale test method called the Room/Corner (ISO 9705) were used for testing wall and ceiling linings. A proposal for classification was presented, based on the time to reach flashover. /5/

The CHARLEMANGE program
Launched in 1991 by LNE (France) and LSF (Italy) with participation from laboratories in Belgium, France and UK. The results from this program where for example that improvement of the reproducibility and the repeatability in the Cone Calorimeter test was suggested and that a data bank was established. The program also provided a proposal for the classification.

These two programs were carried out mainly to provide a sound technical and scientific solution of the problem. But, when the talk about harmonization in Europe started, three different solutions where identified as possible: a political, a mixed political and technical and a technical solution. The political solution intended to keep all the national test methods and make national classes to fit with the new European classes. This solution was soon abandoned since the different national classification systems differ on basic principles and the list of complicated situations would have been too long. A technical solution were found to be necessary in order to obtain a robust classification system, but when each member states had their own philosophies and background this was found difficult to put into practice. Therefore, the decision about the Euroclasses from 1994 is a mixed political and technical solution of the problem.

3. The Euroclasses

In the development of a harmonized way to test, class and certify products many questions have to be considered. For example:

- What data do we need in order to rank products to their hazard?
- How do we get the data?
- How do we use the data in order to do the ranking?

This chapter will try to summarize and analyze the above questions. First the basis for the classification will be investigated. A brief description of the used test methods and what output data are available from them will follow this part. The last part will describe how the parameters from the tests are used to do the final classification and investigate what limits are used for different classes and why.

3.1 Introduction

Around the world today there are many different ways to estimate how dangerous a certain material is in reaction to fire and what test methods should be used. At the beginning of the work with Euroclasses the parameters, mentioned in Section 2.2, were set up for the ranking of building products. It was decided that all these parameters had to be taken into account and the way to the Euroclasses, accepted by all member countries, has been long and difficult. There have been innumerable discussions and debates on which test method to use and how to use the output data to rank the products.

At the Regulators Group (RG) meeting of June 22 and 23, 1998 it was definitely agreed that the basis for ranking products would be the FIre Growth RAte (FIGRA) index. This index is defined as the peak heat release rate of the fire, excluding the contribution of the fire source, divided by the time at which this occurs. It was also agreed that the reference scenario is to be the Room/Corner test (ISO 9705) but the main test procedure to be used is the Single Burning Item (SBI) test /6/. These test methods will be described in Sections 3.3.1 and 3.3.2.

This agreement was a big step towards a harmonized system but the member states agreed that it is not practically possible to rank building products only after the FIGRA index. There were more material properties that needed to be taken into account than the heat release rate. All building materials are not combustible and therefore it is not possible to calculate a FIGRA index. For these kinds of materials it was necessary to find another way to describe the reaction to fire such as determination of the gross calorific potential. However, other materials may produce flaming droplets and particles or produce a lot of smoke, even if the heat release is low. Therefore, it was also decided to take these into account. The conclusion is that to rank building materials it was found necessary to complement the FIGRA index with other parameters.

3.2 Basis of classification

Building regulations and fire safety-theories throughout the world today are based on the fact that a small fire is less hazardous than a big and a rapidly growing fire is more dangerous than a slowly growing fire. There is no doubt about this. Another hazardous point in the development of the fire is when flashover is reached. At this time the whole room is involved in the fire and now it also starts to spread outside the room of origin. When the fire has reached this point the number of deaths increases. Statistics /7/ show an increase by a factor of 3 to 18.

However, it is not only the flames that kill in a fire. Actually, most people that die in a fire never are close to it. The conclusion of an American study, presented in /8/, shows that smoke inhalation is the main cause of fire deaths. The smoke inhalation deaths exceed burn deaths by roughly two to one. This share will be even higher if the fire occurs inside of a building. Another interesting conclusion from the study is that the number of smoke inhalation deaths is growing, due to the fact that more and more hazardous products are used in buildings.

Based on the above mentioned facts, the Swedish National Testing and Research Institute (SP) made a proposal. This proposal suggested that the ranking should be based on fire parameters that describe the maximum size of the fire and the time at which this occurs and the smoke production /7/. In other words the ranking should be based on indices that describe the fire growth rate and smoke production rate. It was finally agreed that the classification should be based only on the parameter that describes the fire growth rate and that the smoke production should be a compulsory additional declaration.

3.3 Test methods

As mentioned earlier the basis for the ranking of building products will be the FIGRA index. The reference scenario for the Euroclass classification will be the Room/Corner (RC) test (ISO 9705) /9/. The Room/Corner test will therefore be used to specify the levels for the classification but to test and classify a product the Single Burning Item (SBI) test will be used. Other test methods that are necessary to make the classification complete are the Non-combustibility test, the Gross calorific value test and the Ignitability test. These tests will be described in the following sections.

3.3.1 The Room/Corner test (prENISO 9705)

The Room/Corner test is a large-scale test method for measurement of the burning behavior of surface lining materials used in buildings. The test apparatus consists of a small compartment with one open door and a gas collection system witch is supplied with necessary instruments to measure the fire gas properties, see Figure 3.1. /7/

Figure 3.1 The Room/Corner test (ISO 9705) /7/

The lining material, which is mounted on three walls and the ceiling, is exposed to a fire placed in one of the rear corners of the compartment.

The compartment measures 2.4 m x 2.4 m x 3.6 m (length x height x width) and the opening has the measure 0.8 m wide and 2.0 m high. The ceiling, the floor and the walls are constructed of non-combustible material. /7/

A propane burner is used as a ignition source and has a heat output of 100 kW for the first ten minutes, thereafter the output level is increased to 300 kW for another ten minutes. The experiment will continue until flashover occurs or until twenty minutes have passed by. The criterion of 1000 kW for the heat release rate is said to be equal to flashover, defined as flames coming out through the doorway, if that has not occurred earlier. /7/

The output data available from the Room/Corner test are mainly the time to flashover and the following parameters as a function of time:

- Heat Release Rate (HRR)
- Smoke Production Rate (SPR)
- CO production rate
- CO_2 production rate
- Oxygen depletion rate.

3.3.2 The Single Burning Item test (prEN)
The Single Burning Item (SBI) test is a new intermediate-scale test method developed in Europe. The SBI test apparatus (trolley, burner, frame, hood and collector), see Figure 3.2, is placed in a small room where the experiment is carried out. /10/

Figure 3.2. The set up for the Single Burning Item test /11/

The test room measures 3.0 m x 3.0 m x 2.4 m (length x width x height) and acceptable wall materials are gypsum boards, all stone type building blocks and fiber boards. Two windows make it possible to observe the experiment from outside the test room. There is also an opening in one wall to allow the passage of the trolley with the specimen. A frame in which the trolley fits and to which a secondary sandbox burner is fixed supports the gas collection hood. /10/

Before the test starts, two pieces of specimen (495 mm x 1500 mm and 1000 mm x 1500 mm respectively) are mounted on a Calcium silicate board and placed perpendicular on the trolley. After that a primary sandbox burner is placed at bottom of the corner between the two parts of specimen. Finally the trolley is placed under the hood in the test room. /12/

After the trolley has been put in place, the specimen will be exposed to a fire from the primary sandbox burner for 20 minutes. The heat output from the burner is 30 kW and the purpose of the secondary sandbox burner is to calibrate the mass flow of propane /12/. The measurements will continue for another 5 minutes after the burner is shut down.

The output data that are available from the Single Burning Item test are time to ignition, flame spread, flaming droplets/particles and the following parameters as a function of time:

- Heat Release Rate (HRR)
- Smoke Production Rate (SPR)
- CO_2 production rate
- Oxygen depletion rate.

Total Heat Release (THR) and the Total Smoke Production (TSP) can be calculated using these test results /13/.

3.3.3 The Non-combustibility test (prENISO 1182)

The Non-combustibility test is a bench-scale test method for determining the combustibility performance of homogeneous[1] building products. If the building products are faced, coated or laminated the test is not applicable /14/.

The test apparatus consists of a furnace, a cone-shaped airflow stabilizer, a draught shield, a specimen holder, an insertion device and thermocouples mounted inside the furnace, see Figure 3.3 /14/.
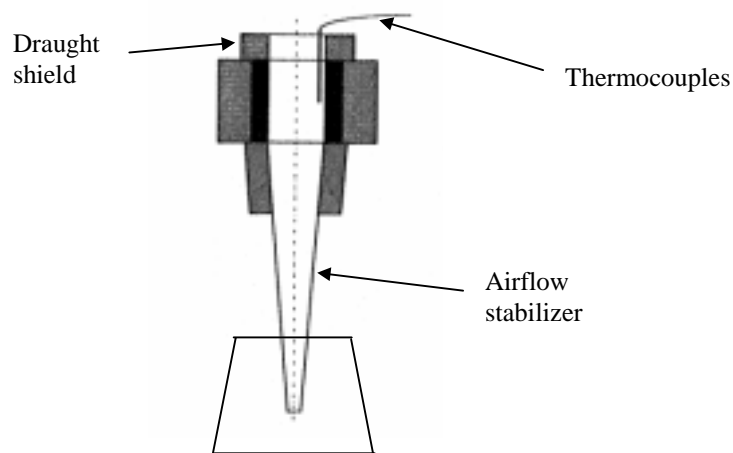
Figure 3.3 General arrangement of the Non-combustibility test /14/

The furnace consists of a refractory tube surrounded by a heating coil and an insulation material. The tube is 150 mm high with an internal diameter of 75 mm and made of an alumni refractory material. To the underside of the furnace, an airflow stabilizer is attached and at the top a draught shield. The items mentioned above are mounted on a stand. Further, the furnace is also equipped with a specimen holder and an inserting devise for the specimen. /14/

The test specimen is cylindrical and has a volume of 80 cm^3, a diameter of 45 mm and a height of 50 mm. The test specimen is taken from a sample that is large enough to represent the product. /14/

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[1]*A homogenous product is, according to /14/, "Material, consisting of a single substance or a homogeneously dispersed mixture of single substances eg metal, concrete, chipboard, mineral wool etc. Homogenous products are not coated, faced or laminated. They are not composites or assemblies."*

The furnace temperature is 750 ^{o}C and normally the test is terminated after 30 minutes. However, if temperature equilibrium has not been reached on the thermocouple during this time the test will continue until the equilibrium has been reached or until 60 minutes have passed. The equilibrium is reached when the variation in temperature does not exceed 2 ^{o}C over a period of 10 or 5 minutes (10 minutes during the first 30 minutes of the test and after that 5 minutes). /14/

The test results from one test is:

- The mass loss in % of the test specimen
- The increase of furnace temperature in ^{o}C over the test period (maximum temperature minus final temperature)
- The duration of sustained flames in seconds.

Five specimens are taken and tested from the same material and the result of the entire test is the average from the five tests.

3.3.4 The Gross calorific value test (prENISO 1716)
The prENISO 1716 is a standard that specifies a methods to determinate the gross calorific potential under constant volume for building materials /15/.

The test apparatus consists principally of a calorimetric bomb, calorimeter (jacket, vessel and stirrer), ignition source and temperature measuring devise, see Figure 3.4.
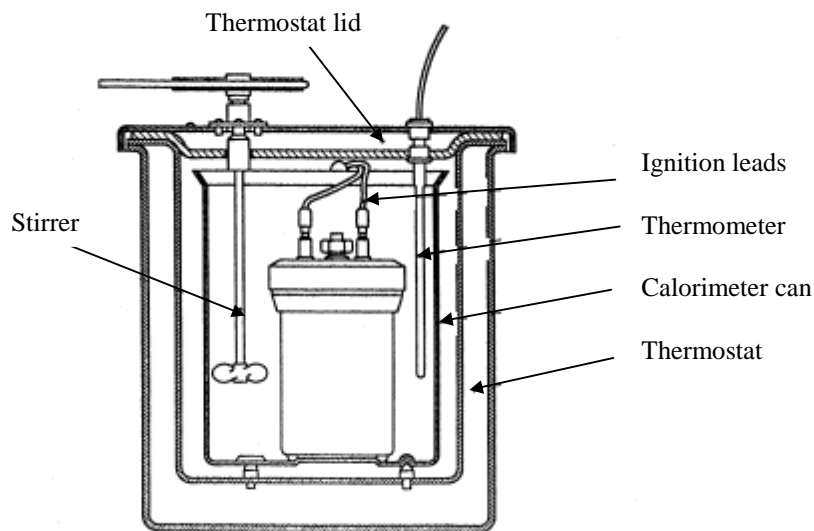
Figure 3.4 The Bomb calorimeter apparatus /16/

The calorimetric bomb is designed to withstand a pressure of 21 MPa and its inner surface is able to withstand an attack by combustion products. The jacket is thermally insulated and also filled with water. /15/

The test specimens are taken from a test sample of a minimum surface area of 0.5 m^2 of the product. If the product is homogenous or non-homogenous but cannot be delaminated, the weight of the specimen is minimum 50 g for thick products and 10 g for thin products. Benzoic acid is added to the specimen to aid the combustion. If the product is non-homogenous and can be delaminated, then each component is separated and treated as mentioned above. /15/

If the apparatus is automatic the gross calorific potential will be the output data from the test. If the apparatus is manual the gross calorific potential has to be calculated on the basis of the observed temperature rise using the following formula /16/:

$$PCS = (E * (T_m - T_i + c) - b) / m$$

where:

PCS   = gross calorific potential
E   = water equivalent of the calorimeter, the bomb, their accessories and the water introduced into the bomb, expressed in MJ/kg
T_i = initial temperature in ^{o}C
T_m = maximum temperature in ^{o}C
b   = correction expressed in kJ required for the combustion heat of the used fuels
c   = temperature correction expressed in K required for the exchange of heat with outside
m   = mass of the test specimen.

The final gross calorific potential of a product is the average gross potential value from three tests /16/.

3.3.5 Ignitability test (prENISO 11925-2)

The prENISO 11925-2 is a standard that specifies a method to determinate the ignitability of building materials by using a small flame impingement on a vertical oriented piece of the test product. The flame is applied either 40 mm above the bottom edge on the surface centerline or on the midpoint of the underside edge, see Figure 3.5 /17/.
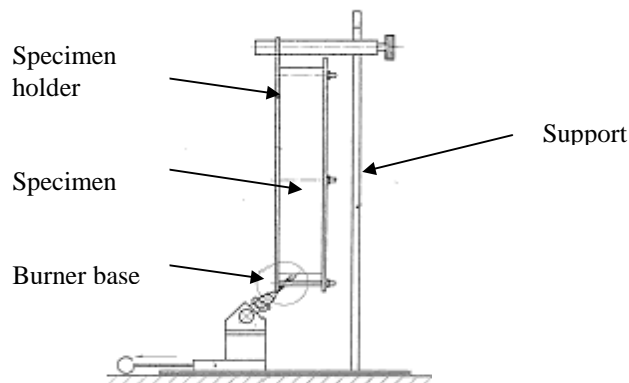
Figure 3.5 Setup for the Ignitability test apparatus

The test apparatus is placed in an enclosure made from stainless steel sheets. The enclosure is equipped with a glazed door to make it possible to observe the test from the outside and to make it possible to enter the enclosure. /17/

The test specimen measures 250 mm x 90 mm (length x width) but if the material may melt and shrink away from the flame without being ignited the specimen must measure 250 mm x 180 mm instead. Six specimens of the same building product are tested. /17/

The impingement flame fuel is propane. During the test the burner is tilted 45° and gives a flame height of 20 mm when applied to the specimen for 15 or 30 seconds. If the flame application time is 15 seconds the test is terminated 20 seconds after the flame has been removed. If the flame application time is 30 seconds the test is terminated 2 minutes after the flame has been removed or earlier if no ignition is observed after removal of the flame, the specimen ceases to burn or the flame tip reaches the upper edge of the specimen. /17/

The output data from the test is:

- Flame spread
- If ignition occurs
- If glowing occurs
- Whether or not flaming debris occurs.

In the case where the test specimen melts or shrinks when exposed to the flame the only output data is whether or not flaming debris occurs /17/.

3.4 Indices and parameters for ranking

The basis for the classification, the test methods and the results from the test methods have now been described. At this point we need to answer two questions. "How do we use the test results to rank the products?" and "What value of an index or a parameter will decide the class limits and give the information that one product is more (or less) hazardous than the other?"

The parameters and indices that will be described and discussed in the following sections are:

- Heat release rate
- Smoke production
- Ignition and Flame spread
- Gross calorific potential
- Non-combustibility
- Flaming droplets/particles.

The values of these parameters and indices, used for the different classes, are a result of political compromises and do not have any scientific basis.

3.4.1 Heat release rate

As mentioned earlier researchers at SP have made an attempt to use the HRR to classify products, which later was accepted by the other member states in EC.

The FIGRA index is defined in /7/ as:

"the peak heat release rate of the fire, excluding the contribution of the fire source, divided by the time at which this occurs. Units are kW/s."

As mentioned in Section 3.3.1, the gas burner in the Room/Corner test will have a heat output of 100 kW for the first 10 minutes and then it is increased to 300 kW for another ten minutes. This means, for example, if the HRR in the Room/Corner test reaches 1000 kW and flashover occurs the peak heat release rate from the product can be either 900 or 700 kW, depending on when flashover occurs. If, on the other hand, the fire is small (HRR from the tested product is equal or less than 50 kW) the FIGRA should be considered as zero as the index might include uncertainties.

When the main test procedure for the classification of a product is the SBI test, and not the Room/Corner test, the FIGRA index must also be defined for the SBI test:

"the FIGRA(SBI) is defined as the maximum value of the quotient of heat release rate and time, multiplied by 1000" /9/.

According to /9/ the overall correlation between FIGRA(SBI) and FIGRA(RC) is good ($R^2 = 0.946$)[2], see also Figure 3.6. For products with low values of the FIGRA(RC) and FIGRA(SBI) indices the correlation is somewhat poorer.
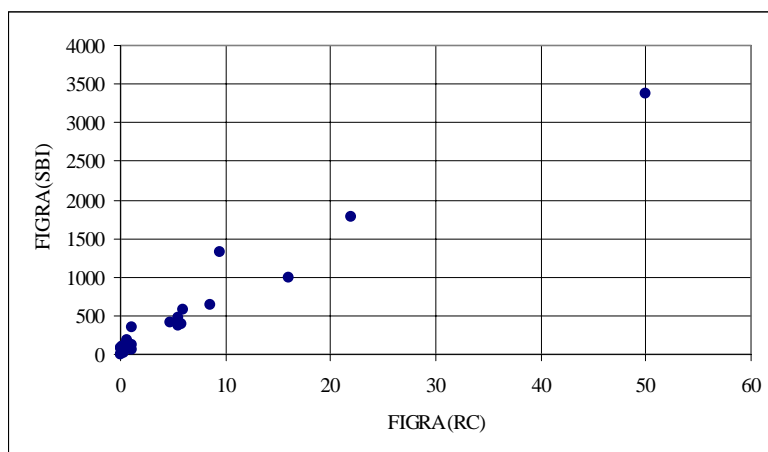
Figure 3.6 The correlation between FIGRA(SBI) and FIGRA(RC)

In order to examine the link further between the two tests, possible classification criteria must be taken into the analysis /9/. As discussed earlier (Section 3.1) the occurrence of flashover is an important factor, which has to be taken into account for the classification. When testing products in the same category, for example wood

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[2] *The relation between the different FIGRA indices is described using the coefficient of determination R^2. This coefficient is according to /18/ "a measure of how much of the residuals that are explained by the regression model".*

based products or gypsum plasterboard, the result will vary from product to product. The reason for the differences is connected to many parameters, for example density and thermal properties. It is important to keep in mind, that at the same time the two products, within the same category, may show a similar burning behavior although there is a variation. As the FIGRA(RC) index will decide the classes and their limits it is important that significant differences in burning behavior are shown by a different class. It is also important to identify possible categories in order to choose the limits in a way that borderline products are avoided. /7/

In the result from /7/ three clusters of products are observed, see Figure 3.7. One is seen for products with a FIGRA between 0 and 0.6 where no flashover occurs in the Room/Corner test. This agrees with the lowest theoretical value of FIGRA(RC), which is 0.58 (i.e. (1000-300)/(20*60)=700/1200). Another cluster of products is observed as the FIGRA index ranges from 0.7 - 1.2. These products reach flashover when the burner effect is increased to 300 kW i.e. after 10 minutes. The materials in the third cluster reach flashover during the first 10 minutes, i.e. when the burner output is still 100 kW. The lowest identified FIGRA value for the tested materials, which belongs to this cluster, is 1.9.
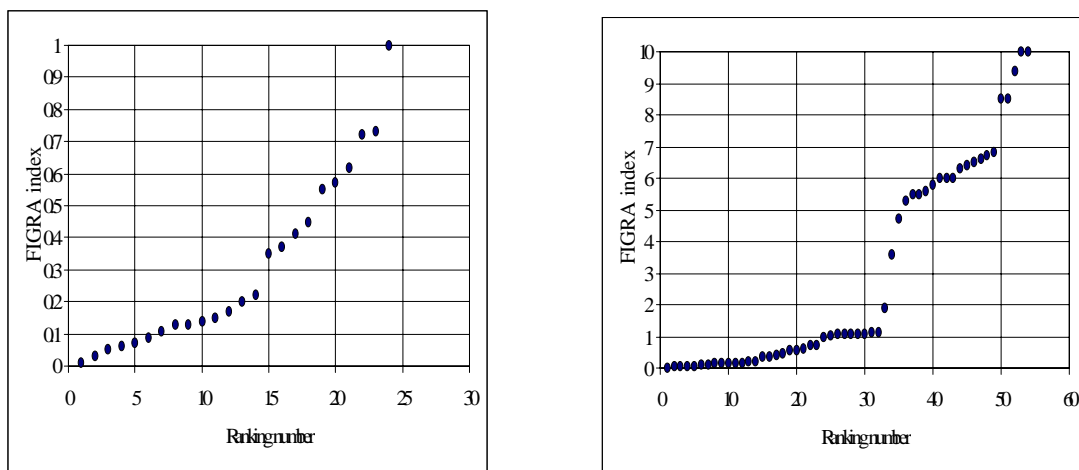
Figure 3.7 The FIGRA index versus ranking number

In the work that followed, the limits dividing the clusters were refined. For an example, two important products that often have been representatives of a certain fire class are plasterboard and wood. The plasterboard has a FIGRA(RC) value of 0.16 and this value is used to define the highest class of the combustible materials, class A2.

The next class, B, would then range between 0.16 to 0.5. Notice that the earlier discussed values of 0.6 and 0.58 are not used for the borderline. A conservative FIGRA(RC) value of 0.5 is used to avoid borderline products /9/.

Further, the division between class B and C is at a FIGRA(RC) value of 1.5, which appears to be very stable with no borderline products. This value represents the lowest theoretical FIGRA value for products that reaches flashover during the first 10 minutes of testing.

The last two classes were separated by a FIGRA(RC) value of 7.5 which equals a flashover time at two minutes and is the border for natural solid wood. According to Figure 3.7, a FIGRA(RC) value of 7.5 is between two clusters and with no borderline products.

This analysis led to the following class limits that were decided on the RG meeting 22 and 23 June 1998 /19/ presented in Table 3.1. Note that the class A from the 1994 decision is divided into two classes, A1 and A2.

Table 3.1 Classification limits for the Euroclasses

Euroclass	Limit value in Room/Corner test FIGRA(RC) (kW/s)	Burning behavior in reference scenario
A1	Does not exists, this is the highest class, non-combustibility.	-
A2	≤ 0.16 (plaster board)	HRR max about 100 kW, no flashover - plaster board or better
B	≤ 0.5	no flashover
C	≤ 1.5	No flashover at 100 kW i.e. flashover occurs after 10 minutes (300 kW)
D	≤ 7.5 (solid wood)	No flashover before 2 minutes (100 kW)
E	> 7.5	flashover before 2 minutes
F		

None of the parameters, peak heat release rate or the total heat release correlates with FIGRA(SBI). Therefore another definition of the heat release, the THR, is presented as an additional independent parameter, addressing a separate fire property. The THR is defined as the total heat released during the first 600 seconds of testing. This gives two properties (FIGRA(SBI) and the THR) that are complementary in describing the burning behavior. /9/

3.4.2 The Smoke production

It is agreed that the parameters to describe the smoke production will be the SMOGRA (SMoke Growth RAte) index and the Total Smoke Production (TSP). The SMOGRA index for the Room/Corner test is defined by SP /7/ in a similar way as the FIGRA index. The definition is as follows:

"*the 60 s average of peak smoke production divided by the time at which this occurs and multiplied with a factor 1000 to achieve practical values. Units are m^2/s^2.*"

Due to the same reason as discusses above for the FIGRA index, the SMOGRA index is set to zero if the HRR of the tested product is equal or less than 50 kW.

The same index for the SBI test, SMOGRA(SBI), is defined by /12/ as:

"*The maximum value of the function smoke production rate/time multiplied by 10000 during the whole period of test, i.e. 10000x SPR/t. The SPR data is calculated as 60s running average to minimise noise.*"

To get a more complete idea how much smoke a given material produces, the total smoke production is also included. The TSP is defined as the total smoke production during the first 600 seconds of testing.

It is also agreed that the smoke production is not a necessary parameter for all the classes A1 to F, see Table 3.1. A product in class A1 does produce very little smoke, if any at all, and for the classes below D it is not a necessary criteria. However, the classes between A1 and D do need some levels to rank them according to their smoke production. It is therefore decided that the smoke production of a given material will be included as a compulsory additional declaration besides the other classification.

The levels for the smoke production are /20/:

- S1 equals SMOGRA ≤ 30 m^2/s^2 and TSP$_{600s}$ ≤ 50 m^2
- S2 equals SMOGRA ≤ 180 m^2/s^2 and TSP$_{600s}$ ≤ 200 m^2
- S3 which is neither S1 nor S2.

This mean that a material in class B will be supplied with a level of smoke production such as B/S1, B/S2 or B/S3.

3.4.3 Ignition and Flame spread

In order to specify how resistant a certain material is to fire, it was found important to find out how fast the flame spreads and the time to ignition. For non-combustible material (class A1) there is no need for these parameters but for the lower classes it is a necessary criteria. As mentioned earlier, there will be two test methods to do this for the Euroclasses.

One of the output data from the SBI test is lateral flame spread (LFS). To receive a certain class the product will have to fulfill a defined requirement. For example, if a product is to receive class B, the material must have a LFS value lesser than a certain length (the length of the edge of the specimen) when the test is finished.

Two parameters that are obtained from the Ignitability test when a product is subjected to direct impingement of flame, are if ignition occurs and if flame spread occurs. In this test the material has to fulfill a requirement of upward flame spread expressed as a value of length during a specified time (F_s). From this value it is possible to rank products according to their ability to ignite. When the specimen is small and it is exposed to the flame a short time it is not a preferable measurement of the flame spread for the product. This requirement is only one among others that is needed for a material to receive a certain class. For example, a material in class B must have an F_s-value lesser or equal to 150 mm in 60 seconds.

3.4.4 Non-combustibility and Gross calorific potential

Materials in the two highest classes (A1 and A2) in the Euroclassification do show little response, if any at all, to the SBI test. Therefore, it was found necessary to have some other criteria than those for the more combustible materials in the lower classes.

The test methods mentioned, that are applicable for this kind of material, is the Non-combustible test and the Gross calorific value test. From the first mentioned test it is

possible to determine the mass loss, the duration of flames and the temperature change under specific conditions. From the latter a material's gross calorific potential can be determined. These parameters will therefore be used to specify products in class A1 and A2.

One reason to use both test methods to determine material properties, is that they have earlier been used separately in different countries and that the correlation between them is poor. Another reason is that the Gross calorific value test allows a higher content of organic material than the Non-combustibility test. /21/

For class A1 it is decided that criteria from both test methods will have to be fulfilled but for class A2 it is decided that a combination of the SBI test and one of the two mentioned tests methods is sufficient /22/. For a material in class A1, flames are not allowed to sustain for more than 20 seconds and the material must have a temperature change lesser or equal to 30 $^{\circ}$C, a mass loss less or equal to 50 % and a gross calorific potential that does not exceed 2.0 MJ/kg.

For a material in class A2 there are two alternatives. One is to fulfill the criteria from the SBI test and that flames do not sustain for more than 20 seconds, the temperature rise is lesser or equal to 50 $^{\circ}$C and the mass loss is less or equal to 50 %. The other way is to fulfill the criteria from the SBI test and that the gross calorific potential is less or equal to 4.0 MJ/kg.

3.4.5 Flaming droplets/particles
Flaming droplets/particles is one parameters that will be used to specify products in classes A2, B, C and D. It has been difficult to decide how to include this parameter in the classification.

The measurement of flaming droplets and particles is based on human observation of occurrence during the SBI test. It is not easy to evaluate the observations and there have been some different proposals on how to estimate the occurrence of flaming droplets or particles. One is simply to have a yes/no criterion and another is to have different levels for the amount of occurrence. The latter leads on to further questions such as "What levels?" and "How to estimate them?" When the final classification system was announced in September 1998, the alternative with different levels was chosen. The way to include this parameter in the classification will be to have a compulsory additional declaration beside the other classification, the same way as for smoke production.

The levels for the amount of occurrence of flaming droplets or particles are as follows:

- D0, which stands for no flaming droplets/particles during test
- D1, which stands for no flaming droplets/particles persisting longer than 10 seconds
- D2, which is neither D0 nor D1. Ignition of the paper in the Ignitability test results automatically in class D2.

This mean that a material in class B will be supplied with a level of occurrence of flaming droplets and particles such as B/D0, B/D1 or B/D2.

3.5 The Classification

Earlier sections have described the test methods, the parameters measured and the criteria used for classification. Below, in Table 3.2, all the parameters needed to specify each class are presented, but first some definitions need to be made.

"Homogenous products: Material, consisting of a single substance or a homogeneously dispersed mixture of single substances eg metal, concrete, chipboard, mineral wool etc. Homogenous products are not coated, faced or laminated. They are not composites or assemblies." /14/

"Substantial components: "A material that constitutes a significant part of a non-homogeneous product. A layer with a weight ≥ 1.0 kg/m^2 or a thickness ≥ 1.0 mm is considered to be a substantial component." /23/

"Internal non-substantial component: A non-substantial component that in its end-use condition is covered by at least one substantial component at its exposed side" /23/

The values in Table 3.2 is of today, November 1998, and some changes might be done in the future.

Table 3.2 Classes of reaction to fire performance for construction products, excluding floorings /20/

Class	Test method(s)	Classification criteria (mean values)	Compulsory additional tests
A1	Non-combustibility test (prENISO 1182) (1); **and**	$\Delta T \leq 30\ ^{\circ}C$ **and** $\Delta m \leq 50\%$ **and** $t_f = 0$ (i.e. no sustained flames)	-
	Gross calorific value (prENISO 1716)	$PCS \leq 2.0$ MJ/kg (1); **and** $PCS \leq 2.0$ MJ/kg (2) $PCS \leq 1.4$ MJ/kg (3) $PCS \leq 2.0$ MJ/kg (4)	-
A2	Non-combustibility test (prENISO 1182) (1); **or**	$\Delta T \leq 50\ ^{\circ}C$ **and** $\Delta m \leq 50\%$ **and** $t_f = 20s$	
	Gross calorific value (prENISO 1716); **and**	$PCS \leq 3.0$ MJ/kg (1); **and** $PCS \leq 4.0$ MJ/kg (2) $PCS \leq 4.0$ MJ/kg (3) $PCS \leq 3.0$ MJ/kg (4)	-
	Single Burning Item (SBI) test	$FIGRA(SBI) \leq 120$ W/s; **and** LFS< edge of specimen; **and** $THR_{600s} \leq 7.5$ MJ	Smoke production (5) and flaming droplets, particles and/or combinations of these (6)
B	Single Burning Item (SBI) test **and**	$FIGRA(SBI) \leq 120$W/s; **and** LFS< edge of specimen; **and** $THR_{600s} \leq 7.5$ MJ	Smoke production (5) and flaming droplets, particles and/or combinations of these (6)
	Ignitability test (prENISO 11925-2) (8) Exposure = 30 s	$Fs \leq 150$ mm within 60 s	
C	Single Burning Item (SBI) test **and**	$FIGRA(SBI) \leq 250$ W/s; **and** LFS< 150 mm within 60 s; **and** $THR_{600s} \leq 15$ MJ or deleted	Smoke production (5) and flaming droplets, particles and/or combinations of these (6)
	Ignitability test (prENISO 11925-2) (8) Exposure = 30 s	$Fs \leq 150$ mm within 60 s	
D	Single Burning Item (SBI) test **and**	$FIGRA(SBI) \leq 750$W/s	Smoke production (5) and flaming droplets, particles and/or combinations of these (6)
	Ignitability test (prENISO 11925-2) (8) Exposure = 30 s	$Fs \leq 150$ mm within 60 s	
E	Ignitability test (prENISO 11925-2) (8) Exposure = 15 s	$Fs \leq 150$ mm within 20 s	Flaming droplets, particles and/or combination of these (7)
F	None	None	No performance determinated

(1) For homogeneous products and substantial components of non-homogeneous products
(2) For any external non-substantial component of non-homogeneous products
(3) For any internal non-substantial components of non-homogeneous products
(4) For the product as a whole
(5) **S1**=SMOGRA ≤ 30 m²/s and $TSP_{600} \leq 50$m², **S2**=SMOGRA ≤ 180 m²/s and $TSP_{600} \leq 200$ m², **S3**=not S1 or S2
(6) **DO** = No flaming droplets/particles during test, **D1** = No flaming droplets/particles persisting longer than 10 seconds
   D2 = not D1 or D2, ignition of the paper in the Ignitability test results in class D2
(7) Pass = no ignition of paper, Fail = ignition of paper
(8) Under end-use condition of surface flame attack and, if appropriate to the end-use condition of the product, edge flame attack

4. Introduction to the situation in Japan

In Japan, the Japanese Building Standard Law (BSL) together with enforcement orders and ministry notifications regulates everything that is connected to building and construction i.e. everything from building inspections to how to use the land. Since 1950 these regulations have been the basic regulations to follow. The BSL is stated by the congress (politicians), which is the highest level of legislative central authority. The Congress states the fundamental regulations, which are similar to a constitution and do not give any detailed descriptions of how the requirements are fulfilled. The next level of central authority is the Cabinet (politicians), which is responsible for the enforcement orders, which are more detailed than the BSL. One example of the Cabinet's responsibility is to state the definitions, which describes the different terms used in the BSL. In many cases not even the enforcement orders are detailed enough and then it is necessary to use the ministry notifications, which are published by the Ministries. A Ministry is composed of technicians and is the lowest level of central authority. The ministry notifications are detailed descriptions including for example test methods and parameters used for classification.

The decision-making process is often slow for the highest level of legislature, but relatively quick in the Ministries. This means that it is possible to have a rapid development concerning test methods and new criteria, which often is useful when research results point at the necessity of quick changes. The hierarchy of the building regulations is showed in Figure 4.1. Beyond the central authorities there are regional authorities which states even more detailed rules than the central authorities. This means that all regions in Japan do not have the same final regulations but they do have the same fundamental regulations.
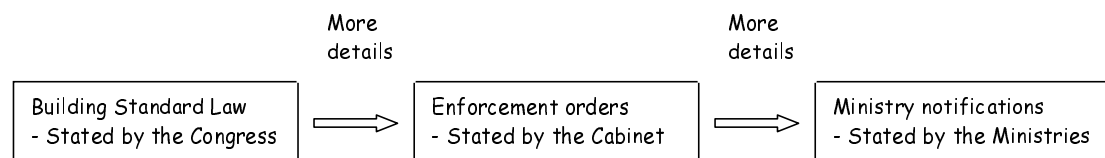
Figure 4.1. The hierarchy for the central building regulations in Japan

4.1 The revision of Building Standard Law

The BSL have been revised a number of times and the latest occasion was in June 1998. From 1993 to 1998 work was carried out to develop a new approach for the law. This development is today not yet ended for all categories of the law, but in year 2000 all parts are supposed to be taken into practice. The aim of the work is to:

- rationalize building procedures
- ensure the effective enforcement of regulations
- rationalize the content of building regulations.

Rationalization of building procedures

In Japan it was believed that the building law situation might be preventing the administrative authorities from efficiently performing buildings confirmations and inspections. Therefore, it was decided that the role shared by public and private organizations had to be renewed. The aim was to increase the field for private and independent organizations and to make it possible for the government authorities to concentrate more on indirect control /24/. Another result from this decision is that the system becomes more effective for the building owners, which can obtain building confirmation and inspection services more easily.

Ensuring the effective enforcement of regulations

Before June 1998 the building inspections in Japan were carried out after the building was built. A number of large catastrophes had pointed at the need for a system where inspections could be undertaken while the building still was under construction. Therefore, it was decided that certain administrative agencies should decide which construction processes must undergo this inspection and the result of this action is that the buildings become safer than they are today /24/.

To ensure that the regulations are followed properly, it is also important that the system allows the public to have access to documents concerning building confirmations and inspections. To create such a system it was necessary to appoint certain agencies, which will be required to create and maintain building registries /24/. The public is then supposed to have access to these registries, which will increase the amount of information about buildings and therefore help to protect consumers and improve the functions of the market.

Rationalization of the content of building regulations

When the situation in Japan did not allow enough freedom in building design it was decided that the regulatory part of the law must be reviewed. The building regulatory system had to allow technological progress and to accept the use of materials from outside Japan. To make this possible, performance-based building regulations had to be adopted, allowing the use of a wide variety of building materials, which fulfill certain performance requirements /24/. This decision will encourage technological development and the use of more rational techniques. Another result from this decision is that there will not be any need to satisfy specification criteria, which also will help to increase the design freedom.

4.2 The development in the fire safety area

Today the regulations in Japan are prescriptive but allow an engineering approach if the Ministry of Construction permits it. To adopt a performance based building regulation and to make it possible to accept material from outside Japan, fire safety standards have to be developed. New test methods have to be investigated and the focus must be directed towards internationally accepted test methods and building standards. To summarize the objectives and goals for the future test methods it can be said /25/, that they shall be:

- accepted world wide
- applicable for any material, structure or equipment

- able to take into consideration how building materials, structures and equipment are used in practice
- able to take the construction processes into account.

Establishment of rigorous quality control to ensure stable fire safety performance for a long period of time is also important when the use of building material is considered. Therefore, a proper quality control procedure is under development so that all certified products have uniform fire safety performance. However, when this development might be confusing on the market the law will be changed gradually until year 2000.

5. The Japanese classification system today

Today the classification system of surface lining materials used in buildings is based on the fact that all materials, which require fire performance, can be divided into three groups. These three groups represent the non-combustible materials, quasi non-combustible materials and fire retardant materials. Different test methods are used to determine the material properties for materials in different groups. Dependent on which group the producing company wants their material to belong to the test method is chosen. Current prescriptive regulations only regulate the use of materials, which belongs to these three groups.

5.1. Test methods

Today there are five different test methods used for the measurement of reaction to fire for surface lining materials used in buildings. These tests are:

- the Non-combustibility test
- the Surface test
- the Hole test
- the Gas toxicity test
- the Reduced-scale Model Box (RMB) test.

The different test methods will be described shortly in the following sections.

5.1.1 The Non-combustibility test (JP Notification # 1828)

This test procedure is only used for materials that are considered to be non-combustible. The test apparatus and the test procedure for the Japanese Non-combustibility test are almost the same as for the ISO Non-combustibility test, see Section 3.3.1. Therefore, only the differences between the two test methods are described in this section.

The Japanese test apparatus is almost identical to the ISO test apparatus. The only significant differences are that the Japanese test apparatus has two thermocouples to measure the temperature and no insulation around the furnace.

The only difference, with regards to the test specimen is the shape. The shape of the test specimen is cubical (50 mm x 40 mm x 40 mm) for the Japanese test, while it is cylindrical in the ISO test.

The way to measure the temperature difference (ΔT) is also slightly different. In the ISO Non-combustibility test ΔT is measured as the difference between the highest temperature peak and the temperature equilibrium. In the Japanese Non-combustibility test ΔT is measured as the difference between the highest temperature peak and the initial temperature. Therefore, the duration of the Japanese test does not need to be as long as the time for the ISO test. The duration of the Japanese test is 20 minutes compared to 30-60 minutes for the ISO test. The difference in measurement of ΔT is shown in Figure 5.1.
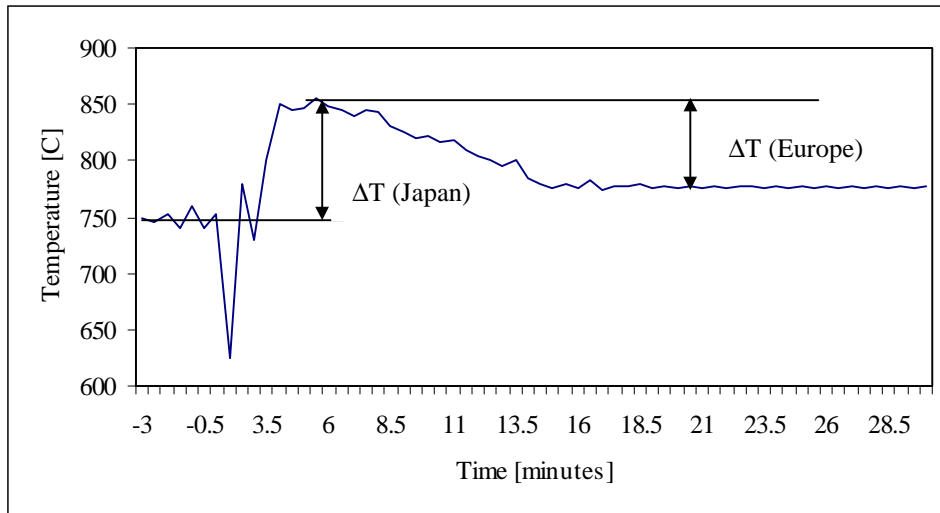
Figure 5.1 The differences in measuring ΔT for the Japanese and ISO non-combustibility test

Another difference between the test is the output data. While the final output data from the Japanese test is the highest result from three tested specimens the final output from the ISO test is the average from five tested specimens. In Japan, the only measured parameter is the temperature change of the furnace and not the mass loss of the specimen or the duration of sustained flames, which is given as output from the ISO test.

5.1.2 The Surface test (JP Notification # 1828 and 1231) and the Hole test (JP Notification # 1231)

The Surface test
The Surface test is a bench-scale test method used to determine material properties for all type of materials. The test apparatus consists basically of an open furnace and smokes chamber, see Figure 5.2.
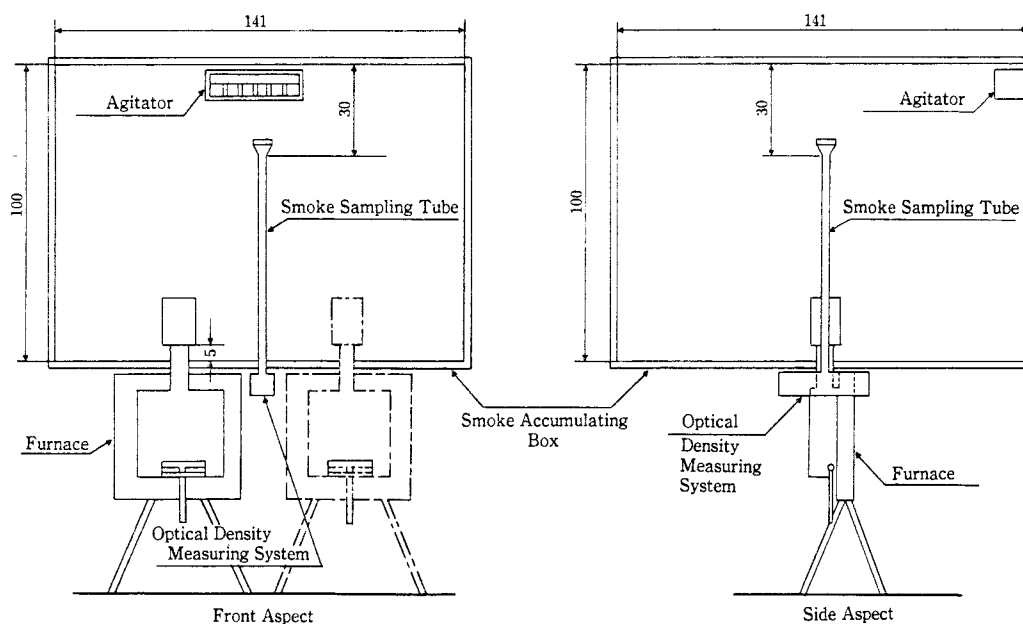
Figure 5.2 Typical set up of the Surface test /26/

The furnace is slightly larger than the test specimen and is connected to the smoke chamber by a short tube. The smoke chamber measures 1.41 m x 1.41 m x 1.0 m (Width x length x height) and is equipped with a stirrer to make the smoke homogenous /27/.

The test specimen measures 220 mm x 220 mm and the heating zone measures 180 mm x 180 mm. The first three minutes the heating source is a propane burner with a heat output of 0.53 kW and after that a radiant heat source is added with a heat output of 1.5 kW. The total time of the test is either 6 or 10 minutes dependent on which group of material (fire retardant or quasi non-combustible) the tested material belongs to.

First a specimen of a reference material (Pearlite board) is tested and after that three specimens of the actual material. One of the results from each test is the $td\theta$ value, which is a measurement of increase in temperature. The $td\theta$ value is calculated as the difference between the temperature-time curve for the standard material and the tested material, see Figure 5.3.
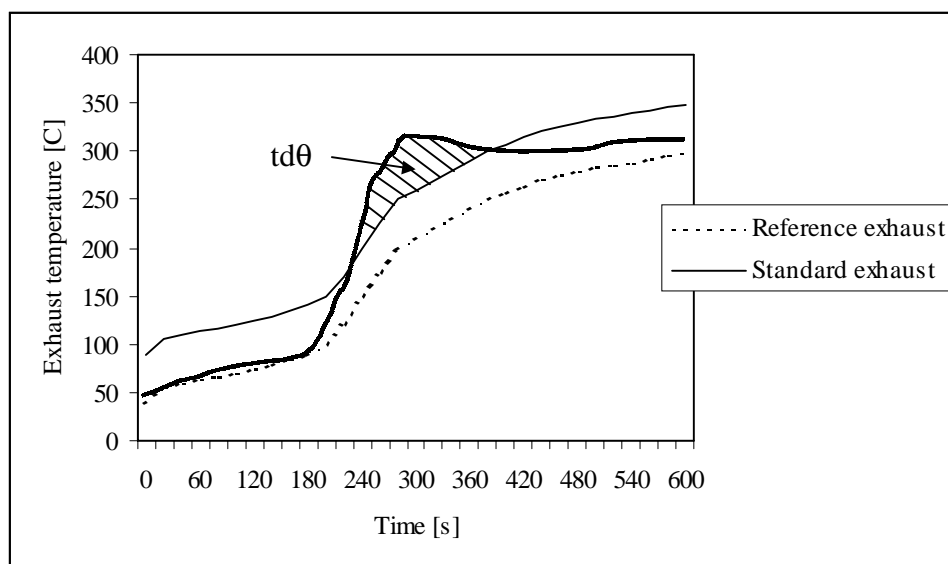
Figure 5.3 Definition of the tdθ value, the thickest line represents the tested material

Another result from the test is the smoke production expressed as the increase in smoke emission, C_A. The increase in smoke emission is calculated by measuring the intensity of the light transmitted through the smoke before the test has started (I_o) and at the end of the test (I). When these values are known the C_A-value is calculated using the following expression:

$$C_A = 240 \times \log_{10}(I_o /I).$$

The final results from the three tests are the highest values of $td\theta$ and C_A from the three tested specimens. For non-combustible and quasi non-combustible materials an additional parameter is measured, the duration of flames on the surface after the heating has been interrupted.

The Hole test

For laminar quasi non-combustible materials the Hole test must be carried out which is the same test as the Surface test but three holes (D = 25 mm) are drilled in the test specimen. The aim of this test is to determine the material properties when all the layers in the material are exposed to heat. The output from the Hole test is the same as for the Surface test.

5.1.3 The Gas toxicity test (JP Notification # 1231)

The Gas toxicity test is a bench-scale test method used to determine the occurrence of hazardous gases when a quasi non-combustible or a fire retardant material is exposed to a heat source. This test was developed in 1980 as a result from a number of multiple death fires. Most of the people who died in those fires died because of the smoke. The aim of the test method is to simulate the situations that can arise in evacuation routes and spaces close by the room of fire origin. The test apparatus basically consists of a closed furnace, a mixing box and an animal exposure box, where eight mice are running in rotary wheels, see Figure 5.4.
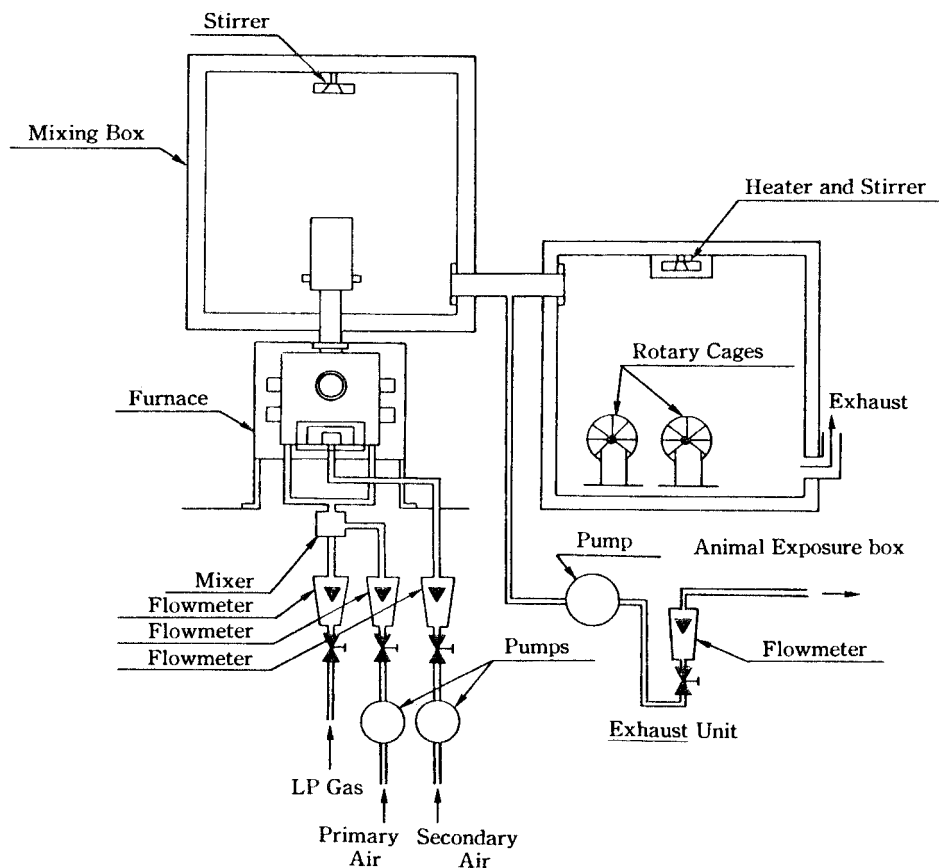
Figure 5.4 Typical set up of the Gas toxicity test /26/

The test procedure is almost the same as for the Surface test. The test specimen is first preheated with a gas burner for three minutes and then a radiant heat source is added. The test is first carried out on a specimen made from a reference material, which is

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Red Lauan (a source material for plywood). After that, two tests are carried out on the material to be tested. The duration of the test is 15 minutes.

The output from each test is the difference in time when the mice stop moving for the reference material and the tested material. The final result is largest time difference from the two tests.

5.1.4 The Reduced-scale Model Box (RMB) test (JP Notification #1231)

The RMB test is 1/3 scale model of the Room/Corner test. The test method is used to determine the behavior of quasi non-combustible material when exposed to fire and was developed in the early eighties. The advantage of the RMB test compared to the Room/Corner test is that it does not need to be terminated immediately after flashover occurs and that the cost of each test is far less than for the Room/Corner test. The actual peak heat release rate and the peak of smoke production often occurs after flashover and therefore the RMB test is convenient for measuring post flashover properties. The test apparatus consists basically of a small compartment, a gas collection system and an ignition source, see Figure 5.5.
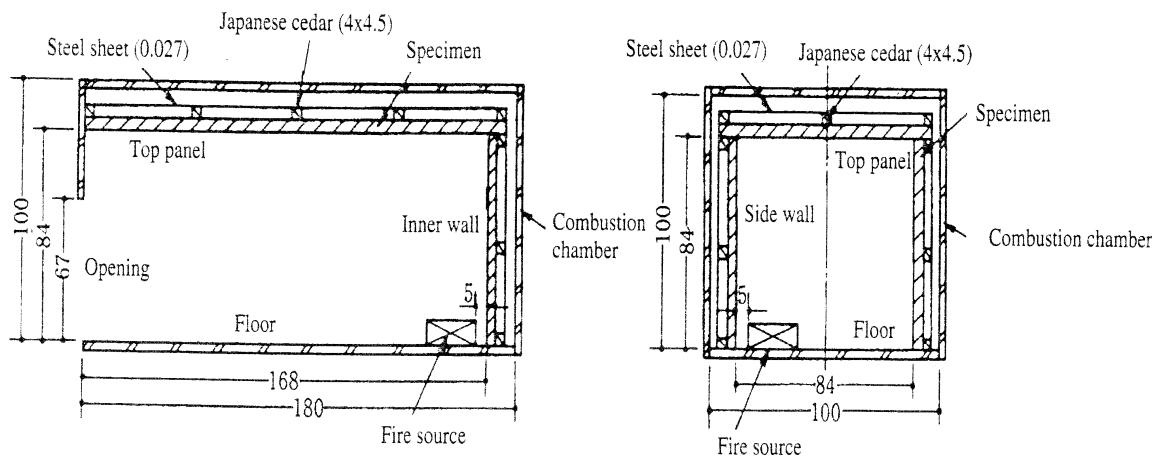
Figure 5.5 The set up for the Reduced-scale Model Box test /26/

The small compartment measures 0.84 m x 0.84 m x 1.68 m (with x height x length), after the surface lining material is mounted and the opening is 0.3 m wide and 0.67 m high. The ceiling, the floor and the walls are made of a non-combustible material.

The lining material is mounted on three walls and the ceiling and is then exposed to an ignition source placed in one of the rear corners. The ignition source consists of a pile of wood cribs (300 mm x 300 mm x 60 mm). The duration of the test is 15 minutes.

The output from the test is the same as for the Room/Corner test, i.e.:

- Heat release rate (HRR)
- Smoke production rate (SPR)
- Oxygen depletion rate
- CO depletion rate
- CO_2 production rate.

The heat release and the maximum heat release rate during the test period are the parameters, which are used for evaluation and classification.

5.2 The classification and the parameters used for ranking

As mentioned before, the different types of surface lining materials used in buildings are divided into three groups in Japan. These three groups also represent the different classes in the classification system and are as follows:

- Class I, the non-combustible materials
- Class II, the quasi non-combustible materials
- Class III, the fire retardant materials.

5.2.1 Class I, non-combustible materials

This is the highest possible class a material can belong to. Earlier this class was only used for structural components and not for surface lining materials, but is now also used as the latter. The test methods used for materials in this class are the Non-combustibility test and the Surface test. The non-combustible materials are of three types, legal (fixed by law), general rule (fixed by industrial standards) and approved by tests. Examples of non-combustible materials are steel and concrete (legal materials), gypsum board (12.5 mm) and calcium silicate board (general rule) and laminar materials (approved by tests).

The criteria to be fulfilled for a material to belong to this class are:

- Non-combustibility test (duration of the test is 20 minutes):
    - $\Delta T \leq 50\ ^oC$

- The Surface test (duration of the test is 10 minutes):
    - $td\theta < 0\ ^oC$ minutes
    - $C_A < 30$
    - duration of flames < 30 seconds

5.2.2 Class II, quasi non-combustible materials

This type material is the most common on the Japanese market and therefore this is also the class to which most of the surface lining materials on the Japanese market belongs to. The major test procedures in this class are the Surface test and the RMB test. If the results from the Surface test are higher than a certain criteria even the Gas toxicity test will be used and if the material is laminated, even the Hole test must be used. There are two types of quasi non-combustible materials, general rule and approved by tests. Examples of the general approved type are gypsum board (9.5 mm) and cement board with wood tips. Examples of the materials approved by tests are new or laminated materials.

The criteria that needs to be fulfilled for a material to belong to this class are:

- The Surface test (duration of the test is 10 minutes):

- $td\theta < 100\ ^oC$ minutes
- $C_A < 60$
- duration of flames < 60 seconds

- RMB test (duration of the test is 15 minutes):
  - THR < 5 MJ
  - $HRR_{max} < 170$ kJ

- The Hole test (duration of the test is 10 minutes):
  - $td\theta < 150\ ^oC$ minutes
  - $C_A < 60$

- The Gas toxicity test (duration of the test is 15 minutes):
  - Time until the mice stop moving (the test specimen must have a time that is equal or less than the time for the reference material)

5.2.3 Class III, fire retardant materials

The fire retardant materials are seldom used in practice when there are few areas in which they are allowed according to the regulations. There are two types of fire retardant materials, general and approved by tests. Examples of the general approved type are fire retardant plywood and aluminum plate. Examples of the materials approved by test are new or laminated materials.

- The Surface test (duration of the test is 6 minutes):
  - $td\theta < 350\ ^oC$ minutes
  - $C_A < 120$
- The Gas toxicity test (duration of the test is 15 minutes):
  - Time until the mice stop moving (the test specimen must have a time that is equal or less than the time for the reference material)

5.2.4 The classification

Earlier sections have described the test methods, the parameters measured and the criteria for each class of material. Table 5.1 summarizes the classification system.

Table 5.1 Classes of reaction to fire performance for surface lining materials used in buildings

Class	Test methods	Classification criteria
Class I	Non-combustibility test (JP Notification # 1828)	$\Delta T \leq 50\ ^oC$ $td\theta < 0\ ^oC$ minutes $C_A < 30$
	Surface test (JP Notification # 1828 and 1231)	$td\theta < 0\ ^oC$ minutes $C_A < 30$ duration of flames < 30 seconds
Class II	Surface test (JP Notification # 1828 and 1231)	$td\theta < 100\ ^oC$ minutes $C_A < 60$ duration of flames < 60 seconds
	Hole test (JP Notification # 1231)	$td\theta < 150\ ^oC$ minutes $C_A < 60$
	RMB test (JP Notification # 1231)	$THR < 5$ MJ $HRR_{max} < 170$ kJ
	Gas toxicity test (JP Notification # 1231)	Time to the mice stop moving (the test specimen must have a time that is equal or less than the time for the reference material)
Class III	Surface test (JP Notification # 1828 and 1231)	$td\theta < 350\ ^oC$ minutes $C_A < 120$
	Gas toxicity test (JP Notification #1231)	Time until the mice stop moving (the test specimen must have a time that is equal or less than the time for the reference material)

6. Proposal for a new Japanese classification system

In order to meet with performance based building regulations and international demands for harmonization the Ministry of Construction (MOC) started a five year research and development program, the So-pro program, in 1993. The So-pro program, "Development of Assessment Methods for Fire Safety in Buildings", is a comprehensive research program encapsulating a large number of research projects for technical development. It includes an evaluation of performance based regulations and development of a new testing and evaluation system for building materials and components.

The objectives concerning building materials can be summarized as:

- specification of fire safety performance of materials
- international harmonization of fire testing methods
- revision of fire testing methods in Japan.

The final decision on the new Japanese classification system is not yet taken. Therefore, this chapter will describe the current situation and the proposals, which are being considered, and there might be some changes in the future.

6.1 Specification of fire safety performance of materials

The specification of fire safety performance required for materials is divided into four types: structures, building equipment, exterior linings and interior linings. This report mainly deals with interior linings so this section will focus on such materials. Where surface lining materials are concerned the objective is to:

- prevent fire outbreak
- ensure life safety for occupants, in the room of fire origin
- ensure the fire safety in evacuation routes and spaces near by the room of fire origin.

Prevent fire outbreak
In order to meet with the objective for surface lining materials, parameters have to be specified to describe the fire safety performance. In the So-pro program it was concluded that a fire seldom starts on the lining material but if for example a sofa, TV or kitchen appliance ignites, the interior lining plays an important role for the fire spread and the risk of a fully developed room fire. Therefore, if the ignitability of the lining material could be reduced the total fire risk is also reduced. Therefore, the ignitability was considered to be the key parameter to prevent fire outbreak. /28/

Ensure life safety for occupants, in the room of fire origin
A safe evacuation is characterized by the fact that people are able to get out of the building before critical conditions for smoke, temperature or visibility occur. In most occupancies it is not difficult to complete the evacuation before these critical conditions occur. However, the evacuation is relatively often influenced by irrational decisions and behavior and in occupancies for health care, disabled people or elderly it

may be difficult to ensure a safe evacuation. Therefore, to ensure life safety for the occupants in the room of fire origin the key parameter could be control of the combustibility. /28/

Ensure the fire safety in evacuation routes and spaces near by the room of fire origin
As described in Section 3.1 most fire deaths are due to the inhalation of smoke and often occur far from the fire itself. To ensure fire safety in evacuation routes and spaces near the room of fire origin it was concluded that it is more reasonable to use smoke control design, rather than control of surface lining material. However, the smoke control design relies on parameters like optical density and gas toxicity, which have to be determined by testing. The fire load in escape routes, such as combustible furniture, is often already controlled but it is also important to control the reaction to fire of the surface lining material. This is especially important in occupancies where fast evacuation is not expected. /28/

When flashover occurs there is a sudden and dramatic increase in the production of carbon monoxide. The escapes routes and spaces near by the room of fire origin are therefore most affected when the fire reaches this stage and to ensure life safety it was found necessary to prevent flashover. One result from the So-pro program is that the interaction between lining materials in ceiling and walls plays an important role in the fire growth. If a non-combustible material is mounted in the ceiling, in the Room/Corner test, the time to flashover will increase with almost 10 minutes, compared to if a combustible material was mounted in the ceiling /28/. Based on this result it might be said that mounting of non-combustible material in the ceiling can prevent flashover for a number of cases where combustible materials are mounted on the walls. Therefore, a design solution might include the use of combustible materials but still have an evacuation time that is enough for most common buildings.

All the key parameters, except the ignitability, and the production of carbon monoxide do have a close connection to the heat release (HRR) /28/. Therefore, it was decided that the most important parameter to measure is the HRR. But, even if the smoke production was found to have a close connection to the HRR it has been discussed if this relation is good enough. The current situation is that the smoke production also will be included in the classification system. When the ignitability not are connected to the HRR, it was decided that this parameter also had to be included in the classification.

6.2 International harmonization and revision of fire testing methods
In order to meet with the objectives of international harmonization and revision of fire testing methods concerning building materials, eleven test methods including five Japanese tests and six ISO tests were studied and compared. The five Japanese tests were the Non-combustibility test, the Surface test, the Hole test, the Gas toxicity test and the Reduced-scale Model Box test. The six ISO tests were the Non-combustibility test (ISO 1182), the Ignitability test (ISO 5667), the Ignition and lateral flame spread test (ISO 5658), the Single chamber test (ISO 5659), the Cone Calorimeter test (ISO 5660) and the Room/Corner test (ISO 9705).

6.2.1 Conclusions about the fire testing methods

As discussed in Section 6.1 the most important parameters that have to be described by the used test method are the ignitability and the fire growth. The So-pro program found that if little flame spread occurs in the fully developed fire stage, the most reasonable test method is the ISO 1182 or Japanese Non-combustibility test. To meet with the objective of international harmonization and based on the good correlation between the two tests the ISO version of the Non-combustibility test was chosen. If little flame spread occurs in the initial fire stage or flame spread is controlled in the room of fire origin, and a safe evacuation is possible the most reasonable test method was found to be the ISO 9705 Room/Corner test.

Based on these conclusions it was decided that the Room/Corner test was to be the reference scenario for the classification. However, to always use the Room/Corner test would be very expensive and therefore it was decided that a bench-scale test, that correlates well with the reference scenario, had to be found. The first bench-scale test to be investigated was the RMB test.

The RMB test has been modified and has changed the heat source from a pile of wood cribs to a propane burner and is now a proposed ISO standard. The experiments with this modified RMB test, from now on simply referred to as the Model Box (MB) test, and the Room/Corner test has this far not succeeded in finding a good correlation between the heat release from the two tests. Therefore, the MB test will probably only be used to measure the smoke production, when it is convenient to measure post flashover properties, see Section 5.1.4.

The most favorable test to determine the smoke toxicity for burning materials was found to be the Gas toxicity test. There are also plans to propose this test to ISO and in order to do this the mice probably has to be replaced by an apparatus that measures the gas properties. It is today not yet decided how to use this test for classification but it will probably be used in combination with the MB test.

The test procedure that shows best relationship to the heat release from the reference scenario was found to be the Cone Calorimeter. With the output from the Cone Calorimeter it is possible to determine which materials that go to flashover in the reference scenario and the time at which this occurs. By plotting the ignition temperature divided by a constant as a function of the peak heat release rate it is possible to identify the materials behavior in the Room/Corner test. This relationship was developed and solved analytically by Thomas and Karlsson /29/ and later represented graphically by Kokkala and Baroudi /30/, which is shown in Figure 6.1. The output from the Cone Calorimeter can also be used for performance based design solutions and an engineering approach. Based on these facts it was decided that the Cone Calorimeter test was going to be the main test procedure for surface lining materials. However, the results from the Cone Calorimeter do not always show a good relation to the reference scenario. Therefore, it was decided that the Room/Corner test would be used for materials where the result from the Cone Calorimeter points at a poor relation. A short description of the Cone Calorimeter is presented in the next section.

$\lambda\tau = (1 + \sqrt{a})^2$

$\lambda\tau = a - 1$
$(\alpha = 0)$

Deceleration
(for all times)
No Flashover

IV

Deceleration at time = 0+
No Flashover

Acceleration at time = 0+
subsequent deceleration

Possible flashover
close to Line A

$\lambda\tau = (1 - \sqrt{a})^2$

III

Line A

II

Acceleration
(for all times)

I

Flashover

$a \ (= K \ \dot{Q}''_{max})$
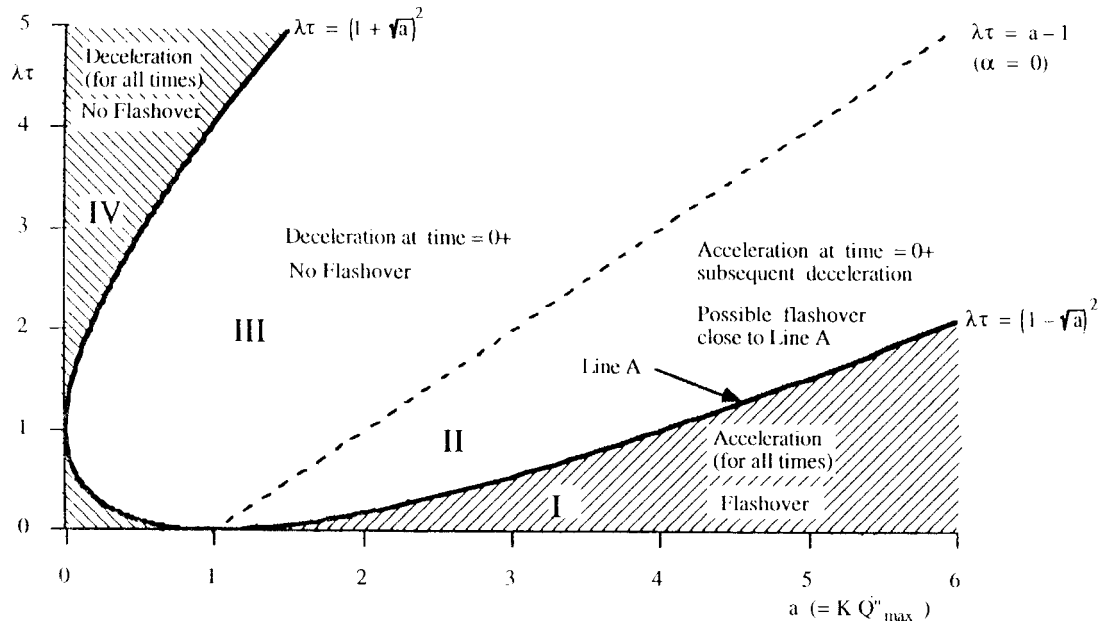
Figure 6.1 The graph, which determine the flame spread acceleration for a material tested in the Cone Calorimeter /31/

The output from the Cone Calorimeter test can, as mentioned, be used for performance based design but many calculation and computer programs uses the output from the American or International version of the Lateral Ignition and Flame Spread test, LIFT. Therefore, it is not yet decided if the Cone Calorimeter test will be accompanied by one of these tests.

6.2.2 The Cone Calorimeter test (ISO 5660)

The Cone Calorimeter test is a bench-scale test used to determine the reaction to fire for surface lining materials used in buildings. The test apparatus consist basically of an electric heater, an ignition source and a gas collection system, see Figure 6.2.
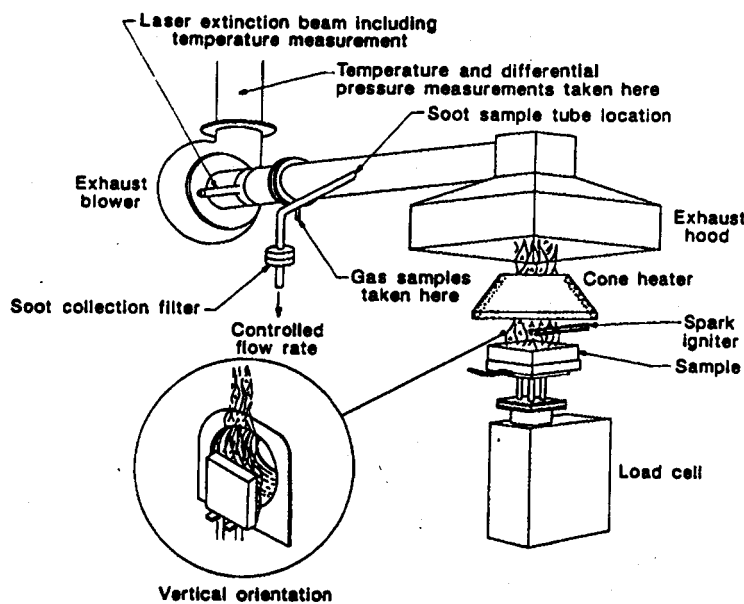
Figure 6.2 Typical set up for the Cone Calorimeter test /32/

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The test specimen measures 100 mm x 100 mm and has a thickness between 6 mm and 50 mm. During the test the specimen is mounted horizontally on a low heat loss insulating ceramic material. The orientation of the specimen can also be vertical, but this is most often used only for exploratory studies. /32/

After the test specimen has been mounted and placed in the right position, it is exposed to a heat flux from the electric heater. The output from the heater can be chosen in the range of 0–100 kW/m^2, but usually the heat output is in the range of 25–75 kW/m^2 /31/. When the mixture of gases above the test specimen is higher than the lower flammability limit, it is ignited by an electric heat source. The duration of the test is normally 10 minutes but is not fixed and can vary depending on the material.

The results from each test are:

- Time to ignition
- Mass loss rate
- Heat release rate.

If a gas analyzer is added to the test equipment it is also possible to take the production of smoke and toxic gases into account.

6.3 Design solutions for surface lining fires

The proposal from the So-pro program today includes three different routes of design solutions, A, B and C. Route A is the most conservative of the three and is meant to be used in cases where a prescriptive approach is favorable. To make it possible to accept "new" solutions as large structures made of wood or designs that can not be described using route A, a second route can be chosen, route B. This route is a performance based approach which is based on calculation methods and criteria given in law. If routes A or B are not applicable, there will be an opportunity to chose a third approach, route C. When choosing this route it is possible to use other calculation methods than those given by law. The only regulation is that the solutions have to be approved by experts. The proposed routes are not finally decided and therefore this section will describe the current situation but there might be some changes in the future. In Figure 6.3 the three different proposals for design solutions are illustrated.

Figure 6.3 Illustration of the three different approaches, route A, B and C

6.3.1 The Conservative approach, Route A

Route A is, as described above, the most conservative approach. Here the designer chooses an approach with prescriptive requirements, with materials tested and classed by methods given by law. Due to the good correlation to the Room/Corner test, the Cone 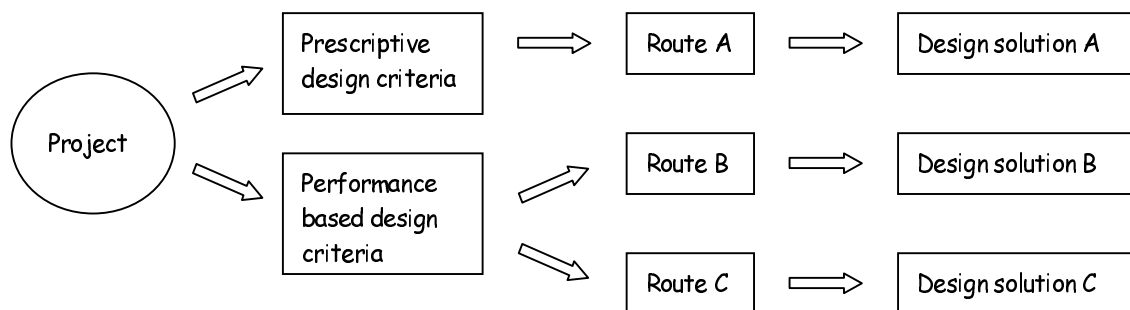Calorimeter will be the main test procedure but the MB test or the Gas toxicity test will probably accompany this test. Some materials might even be tested in the ISO Non-combustibility test. The classification will be based on the Room/Corner test and will most probably include three different classes:

- Class 1, where materials not reach flashover
- Class 2, where materials reach flashover after a time longer than 10 minutes
- Class 3, where materials reach flashover within 10 minutes.

These classes will be very similar to the ones used today. The new classes can be said to represent the non-combustible materials (Class I), the quasi non-combustible materials (Class 2) and fire retardant materials together with combustible materials (Class 3).

For structural materials there will also be a non-combustible class for which the main test method is the ISO Non-combustibility test. If a material from this class is used as interior lining there will be no need to use the Cone Calorimeter test to determine material properties. If a material fulfill the requirements for the structural non-combustible class it is certain that it will fulfill the requirements from the Cone Calorimeter for material in Class 1. Therefore, a material in Class 1 can be tested in either the Non-combustibility test or in the Cone Calorimeter test, which will be the main test method. However, there are also two other proposals for the class limits.

A second proposal for class limits suggests that Class 3 in the most probable proposal be divided into two classes, Class 3.1 and Class 3.2. Materials in class 3.1 do not reach flashover before 5 minutes of testing and materials in Class 3.2 reach flashover before five minutes of testing, in the Room/Corner test. This proposal leads to a classification, where the fire retardant and the combustible materials are divided into two different classes.

There is also a third proposal for class limits, which suggests that Class 2 in the first mentioned proposal be divided into two classes, Class 2.1 and 2.2. Class 2.1 would represent materials that reach flashover during the last 10 minutes of testing but does then decrease so the fire spread is limited. Class 2.2 represents materials, which reach flashover during the last 10 minutes of testing and for which the fire intensity always increases. However, it is not yet decided how to identify these class limits with the output data from the cone calorimeter. It is most likely that the first alternative for class limits will be used and therefore that classification will be used as the base for further studies and comparisons in this report.

The mentioned class limits are based on a study of evacuation planning /33/. If flashover is consider as the critical point for evacuation and that no further evacuation can be performed after flashover has occurred this can easily be used for design. For an example could materials in Class 1 be used for surface linings in buildings like hospitals or for elderly people where a quick evacuation not can be expected.

Materials in Class 2 and Class 3 would then be more suited for use in buildings where a quick evacuation can be expected.

6.3.2 The Performance Based approach, Route B
In this approach, the intention is that a room fire model will be used to fulfill certain requirements given by law. Also the accepted room fire models and test methods will for this route be given by law. In order to introduce room fire models in practice, the So-pro program invited authors of "open" room fire models to co-operate on validation by a third person and improvement of their models. Prof. J. Quintiere, Maryland University, and Dr. B. Karlsson, Lund University accepted the invitation. This project is still under development but has led to some calculation methods to simulate fire growth behavior in the Room/Corner test /34/. The methods is based on the work done by Karlsson /31/ and Quintiere /35/ and shows good agreement with the heat release rate from experiments in the Room/Corner test. There is especially a good agreement for wooden based products and when most materials used for lining are wooden based products this is a hopeful result.

At least two problems are under investigation before the calculation models can be used in practice. First, the assessment methods on material properties, such as thermal inertia and ignition temperature, have to be established. These necessary parameters, used as input to the models, are obtained from either the Cone Calorimeter test (ISO 5560) or the LIFT. Since the number of LIFT apparatuses is very limited in Japan, the intention is to establish the assessment method by only using the Cone Calorimeter test. Second, the present calculation models have to be modified to describe not only the Room/Corner test configuration but also compartments with a larger area and/or higher ceiling height. When the work with this computer program is completed, it will be recommended as a tool for route B in the law.

6.3.3 Route C
While route A is the descriptive approach and B a performance based, route C is the approach with largest freedom for the designer. Here, the designer is free to use any test methods or calculation models for the basis of the design. The only regulation is that the test methods and calculation procedures have to be approved by experts. There will probably be a number of suggestions for calculation procedures, but the designer is free to choose any available calculation model and test method. The requirements for this route have not been formulated yet but will probably be similar to those for route B. The discussions are still vague and nothing is decided today but it is concluded that this approach could be very useful in the future with other conditions than today.

7. Possibilities to a direct link between the systems

When now both the Japanese and the European classification systems have been described it can be questioned if there are any possibilities to link them together. The first question that must be answered is if there are any possibilities to find a direct link between the two classification systems. Therefore, this question will be discussed and examined closer in this chapter. The comparison of the systems is made between both the Japanese system today and the Euroclasses and the proposed Japanese system and the Euroclasses. In this report, a direct link means that it is possible to translate one class from one system into a specific class in the other system without any necessary additional tests or advanced calculations. This might be done one or both ways but it is still considered to be a direct link in this report, see Figure 7.1.
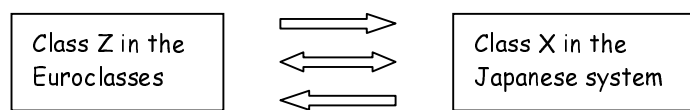
Figure 7.1 The definition of direct links between the systems

7.1 The Euroclasses and the Japanese system today

Today's classification system in Japan, for surface lining material, will only be in use until June year 2000. After this, the new proposed Japanese system will be taken into practice and therefore, the comparison in this section is only a brief study of similarities and differences between the Japanese system and the Euroclasses. This comparison might still be of some importance when trying to understand the situation in Japan today.

As the reader probably has observed, there are some major differences between the Euroclasses and the Japanese classification system today. The most obvious are the differences in the test procedures, the parameters used for the ranking, and the number of classes, see Table 7.1. Another difference that might be important for the comparison is that the Euroclasses are based on a reference scenario, the Room/Corner test, since the Japanese system is not based on a reference scenario.

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Table 7.1 The different test methods and parameters used for classification in Europe and Japan today

	European test methods and parameters	Japanese test methods and parameters , today
Reference scenario	Room/Corner test (ISO 9705)	No reference scenario
Non-combustibility tests	Non-combustibility test (ISO 1182) Parameters: ΔT, Δm, t_f Gross calorific value test (ISO 1716) Parameter: PCS	Non-combustibility test (JP Notification # 1828) Parameter: ΔT Surface test (JP Notification 1828 and 1231) Parameters: $td\theta$, C_A, duration of flames
Main and additional tests	Single Burning Item (SBI) test (prEN) Parameters: FIGRA(SBI), LFS, THR_{600s}, smoke and flaming droplets/particles Ignitability test (ISO11925-2) Parameter: Fs	Surface test (JP Notification 1828 and 1231) Parameters: $td\theta$, C_A, duration of flames Hole test (JP Notification 1231) Parameters: $td\theta$, C_A Reduced-scale Model Box test (JP Notification # 1231) Parameters: THR, HRR_{max} Gas toxicity test (JP Notification 1231) Parameter: Time to the mice stop moving

To find a direct link there is need for research on the correlation between the parameters available from the used test methods. The fact that very few research projects have been carried out in this area complicates the comparison. The results used in this report are mainly from projects in the So-pro program, which makes it possible to state some conclusion on a possible direct link.

7.1.1 Non-combustible materials

One of the similarities of the classification systems in Japan and Europe is that both systems have one class for non-combustible materials. The criteria for these classes are specified by two test methods for each system, see Figure 7.1. The two Non-combustibility tests are very similar, see Section 5.1.1 and from the So-pro program it has been concluded that the correlation between ΔT from these tests is good (R^2=0.9788) /36/. However, there are two more test methods (Gross calorific value test and Surface test) that are used and no research has been carried out to find a correlation between them. The correlation between the ISO Non-combustibility test and the Surface test is also unknown, which complicates the situation even more. If only the two Non-combustibility tests were used to determine the parameters describing the different non-combustibility classes, there would have been at least a one-way direct link between systems. The reason for only a one-way link would have been that Δm and t_f not are measured in the Japanese test. With the information available today, it is impossible to find a direct link, neither one-way nor both-ways, between the Japanese and European non-combustibility classes.

7.1.2 Other than non-combustible materials

For the classes that represent other materials than the non-combustible (Euroclass A2 to E in Europe and Class II and Class III in Japan) there are few similarities. As seen in Table 7.1, most test methods and parameters are different. However, some projects in the So-pro program have shown that there is a relationship between some of the parameters available from the different test methods.

One of the results /37/ is that the Surface test, which is used to determine material properties in all Japanese classes, does show a relationship with the Room/Corner test. The result is based on tests carried out with non-combustible and quasi non-combustible materials and concludes that it is possible to identify these materials by using the Room/Corner test. However, the relationship is vague and no direct link can be found.

With the purpose of proposing the RMB test to the ISO standards a study, using nine materials was made to investigate the relationship between the RMB test and the Room/Corner test. The study was carried out by Saito et al. /38/ and found that there is a reasonable correlation between the two test methods and therefore some conclusion could be drawn from the experiments, see Table 7.2.

Table 7.2 The result from the comparison between the Room/Corner test and the Reduced-scale Model Box test

Room/Corner test (ISO 9705)		Reduced-scale Model Box test
No flashover	$\Longleftrightarrow$	No flashover
Time to flashover > 10 minutes	$\Longleftrightarrow$	Peak heat release rate < 100 kW
Time to flashover < 5 minutes	$\Longleftrightarrow$	Peak heat release rate > 200 kW

If these results are verified, it is possible to state that materials in Euroclasses A1, A2 and B, which do not go to flashover during the first 10 minutes in the Room/Corner test, can be translated into Class II in the Japanese system. This is based only on the heat release rate from the RMB test. However, if a complete classification should be done there are more parameters than the heat release rate that has to be taken into account. Such parameters are total heat release, $td\theta$ and C_A, but no further studies have been carried out in this area. European materials can therefore not be used in Japan without going trough some additional tests.

The results from the study by Saito et al. are not detailed enough to allow a statement that materials in any of the Japanese classes can be translated into one of the Euroclasses, based on the heat release rate. If this had been possible, it would still not have been enough since there are more parameters that are necessary for a complete classification in Europe. The only way to use Japanese materials in Europe is to translate them into Euroclass F, which does not have any requirements.

Based on the fact that no further research has been carried out and that the classification systems are very different in their basic structure no further effort has been made to find a link between these two systems.

7.2 The European and proposed Japanese system

Soon the new proposed Japanese classification system will be taken into practice. Therefore, it is more important to evaluate and try to find the link between the proposed Japanese system and the Euroclasses than trying to find a direct link between the classification systems used in Japan today and the Euroclasses. As shown in Section 7.1 the test methods in Japan today have few similarities with the test methods used in Europe. The only exception is the Non-combustibility test, which is very similar and correlates well with the ISO Non-combustibility test. The new proposed Japanese system will be based on international standards and this fact should make it more probable to find a direct link to the European system, which also mainly is based on international standards. The test methods that will be used for classifying surface lining materials in Europe and Japan are shown in Table 7.3.

Table 7.3 The test methods in Europe and the new proposed test methods in Japan

	European test methods	**Japanese test methods**
Reference scenario	Room/Corner test (ISO 9705)	Room/Corner test (ISO 9705)
Main and additional tests	Non-combustibility test (ISO 1182) Gross calorific value test (ISO 1716)	Non-combustibility test (ISO 1182), ***NOT COMPULSORY***
	Single Burning Item (SBI) test Ignitability test (ISO11925-2)	Cone Calorimeter test (ISO 5660) Modified Gas toxicity test (proposed ISO) **or** Model Box (MB) test (proposed ISO)

7.2.1 Reference scenario

Since the reference scenario in both Europe and Japan will be the Room/Corner test the possibility to link the systems arises. As discussed in Section 3.4.1, three clusters of materials were defined when the evaluation of the class limits based on the FIGRA index was made. First, FIGRA values ranging from 0 to 0.6 were defined with the characteristics that no flashover occurred during the test period. There was also a discussion on the upper limit of this cluster (0.6), when the theoretical value is 0.58 and some materials could get a slightly higher FIGRA value (0.73) before flashover is reached. Finally a conservative value of 0.5 was chosen to represent this cluster. Second, if the FIGRA index is in the range 0.7 - 1.2, flashover was observed after 10 minutes of testing i.e. when the burner effect is increased to 300 kW. Third, flashover was observed during the first 10 minutes for materials with a FIGRA index lager than 1.9. Therefore, the theoretical value of 1.5 (900/600) was chosen to be the limiting

value between materials that reaches flashover before and after 10 minutes of testing. After these clusters were defined they were split into seven different classes, which now represents the Euroclasses. However, if these three identified clusters are compared with the most probable class limits in the proposed Japanese classification system they are found to be basically the same. Materials in Class 1 do not reach flashover during the test. Flashover occurs after 10 minutes for materials in Class 2 and flashover occurs within the first 10 minutes in Class 3. The comparison is shown in Figure 7.2.
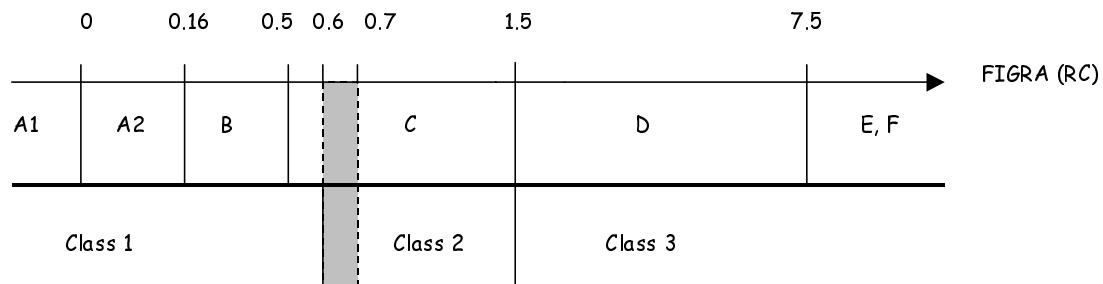

Figure 7.2 The comparison between the Euroclasses (A1 to F) and the classes in the proposed Japanese classification system (Class 1 to Class 3)

From this comparison it is possible to state that there is at least one main direct link between the different classification system. Based on the reference scenario, Euroclasses A1, A2 and B can be directly translated into the Japanese Class 1 and Euroclasses D, E and F can be direct translated into the Japanese Class 3. Euroclass C is a little more problematic when this class includes an area where the FIGRA values can indicate two different behaviors i.e. no flashover during test and flashover after 10 minutes of testing.

Those materials that have a FIGRA value in the range 0.5 - 0.6 can be directly translated into the Japanese Class 1. In the problem area, shadowed area in Figure 7.2, where FIGRA ranges between 0.6 and 0.7, a material might or might not go to flashover after 10 minutes of testing. Material with a FIGRA that belongs to this problem area can therefore only be translated into the Japanese Class 2, together with materials with a FIGRA value between 0.7 and 1.5.

Unfortunately, the Japanese classes can only be translated into the lowest represented Euroclass. For example, Class 1 in the Japanese system can be direct translated into no higher class than Euroclass C. The reason is that there are fewer Japanese classes than there are Euroclasses and that the different classification systems are not based on the same output from the Room/Corner test. The class limits in the Japanese system are based on the *fact* that materials do or do not go to flashover in the Room/Corner test and the time at which this occurs. In Europe the FIGRA index, based on parameters from the reference scenario, is used to define the class limits not the *fact* that flashover occurs or not. This index does also define the different behavior in the Room/Corner test fairly well, but not exactly. Due to this difference the problem area in Figure 7.2, is not represented in the Japanese system, when the reference scenario is under consideration.

If the second classification alternative is chosen in Japan, i.e. the alternative with four classes where Class 3 above is divided into two classes, see Section 6.3.1, it would be more favorable to translate the Japanese classes into Euroclasses. The FIGRA value for materials, which go to flashover during the first five minutes of testing, is not defined today but from /7/ it is found that a FIGRA value of 4.7 indicates that a material reaches flashover after less or equal to 3 minutes and 10 seconds. This shows that that the border between Class 3.1 and Class 3.2 will be within Euroclass D. Therefore, it is possible to state that, if this alternative is chosen, material in Class 3.1 can be directly translated into Euroclass D and Class 3.2 can be directly translated into Euroclass E.

If the third classification alternative is chosen in Japan, i.e. the alternative where Class 2 in the first presented alternative is divided into two classes see Section 6.3.1, this would not change the translation compared to the most probable case. The two new Japanese classes could only be translated into Euroclass C, while Euroclass C only could be translated into Class 2.2.

Since some materials in Japan might be tested in the Room/Corner test, see Section 6.2.1, it will be possible to calculate a FIGRA index for these materials and direct translate them into a certain Euroclass.

7.2.2 Main and additional tests
In Japan the parameter used for classification of surface lining materials will be the heat release from the Cone Calorimeter and for some materials also the smoke production in the MB test or the modified Gas toxicity test. Compared to Europe, Japan will use relatively few parameters for the classification. When all the parameters from the used test methods in Europe are counted, the result is that 11 different parameters will be used.

Heat release
The relation between heat release from the Room/Corner and Cone Calorimeter is found good /37/ and models have been developed to link the two test methods. Also the FIGRA(SBI) index correlates well with the FIGRA(RC) index ($R^2=0.95$) /7/. Based on these facts it can be stated that it is possible to use the reference scenario as the way to link the systems, based on heat release, but the problem in Section 7.2.1 remains. A study by Tsantaridis and Östman /39/ concludes that there is an interesting correlation between both the peak heat release and the THR from the Cone Calorimeter and the SBI test. However, the result from their report does not give all the needed information to translate the products tested in the Cone Calorimeter into a certain Euroclass or vice versa, based on heat release.

One way to allow the division the Japanese classes into different Euroclasses based on peak heat release is to investigate if it is possible to calculate a FIGRA value from the Cone Calorimeter, which correlate well with the FIGRA values from the Room/Corner test. In order to do this, a FIGRA index was calculated from the Cone Calorimeter, FIGRA(Cone), using the result in /39/, see Annex A. The FIGRA(Cone) index was calculated as peak heat release rate divided by the time to ignition. The time to peak heat release rate was approximated to the time to ignition, which can be assumed to be reasonable. The materials used in /39/ are the same as in /7/, therefore a

comparison between the ranking orders according to FIGRA(Cone) and the FIGRA(RC), calculated in /7/, could be made. The result from this comparison is that some correlation between the different FIGRA indices seems to exist. But, further investigations need to be made before definite conclusions can be drawn. The result is shown in Figure 7.3.
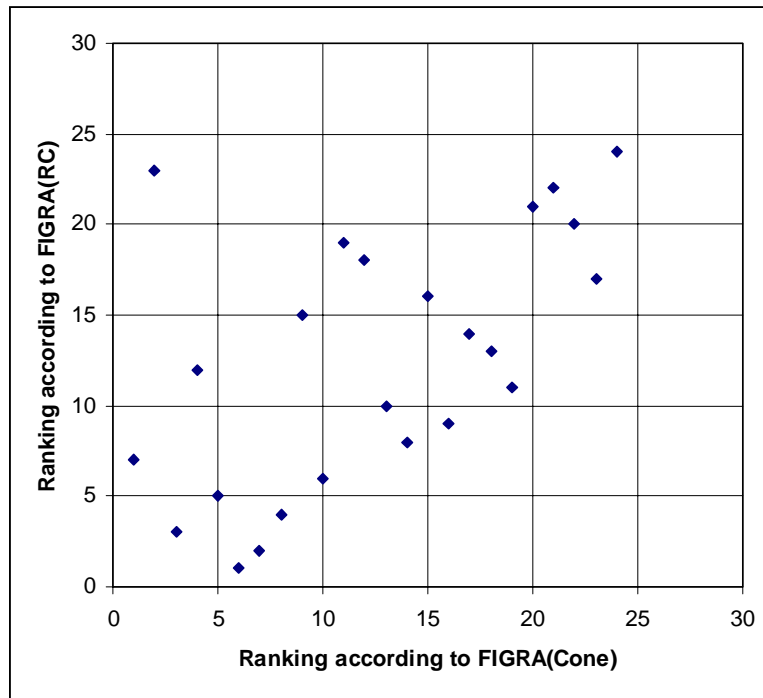
Figure 7.3 Ranking according to FIGRA (Cone) and FIGRA (RC)

Another alternative solution to the translation of classes might be to identify the different Euroclasses in the graph, which will be used when, identifying the classes in Japan, see Figure 6.1. Therefore, FIGRA values were calculated for some of the Japanese materials that have been tested in both the Cone Calorimeter and the Room/Corner test, see Annex B. The calculated FIGRA values are not exact due to the fact that the time to peak heat release rate had to be determined from graphs. When trying to identify the different Euroclasses it appears difficult. The maximum number of classes that can be determined might be the number of classes that will be used in Japan. Further investigations need to be made before definite conclusions can be drawn, but the comparison made in this report indicates that it will be difficult, and maybe also impossible, to identify all Euroclasses by using the output data from the Cone Calorimeter.

Smoke production
The second parameter that will be used to describe materials in Japan is the smoke production. There is no study available that shows a direct relationship between the smoke production from the SBI test and the MB or modified Gas toxicity test. In /7/ the relation between the SMOGRA(RC) index and the FIGRA(RC) index was discussed and it was concluded that the ranking of products based on SMOGRA(RC) or FIGRA(RC) would be similar. Since there is a close connection between the heat

release and production of smoke in many test methods it could be possible to link the parameters for smoke production together using the heat release.

There is some correlation found between the heat release from the RMB test /38/ and the Room/Corner test and therefore, the MB test should also show some correlation to the Room/Corner test. On this basis there might be some correlation between the smoke production from the MB test and the SBI test. However, there is little direct correlation between SMOGRA(SBI) and SMOGRA(RC) /9/. This fact complicates the problem and makes it even more difficult to find a direct link for the smoke production.

In the study by Tsantaridis and Östman /39/ it was concluded that there is some relationship between the smoke production in the SBI test and the Cone Calorimeter. Since the Cone Calorimeter will be the main test method in Japan, using cone data for smoke production might be an alternative way to translate Japanese material into the Euroclasses. To make this possible, further studies must be made concerning the relationship between the SBI test and the Cone Calorimeter. Because the complexity of the problem and lack of available information no further statements concerning the direct link for smoke production are made in this report.

Flame spread and Ignitability
In Europe one parameter, used to describe material properties for most classes, is flame spread. The lateral flame spread is determined in the SBI test where the proceeding of a flame in a specific time gives the material its class. Also the ability of a material to ignite is measured in a similar way. Here, the Ignitability test is used to measure the upward flame spread during a specified time. In Japan there are no plans to use flame spread for classification. The ignitability will be expressed as time to ignition from the Cone Calorimeter test instead of being based on flame spread. No correlation between time to ignition from the Cone Calorimeter test and the upward flame spread in the Ignitability test has been found and therefore no direct link has been observed.

Flaming droplets/particles
The occurrence of flaming droplets/particles is one parameter that is used for some of the Euroclasses, but this parameter will not be taken into account in the proposed Japanese system. It might be possible to take this criterion into account in the MB test but further studies have to be made to investigate this possibility and to find how the output from the MB test correlates with the output from the SBI test.

Non-combustibility
One test method that will be used to determine the parameters for non-combustible materials in Europe is the ISO Non-combustibility test. As mentioned in Section 6.3 some materials in Japan might also be tested in the same test. These are structural materials, which also can be used for interior linings. Based on this test it should be possible to translate the Japanese non-combustible materials into Euroclass A1 or A2. The problem with Euroclass A1 is that even the gross calorific potential has to be determined. Since the correlation between the Non-combustibility test and the Gross Calorific value test is poor /21/ it is impossible to translate the Japanese materials into Euroclass A1 without using the Gross Calorific value test. For materials in Euroclass

A2 the SBI test is used and completed with either the Non-combustibility test or the Gross Calorific value test. It is therefore impossible to directly translate the Japanese materials, which are tested in the Non-combustibility test, into this class as well. However, since the criteria for non-combustible materials in Japan not is decided yet it is not possible to state that European materials, that are tested in the Non-combustibility test, can be directly translated into the Japanese Class 1, based on these parameters. But, it will most probably be possible to direct translate European materials tested in the Non-combustibility test into the Japanese class 1.

8. Alternative ways to link the systems

So far the direct link between the European and Japanese systems has been discussed. The results point at the fact that there is a close relationship between some of the parameters used for classification. In Section 7.2 it is found that both systems are based on the heat release in the Room/Corner test and that a reasonable translation is possible, based on the heat release. There is also a close connection concerning the testing of non-combustible materials, where the Non-combustibility test is used. However, there is no direct link found concerning the other parameters.

This chapter will discuss alternative ways to link the systems without using additional tests, but does not intend to give a direct answer on how to link them. Some difficulties and possibilities concerning different alternatives will be described. The alternative solutions discussed in this chapter are:

- The use of calculations
- Political solutions
- Performance based approach.

8.1 The use of calculations and/or political solutions

From Section 7.2 it was concluded that a reasonable translation based on the materials' behavior in the Room/Corner test is possible, but there are more parameters that have to be taken into account to obtain a complete translation between the two systems. This section will discuss two different possible ways to do this. First, the use of calculations and/or computer programs will be considered and second a political solution.

Concerning the use of calculations and/or computer models there are at least three difficulties: the development of models, the input data to the models and the output that is provided by the models. These problems can be illustrated by two examples: the smoke production and the lateral flame spread.

The smoke production is included in both the Euroclasses and the proposed Japanese system. In Europe the SMOGRA index and the total smoke production obtained from the SBI test will be used and in Japan the smoke production from the MB test will most probably be used. One way to obtain a model for the prediction of smoke production is to use the heat release rate as the basis and then combine this with relationships that consider smoke production. This might make it possible to translate the smoke production between the two systems. However, to base the smoke production on the heat release might lead to some complications when the results are used for the actual classification. The smoke production and the heat release rate are often closely connected to each other and the purpose of using the smoke production as one parameter in a classification system is to identify materials that produce a relatively large amount of smoke compared to the heat release. With a model based on heat release it can be questioned if the output data provided will fulfill this purpose.

Work has been carried out to predict the smoke production in the Room/Corner test by using smoke parameters from the Cone Calorimeter and a good correlation has been

observed /39/, /40/. Unfortunately, such a model can not be applied concerning the Euroclasses and the proposed Japanese system. First, the Cone Calorimeter test is not used for measuring smoke properties in Japan. The needed smoke measuring devices are rare and today there is nothing that indicates that the Cone Calorimeter will be used for this purpose. Second, even if smoke parameters were measured in the Cone Calorimeter test and used to predict the smoke production in the Room/Corner test, the correlation is poor between the smoke production in the SBI and Room/Corner test. This complicates a translation between the two systems based on calculations even further.

Within the flame spread area most of the work has been dedicated to predict upward flame spread. These prediction models are divided into mainly two types. First, thermal theories, using data from the Cone Calorimeter, have been used to predict flame spread and the resulting heat release in the Room/Corner. These models predict the upward flame spread and not the lateral that is used in the Euroclasses. To be able to calculate the lateral flame spread the needed input data has to be derived from other tests than the Cone Calorimeter, such as the LIFT. Even if it would be possible to calculate the lateral flame spread with input from the Cone Calorimeter test, there are still unsolved problems concerning the translation to the SBI scenario and if the result can be used for the specific criteria in the Euroclasses.

Second, more fundamental work has been carried out using CFD models and pyrolysis models to predict fire growth in the same full-scale scenario. Such models are still under development and need much more sophisticated input data than that available.

Similar difficulties can be discussed for other parameters. For some parameters, such as the occurrence of flaming droplets/particles and the gross calorific potential, it is impossible to calculate the classification with help from calculations at all. The conclusion from this brief discussion is that it might be impossible to describe all used parameters with help from calculations.

However, there might be a political way to solve the problem. As earlier, the smoke production is used as an example. If it is agreed that the smoke production, in most cases, is described by the heat release rate and that the smoke production only becomes important in extreme cases. Then it might be possible to define the value of these "extreme cases" for SMOGRA and total smoke production in the SBI test and the smoke production in the MB test. If a material exceeds this "extreme value" further evaluation has to be done otherwise a direct translation could be possible only based on the heat release. Such a political solution will probably be a very difficult and time consuming process. This because all other parameters must be evaluated in a similar way. Innumerable discussions and debates of which test method to use and how to use the output data to rank the products have just been concluded in Europe and the above described needed efforts might therefore not be considered in the near future.

8.2 Performance based approach

In the last sections, the difficulties in finding a link between the Japanese and European classification systems has been discussed. Too few direct links have been

found and the calculation models, which must be used to calculate the missing parameters, will be difficult to develop. Based on these facts, the possibility to use a political solution to link the system was also mentioned. Now, if the possibility to use performance based approach is considered, it might be possible to use materials tested in Japan in Europe and vice verse. A performance based approach can be more or less sophisticated, but with a sophisticated computational tool and the right input data it is possible to simulate a number of fire scenarios, compare the results with a performance based criteria and evaluate if the design is acceptable or not. When such an approach is considered there is no need to include a specific classification system, only the measuring of certain material properties.

Since the 1960s there have been attempts made to develop a mathematical model for predicting fire behavior. Peacock et al. /41/ reports that there are today about 62 actively supported single- and multi-room fire zone models identified. These models predict the environment generated by the fire, mainly temperature and smoke, fire endurance, sprinkler or detector response and evacuation times. These models can be very useful for a performance based design, but there are still problems that need to be solved. For example, in 1995 there was still not a single room fire model that incorporates flame spread /42/. Today there are some programs that are under development to take this into account, such as BRANZFIRE /43/, which is based on the flame spread models presented by Quintiere /35/ and Karlsson /31/.

In addition to the zone-models above there are about 10 field models identified by Peacock et al. The technique with field or computational fluid dynamics (CFD) modeling has been used successfully in many engineering areas such as car body design and to predict wind flows around buildings. The CFD technique has also been used in many combustion applications where the partial differential equations describing the conservation of mass, momentum and energy are solved numerically. Such models can provide more detailed information about the environmental conditions generated by a fire than the zone-models. For example has the assessment and design of smoke control systems in buildings and fire growth on wall lining materials been described successfully by using CFD models /44/. However, CFD modeling is typically far more time-consuming than zone modeling and requires expert knowledge, but provides more accurate results.

As mentioned, there are still some unsolved problems in the model development, but there might be even more problems to solve in the way input to the models are obtained. Babrauskas /42/ points at the fact that the progress tends to be faster in the modeling area than for the development of tests that provide input data for the models. This mainly because of the larger number of researchers, laboratories, universities and institutions that work with improving models than in the fire testing field and its applications. The more sophisticated the computational tool becomes, such as the CFD models, the more sophisticated the input data need to be. Today there are no general accepted test methods for deriving these more sophisticated material properties.

Despite this slower development in the fire testing field, the last twenty years of development has led to test methods, which can capture material fire properties that can be used in models and predict something more than just the performance in the

test itself. As briefly discussed earlier, it has been shown that the Cone Calorimeter test is a very powerful tool for this purpose. Babrauskas /45/ mentioned that the Cone Calorimeter can be used to:

- provide data for state-of-the art fire models for flame spread modeling and the prediction of flashover etc.
- provide data used to predict real-scale fire behavior by means of simple formulas or correlations
- rank products according to their performance.

A second example of a powerful tool is the LIFT apparatus. This test method does also provide important data for the predicting of room fires, such as the model presented by Quintiere /35/. The Cone Calorimeter and the LIFT apparatus are therefore the two bench-scale tests that are mostly used for deriving basic material properties around the world. In Table 8.1 some work that was going on in 1997 and the used test methods are presented /46/. Similar work was also carried out at Factory Mutual Research Co. (USA), SP (Sweden), University of Edinburgh (UK), University of Gent (The Netherlands) and University of Maryland (USA).

Table 8.1 Some work that was going on in 1997, after /46/

Institute	University of Lund	VTT, Finland	FRS, England	BRI, Japan	Worchester Polytechnic Institute
Bench-scale experiments	Cone Calorimeter, LIFT	Cone Calorimeter, LIFT	Cone Calorimeter, LIFT	Cone Calorimeter, LIFT	Cone Calorimeter, LIFT
Full-scale experiments	ISO 9705, 1/3 ISO 9705	ISO 9705, Walls	ISO 9705	ISO 9705, intermediate-scale room	ISO 9705, Walls
Modeling	TT, TT+ zone models, CFD+ cone, CFD+ pyrolysis	TT, TT+ zone models	CFD+ cone, CFD+ pyrolysis	TT, TT+ zone models	TT, TT+ zone models

Key to symbols:

1/3 ISO 9705 = 1/3 scale of the ISO 9705 Room/Corner test
Intermediate-scale room = a smaller room than the ISO 9705
TT = Thermal Theories for upward flame spread
TT+ zone models = Thermal Theories for upward flame spread incorporated into zone models
CFD+ cone = CFD models using result from the Cone Calorimeter as input data
CFD+ pyrolysis = CFD models with pyrolysis and combustion models incorporated

As seen there is considerable work going on to develop a useful tool for a performance based approach, but to only use a performance based approach, with a computational prediction of fire growth etc. might not be suitable for all applications. In practice, this type of approach has its disadvantages especially for "common buildings" where it probably will be too expensive to use this approach. In areas where a computational tool not is available or useful, a classification may still be a functional way. A sound solution to this problem might be the proposed Japanese system, with the opportunity for both a performance based (route B and C) and a prescriptive approach (route A). Even if route B and C are still under discussion and the computational tool is under development, the basis for their application is clear.

The Euroclasses do not provide the necessary basis and input data for state-of-the art fire models. However, each country in Europe is still free to put up their own building regulation. When doing this, each country is also free to choose a prescriptive or performance based regulation. Based on this fact the countries, with performance based building regulations, have the opportunity to use Japanese materials in design, if data from the Cone Calorimeter can be used in the available calculation models.

It appears very strange that such a recently developed classification system as the Euroclasses does not include test methods that provide data for state-of-the art fire models, such as the Cone Calorimeter test or LIFT apparatus. However, there might be a chance to also use the result from the SBI test for performance based design. In the work presented by Höglander and Sundström /47/ the different classes for interior linings in Sweden are represented by a design fire for preflashover conditions, mainly by representing the heat release by αt^2- or Gaussian-curves. These curves were derived by large-scale experiments and can be used for a performance based approach. The same procedure might be used to derive representative curves for the materials tested in the SBI test. If representative curves are found, for the different Euroclasses, materials from Europe could also be used for a performance based approach. This approach might not be very sophisticated but since the output from the SBI test is not enough for a more advanced computational tool this might be the only way to use the Euroclasses for a performance based approach. Therefore, Japan might be able to use materials tested in Europe if route C is chosen and the mentioned curves are derived.

9. Conclusions and Discussion

In the following sections the results in this report will be summarized and discussed. First the conclusions on the link between the systems are presented and after that some thoughts on the differences in the two classification systems are discussed from a designers point of view.

9.1 Conclusions about the link between the system

The Japanese system today and the Euroclasses

From the comparison between the Euroclasses and the Japanese system today it is possible to make some conclusions. First, the different Non-combustibility tests show a close relationship in their measuring of ΔT, but even if Δm and t_f were measured in the Japanese test this would not be enough for a direct both-way link. This because the Gross calorific value test is compulsory in order to describe the non-combustibility in Europe. Second, the direct link between other classes than the non-combustible is also difficult to find with the research material available today. The only possible direct link is to use all Japanese materials as materials in Euroclass F, but this would not be economically reasonable. Third, since the Japanese system is under development and the focus is directed towards this program it is not probable that any further links will be explored or found.

The proposed Japanese system and the Euroclasses

Concerning the comparison between the proposed Japanese system and the Euroclasses there are some important basic similarities, which are very useful for a direct link. First, both classification systems are based on the Room/Corner test. A close relationship has been found between the Japanese class limits and a certain FIGRA value. This makes it possible to directly translate Euroclasses A1, A2 and B into Japanese Class 1 and D, E and F into Class 3, based on the Room/Corner test. The translation of Euroclass C is more complicated since this class includes materials that do not reach flashover as well as those that do. Therefore, Euroclass C can only be translated into Class 2.

Unfortunately, the Japanese classes can only be translated into the lowest represented Euroclass. This means that Class 1 and 2 only can be translated into Euroclass C and Class 3 only can be translated to Euroclass E (Euroclass F does not have any requirements).

There is some correlation found between the parameters for the heat release from the SBI test and the Cone Calorimeter test, but further studies have to be made before it can be stated weather this can be used for a direct link or not. There are also similarities concerning the testing of non-combustible materials, where the ISO Non-combustibility tests is used in both Europe and Japan. Since the gross calorific potential is a compulsory parameter to describe the non-combustibility in Europe it is impossible to translate materials from the Japanese Class 1, that are tested in the Non-combustibility test, into Euroclass A1. In Japan it is decided that materials which fulfill the requirements from the Non-combustibility test automatically fulfill the requirements for the Cone Calorimeter. Depending on what criteria is chosen in Japan

for non-combustible materials, it might be possible to direct translate materials from Euroclass A1 and A2 into the Japanese Class 1.

Besides, the mentioned difficulties in finding a direct link, there are a number of other parameters that also have to be considered. These parameters are ignitability, flame spread, flaming droplets/particles and smoke production. Flame spread and flaming droplet/particles are not measured in the proposed Japanese system and there is no correlation observed for the parameters describing the ignitability and smoke production in the two systems. Therefore, no direct links are found for these parameters.

The conclusion from the discussion on using calculations and/or computer programs is that is might be very difficult or even impossible to describe all the used parameters without additional tests. This, due to difficulties in the models that have to be developed the input data that must be obtained from the tests and the output data from the models that must be detailed enough to be used for classification.

A political solution was also discussed as an alternative way. Here, the parameters might be described by the heat release rate and only extreme values of the parameters are considered and leads to further investigation. Such political solution will probably be very difficult and followed by a very time consuming process. Since the decision on the Euroclasses, which included innumerable discussions and debates, recently was made in Europe a political solution might not be considered in a near future.

From the conclusions this far it is possible to say that even if the Euroclasses and the proposed Japanese classification systems mainly are based on tests specified by ISO standards it is difficult to find a link between them. If a sophisticated computational tool and the right material properties as input data new possibilities arise. When approaching the problem from this direction it might be possible to simulate any fire scenario, compare the result with a performance based criteria and evaluate if the design is acceptable or not. This could be done without including a specific classification system, only the measuring of certain material properties. In order to reach regional harmonization within Europe the development of the Euroclasses is of course a large step in the right direction. It was necessary to get a united European classification system but it is strange that the European work did not lead to a basis where tests like the Cone Calorimeter or the LIFT are represented. These tests are considered to be very useful for providing material properties that can be used as input for state-of-the art fire models. Performance based building regulations can be expected to be the next generation's system and therefore it is natural that tests and classification systems should provide the basis for this kind of approach.

However, there might still be a chance to use the result from the SBI test for performance based design. The work presented by Höglander and Sundström /47/ is discussed in Section 8.2 where representative heat release-curves (αt^2 or Gaussian) for preflashover conditions are derived for the different classes for interior linings in Sweden. A similar procedure might be used to derive representative curves for the heat release from the SBI test. This might be the only way to use, materials from Europe in performance based design.

9.2 Discussion about the Euroclasses and the proposed Japanese system

Calculations as a help in the classification
The conclusion in Section 9.1 points at the need for calculation models if the two systems are to be linked together, both through calculation of the missing parameters and for a performance based approach. Law /48/ claims that there often is a tendency that calculations are directly rejected in the decision making process of codes and rules. There is a worry that lack of education and misjudgment combined with calculations will lead to unsafe solutions and in the end, unsafe buildings. This worry is defendable, but one has to keep in mind that the calculations should be used as an aid to the judgement and not as a substitute. The computer is playing an important role in all kinds of areas today and when computer power is available to a low cost this opens the door for future development for a more useful and sophisticated tool than exists today.

Calculations and computer programs could also be a good and inexpensive aid to classification of materials to their reaction to fire. For example, a CFD model could simulate expensive full-scale experiments, which describe a "real fire" in a better way than the tests often used for classification today do. This could be a very useful aid to the more traditional way of classifying products, which would make it possible to "test" the products in a wide range of configurations and scenarios.

Some harmonization aspects
The test methods used to specify the seven Euroclasses are mostly ISO standards except for the main test procedure, the SBI test. This test procedure was developed after the 1994 decision with the aim to make it possible to determine all the needed parameters from the 1994 decision, except those for the non-combustible materials, with the same test. When the final decision of the Euroclasses was taken in September 1998 the SBI test was used to define six parameters and one additional test, the Ignitability test, was chosen to determine a material's ability to ignite. To obtain a regional harmonization within Europe the Euroclasses was an important decision, but if the aim of the Euroclasses was to come closer to an international harmonization it is strange that a non-ISO standard was chosen to be the main test method. The SBI test does, to a high degree, provide information on one specific scenario, which today only can be used, for classification.

However, in general it seems that those who makes rules and codes have a tendency to not always take measurements and science into account /48/. It appears that this has been the situation in Europe when the decision of using the SBI test was taken. A more useful way towards harmonization would have been to choose an international accepted test method, which also provides information for a performance based approach.

The possibility to use the output from the SBI test for other purposes than classification
A designer is, in the first place, interested in the heat release rate, but there are of course more parameters of interest depending on the design objective and the building features. These parameters are for example ignition (and combustibility), smoke

production, flame spread and flaming droplets/particles. All these parameters are included in the Euroclasses, but are the parameters from the SBI test and the criteria of interest for other purposes than classification?

For example, there is a close connection between the heat release and the smoke production. The reason for not only using the heat release for classifying materials in Europe is to identify materials where the production of smoke is very large compared to the heat release. This would otherwise lead to a classification with uncertainties. This is an important matter and some kind of measurement of the smoke produced in a fire is necessary. But, it can be questioned if the SBI test gives useful information on a material's ability to produce smoke, when poor correlation is observed with the production of smoke in a large-scale test as the Room/Corner test.

Another example is the flame spread, which is playing an important role for the fire growth. When the upward flame spread is much faster and therefore also more hazardous, and when often the upward flame spread is included in the heat release, the use of the lateral flame spread can be questioned. What information does a criteria give that states: lateral flame spread less than the edge of specimen in the SBI test (25 minutes) when flashover is reached within 20 minutes in the Room/Corner test for the same material (Euroclass C)?

In a similar way, the criteria used concerning flaming droplets/particles can be questioned. Here, the criterion D0, D1 and D2 are based on the whole duration of the SBI test (25 minutes) and are compulsory in classes A2, B, C, D and E even if flashover occurs in the Room/Corner earlier than that (after 10 minutes in Euroclass C, after 2 minutes in Euroclass D and before 2 minutes in Euroclass E).

According to Babrauskas and Peacock /49/ the single most important factor to characterize a fire hazard is the heat release rate in a compartment and it is therefore important that the result from the SBI test provides this data. The FIGRA(SBI) is used for this purpose and the fit with the Room/Corner test and the stability of the classes are reported to be (very) good /50/. Therefore, the performance of a material's behavior in the Room/Corner test is easy to identify with help from the FIGRA(SBI) and the classification. The other parameters from the SBI test are introduced to provide a "safety net" of requirements /50/ to identify materials with extreme values of these parameters, but based on the discussion above it can be questioned if not the criteria in many cases are included in the heat release rate.

The proposed Japanese system, a good solution?
In the proposed Japanese system the classes are also based on the reference scenario, the Room/Corner test. The heat release rate from this test will be the most important parameter for classification. The final decision upon the Japanese system is not taken yet, but there are some aspects that are important and interesting from a fire safety engineering point of view. First, the main test procedure in the classification system is the Cone Calorimeter test, which is considered to be one of the most important tests for providing input data to state-of-the-art calculation models. Second, the proposed Japanese system includes both a prescriptive and a performance based approach and considerable work is also made to provide a useful computational tool for the latter approach.

9.3 Final remarks

The conclusions in section 9.1 points at the fact that even if the Euroclasses and the proposed Japanese system mainly are based on tests specified by ISO standards it is difficult, maybe impossible, to find a complete direct link between them, without any additional tests. Alternative ways, such as calculations to describe some missing parameters, political solutions and a performance based approach, have also been discussed. These alternative solutions do all include problems that have to be solved before it is possible to use them as a way to link the two systems. This report intends to be a first step towards a harmonization of the classification system in Europe and Japan, which explores the link between the two systems and point at difficulties and possibilities in order to find it, but further work must be done in this area. The decision on the Euroclasses is a step in the right direction, when regional harmonization is considered, but it can be questioned if the development, especially the development of the SBI test, is a step in the right direction concerning international harmonization. The practical use of the results from some tests and their criteria can also be questioned from a fire safety engineering point of view, when most test procedures only can be used for classification and not for design. On the other hand, the proposed Japanese system includes many interesting aspects from a fire safety engineering point of view. It will be very interesting to follow the development in this area into the 21st century.

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Annex A - *The result from the comparison between FIGRA(RC) and FIGRA(Cone)*

As an attempt to link the different classification systems, a FIGRA index for the Cone Calorimeter test, FIGRA(Cone), was calculated. The definition of FIGRA(Cone) is:

The peak heat release rate per meter squared (HRR_{max}) divided by the time to ignition (t_{ign}).

The data used in this comparison are taken from the report "Cone Calorimeter Data and Comparisons for the SBI RR Products"/38/, see Table A1. The tested materials in this report were also tested by SP /7/. Therefore, the ranking of the materials according to FIGRA(RC) and FIGRA(Cone) could be compared, see Table A2 and Figure A1.

Table A1 The result from the Cone Calorimeter /38/ and the calculated FIGRA(Cone)

Product code	t_{ign} [s]	HRR_{max} [kW/m^2]	FIGRA(Cone) [kW/m^{2}s]
M01	39	122	3.1
M02	55	319	5.8
M03	36	459	12.8
M04	75	115	1.5
M05	12	234	19.5
M06	680	106	0.16
M07	81	639	7.9
M08	43	148	3.4
M09	30	206	6.9
M10	14	163	11.6
M11	24	95	4.0
M12	22	202	9.2
M13	38	128	3.4
M14	20	46	2.3
M16	40	268	6.7
M20	46	262	5.7
M22	35	236	6.7
M23	29	675	23.3
M24	31	254	8.2
M25	39	401	10.3
M26	10	194	19.4
M27	56	121	2.2
M29	30	259	8.6
M30	3	353	118

Table A2 The different ranking according to FIGRA(RC) and FIGRA(Cone)

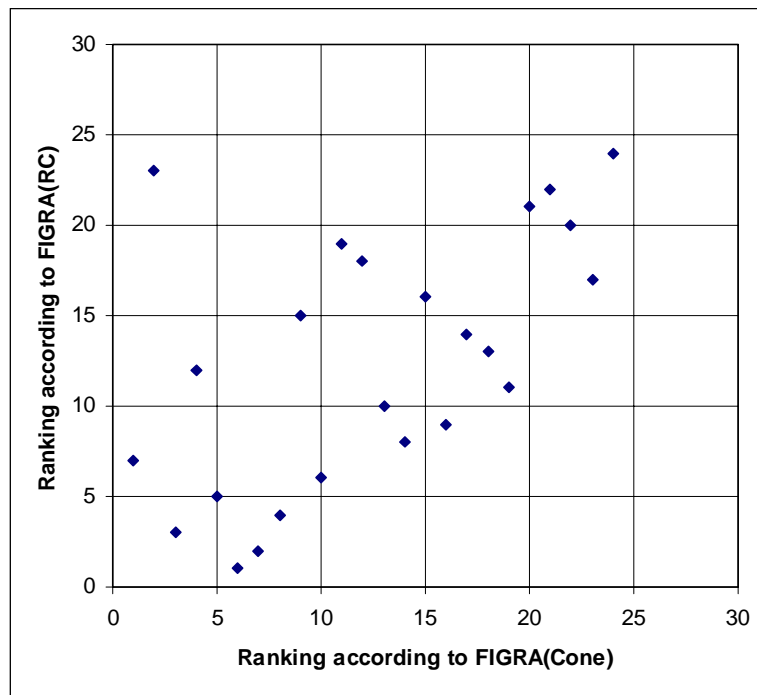|	FIGRA (Cone) ranking	FIGRA (RC) ranking
M06	1	7
M04	2	23
M27	3	3
M14	4	12
M01	5	5
M08	6	1
M13	7	2
M11	8	4
M20	9	15
M02	10	6
M16	11	19
M22	12	18
M09	13	10
M07	14	8
M24	15	16
M29	16	9
M12	17	14
M25	18	13
M10	19	11
M03	20	21
M26	21	22
M05	22	20
M23	23	17
M30	24	24

Figure A1 The different ranking according to FIGRA(RC) and FIGRA(Cone)

Annex B – *The results from the attempt to identify the Euroclasses in the graph used in Japan*

In one attempt to link the systems a FIGRA(RC) value was calculated for some materials tested in Japan. These materials, see Table B1, are tested in both the Room/Corner test and the Cone Calorimeter test and all necessary information to calculate a FIGRA(RC) value and to derive the constant τ are available. Therefore, it is possible to try to identify the FIGRA clusters determined in /7/, in the graph, which will be used in Japan to determine a material´s behavior in the Room/Corner test.

Table B1 The calculated FIGRA indices for the Japanese materials

Material	Time to HRR_{max}	HRR_{max}	FIGRA(RC)
8A	720	342.9	0.48
8D	610	403.6	0.66
8E	614	332.7	0.54
8F	706	514.4	0.73
7A0	629	1360.8	2.16
7A1	662	5885.9	8.9
8B	696	1081.8	1.56
8L	824	728.3	0.88
7F1	33	13430.2	407

To make it possible to determine a materials behavior in the Room/Corner test by using output data from the Cone Calorimeter a constant τ must be derived. This constant has been derived in two ways in Japan, dependent on how q_{max} is evaluated, see Figure B1.

Figure B1 The differences in evaluating q_{max} and τ

The attempts to identify the FIGRA clusters have been made using output data from the Cone Calorimeter presented in /35/ and /36/. Two different radiant heat fluxes (30 kW/m^2 and 50 kW/m^2 respectively) and two different values of τ (τ_A and τ_B respectively) have been used. The used output data are shown in Tables B2 to B5 and the in Figures B2 to B5 T$_{ig}$/τ_A are plotted against q$_{max}$ for all the materials in Table B1. The values shown in the figures are the representative FIGRA(RC) value for each material.

Table B2 Output from the Cone Calorimeter and τ_A, 30 kW/m^2 radiant heat flux

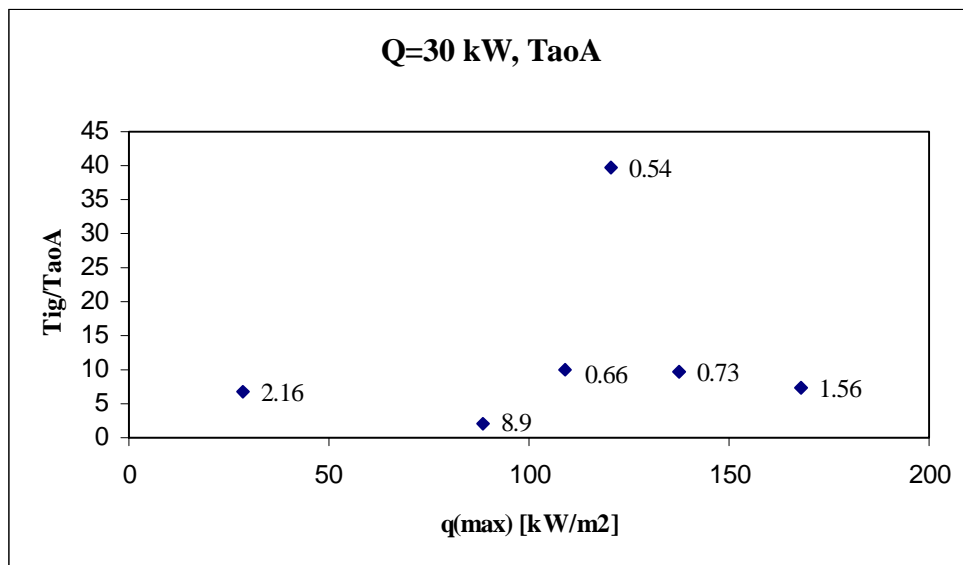| Material	q$_{max}$	T$_{ig}$/τ_A (30kW)
8A	57.6	
8D	108.8	9.96
8E	120.5	39.85
8F	137.5	9.82
7A0	28.6	6.73
7A1	88.3	1.96
8B	168	7.22

Figure B2 T$_{ig}$/τ_A plotted against q$_{max}$ when the radiant heat flux is 30 kW/m^2

Table B3 Ouput from the Cone Calorimeter and τ_A, 50 kW/m^2 radiant heat flux

Material	q$_{max}$	T$_{ig}$/τ_A (50kW)
8A	134.8	6.64
8D	170.8	3.11
8E	243.7	10.65
8F	190.6	2.74
7A0	98.5	0.77
7A1	138.1	0.21
8B	216.3	1.87
8L	111	0.15
7F1	115.2	0.1

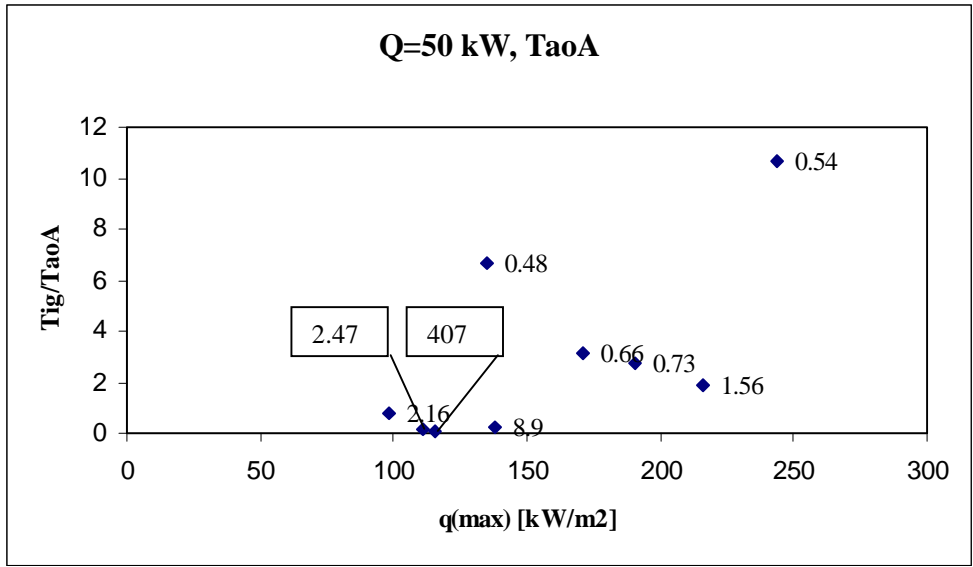*Figure B2 T_{ig}/τ_A plotted against q_{max} when the radiant heat flux is 50 kW/m^2*

Table B4 Output from the Cone Calorimeter and τ_B, 30 kW/m^2 radiant heat flux

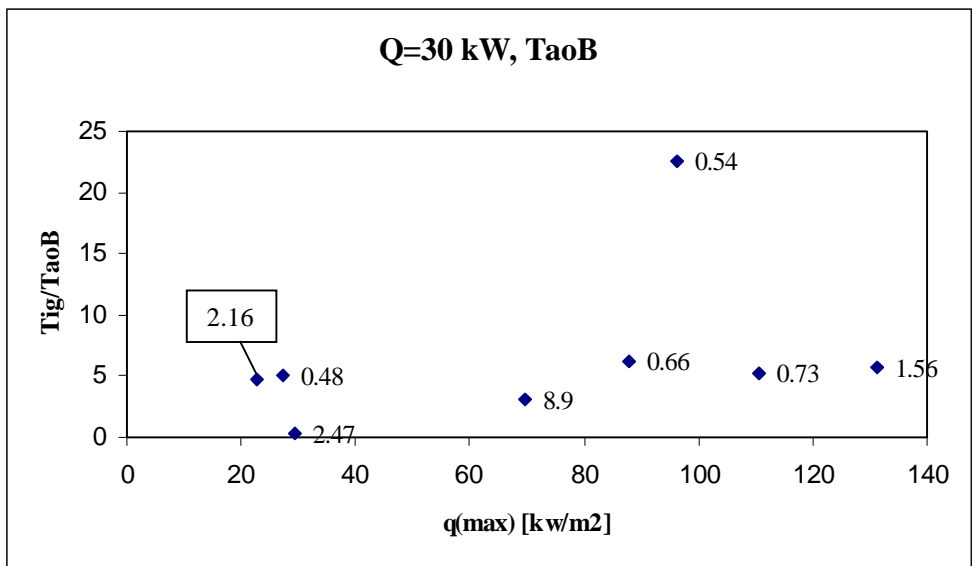| Material	q_{max}	T_{ig}/τ_B (30kW)
8A	27.3	5.05
8D	87.7	6.17
8E	96.3	22.63
8F	110.7	5.16
7A0	22.7	4.66
7A1	69.7	3.06
8B	131.3	5.66
8L	29.3	0.33

Figure B2 T_{ig}/τ_B plotted against q_{max} when the radiant heat flux is 30 kW/m^2

Table B5 Output from the Cone Calorimeter and τ_B, 50 kW/m^2 radiant heat flux

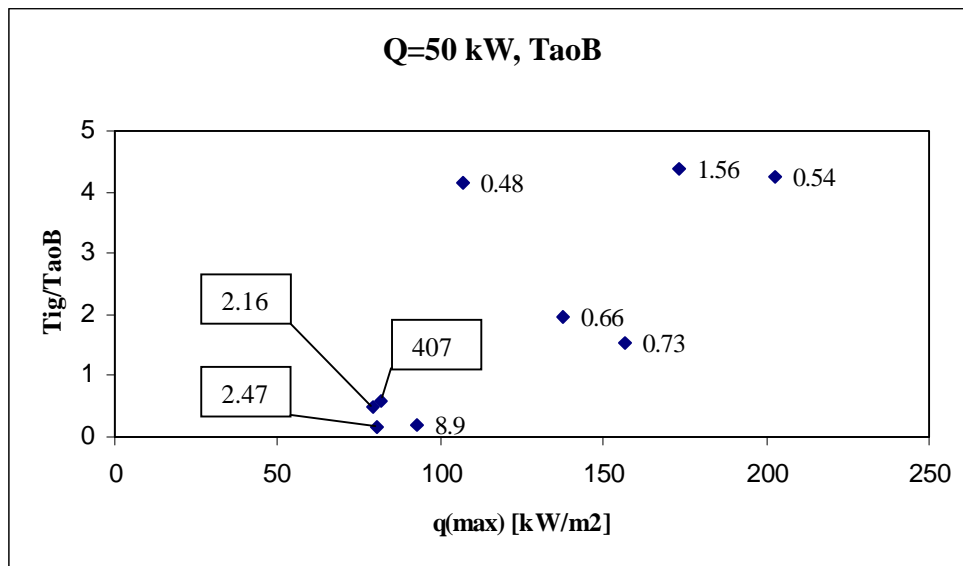| Material	q$_{max}$	T$_{ig}$/τ_B (50kW)
8A	106.7	4.14
8D	137.3	1.95
8E	202.7	4.25
8F	156.7	1.53
7A0	79	0.5
7A1	92.7	0.2
8B	173.3	4.38
8L	80.7	0.17
7F1	82	0.6

Figure B2 T_{ig}/τ_B plotted against q_{max} when the radiant heat flux is 50 kW/m^2