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VOLUME 2

Sheilda L. Bryner, Editor

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Revision of Zone Fire Model BRI2 for New Evaluation System

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ABSTRACT

The revision of zone fire model BRI is undergoing. This paper summarizes the historical development of BRI2, while pointing out the needs for improvement in the aspect of physical sub-models. The possibility of inclusion of the species yield model as a function of equivalence ratio (normalized fuel air ratio), convective heat transfer model between wall surface and smoke, upward hot current along the rear (non- heated) surface of thin wall elements, effectiveness of mechanical smoke exhaust systems, and so on.

1. INTRODUCTION

Zone fire models are one of the important tools for fire safety engineering (FSE). So far, the development of the zone fire models accelerates the spread of FSE. Contrary, the expansion of FSE rouses the needs for further revision of the code in order to cover more complex and difficult problems. In Japan, a computer code BRI2 has been in this cycle.

At this moment, the world of fire safety is moving toward the performance- based system. Performance-based code is one of the mainstreams of moving. Reflecting the change in circumstance, the zone model code BRI2 is being revised so as to fit to the new system, namely so as to includes more performance-related physics and to evaluate the effectiveness of new type of construction. This paper briefly summarizes the historical development of BRI2, current activities to revise BRI2 and possible future development.

2. HISTORICAL DEVELOPMENT

Before we discuss the possible revision of zone models, we look back the history of BRI2 briefly. The code was developed to meet the needs in fire engineering. The prototype was developed by Tanaka in 1976[1]. The motivation was to evaluate and indicate the degree of fire safety of apartment houses to those who design, construct or buy them. Typical example calculation result is shown in Figure 1. In this stage of development, calculation was limited only to relatively small-scale apartment houses[2]

During the Ministry of Construction's developmental project on Total Fire Safety Design System, full-scale smoke experiments were carried out. The validity of BRI2 was checked against experiments in those tests. Figure 2 shows one of the verification results[3]. After the validation to large-scale spaces, BRI2 got more popularity to FSE for commercial buildings.

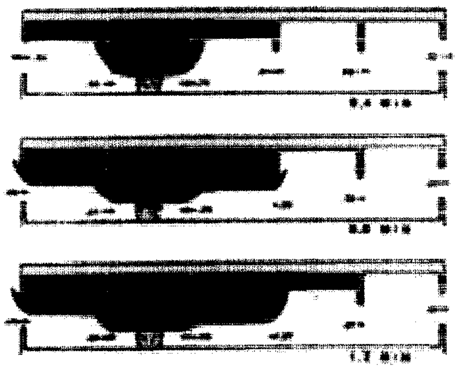

Figure 1 Calculation Results by Prototype code TANAKA (1976-78)

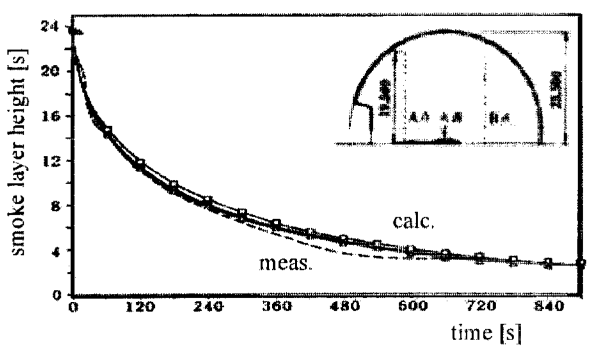

Figure 2 Smoke Filling Experiment at Tsukuba Exhibition Pavilion (1986)

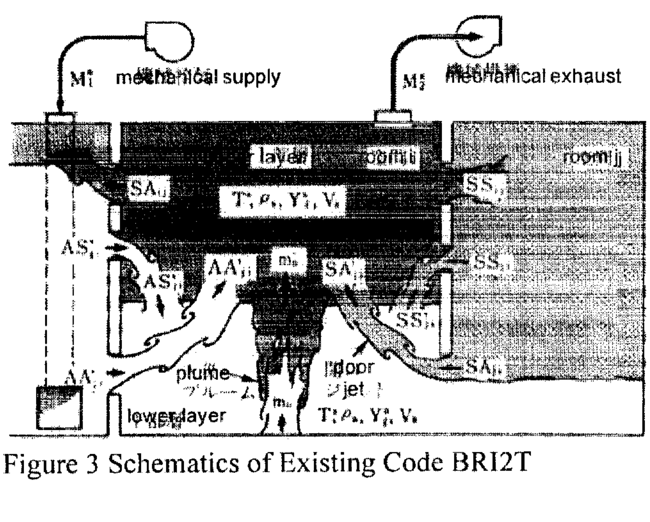

Figure 3 Schematics of Existing Code BRI2T

Then it is not surprising that building designers and engineers hopes to include smoke management provisions such as smoke compartment, smoke exhaust system and so on. The work was completed by Nakamura and Tanaka[4] in 1989. The schematic idea is shown in Figure 3, which is still up to date. After Nakamura and Tanaka's work, the code was made open to fire engineering community for FSE purpose[5]. An important issue is that through the development, standard fire (default design heat release rate) was established for use in BRI2 and other zone-type smoke calculations.

3. REVISION OF BRI2

After about ten years of BRI2 for practical use in FSE, innovations were made in fire provisions as well as building construction and materials. Thus there is a need to revise the code in order to follow up to today's construction technology. At the same period, bases for sub-models were established to replace or to add some sub-models.

In order to revise the BRI2 to fit to new system, a research Working Group was established under the closure of Building Center of Japan. All the members are volunteers from university and industry. The list of participants is in Appendix-1. Before starting actual revision, the member discussed the target for revision. The following list specifies the needs of revision that we consider at this moment. They are classified into three categories- physics, numerics and utilization.

3.1 Revisions to Adding/Replacing sub-models to Describe Better Physics

The first category is concerned with the replacement and/or addition of sub-models to calculate physical phenomena better.

(1) Species Yield Model (EQIVRT, SPECS2)

The combustion process would be altered by the air supply to fire source. To reflect this effect, combustion model is revised to give variable species (CO, CO_2, H_2O and soot) yield. By altering the parameters in the combustion model, species yield could be approximated with reasonable accuracy as shown in Figure 4. The functional forms of the parameters are proposed by Yamada and Tanaka[6,7] as shown in Table 1. Putting these formulas into the combustion model shown in Figure 5, species release rate could be estimated.

Table 1 Ratio of perfect combustion, soot, CO, CO2 and Water Vapor Formation

	$\Phi \leq 1$ (fuel control)	$\Phi > 1$ (Oxygen control)
Ratio of perfect combustion	$r=1-0.25^{(1/\Phi)^2}$	0.75
Ratio of soot residual	$s=0.4$	$1-0.6^{(1/\Phi)^2}$
Ratio of CO formation	$p_1=0.6$	$0.6\sqrt{\Phi}$
Ratio of CO_2 formation	$p_2=0.1$	0.1
Ratio of H_2O formation	$q_1=0.25$	$0.25\sqrt{\Phi}$

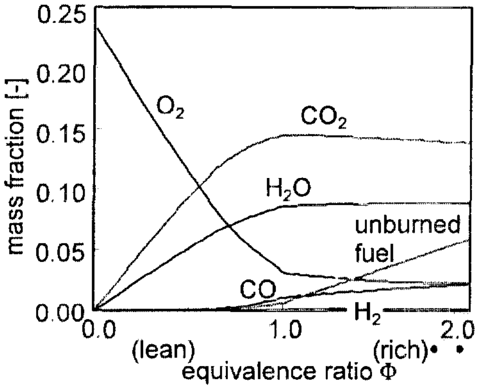

Figure 4 Equivalence Ratio versus mass fraction of Chemical Species of Propane Fire[8)]

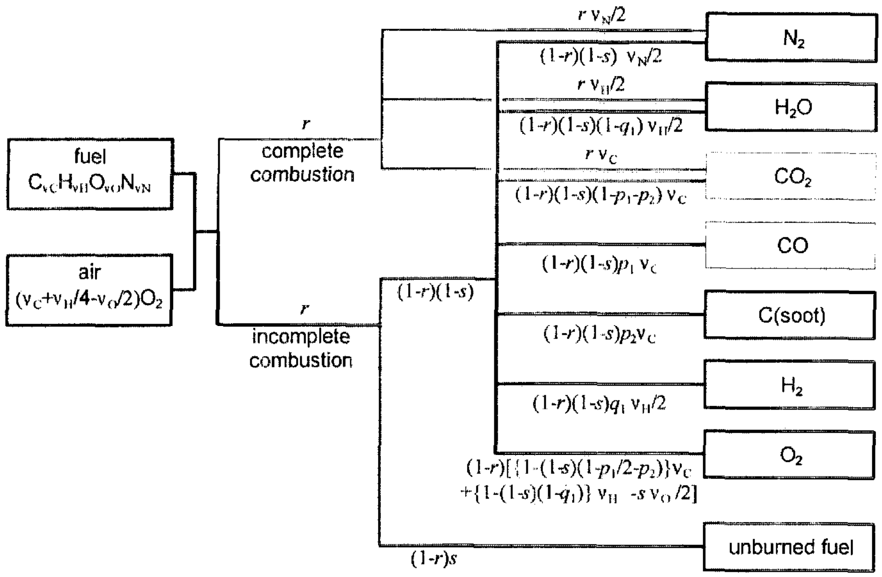

Figure 5 Combustion Model in BRI2

(2) Convective Heat Transfer Coefficient (CHTRAN)

The convective heat transfer coefficient is dependent on the magnitude of velocity field. As to the room of fire origin, experimental correlation is derived by Yamada *et al*[9)] as

$$h_c = \begin{cases} 8.3\times10^{-3} & (Q^* < 2\times10^{-3}) \\ 0.1Q^{*2/5} & (2\times10^{-3} \le Q^*) \end{cases} \quad [\text{kW/m}^2.\text{K}] \tag{1}$$

where the non-dimensional heat release rate is

$$Q^* = \frac{Q}{c_p \rho_0 T_0 \sqrt{g} L^{5/2}} = \frac{Q}{1116\{(room\ volume)^{1/3}\}^{5/2}}. \tag{2}$$

This change will results in increasing heat flux to the compartment boundary in the early stage of fire.

(3) Door Jet Plume (DPLUM)

Existing version approximates the mass flow rate of door jet plumes by an unconfined wall plumes by putting its origin at the level of pressure center. However experiments by Yamaguchi et al[10) indicated that the origin should locates at the height (1/3) of the door jet thickness.

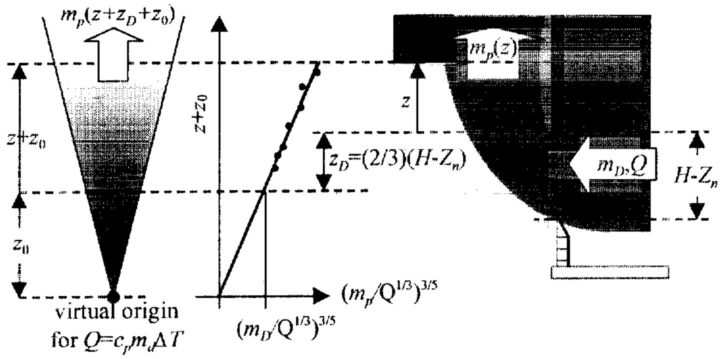

Figure 6 Mass Flow Rate of Door Jet Plume

(4) Heat Penetration through Thermally Thin Elements (WPLUME)

Quite often, fire and smoke compartmentation is provided by thermally thin elements such as shutters, wired glass. In those situations, heat penetrates through the element to result in upward wall plume along the non- fireside surface. Even if smoke is not contained in the wall plume, it an easily cause danger. To evaluate these phenomena, a model was developed to combine heat conduction, radiant heat transfer between thin elements and surrounding fire gas and upward wall plume[11). By virtue of this sub-model, we can evaluate the effectiveness of new separation elements such as insulated glass, silicate-coated screen shutters. Schematic idea is shown in Figure 6, followed by an example calculation result in Figure 8. In this example, the corridor is easily contaminated by penetrated heat, not by smoke leakage.

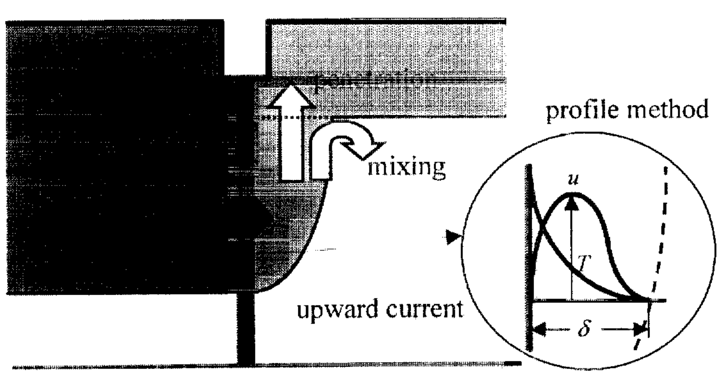

Figure 7 Heat Conduction through Thermally Thin Elements and Upward Current

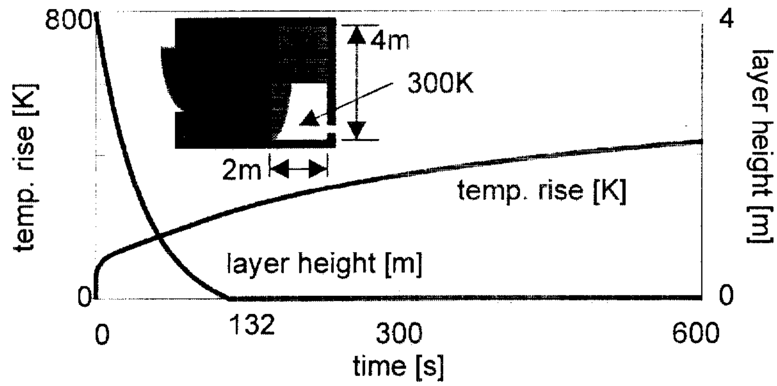

Figure 8 Calculation Example of Hot-Air Filling in a Corridor

(5) Smoke Vent Effectiveness (SMCSYS)

In the zone type smoke calculations, smoke exhaust is modeled as a sink of mass at the upper layer. However, if the rate of exhaust is large enough, air is induced from the lower layer, which reduces the efficiency of smoke exhaust. The efficiency of smoke vent (exhaust smoke volume / total vented volume) would be (see Figure 9 for symbols)

$$\beta = 1 - V_a / V_{ex} = \begin{cases} d_s / R_{cr} & (d_s < R_{cr}) \\ 1 & (R_{cr} < d_s) \end{cases}, \tag{3}$$

where R_{cr} is the critical radius to prevent the air from being entrained into exhaust flow, which is derived by expanding the concept of Spratts *et al*[12]. In a simple manner, critical radius is approximated by as long as the smoke temperature is not so high,

$$R_{cr} = \frac{1}{(1.33)^{1/3}(\Delta\rho g)^{1/6}} V_{ex}^{1/3} d_s^{1/6}. \tag{4}$$

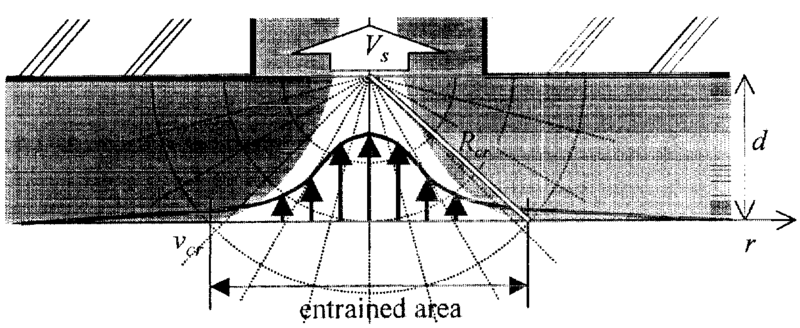

Figure 9 Potential Flow into Mechanical Smoke Vent[13]

3.2. Revisions to Increase the Robustness (VENTLE)

The existing version of BRI2 is not robust enough to yield reasonable results for "any" combination of input data. In a practical sense, robustness of the numerical code is desirable.

One of the reasons for insufficient robustness is the convergence criteria for Newton-Raphson iteration procedure. The program uses

(error in mass balance in each layer) < (tolerance limit)

as a criteria for convergence. However, this type of criteria is sometimes too severe to achieve. Thus it is reasonable to use

(error in mass balance in each layer) / (opening area) < (tolerance limit)

in order to adjust the tolerance limit depending on the stiffness of the problem.

3.3. Revisions to Increase the Utilization

There are several points that are minor, but important in the viewpoint of practitioners.

(1) Control Sequence of Active Fire Provisions (OPENDT)

The control sequence of fire doors and/or shutters will be included in a manner that simulates intended behavior. Change in opening height is included in addition to the change in width.

(2) Smoke Control Sequence (SMCLDT)

As to the mechanical smoke control systems, the time to trigger, time to normal operation will be included in the sequence of smoke control system. This sub-model reflects the popularization of active (intelligent) fire control.

(3) Other Proposed Changes

There are other points to be revised. For example, the followings are under consideration.

Inclusion of t^2-fires in design fires (FIREDT, FPLUME)
Combustion Rate in Gasified Volatile (GPBRAT)
Modeling of long corridor by using virtual openings (adding new rule ?)
Horizontal Openings (OPENDT)

4. FUTURE DEVELOPMENT

New version of the BRI2 is not ready for use at the moment of describing this text. However we will finish the task soon to make the new code available in our new performance- based system. As it is at present, new version will again be an open program including its source code. We believe that open system will be an effective way to keep the FSE in good condition.

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APPENDIX List of Participants on the Revision of Smoke Propagation Programs

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