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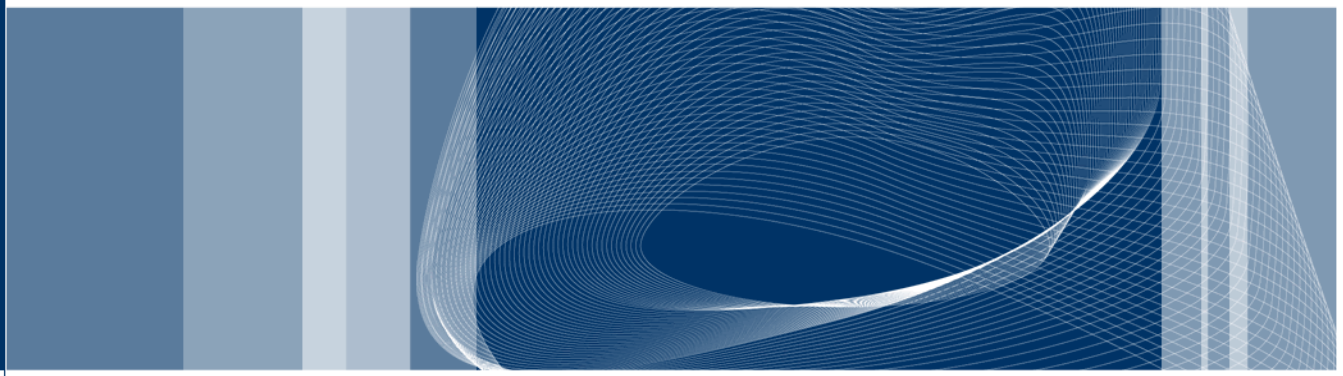
PSAM 9 International Probabilistic Safety Assessment and Management Conference
An IAPSAM Conference

18-23 May 2008 – Hong Kong, CHINA



Future Challenges in Plant Safety: beyond the OTS paradigm

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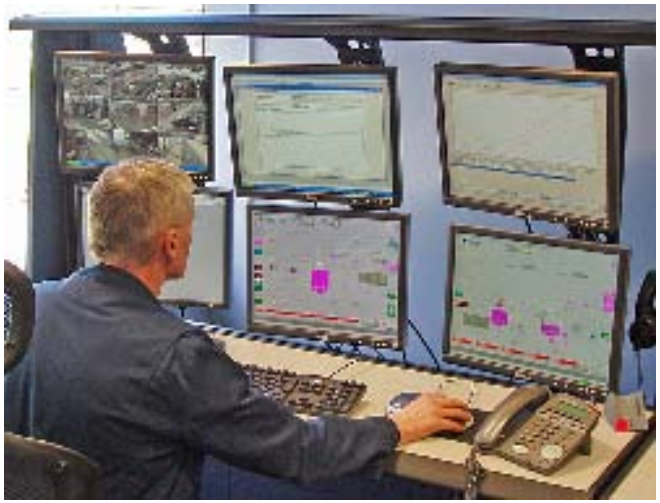
Presentation outline

- **Dynamic Process Simulation**
- **Dynamic Accident Simulation**
- **The coupling**: Process and Accident Dynamic Simulation
- **Virtual Reality** (VR)
- **Augmented Reality** (AR)
- **Mixed Reality** (MR)
- **Discussion** and **Conclusions**

Dynamic Simulation

- **From steady-state process simulation…**
  - Design of industrial processes
  - Qualitative and Quantitative Risk Analysis
  - HAZOP, Event, and Fault Tree Analyses, ….



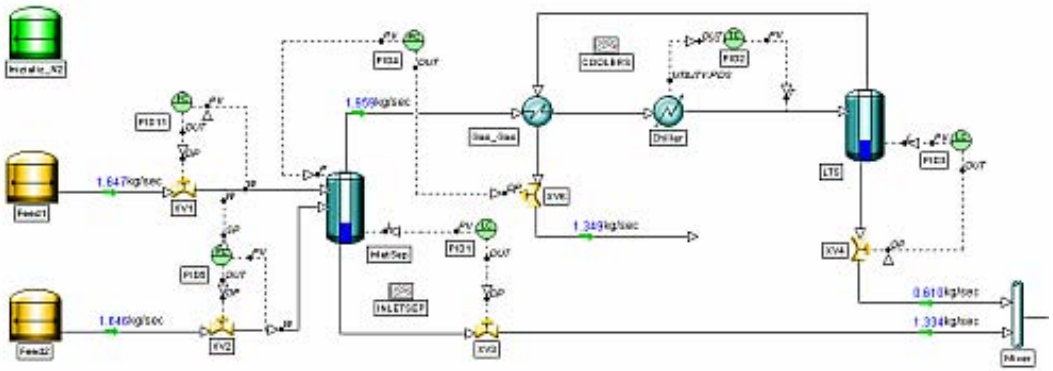
- **…to dynamic process simulation for:**
  - process understanding
  - process design
  - a priori inspection of control loop alternatives
  - effectiveness of start-up and shutdown procedures

- SimSci-Esscor (**Dynsim**)
- Honeywell (**HYSYS**)
- Aspentech (**Aspen HYSYS**)
- PSE (**gPROMS**)
- CreateaSoft (**Simcad**)
- …

Dynamic Simulation features

- **Rather high cost** for the annual license of the DS
- Rather **high number of hours** of a team of specialized engineers
- **Reduced set** of operating conditions

- A DS study is **usually commissioned by the plant buyer to**:
  - understand and assess the design quality
  - verify a priori the control structure and performance respect to external disturbances
  - analyze the process behavior under nominal and off-spec operating conditions



Operator Training Simulation

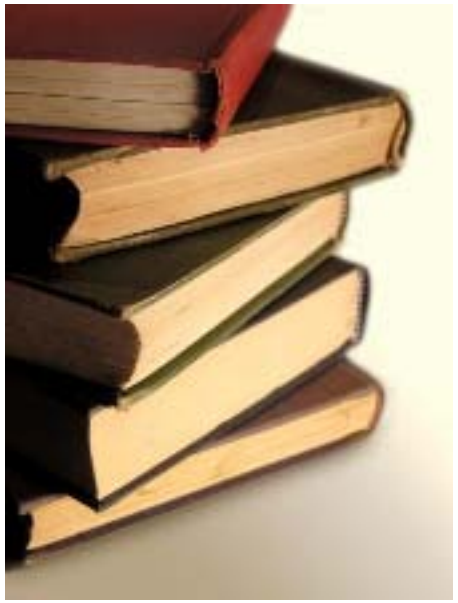
- **Conventional Operator Training Simulation**
- From the design realm to the **on-line** process control domain

- The main reason for OTS is **training from scratch the operators**
- Training of specialized manpower
- Usually **focused on control-room operator** training

- Important for simulating both rare and unconventional events:
  - off-spec conditions
  - grade changes
  - start-up and shutdown procedures
    - planned shutdown
    - emergency shutdown

Operator Training Simulation

- **Need for field operator training**
  - conventional OTS are not so good at training field operators
  - **Conventional OTSs are not capable of simulating accidental events**
  - Need for a dynamic process simulation of industrial accidental events
  - **Coupling of Dynamic Process and Accident Simulation**

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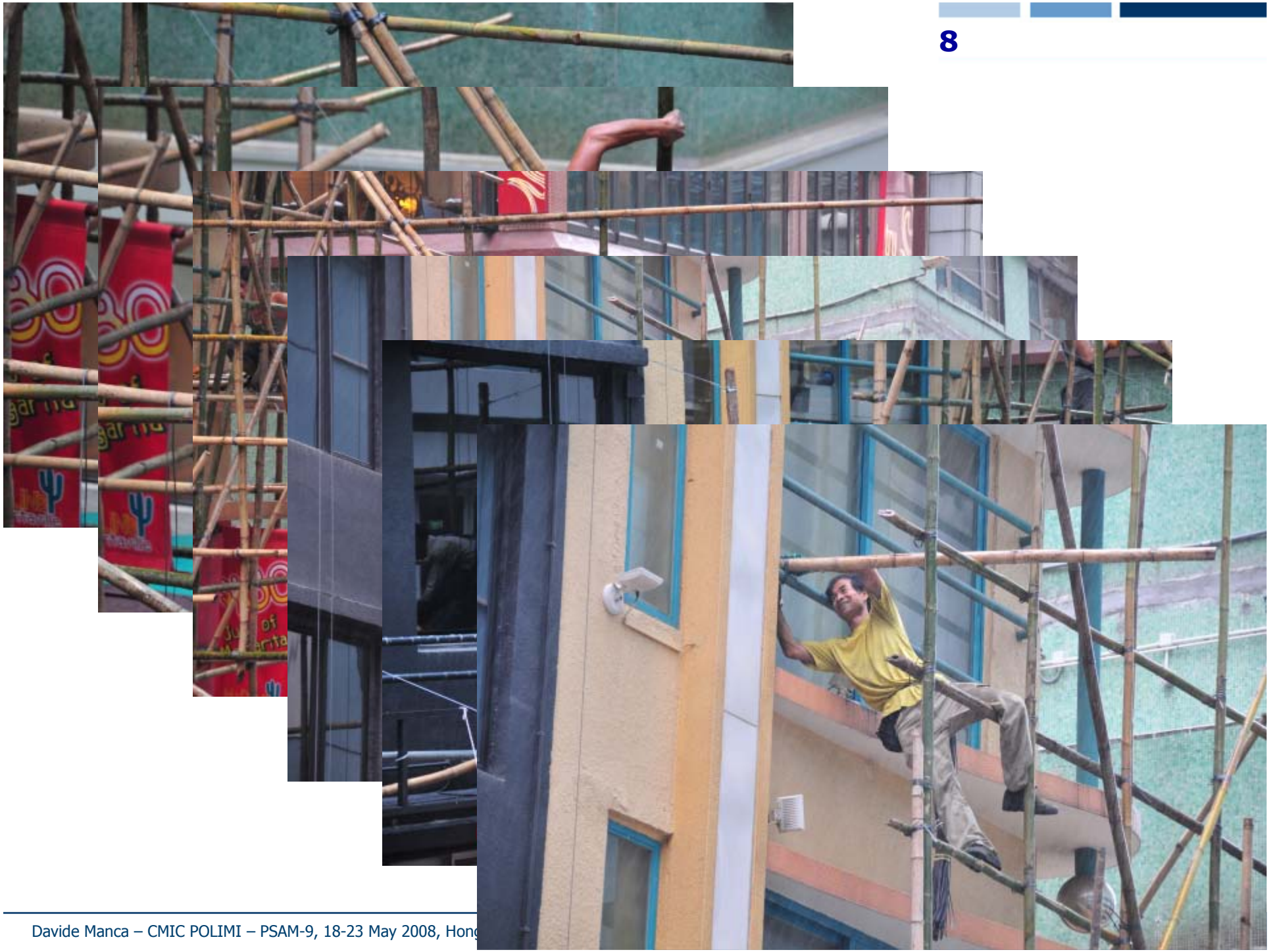
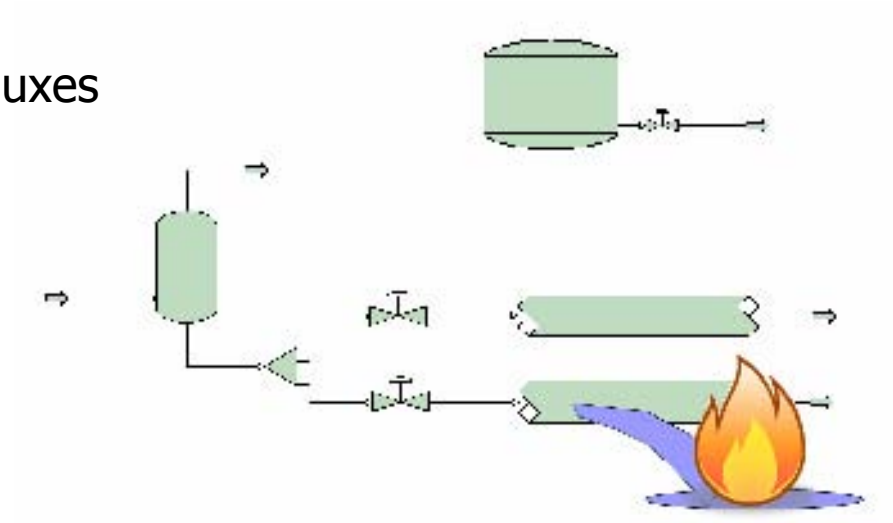


Operator Training Simulation

- **Dynamic Accident Simulation**
  - Emission of liquid, gas and liquid/gas streams
  - Pool spreading and shrinking on soil and water
  - Pool boiling and evaporation
  - Ignition of the pool and pool fire
  - Jet stream and jet fire
  - Fireball, Unconfined Vapor Cloud Explosion, …
  - View factors between the fire and the surrounding process units
  - Quantification of radiative heat fluxes towards the nearby units
  - Dispersion of dense gases in complex environments
  - …



The coupling

Dynamic Process Simulator

$$\dot{m}_L(t_n), \dot{m}_V(t_n), T(t_n)$$

$$Q_{irr}(t_n), \tilde{c}_i(t_n)$$

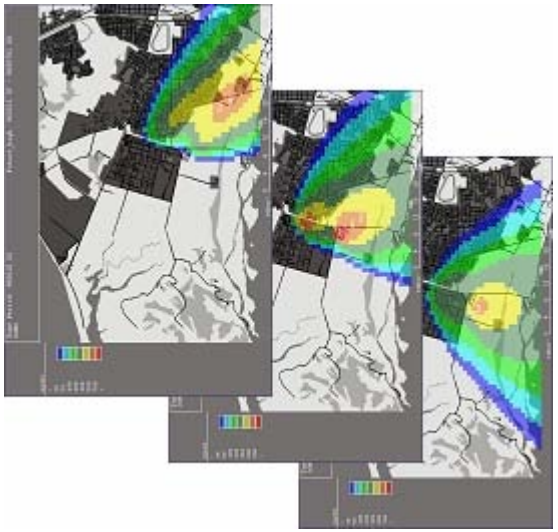
Accident Simulator

DYNAMIC SIMULATION

Process and Accident OTS

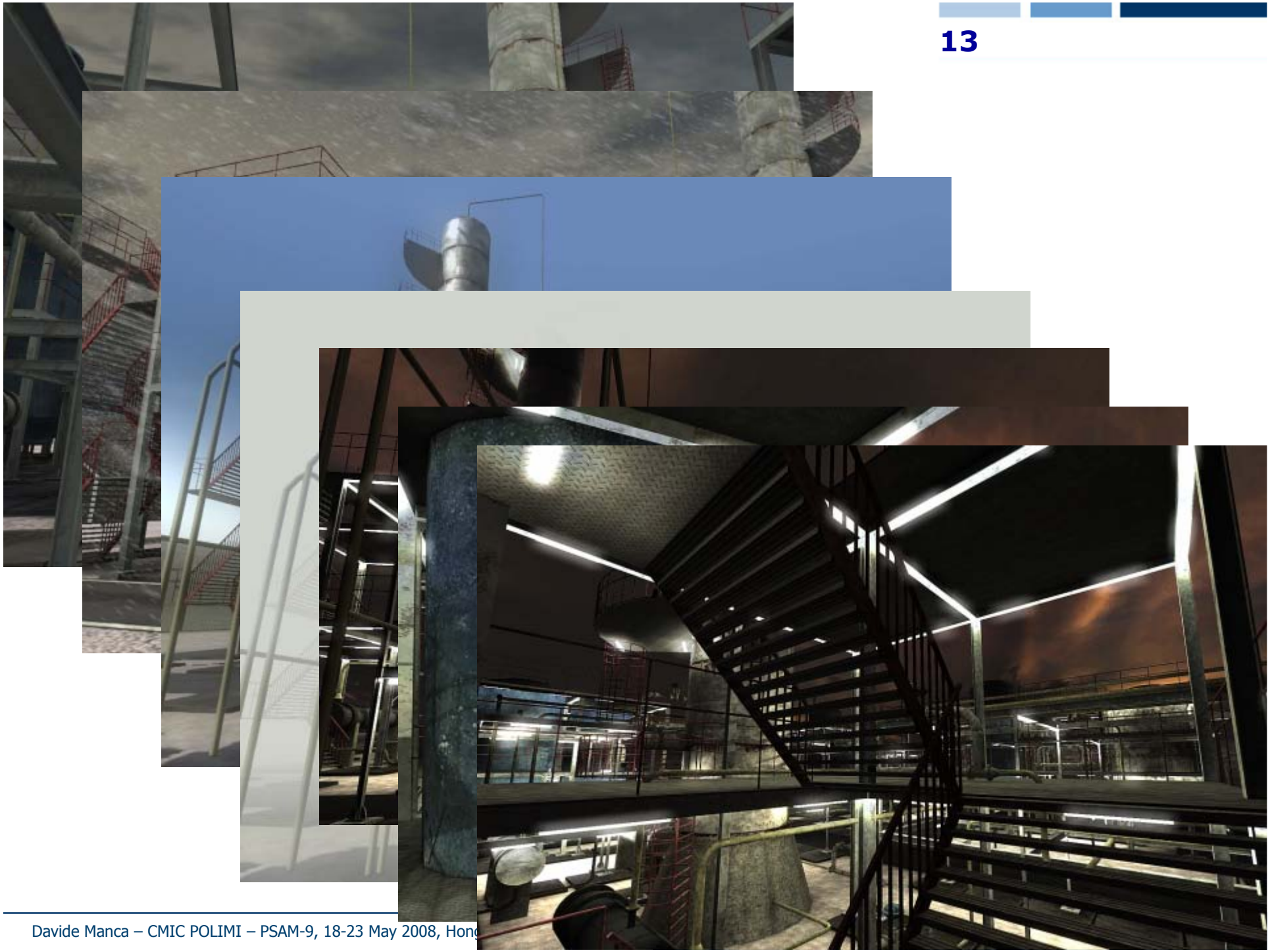
- **Benefits** of coupling Process and Accident dynamic simulators:
  - improvement of the operator knowledge
  - **analysis of very rare accidental events**
  - understanding of **process behavior under emergency**
  - quantitative evaluation of accidental outcomes
  - **slow-motion** and **fast-motion** analysis of accidental events
  - recording and playback of operator actions
  - **performance evaluation of operator actions**

- **Outcomes**
  - Quantification and visualization of iso-radiative flux curves
  - Quantification and visualization of iso-concentration curves
  - Evaluation of the toxic dose absorbed in a point of the plant
  - …



Virtual Reality

- A **virtual reality** environment based on the real structure of the plant allows **increasing the immersivity** of the software:
  - full 3D visualization and rendering of the plant
  - immersive participation to:
    - **meteorological conditions**: wind, sun, light, night, fog, …
    - **stereophonic sounds** of process units
    - equipment materials and ground features
    - **High detail** of secondary equipment and plant features:
      - Valves, pumps, pipe rack, structures, …



Virtual Reality

- The **operator wears stereoscopic goggles** and walks in the 3D representation of the real plant
- The operator can **experience events and concepts** that a conventional OTS is not capable of simulating and rendering

Augmented Reality

Virtual Reality substitutes the real world,
Augmented Reality supplements it
(*Stedmon & Stone, 2001*)

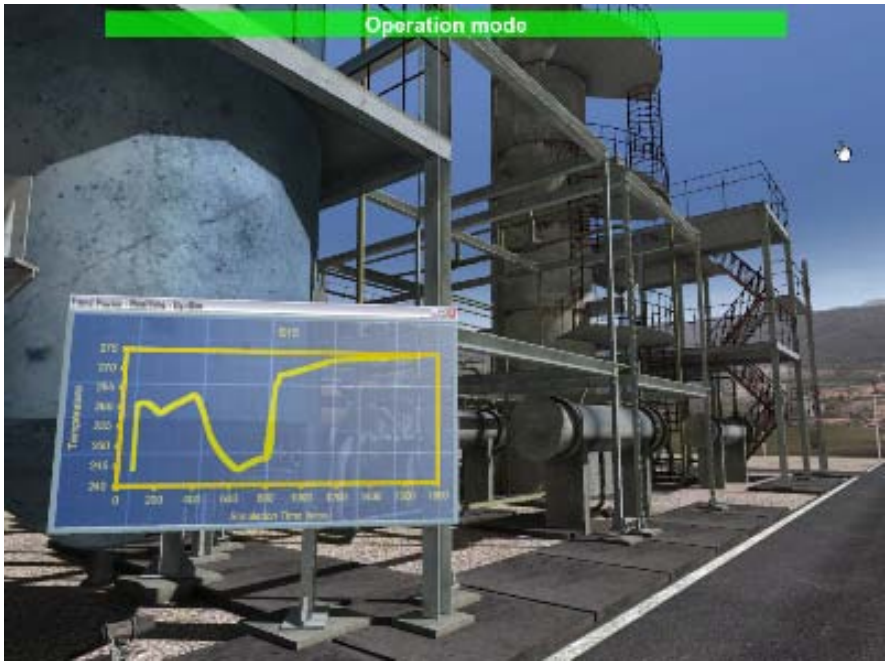
- A step further in the training of field operators is the adding to the 3D representation of the plant some **additional information that is neither visible nor available in the real world**.
- The dynamic process and accident simulator allows visualizing:
  - names of process units, valves, pipes, …
  - level, temperature, pressure and concentration of process units
  - flowrates in the pipes
  - radiative heat fluxes from fires
  - concentration of released toxic substances

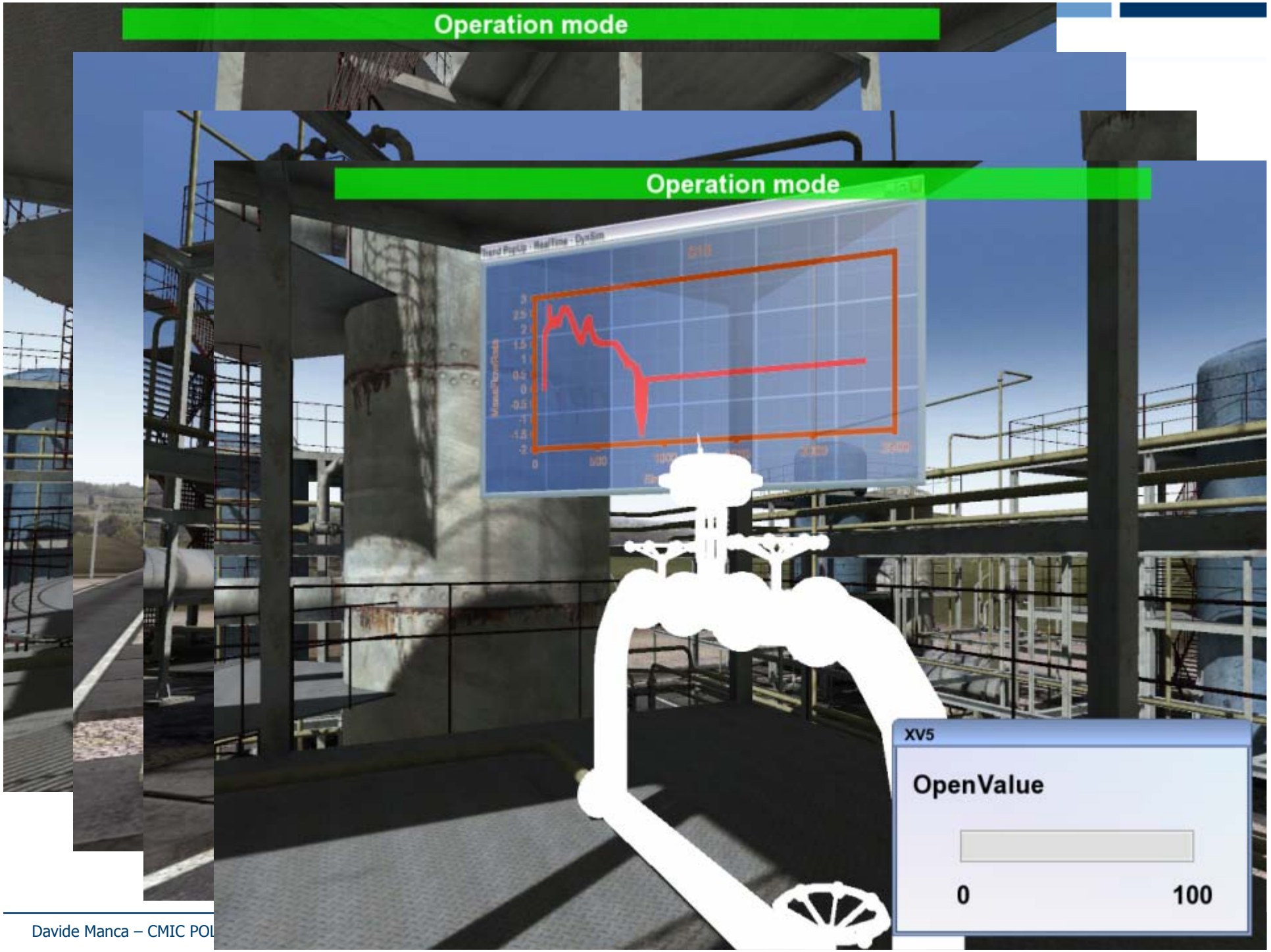
Augmented Reality

- The **trainer** can activate or deactivate these data and test the efficiency of the **trainee** in:
  - **responding to an alarm**
  - **disentangling with respect to a toxic cloud**

Augmented Reality

- With reference to an accidental event it is possible to **visualize**:
  - a **toxic gas** cloud in terms of false-colors while it moves inside the plant
  - the **isoconcentration curves** produced by a toxic release
  - the **isoradiation curves** produced by a pool fire, jet fire, or fireball
  - a diagram with the **alarm thresholds**
  - these events may be played in slow motion to increase the operator understanding of the phenomenon

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Augmented Reality

- By tracking the operator path across the plant it is possible to evaluate the **cumulative dose breathed** and **measure his/her stamina**.
- According to several authors, the simulated interaction between men and machines is of paramount importance for risk prevention and risk assessment

- **Advantages**
  - **reduced learning costs**
  - reduced equipment procurement and maintenance
  - **increased transfer of training and knowledge**
  - **just-in-time operator training**

Mixed Reality

- Ingredients of mixed reality are:
  - **process dynamic and accident simulator**
  - **virtual reality environment**
  - only **some physical units or process devices**
    - valves
    - switches
    - pipe rack
    - stairs

- The field operator wears 3D immersive goggles and walks through the virtual reality plant, finds some real pieces of equipment, and experiences:
  - the **effort of wearing a breathing mask and a protective overalls**
  - the **effort of going upstairs**
  - the **effort of opening an encrusted or clamped valve**
  - how a **real valve stem** is hard to **open** or **close** and the **time taken** for this operation

Mixed Reality

- **Advantages**
  - **increased immersivity** respect to VR and AR
  - stimulation of the operator **kinesthetic sense**
  - **feed back of the forces** that physically work on the operator body
  - increased likelihood of the time and effort spent by the operator to perform an action

Discussion and Conclusions

- The proposed DS, VR, AR, MR tools allow addressing and **reducing**:
  - **Stress**
  - **Lack of coordination**
  - **Inadequate training**
  - **Deviations from safety procedures**

- **Safety management**
  - evaluate impact of new procedures
  - estimate safety-related costs

- **Accident investigation**
  - mix of DS, VR, AR, MR
  - "what-if" approach to discover possible causes

Discussion and Conclusions

- **Risk assessment**
  - identify hazards in the plant
  - spot potential problems in the procedures

- **Training activities**
  - integrated training and team-work
  - assessment of training results
  - customized training scenarios