

SIMPLE EVALUATION MODEL FOR LONG TERM DEBRIS TRANSPORT VELOCITY IN THE TORUS OF A MARK I CONTAINMENT

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Introduction

After the Barsebäck 2 strainer clogging incident from 28 July 1992, a first review of the design features of a Mark I containment and the thermal insulation typically employed revealed a potential for the transportation of larger amounts of insulation into the wetwell (torus) of the containment during a LOCA. Although Switzerland took a quick decision to increase the strainers of all BWRs till the end of 1993 (as it was performed by the Swiss Utilities) for the meantime it was necessary to develop tools for assessing the effectivity of accident management actions proposed by the utilities for the existing (old strainer) design. Among others tools a simple evaluation model for assessing the transport velocity of insulation debris caused by the suction of operating strainers was developed, which was applied for a BWR with a Mark I containment and can as well be applied for sump pool conditions of a PWR (submerged sump strainers).

Model description

Basic modelling assumptions

Based on a review of the containment design features and the allocation of the torus strainers in relation to the possible entry paths of insulation it was concluded, that the following assumptions for long term operation of emergency core cooling systems can be applied to develop the model:

1. The flow in the torus can be modelled as a multidimensional steady state potential flow with distributed flow sinks (strainers).
2. The distance between the strainers is large enough to neglect the effects of superposition of the flow fields in the immediate surrounding of the strainers.
3. The flow sinks are modelled to have point shape and are located at the elevation of the strainers. The water below the strainers does not take part in the water exchange between the different torus layers.

1. The work presented was performed while the author was working with the Swiss Nuclear Safety Inspectorate.

Basic equations

The model developed based on the assumptions above can be solved analytically for the spatial velocity distribution of water in the torus. The corresponding equations (in polar coordinates) for the velocities in radial and vertical directions are given below. Q is the volumetric flow of the system taking suction from the strainer of interest.

$$C_r = \frac{Q}{(2 \cdot \pi \cdot z \cdot r)} \quad (1)$$

$$C_z = C_{\text{strainer}} \cdot \frac{A_{\text{strainer}}}{A_{\text{torus}}(z)} \quad (2)$$

Goals and object of the investigation

The model was used to estimate the transport velocities of insulation material (rockwool) floating in the torus of a BWR with Mark I containment. The main goal of the investigation consisted in the evaluation of the success chances of accident management measures like:

- throttling of suction flow;
- temporarily transferring ECCS injection to the cold condensate storage tank interrupting suction from the torus;
- restarting suction from torus after drain of cold condensate tank assuming settlement of insulation material.

Figure 1 shows a cross section of the plant containment.

In the original design (meanwhile the strainers were replaced) the plant possessed three small suction strainers spatially separated from the blowdown lines in different segments of the torus. The plant of concern has 6 different trains of ECCS systems:

- TCS – torus cooling system – 2 trains.
- CS – core spray system – 2 trains.
- ALPS – alternate low pressure system – 2 trains.

The total suction flow in case of operation of all trains consists of $0.43 \text{ m}^3/\text{s}$. The minimal suction flow in case of operation of one train of the torus cooling system and one train of ALPS consists of $0.085 \text{ m}^3/\text{h}$. All strainers are connected to a common ring line below the torus area subdivided to the different system trains. The free flow area of one strainer was 0.206 m^2 . The distance between the strainers and the next blowdown line into the torus is 8.1 m in horizontal direction and 1.71 m in vertical direction. The strainer surface was allocated 3.58 m below the normal torus water surface.

The suction strainer thus was well separated from the possible entry points of insulation with the blowdown flow.

Results and conclusions

A large set of calculations for different operating conditions of emergency core cooling systems was performed. Table 1 gives an overview of the conditions considered.

Table 1. Operational conditions investigated

ECCS suction flow	Number of strainers in operation	Comment
0.430 m ³ /s	3	Maximum suction flow with all strainers in operation
0.430 m ³ /s	1	Maximum suction flow with 2 strainers clogged
0.085 m ³ /s	3	Minimum suction flow with all strainers in operation
0.085 m ³ /s	1	Minimum suction flow with 2 strainers clogged

Figures 2-7 show the velocity distribution in the surroundings of a suction strainer for different operating conditions. Based on a comparison with typical settlement velocities of thermal insulation debris (mainly rockwool of different age) it was demonstrated, that the flow suction from the strainers has only minor effect on the settlement velocity of the debris. The suction effect in radial direction is also very limited, once stabilised flow conditions are achieved in the torus. On the other hand this means, that material which is able to float (old insulation material) can keep floating for a very long period of time not being directed to the strainers. Only material transported close to the strainer position is expected to participate in a potential strainer clogging. Spatial separation of strainers from the blowdown lines gives some reasonable protection against strainer clogging. The largest uncertainty remained was the distribution of thermal insulation during and immediately after the blowdown phase of the accident.

With regard to accident management actions it was concluded:

- that flow reduction for operating emergency core cooling systems is an effective measure to reduce the risk of strainer clogging;
- that it is unlikely, that once settled debris, for example after an interruption of ECCS operation or back flushing will relocate to the strainers;
- that the accident management actions implemented by the utility as an intermediate measure:
 - Injection from an alternate water source (cold condensate storage tank) allowing to stop suction from the torus.
 - Back flushing of strainers from cold condensate system is efficient to limit the consequences of a LOCA accident within the regulatory safety limits.

On the other hand, it was concluded that human interaction may be necessary within the first 30 minutes after an accident to avoid partial clogging and to circumvent the uncertainty related to the initial insulation distribution in the torus. This situation was not in compliance with the deterministic 30 min-rule (Swiss Regulation R-101), requiring that design basis accidents shall be governed mainly by automatic means not allowing for not safety directed human interactions (like throttling or turning off ECCS-systems) during the first 30 minutes of an accident.

That's why in 1993 the effective strainer surface of all BWRs in Switzerland was enlarged substantially.

Figure 1. Mark I containment

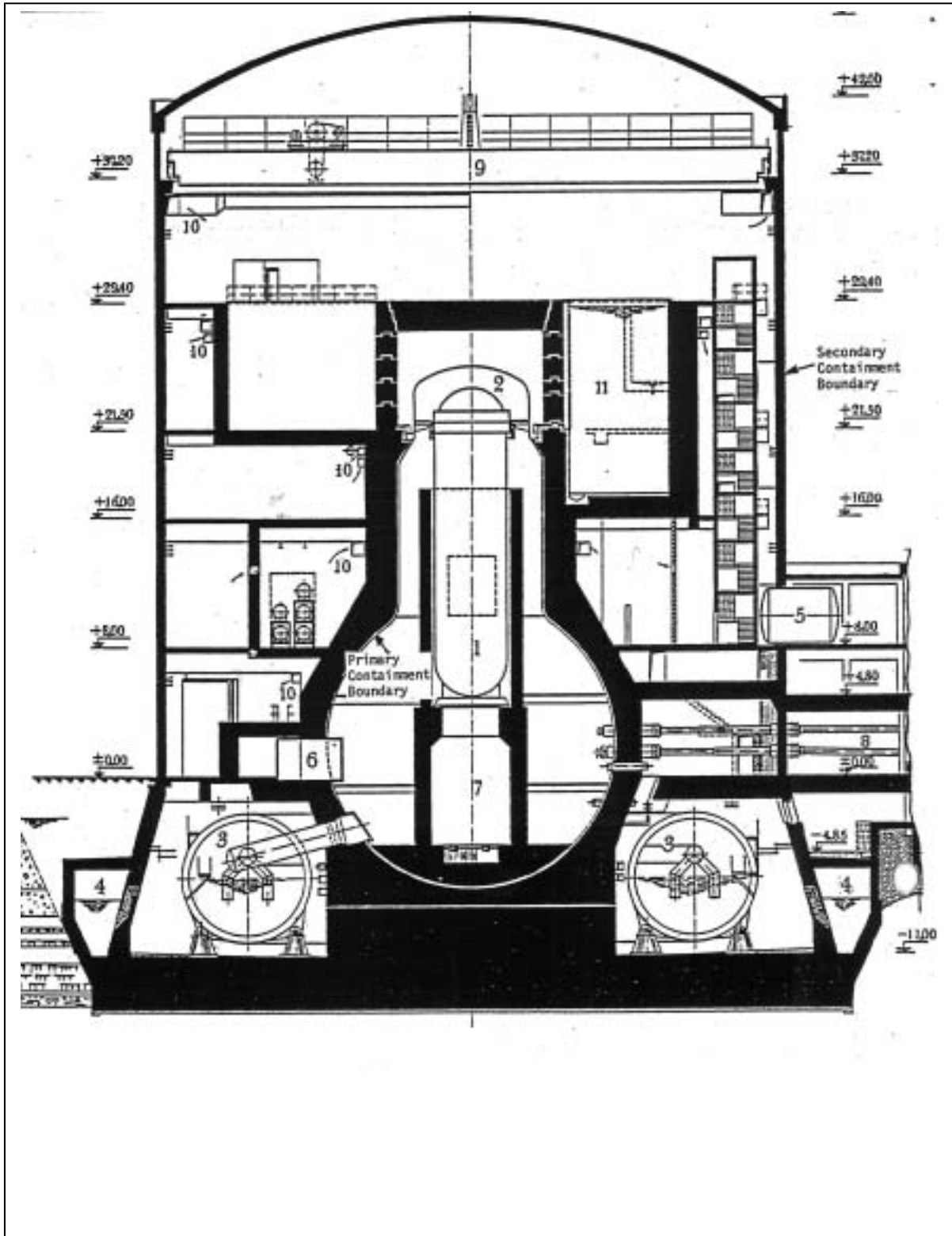


Figure 2. Radial velocity distribution, $Q = Q_{max}$, 1 operating strainer

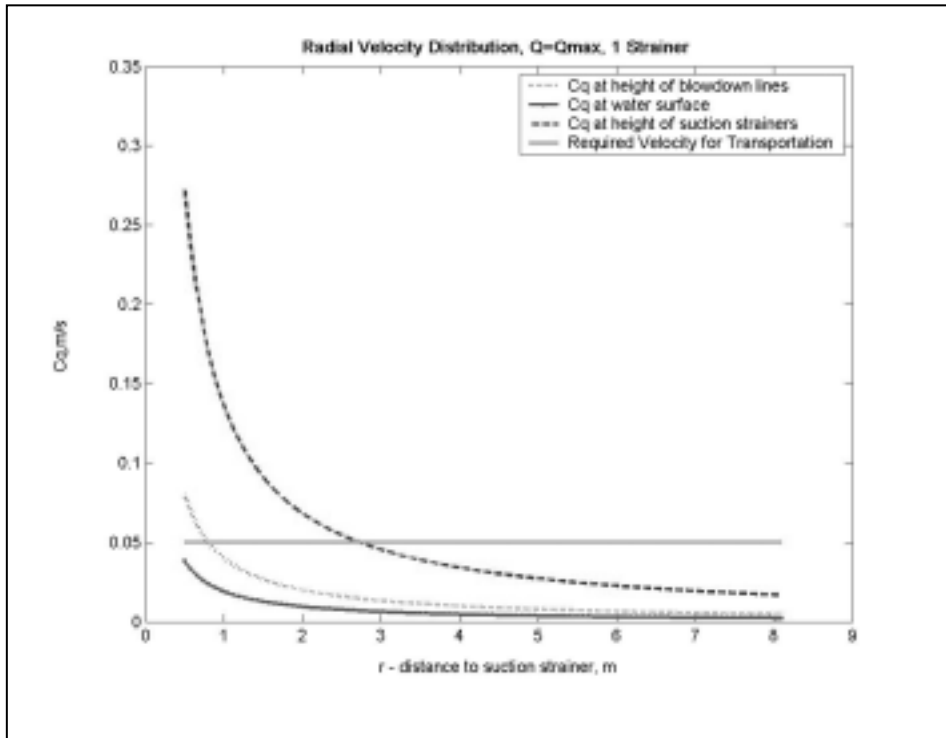


Figure 3. Radial velocity distribution, $Q = Q_{max}$, 1 operating strainer – Surface plot

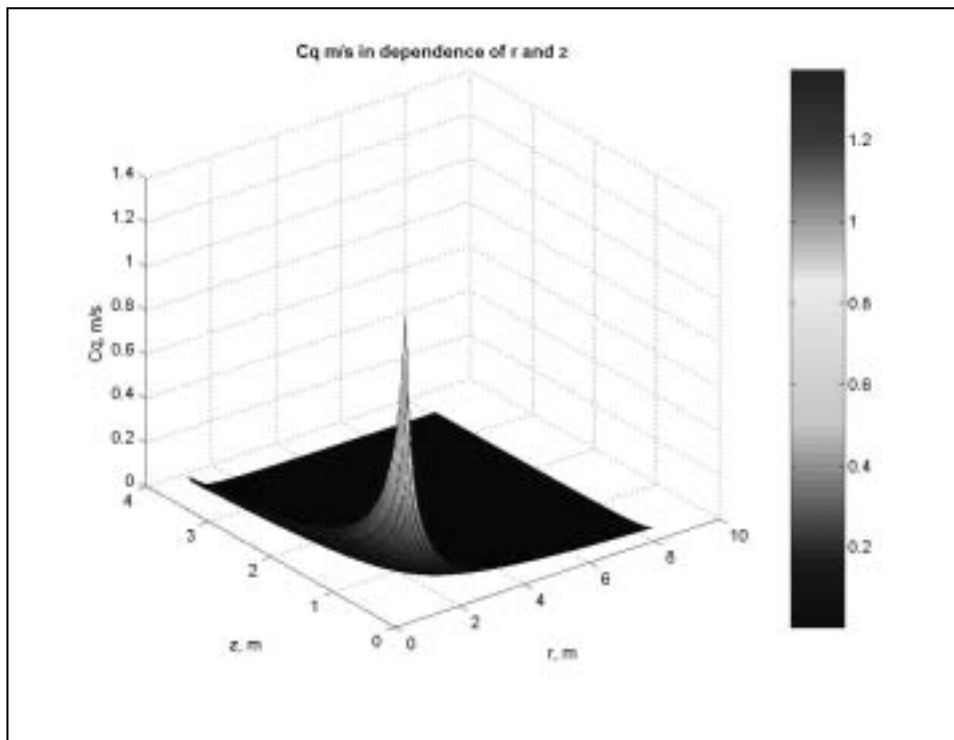


Figure 4. Axial velocity distribution, $Q = Q_{max}$, 1 operating strainer – Surface plot

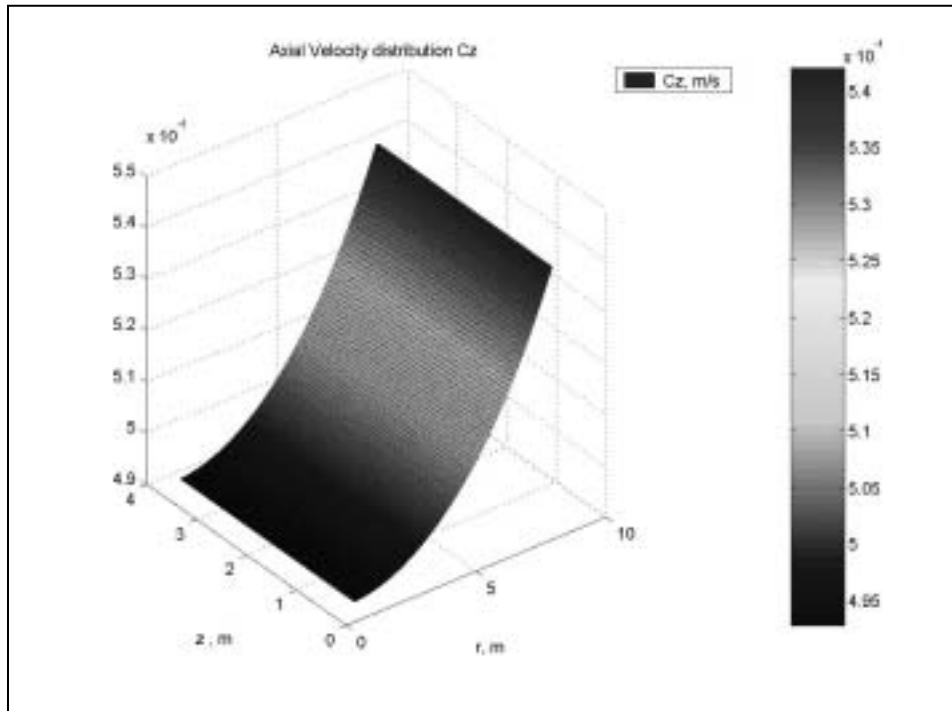


Figure 5. Radial velocity distribution, $Q = Q_{max}$, 3 operating strainers

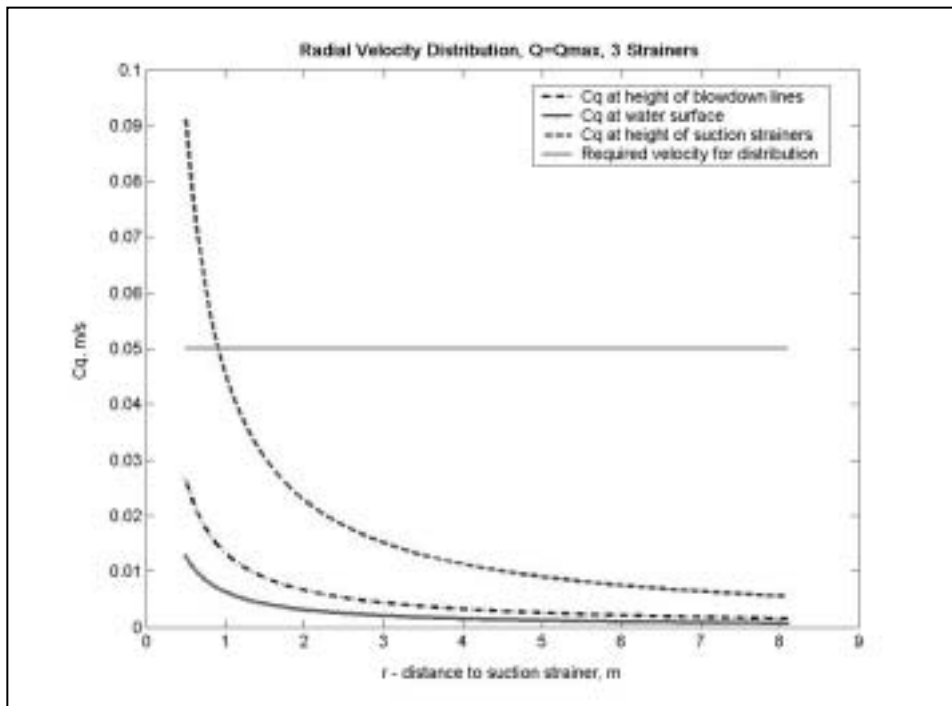


Figure 6. Radial velocity distribution, $Q = Q_{min}$, 1 strainer

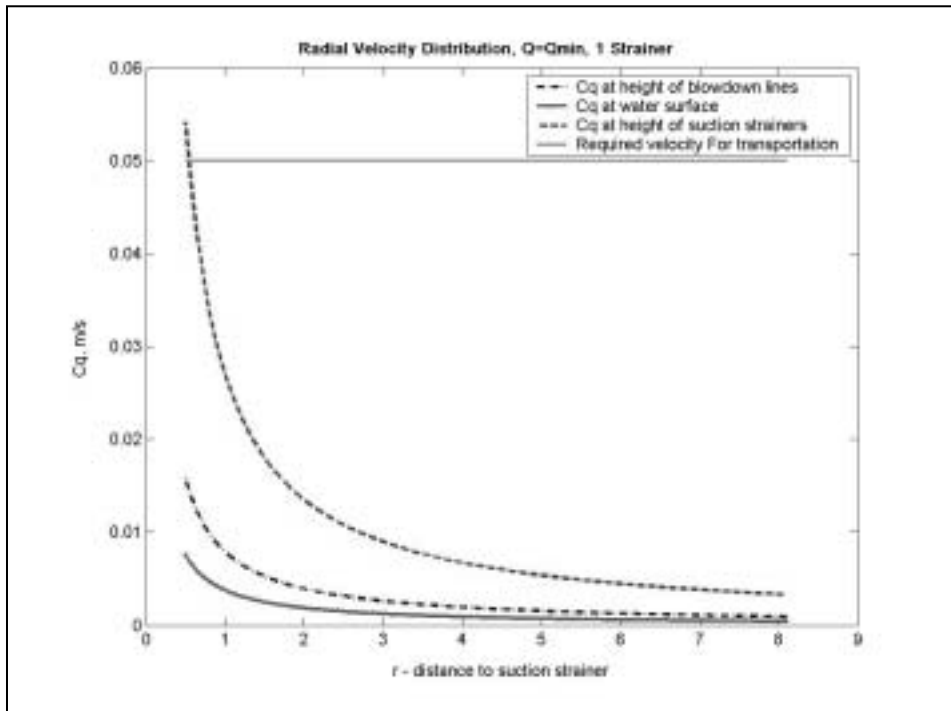
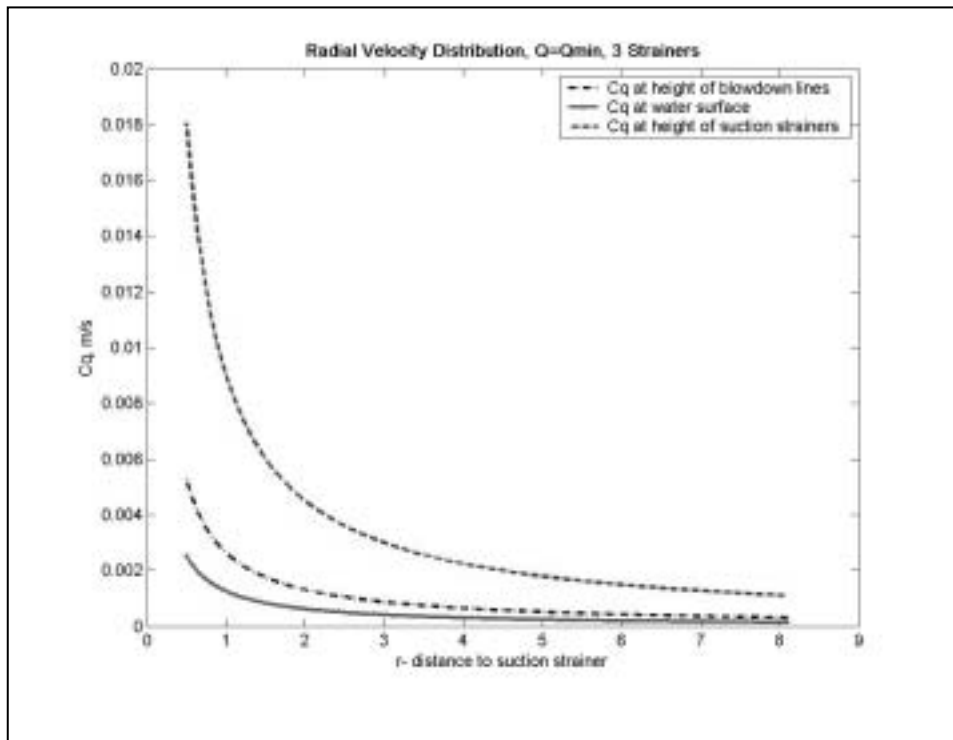


Figure 7. Radial velocity distribution, $Q = Q_{min}$, 3 strainers



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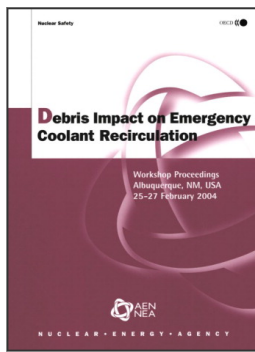
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