Zonal Network Platform (ZNP): Applications of a state-of-the-art deterministic CFD based scientific computing tool for environment, nuclear and thermal hazards

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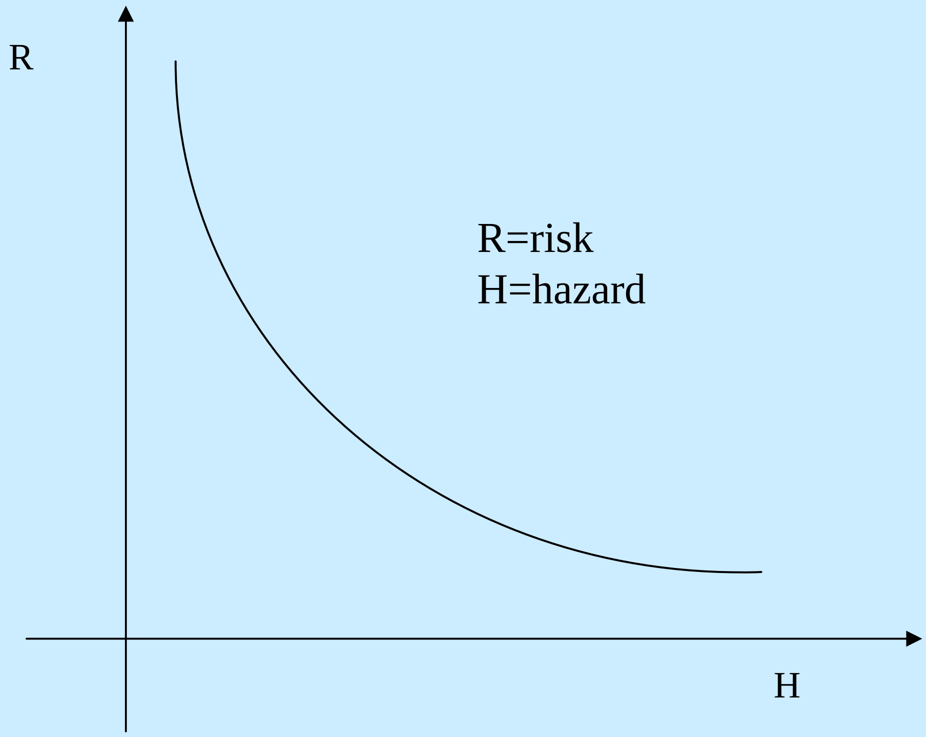
- Prior to introducing ZNP, we would like to foremost yet briefly re-introduce HARA (Hazard and Risk Assessment) Methodology *

* Wong, D. H., "**HARA: State-of-the-art Scientific-Engineering Optimal Hazard-Risk Managerial Platform for Micro and Macro Environmental and Transportation Systems, "** *Hong Kong & Shanghai Symposium on Science & Technology*, HKIE-SAST, May 2004

- Hazard strictly refers to physical (including mechanical, thermal, chemical, electrical, radiological), biological, and psychological phenomena, effects and impacts
- Risk strictly refers to qualitative or quantitative likelihood (probabilities, chances) of the occurrences of the hazard



Hazard vs. risk magnitudes

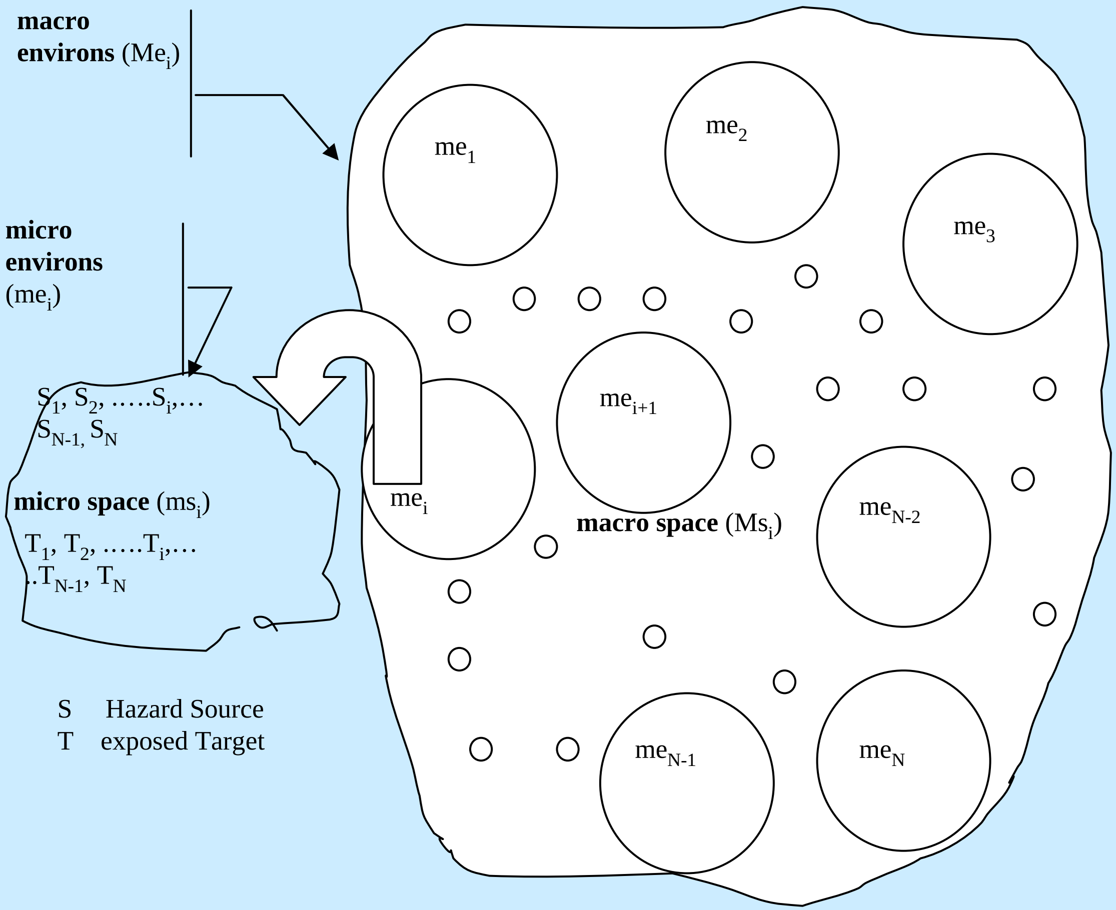
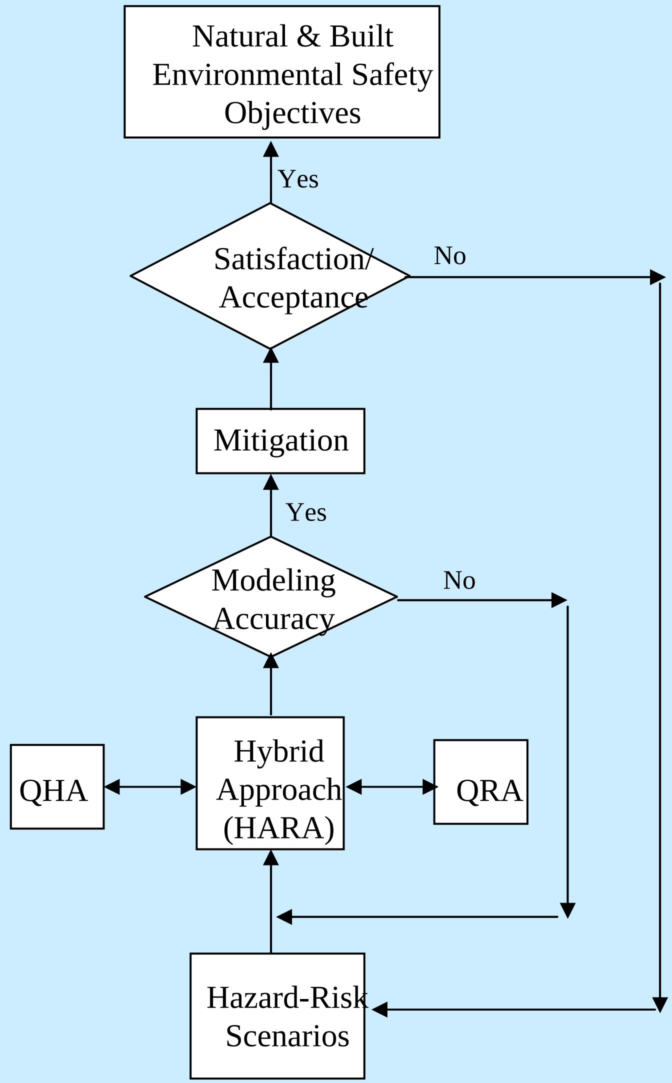


Fig. 2 Micro and macro spaces and environs

- Typical Micro stakeholders are private organizations (including companies and firms) and individuals
- Typical Macro stakeholders are public governments and agencies, and non-profit technical and non-technical organizations, having jurisdictions over localities, nations, regions, continents and the world

- Micro and macro demarcations (i.e., spaces and environs) are mutually relevant and salient in the contexts of Hazard-Risk assessment
- For example, hazardous sources and impacts (onto exposed targets) do not necessarily have the same magnitudes due to space separations
- A high earthquake frequency (risk) in San Francisco does not imply the rest of the world



A modular HARA platform

- HARA attempts to bridge the gaps between hazardous and risky taxonomies
- HARA helps clarify whether we are mitigating the extent and magnitude of a "hazard" ***or*** a "risk", which both are NOT interchangeable or directly proportional
- HARA furnishes deterministic-stochastic iterative convergence studies

- Returning to ZNP-CFD, it is a hazardous deterministic scientific-engineering tool (i.e., QHA inside HARA) applicable to fluid-thermal-species-nuclear analyses
- ZNP-CFD predicates upon phenomenological or conservation laws governing all zonal and CFD modeling

- The three required conservation laws are Continuity; Momentum; and Energy invoked at the zonal or elemental level
- Auxiliary conservation laws are Equate of (Thermodynamic) State (i.e., Ideal Gas Law); Poisson equation; Species (Mass Transfer); Equation of Radiative Transfer

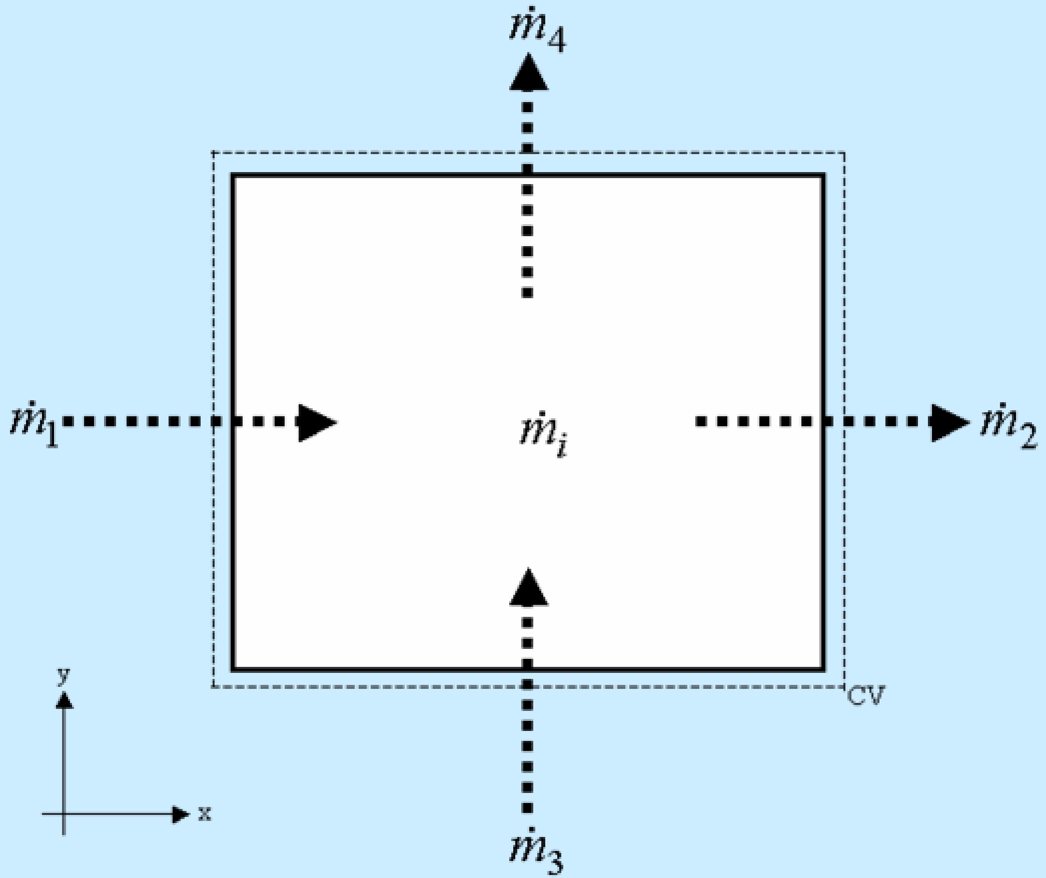
- Why do we need ZNP, seemingly if CFD is a much more refined and well established engineering tool?

- The motivation is twofold:
  - numerical difficulties (i.e., dispersion, dissipation and instability) inherent to CFD
  - relatively high CFD computing costs

- What is ZNP or ZNP-CFD?
- It comprises:
  - a Primary Zonal platform; and
  - a Secondary CFD platform
- A Primary Zonal platform can either invoke as a post-processor or fully couple with a Secondary CFD platform

- What is the backbone of a Primary Zonal platform?

- Kirchhoff’s First Law (Current Flow); i.e., Zonal/Nodal/Elemental Continuity=0
- Kirchhoff’s Second Law (Voltage Drop); i.e., Looped Energy=0

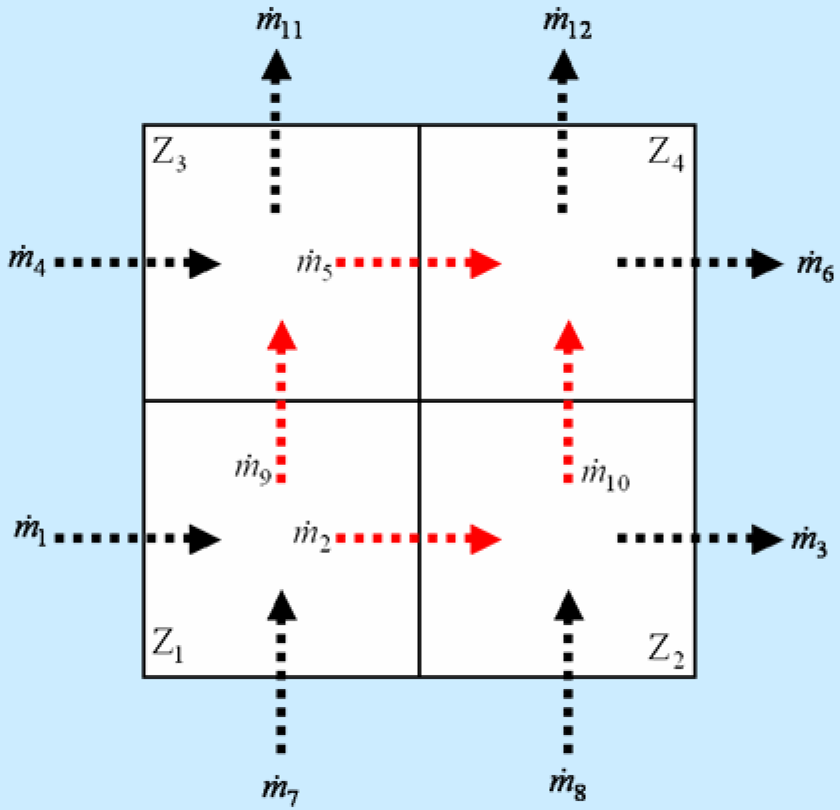


$$L(\dot{m}_i) = (\dot{m}_2 - \dot{m}_1) + (\dot{m}_4 - \dot{m}_3) - \dot{m}_i = 0$$

Kirchhoff's First Law of Zonal Continuity

A generic connector energy differential between two zonal (nodal, elemental) control volumes is:

$$\Delta e = \frac{1}{2}\bar{v}^2 = \frac{1}{2}\left(\frac{\dot{m}}{\rho A}\right)^2$$



$$L(\upsilon) = \frac{1}{2}\upsilon_2^2 + \frac{1}{2}\upsilon_{10}^2 - \frac{1}{2}\upsilon_5^2 - \frac{1}{2}\upsilon_9^2 = 0$$

$$L(\upsilon) = \left(\frac{\dot{m}_2}{\rho_2 A_2}\right)^2 + \left(\frac{\dot{m}_{10}}{\rho_{10} A_{10}}\right)^2 - \left(\frac{\dot{m}_5}{\rho_5 A_5}\right)^2 - \left(\frac{\dot{m}_9}{\rho_9 A_9}\right)^2 = 0$$

Kirchhoff's Second Law of Zonal Continuity

Boundary conditions:

$$\text{Solid:} \qquad \dot{m}_{bc} = 0$$

$$\text{Influx/Efflux:} \qquad \left.\frac{\partial \dot{m}}{\partial n}\right|_{bc} = 0$$

Mathematical requirements for ZNP:

- Number of interior connector mass flow rates=(Z-1) Zonal Continuity equations + 2*(Rows-2)*(Columns-2) Looped Energy equations
- Number of exterior (boundary) connector mass flow rates=2*Rows*Columns
- Number of zonal mass flow rates=Z source term equations (*a priori* or from Secondary Zonal Platform; i.e., CFD/Navier-Stokes)

Secondary Zonal Network Platform - Navier Stokes/CFD:

- Once all connector mass flow rates, both interior and exterior, are solved by the Primary ZNP, the zonal (interior) velocity components can be post process by Navier-Stokes Equations
- Energy equation, in conjunction with Ideal Gas Law, is used to calculate the temperature profile

Linkage between Primary and Secondary ZNPs as a zonal (interior) mass flow rate source term in terms of zonal density:

$$\dot{m}_i = \frac{\Delta\rho_i}{\Delta t}\Delta V_i$$

Optional CFD features inside the Secondary ZNP:

- Inviscid or Euler (Nonlinear Burger) flow
- Laminar or viscous flow
- Turbulent flow: k-ε; LES; DNS
- Thermal radiation: isotropic/anisotropic spectral/gray participating media - emitting; scattering; and absorbing with gray-diffuse, specularly, or black boundaries
- Mass transfer or species equations

"Seamless" ZNP-CFD Strategy:

- In the near field where the engineering gradients are stiff, pack with dense zones to capture the detailed engineering information
- In the middle and far fields where the gradients are mild or monotonously converging, sparse zones are utilized to minimize computing costs
- "Toggle-switch" CFD features for simulation requirements to save cost and provide better clarity of numerical solutions

Applications of ZNP-CFD:

- Although the illustrative example in the paper is simple, ZNP-CFD can be naturally extended to highly irregular geometries or packed CFD features, or both
- Highly adaptable for Finite Element methods
- ZNP-CFD can be applied to Low Speed (Mach number) Thermally Driven Flows; Deflagration;Toxicological-Explosive-Nuclear dispersion, both indoor and outdoor

Conclusions:

- ZNP-CFD is not only innovative but also potentially versatile, powerful and economical
- It strategically circumvents CFD numerical difficulties while tremendously minimizing its running costs
- It is a single platform without complicated conventional zonal-CFD interfaces
- It is easily adaptable for parallel processing