RECENT DEVELOPMENTS IN THE DETAILED MODELLING OF POWERHOUSE ENVIRONMENTAL CONDITIONS USING GOTHIC

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ABSTRACT

Environmental qualification of safety equipment in the powerhouse requires detailed information on the predicted harsh conditions that can arise following a steam line break. Although lumped parameter codes provide quick assessments of global conditions, the results are unsatisfactory because the spatial detail needed to evaluate specific equipment, or indeed to optimize and confirm the design adequacy of mitigating features, is not available. To overcome these problems, new models have been developed to provide detailed three-dimensional information using the GOTHIC code. Furthermore, new animated graphical displays help the designer visualize and fully comprehend the buoyancy driven steam flow within the powerhouse. This has lead to quick optimization of the placement, size and opening time of the emergency venting system, thereby mitigating the conditions for which safety equipment must be qualified. This has resulted in significant cost savings for the environmental qualification programme.

INTRODUCTION

As in most nuclear generating stations, the high energy piping associated with the steam supply to the turbine is located outside containment in either the auxiliary buildings or the powerhouse. Essential safety equipment required to function under such accident conditions may also be located in these buildings. Therefore, it is important to assess the harsh environmental conditions in which the equipment must perform its function, to ensure that the equipment is qualified to operate under those conditions. In some cases, operator field action may be required and the accessibility for personnel must be considered and assessed. The assessments provide important information needed to specify design requirements and costs of the Environmental Qualification (EQ) Programme.

Following a steam line break, a large amount of high energy steam (up to about 840 Mg) is discharged into the powerhouse within a short period of time (15 minutes). Since the powerhouse represents a very large volume (typically 1.5 million cubic meters), the local conditions throughout the powerhouse can vary considerably, depending on the size and location of the break and the distribution of steam. The migration of steam depends on a number of factors such as the buoyancy induced recirculation flow, turbulent mixing of the plume, location of the break, location and opening time of vents and the location of other openings through internal structures. Local temperatures also depend on the amount of heat transfer to the structures and the amount of droplets re-entrained to the flow field to reduce the level of superheat.

A number of design features are incorporated to mitigate the harsh environmental conditions following the main steam line breaks. These include protection of essential equipment in special sealed enclosures, dedicated air-conditioning and/or ventilation systems, isolation dampers in ventilation ducting, baffle walls, turbine floor openings, insulated water piping and ventilation ducting, etc. The most important feature is the powerhouse emergency venting system. A high powerhouse pressure and/or temperature signal will initiate the opening of the vents to provide pressure relief, and to minimize temperatures by releasing steam out of the powerhouse while entraining cool outdoor air through bottom vents.

To optimize the design of the venting system, and confirm its performance, it is essential to study the general flow patterns of steam and air in the powerhouse by means of a three-dimensional computer code to derive the local environmental conditions for the purpose of equipment qualification. The adequacy and the effectiveness of any of the above mentioned mitigating features following a steam line break can be assessed as well to ensure an adequate, cost effective design.

BACKGROUND

In 1983, a study was initiated using an in-house lumped-parameter code. A three node model was created to calculate the pressurization in different regions of the powerhouse. In 1985, the two-dimensional BEACON [1] computer code was use to model the powerhouse in nine general areas. Both pressure and temperature conditions were evaluated. In 1987, a 55 cell two-dimensional BEACON model was used to estimate pressure, temperature, as well as humidity conditions in the powerhouse of another station. The analysis results were used as boundary conditions for lumped-parameter models of individual "steam protected rooms". This two-step calculation provided environmental qualification conditions for equipment located both inside enclosed rooms and in the open areas of the powerhouse.

In these previous assessments, both lumped-parameter and two-dimensional models were used. However, the use of these models produced unsatisfactory results because:

- they provide only bulk conditions which may not apply to specific locations
- lumped parameter codes are not formulated to simulate buoyancy recirculation flows
- two-dimensional codes neglected the distribution of steam and air in the third dimension.

The third dimension is important because significant variations of steam content and temperature occur affecting equipment placed locally in that direction.

In order to provide more realistic conditions in specific locations, and to significantly reduce the cost of the Environmental Qualification Programme, the detailed time dependent distribution of steam and air throughout the powerhouse using a three-dimensional code was needed.

METHODS

Computer Code

In order to model the buoyancy driven flow phenomenon and to generate detailed local conditions in various parts of the powerhouse, a three-dimensional model is required. Required features of the model include:

- break mass and energy discharge transient
- buoyancy driven re-circulation flow
- turbulence generation and dissipation
- obstructions or blockages within control volumes
- heat structures as passive heat sinks
- valves and trips to model opening of powerhouse emergency vent panels
- pressure boundary conditions for venting to the atmosphere
- evaporation and condensation
- droplet depletion and transport processes
- homogeneous and heterogeneous nucleation of droplets
- water film on walls and water pools on floors, and their movement
- heat transfer between phases and heat structures
- operation of ventilation fans
- heat load in enclosed rooms
- air-conditioning system behaviour

To meet these modelling requirements, the GOTHIC (Generation Of Thermal Hydraulic Information in Containment) [2] containment code was chosen. GOTHIC is a general purpose thermal-hydraulic computer program for design, licensing, safety and operating analysis of nuclear power plant containments and other confinement buildings. It solves the conservation of mass, momentum and energy equations in a multi-phase, multi-component system. It is owned by EPRI (Electrical Power Research Institute) and is developed and maintained by NAI (Numerical Application Inc.).

In addition to the modelling features listed above, GOTHIC has other advantages:

- a large user base (co-funded by 22 US Utilities and four other foreign companies)
- low annual maintenance cost for the amount of code development and upgrades provided
- a user friendly pre- and post-processor
- Quality Assurance by NAI to current standards

- a vast amount of validation tests have been performed
- versatile in modelling applications

Powerhouse Models

Using GOTHIC, a powerhouse model has been developed as illustrated schematically in Figure 1. This is typical of what has been developed for various stations. The grid sizes were chosen such that adequate spatial resolution in specific local areas is achieved while at the same time computer run time is optimized. The individual "cell" is typically 10 m x 30 m x 10 m in size. This size is sufficient to generate reasonable localized conditions for this application. Some of the features in this model include:

- all major floors in the powerhouse define cell boundaries
- enclosed areas such as the control room complex were excluded from the modelled volumes
- all major concrete structures, structural steel and steel grating were modelled as heat sinks
- all major openings on floor as well as corridors and access ways connecting open areas
- activation of the venting system
- building leakage, opening of service doors
- fixed louvres and roof ventilators with blow-open type dampers

Modelling of the Emergency Venting System

The emergency venting system is one of the most important features installed in the powerhouse to mitigate the consequences of a main steam line break. It features vents at both the top and the bottom of the powerhouse, as well as an active initiation mechanism. In the modelling of the pressure and/or temperature activation, trip parameters are used to monitor the local cell pressure and/or temperature. When one or more of these parameters exceeds the setpoint, the vents will start to open after a brief delay. This time delay represents the instrumentation and mechanical delay that may be included as part of the system design. The opening of the panels is assumed to be uniform such that the vent area will linearly increase with time until the panels are fully open. Sensitivity cases are used to optimize the design requirement for opening time.

Break Discharge Conditions

A matrix of cases are considered to maximize the challenge to the safety systems and effectiveness of mitigating features. For peak pressure calculations, the large breaks such as the 100% main steam line break and the 100% steam balance header breaks are considered. For peak temperature calculations the amount of steam distributed into the powerhouse is maximized by analyzing a "trip blinding" break. A trip blinding break is a theoretical break discharge that is nearly capable of activating the automatic reactor trip. This is conservative as it results in more steam released into the powerhouse prior to operator action at 15 minutes or depletion of the secondary side water inventory.

Initial Conditions

Typically, summer conditions are used to maximize the temperature conditions in the powerhouse. An outdoor air temperature of 30°C is conservatively assumed. Brief periods of outdoor temperatures exceeding 30°C would not have a significant effect on the assumed powerhouse ambient temperatures due to the thermal inertia in the powerhouse. Initial temperatures in the powerhouse were assumed to range from 30°C on the lower elevations to 45°C on the upper elevations.

TYPICAL RESULTS AND THEIR POST-PROCESSING

Since there is a vast amount of information generated from the three-dimensional GOTHIC models, results are organized in the following formats.

Transient Line Plots (See Figure 2)

Each data point in the transient of a particular parameter is written to a library file and used later to create bounding composite transient plots for each cell based on a combination of cases. This is used so that equipment can be qualified to cover all break scenarios.

Peak Temperature/Pressure Maps (See Figure 3)

These show maximum values in each cell for each simulation. These are created separately to help identify the peak conditions in each cell. Also, bounding composite maps which combine maximum values from different simulations can be created to determine the maximum values in accident unit, adjacent units and remote units.

Contour and Vector Plots (see Figure 4)

These are produced for any vertical or horizontal planes to assist in analyzing/comparing the buoyancy induced flow patterns for different cases.

The Visualization Program (See Figure 5)

A commercial visualization program is used to create an animation that easily demonstrates how a certain parameter, such as temperature, changes in a three-dimensional view.

Some typical observations from the visualization of GOTHIC predictions are summarized as follows:

- the buoyancy induced flows predicted by this model illustrate that the temperatures are highest in the vicinity of the break and that stratification of steam will occur near the roof of the powerhouse
- because steam will accumulate near the roof, early activation of vents (top and bottom) is the single most important mitigation feature in terms of powerhouse high temperatures

BENEFITS OF THE GOTHIC MODELS

Benefits of the three-dimensional GOTHIC models include:

- more realistic environmental conditions in local areas can be obtained
- optimization of the design of the mitigation features results in cost saving to the EQ Programme
- physical phenomena such as steam condensation and droplet nucleation can be simulated
- ease of using and executing the code translates to cost savings
- visualization program helps to ensure that the vast amount of information is processed efficiently and understood fully by the designer

CONCLUSION

The use of the GOTHIC powerhouse model has significantly enhanced the ability to generate localized temperatures throughout the powerhouse for various steam line break scenarios. For example, the buoyancy induced flows predicted by these models illustrate that the temperatures are highest in the vicinity of the break and that stratification of steam will occur near the roof of the powerhouse. Visualization of this phenomenon helps the designer to justify a venting system that opens early to release the steam before it migrates to other areas of the powerhouse. Applying GOTHIC models to optimize the design of systems for mitigating accidents will have a significant economic benefit to the overall Environment Qualification Programme.

REFERENCES

[1] Broadus, C.R., et al, "BEACON/MOD3: A Computer Program for Thermal Hydraulic analysis of Nuclear Reactor containments - User's Manual", EG&G Idaho, Inc., NUREG/CR-1148, April 1980.

[2] George, T.L., el al, "GOTHIC Containment Analysis Package User Manual", Version 5.0, EPRI RP4444-1, Numerical Applications, Inc., NAI 8907-02 Rev 6, December 1995.

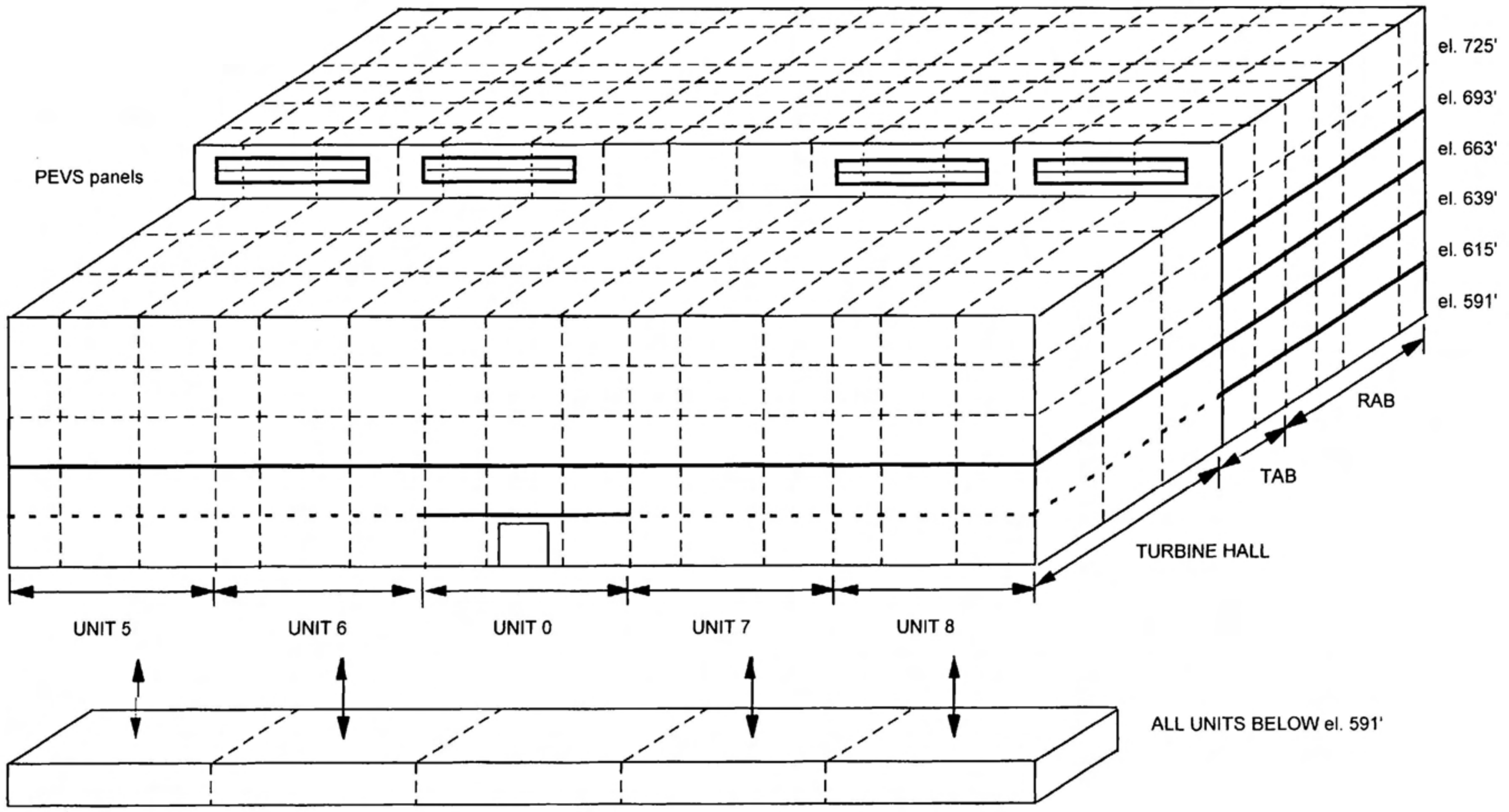


FIGURE 1 Sample Powerhouse GOTHIC Model

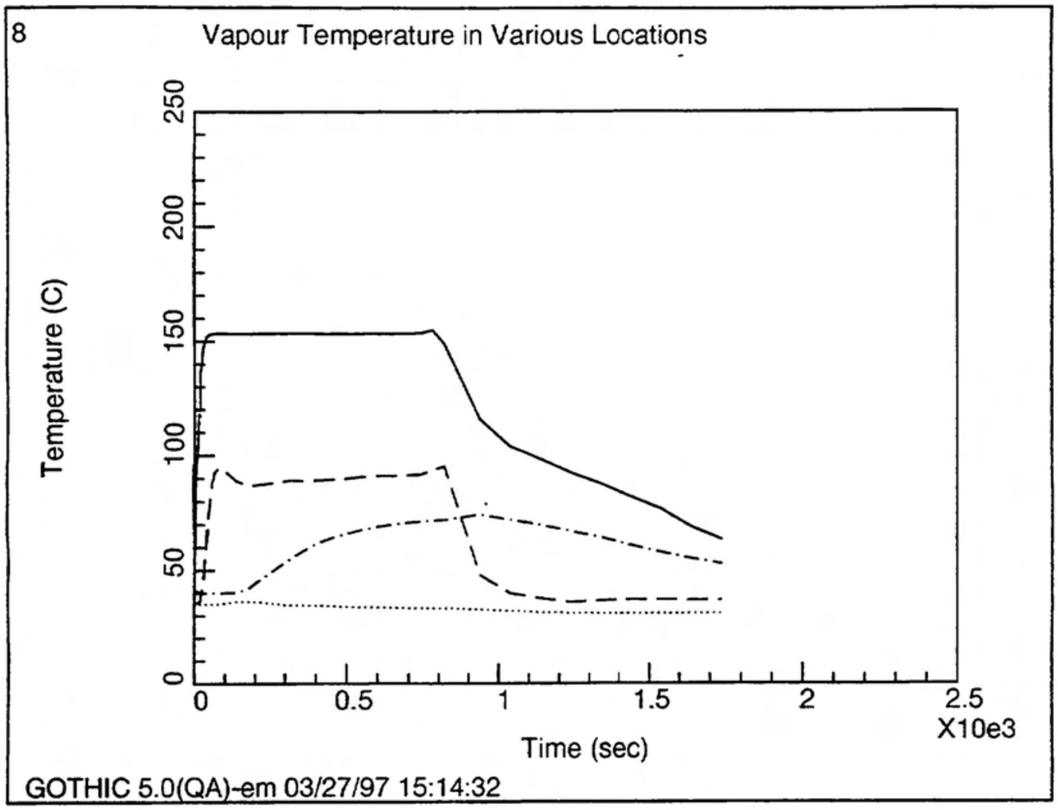
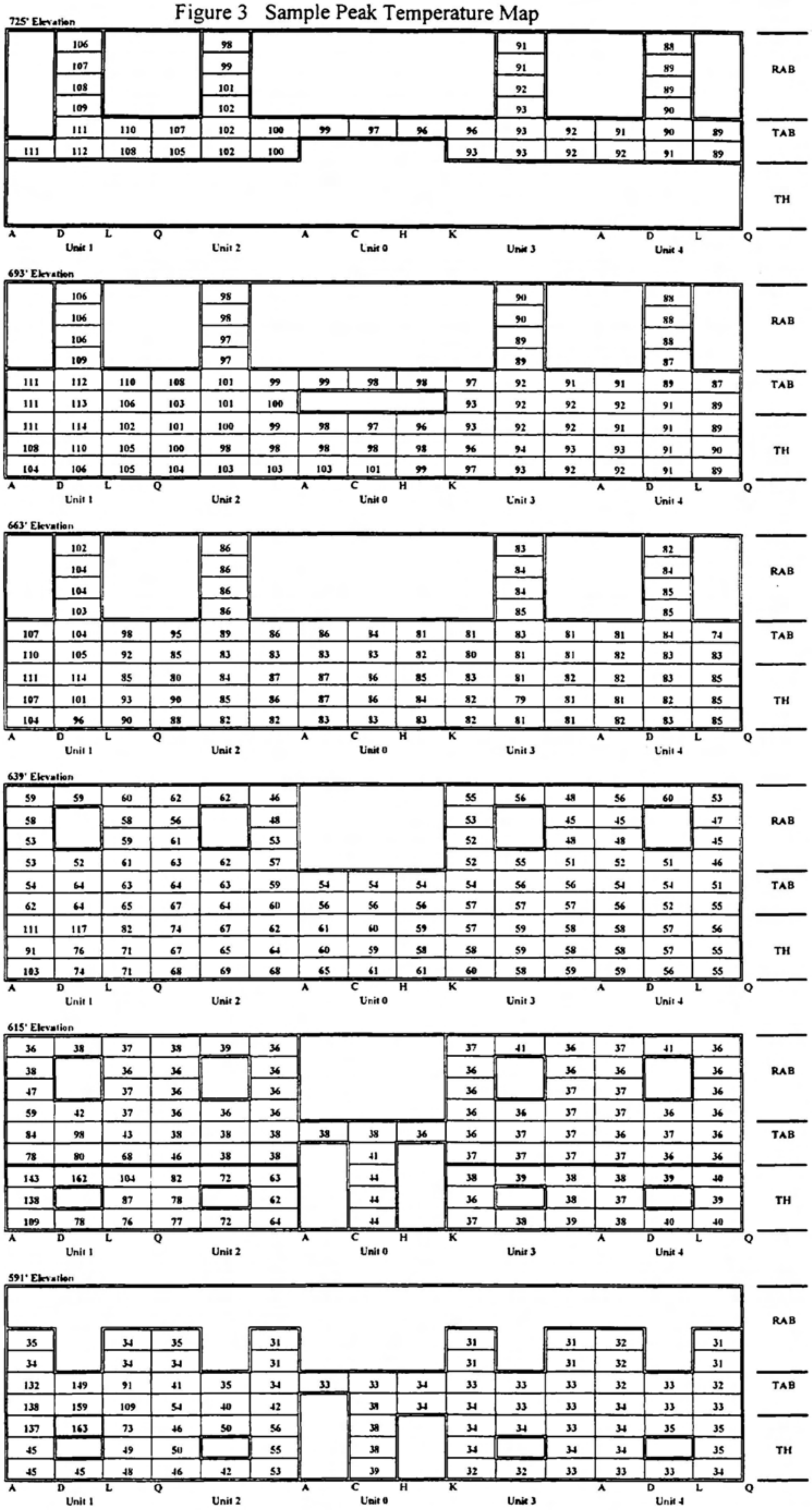


Figure 2 Sample Transient Line Plot

Figure 3 Sample Peak Temperature Map



- Break Cell
- Baffle Wall

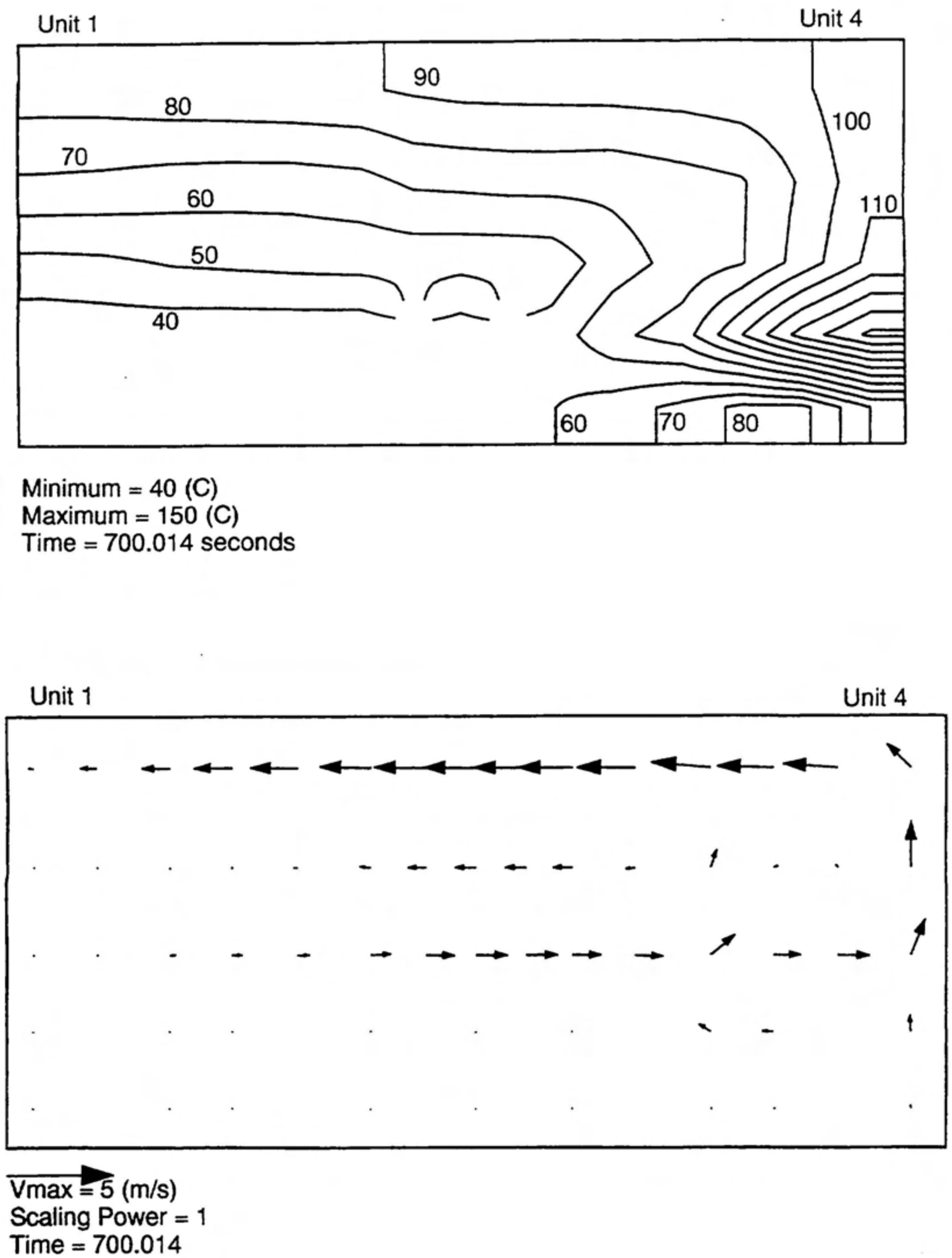


Figure 4   Sample Contour (Isotherm) and Velocity Vector Plots

Figure 5: TECPLOT Illustration of Temperature Distrubution In Powerhouse