
# A Short History of Open PSA

Woody Epstein
ABS Consulting
woody@woody.com
SKYPE woodyep

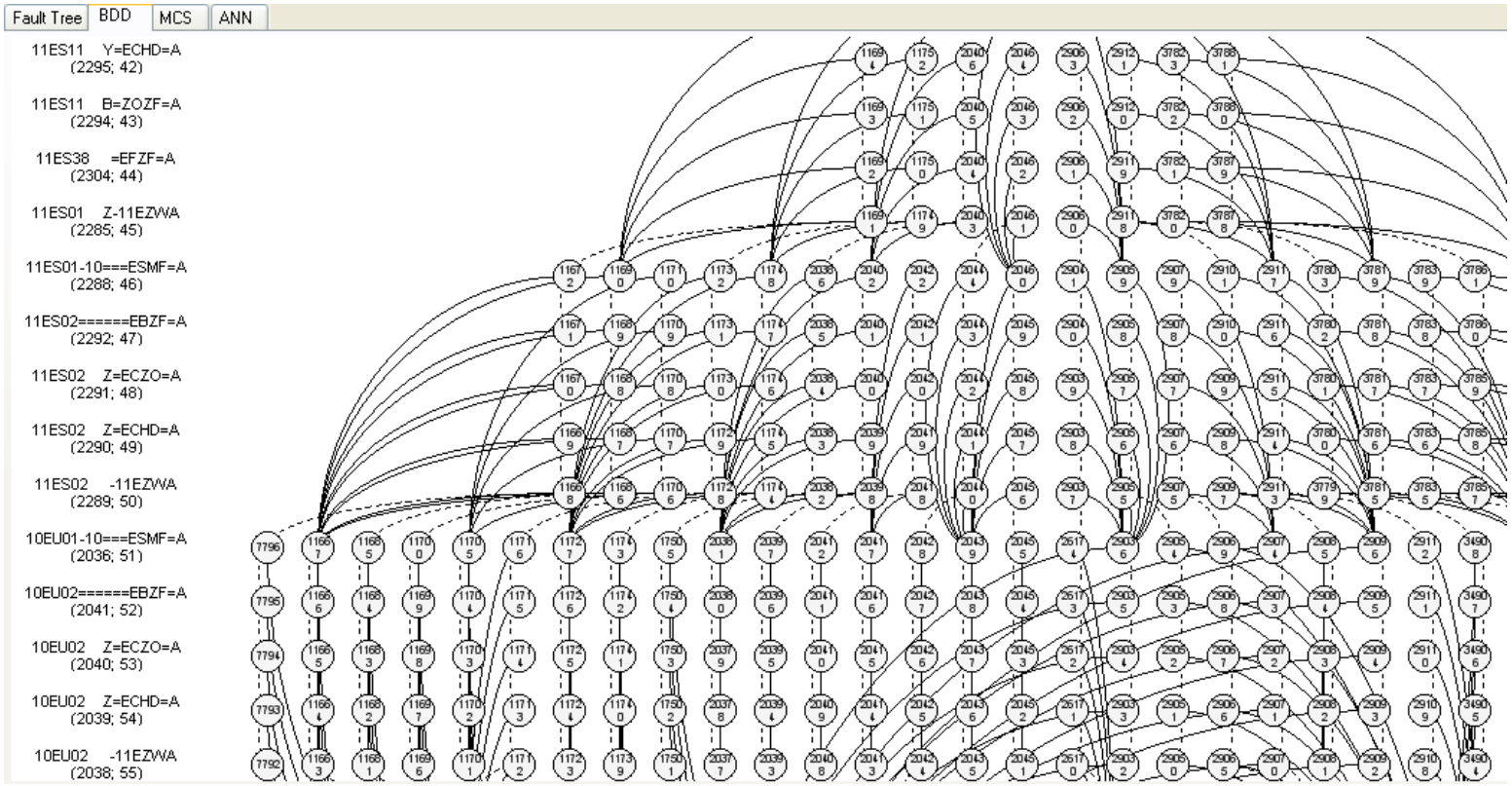
It was in Osaka, eight years ago, on the first evening of the late autumn rains. After a hard day at PSAM 6, my head ached.

I sat in a small yakatori joint in Kita Shinchi, nursing a sake, when a guy wandered in and ordered a shochu straight up. From the look of his shoes, I knew he was French. I soon found out that we had more in common than just Japanese booze and chopsticks.

# La BDD

## Binary Decision Diagrams

- La BDD complexity, she is not related to the number of prime implicants of the encoded formula
- Zee petite BDD here, she encodes a total of $10^9$ cutsets

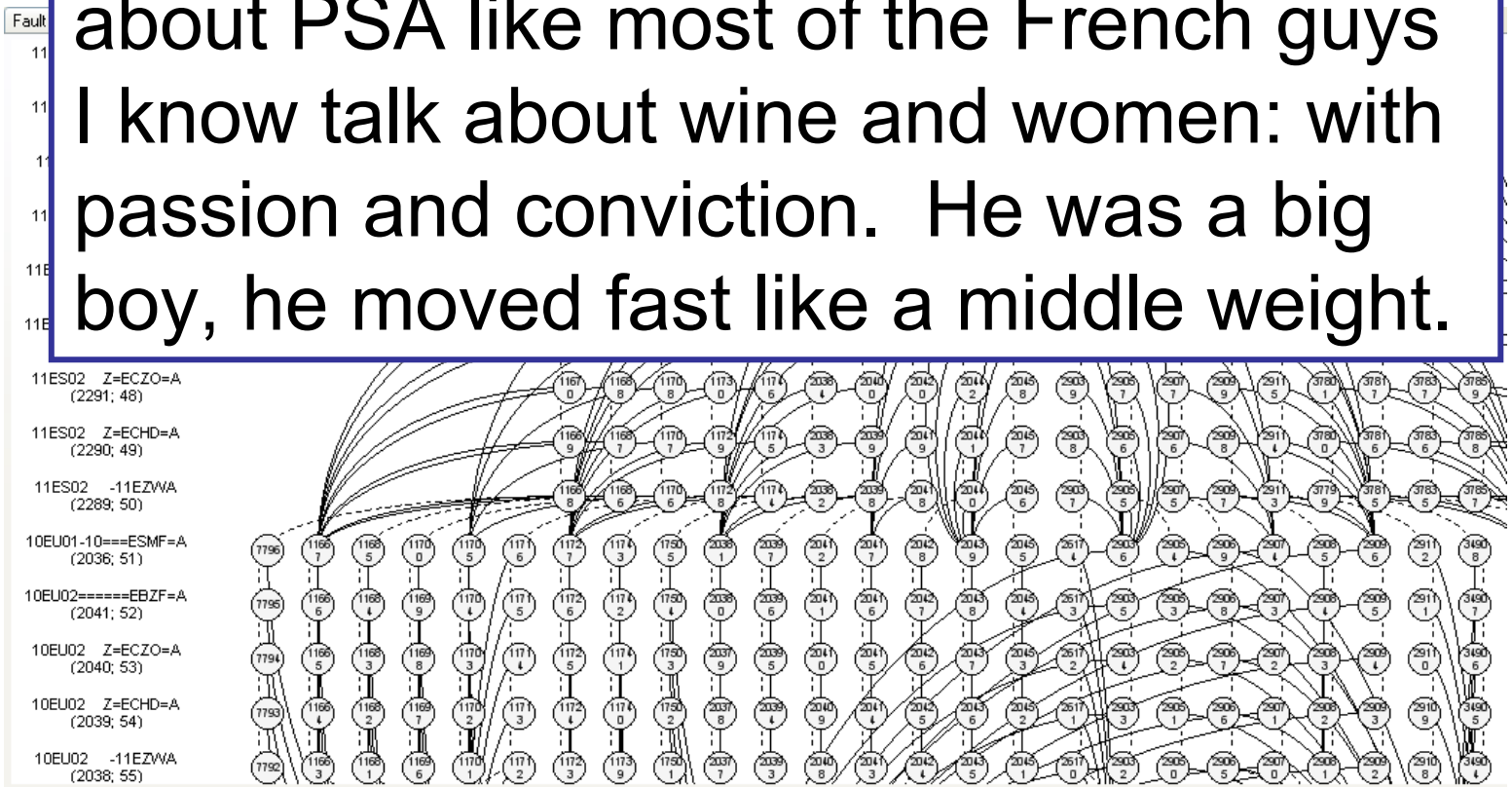


# La BDD

## Binary Decision Diagrams

- La BDD complexity, she is not related to the number of prime implicants of the encoded formula
- Ze
cut

He called him self Rauzy and he talked about PSA like most of the French guys I know talk about wine and women: with passion and conviction.  He was a big boy, he moved fast like a middle weight.

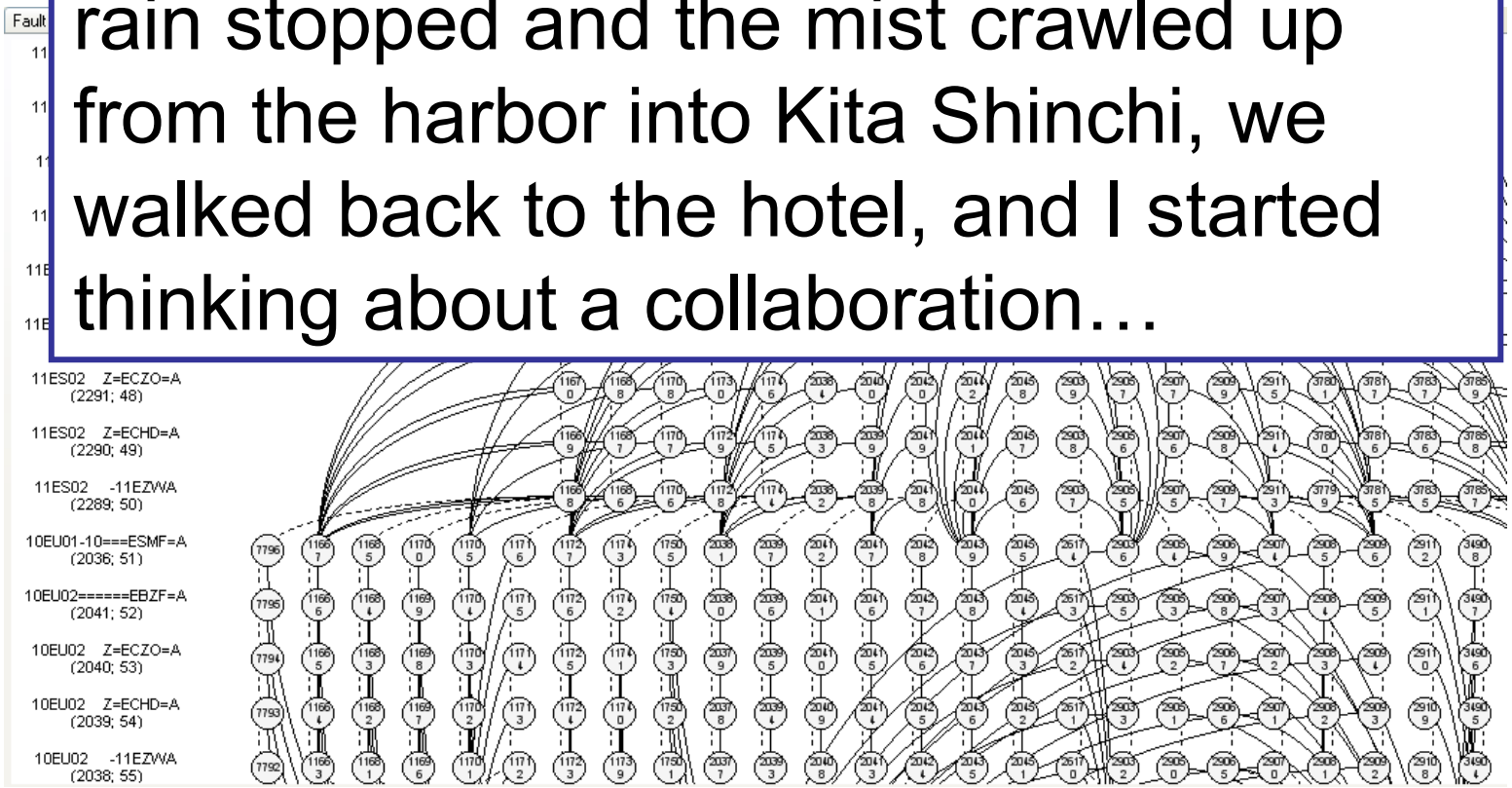


# La BDD

## Binary Decision Diagrams

- La BDD complexity, she is not related to the number of prime implicants of the encoded formula
- Ze
cut

We talked late into the night. And as the rain stopped and the mist crawled up from the harbor into Kita Shinchi, we walked back to the hotel, and I started thinking about a collaboration…



# La BDD

## Binary Decision Diagrams

- La BDD complexity, she is not related to the number of prime implicants of the encoded formula
- Zee
cuts

We talked l And as the rain stoppe wled from the harbor hi, we walked bac I started thinking ab a bit on the road …

We began working together all over the world. Other PSA professionals joined us for new, interesting, and challenging projects. But our interests took an unexpected turn when we saw important issues which needed to be addressed:

- Quality assurance by comparison;
- Peer review of algorithms;
- Portability of the models between different software;
- Clarity of the models;
- Correct uncertainty and importance calculations;
- A universal format for industry data.
- Assurance of model completeness as quantified;
- Overuse of classical tools;
- Inadequate models of human/organization/machine interactions;
- Difficulty of explaining risk in financial (not technical) terms;
- Formal verification of calculation methods;

# So we banded together to do something about the situation.

# Workshop Announcement

## Next Generation PSA Software, Declarative Modeling, and Model Representation Standards

June 12th, 2007

Kernkraftwerk Gösgen-Daeniken, Switzerland

**Call for Participation:** To meet and discuss efforts, visions, and future needs with regards to software, PSA analysts, and model representations in large, safety critical PSA. All attendees are encouraged to present ideas, work-in-progress, research, and production systems, especially in the following areas:

- Quantification Methods;
- User Interfaces;
- Declarative Modeling;
- Standard Model Representations;
- PSA Visualization;
- PSA Software Architectures;
- New Algorithms;
- Modeling Styles and their Effects on Clarity and Quantification;
- PSA Software Verification, Benchmarks, and Quality Assurance.

**How to Participate:** Please fill out the attached form and eMail to Steve Epstein at sepstein@absconsulting.com as soon as possible. Please put the word "Workshop" in the subject line. We will make every effort to make time for anyone who wants to talk, make a presentation, or make a demonstration. We would like to make this an open forum for the exchange of ideas.

**Organizers:** This workshop is organized by ABS Consulting, ARBoost Technologies, and hosted by Kernkraftwerk Gösgen. Please do not hesitate to contact any of the following members of the organizing committee if you have any questions:


| | |
|---|---|
| Steve Epstein | sepstein@absconsulting.com |
| Antoine Rauzy | Antoine.rauzy@arboost.com |
| Don Wakefield | dwakefield@absconsulting.com |


# We created the Open PSA Initiative

EdF
AREVA
KAERI
PSI
RelconScandpower
IAEA
Gesellschaft für Anlagen-und Reaktorsicherheit
AXPO/NOK
KKL
ABS Tokyo
ABS Irvine
ARBoost Technologies
Empresarios Agrupados
KKG
Swiss Federal Institute of Technology (ETH)
BKW FMB
UTT
RISA
Instituto de Investigacion Tecnologica.Universidad Comillas Madrid

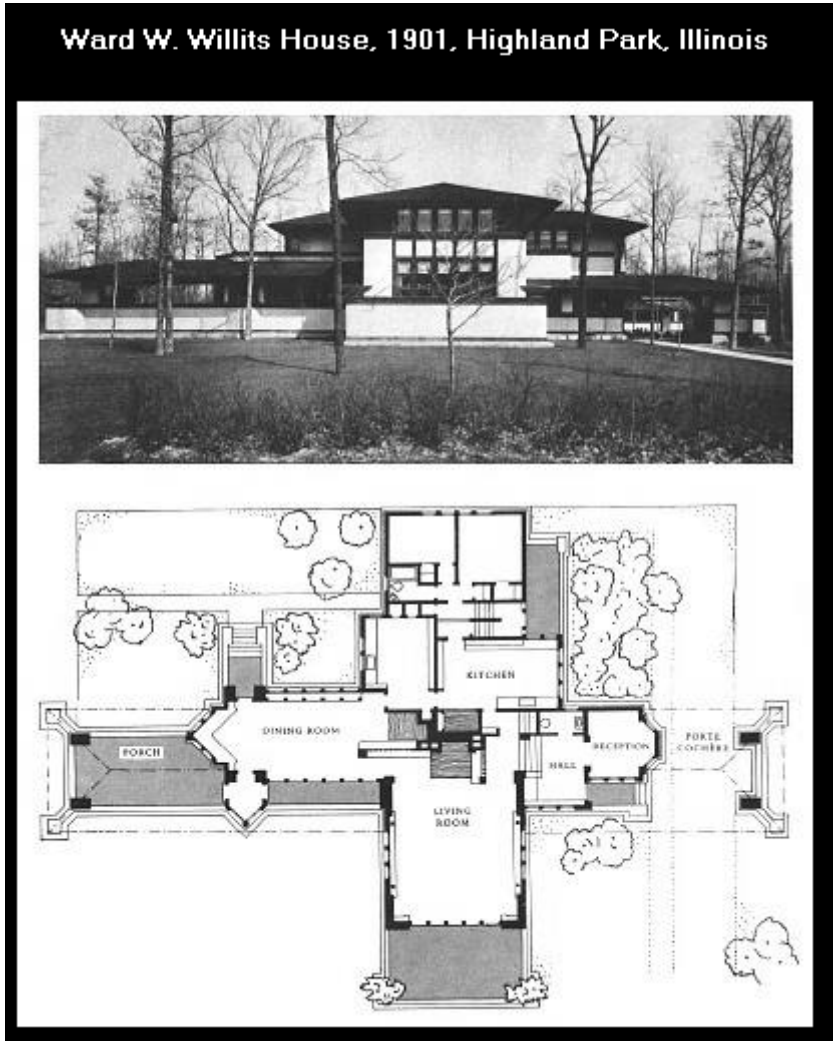

# We wrote a Statement of Purpose ...

"We hope to provide an open and transparent public forum to disseminate information, independently review new ideas, and spread the word. We want to emphasize an openness which will lead to methods and software with higher quality, lead to better understanding of PSA models, encourage peer review, and allow the transportability of models and methods." --- from www.open-psa.org

# and created a web site to share ideas

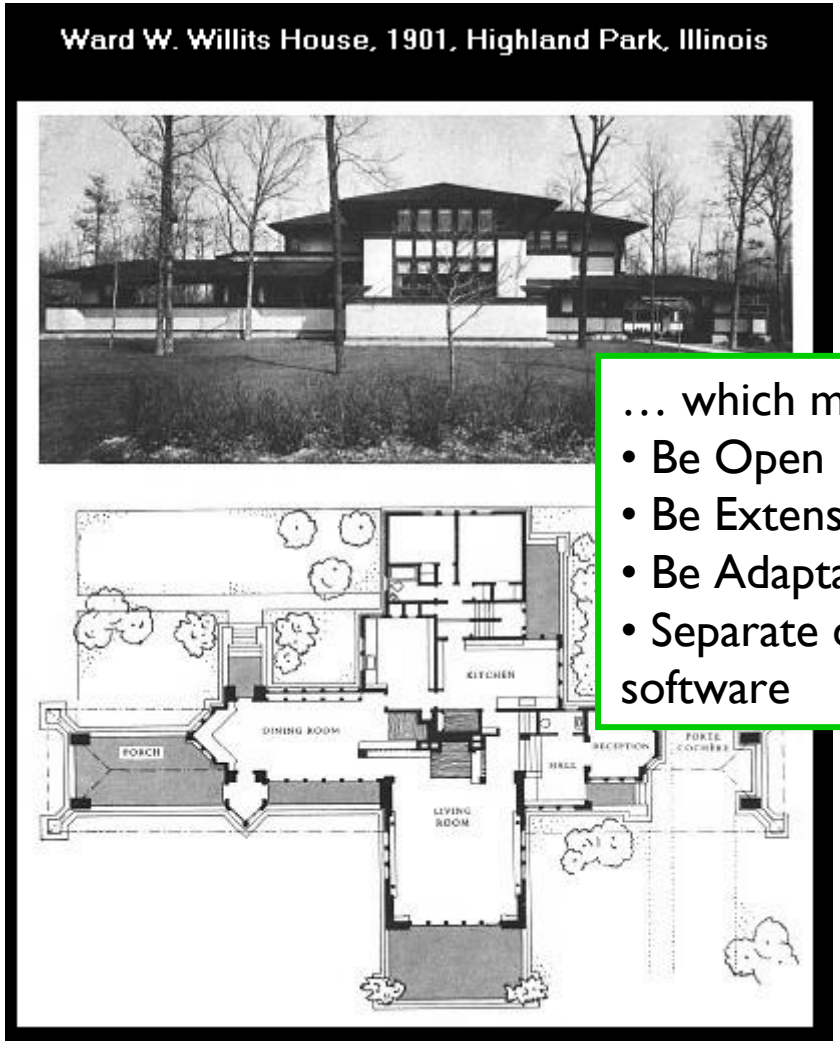
Then we made a decision as to what was important:

## A Standard PSA ARCHITECTURE



Then we made a decision as to what was important:

## A Standard PSA ARCHITECTURE

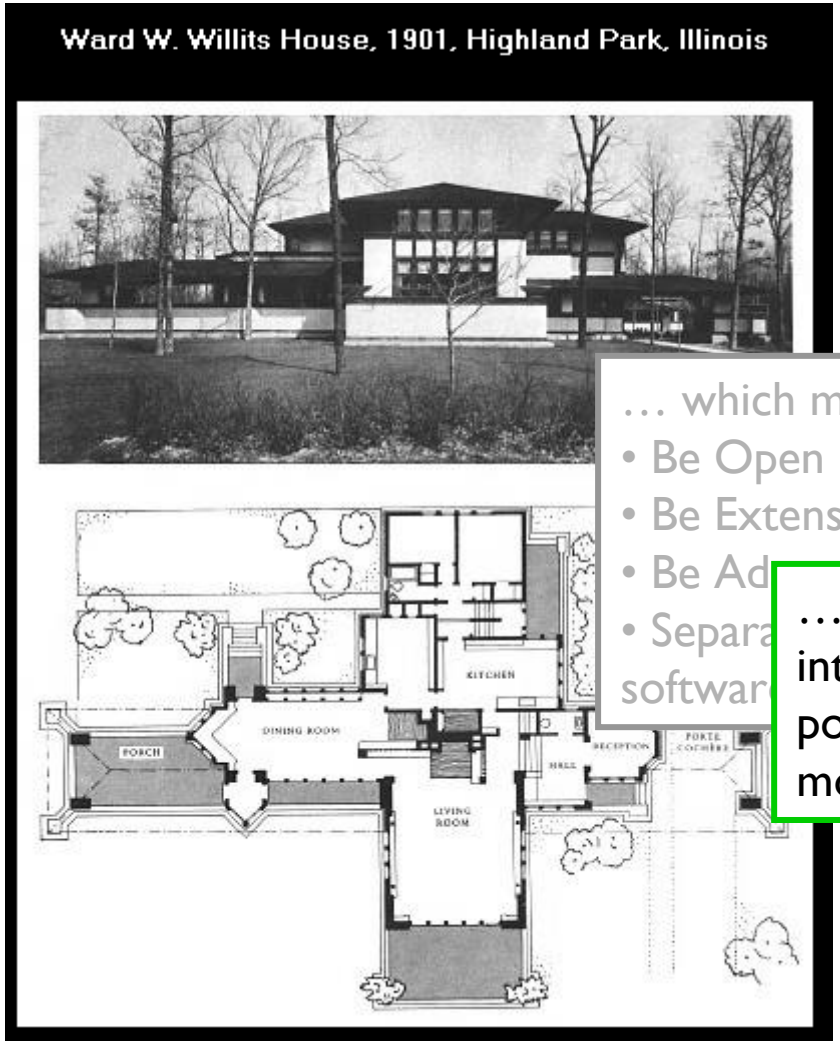



… which must:

- Be Open
- Be Extensible
- Be Adaptable
- Separate data and software

Then we made a decision as to what was important:

## A Standard PSA ARCHITECTURE




… which must:

- Be Open
- Be Extensible
- Be Ad
- Separa

softwar

… to allow the greatest inter-connectivity and portability between data, models and software.


# … and in this way, we can make progress against complexity.

- Model Size
  - Elements of Modeling Style
  - Declarative Modeling
- Problem Complexity
  - Modeler based heuristics
  - Structured Modeling

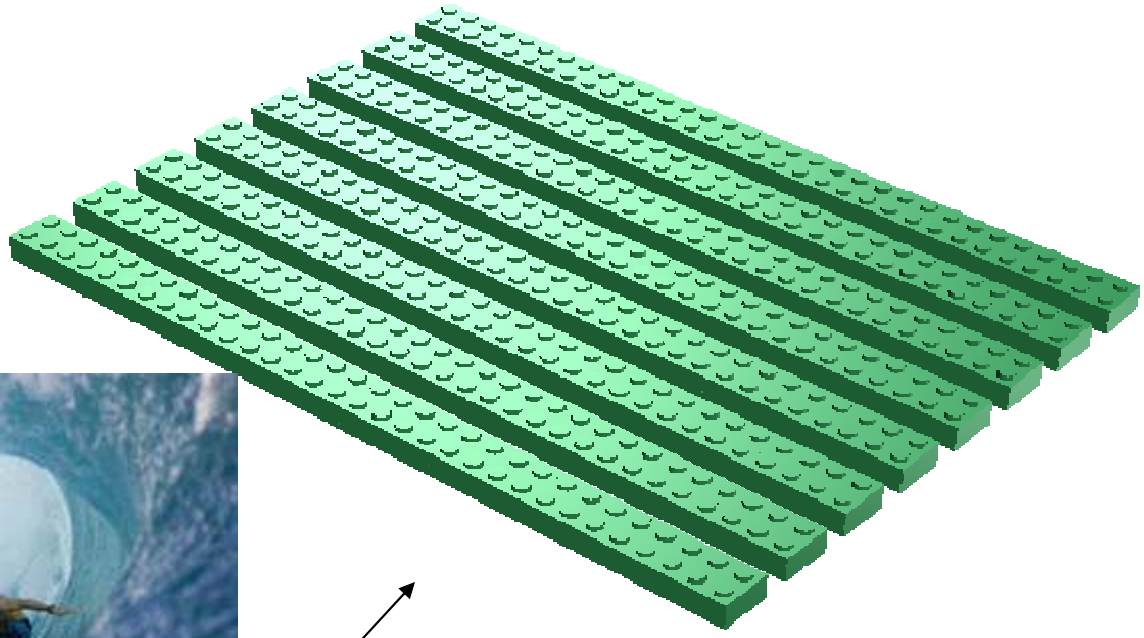
# Our Proposed PSA Software Architecture

- The foundation is a standard for representing a PSA model, therefore facilitating independence between model representations and software;
- Each risk application would generate a model in this standard from it's own internal representation;
- Viewers and calculation engines would interface with models via the standard representation.

**… but enough words, let's look at this like engineers ...**

# The LEGO Model of the PRA Architecture

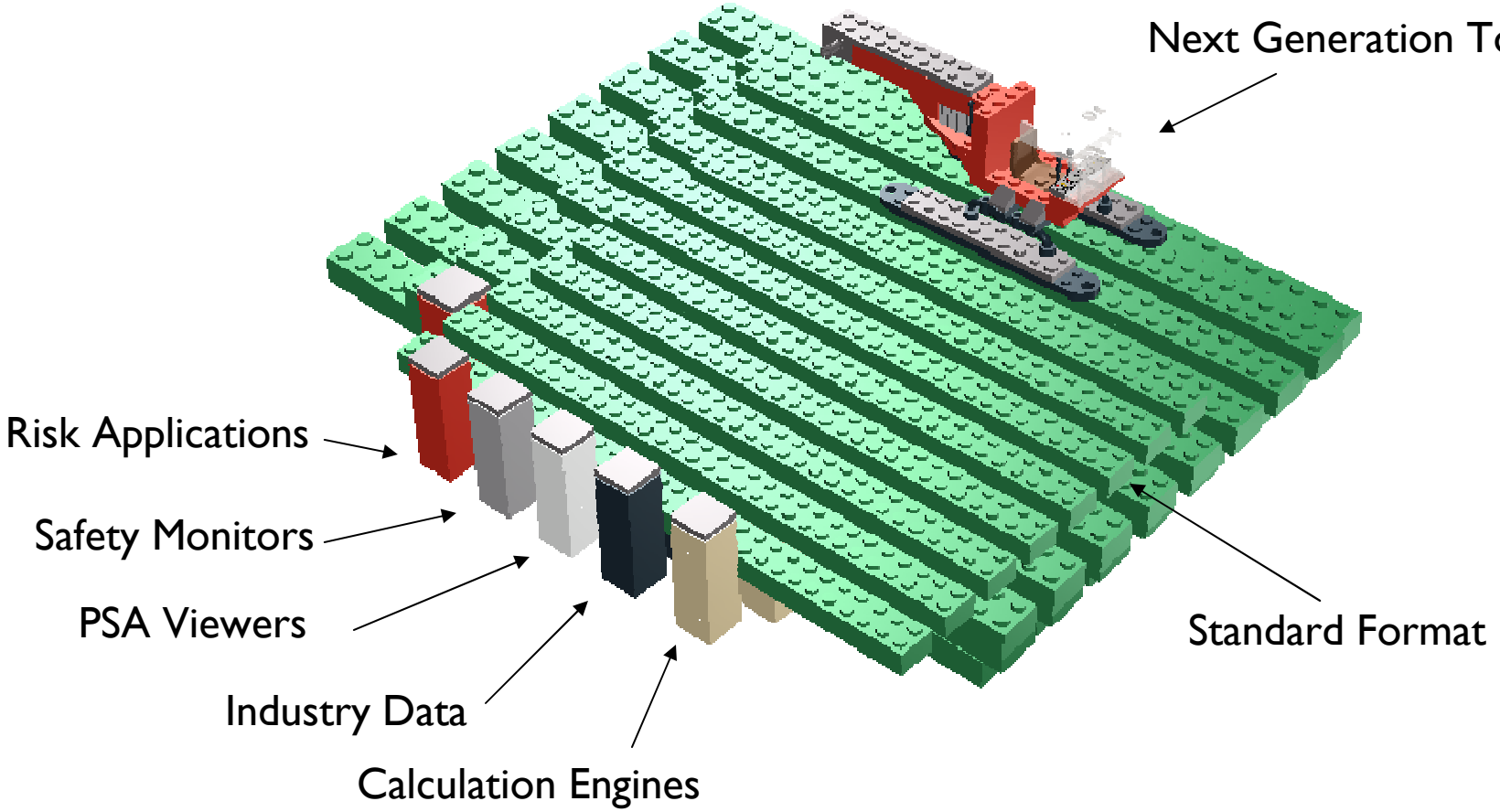
… first the foundation …



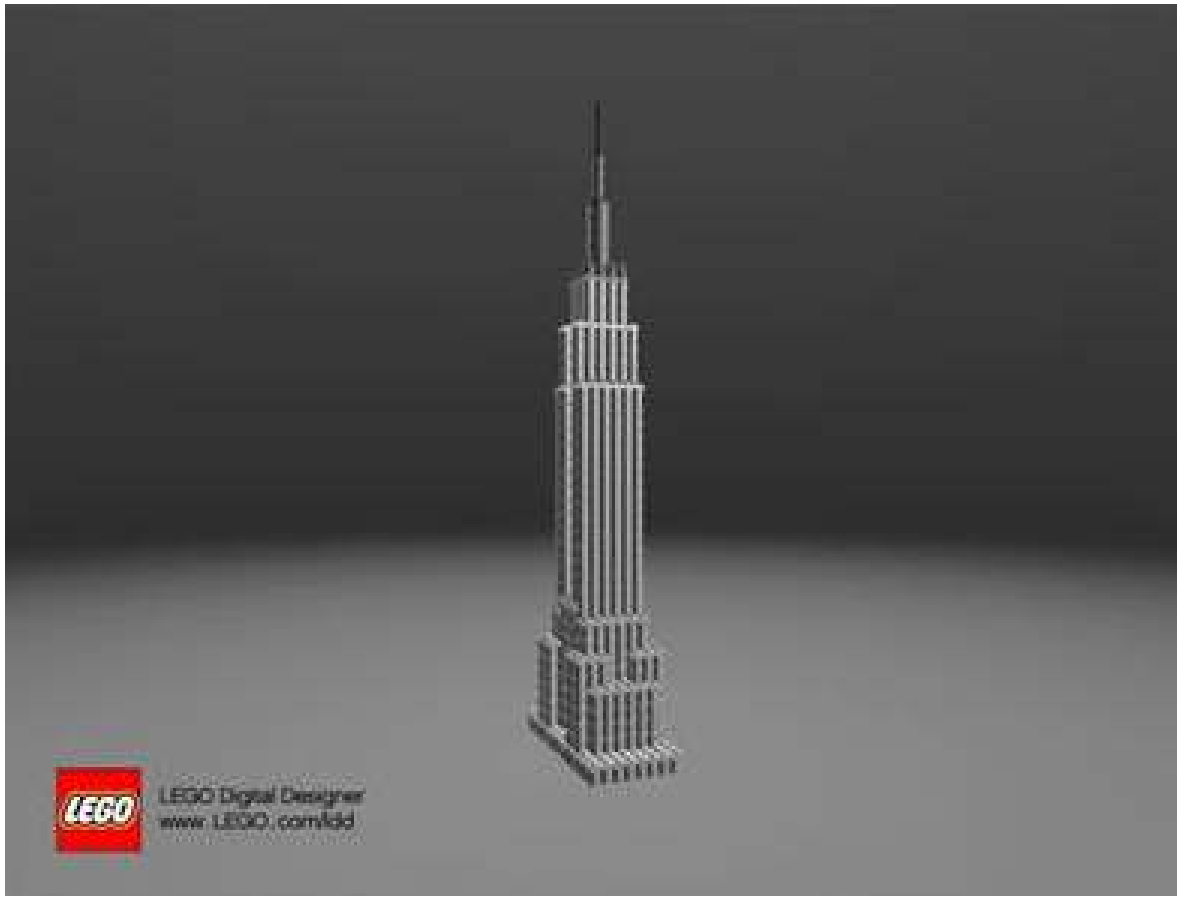
The Open PSA Model Exchange Format

catch the wave of the future

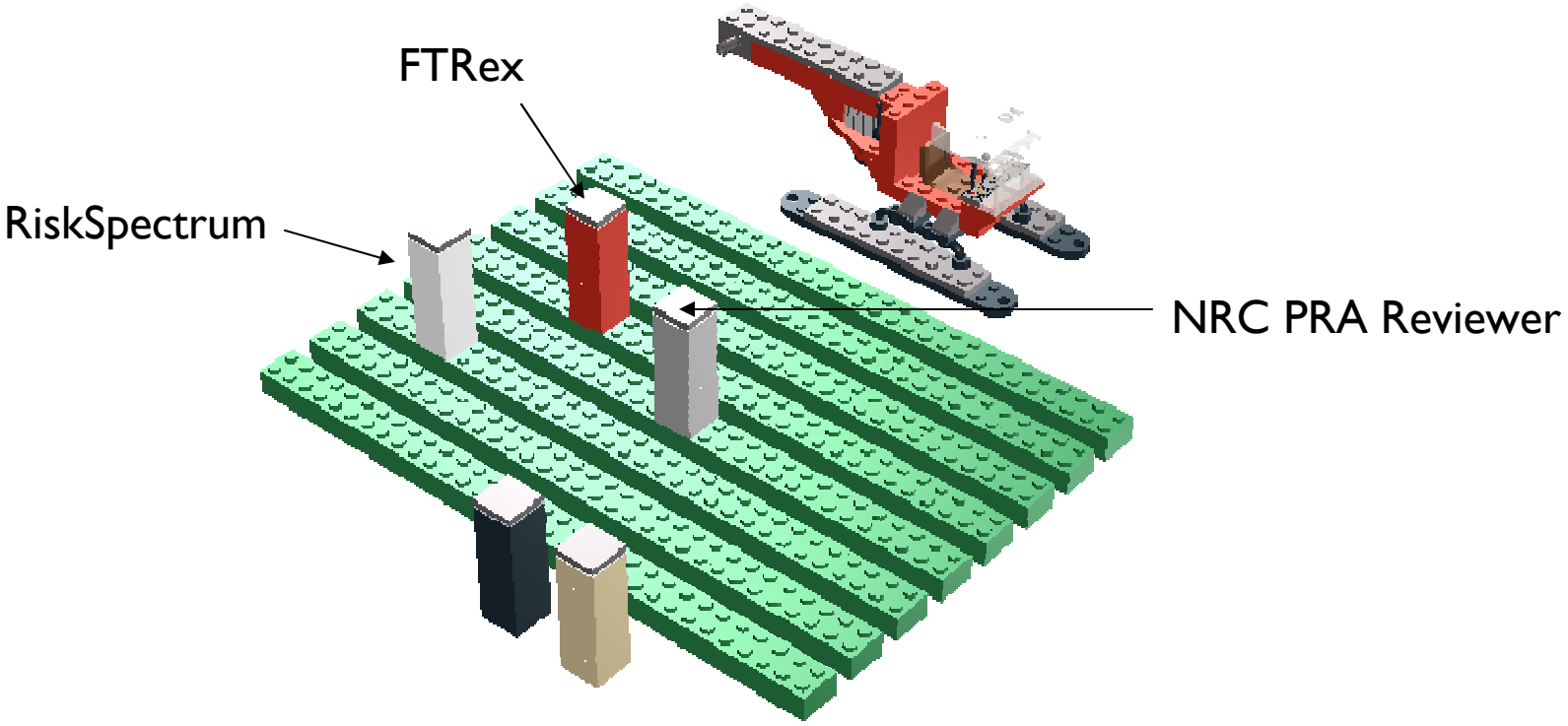
# … now assemble the risk applications and data …



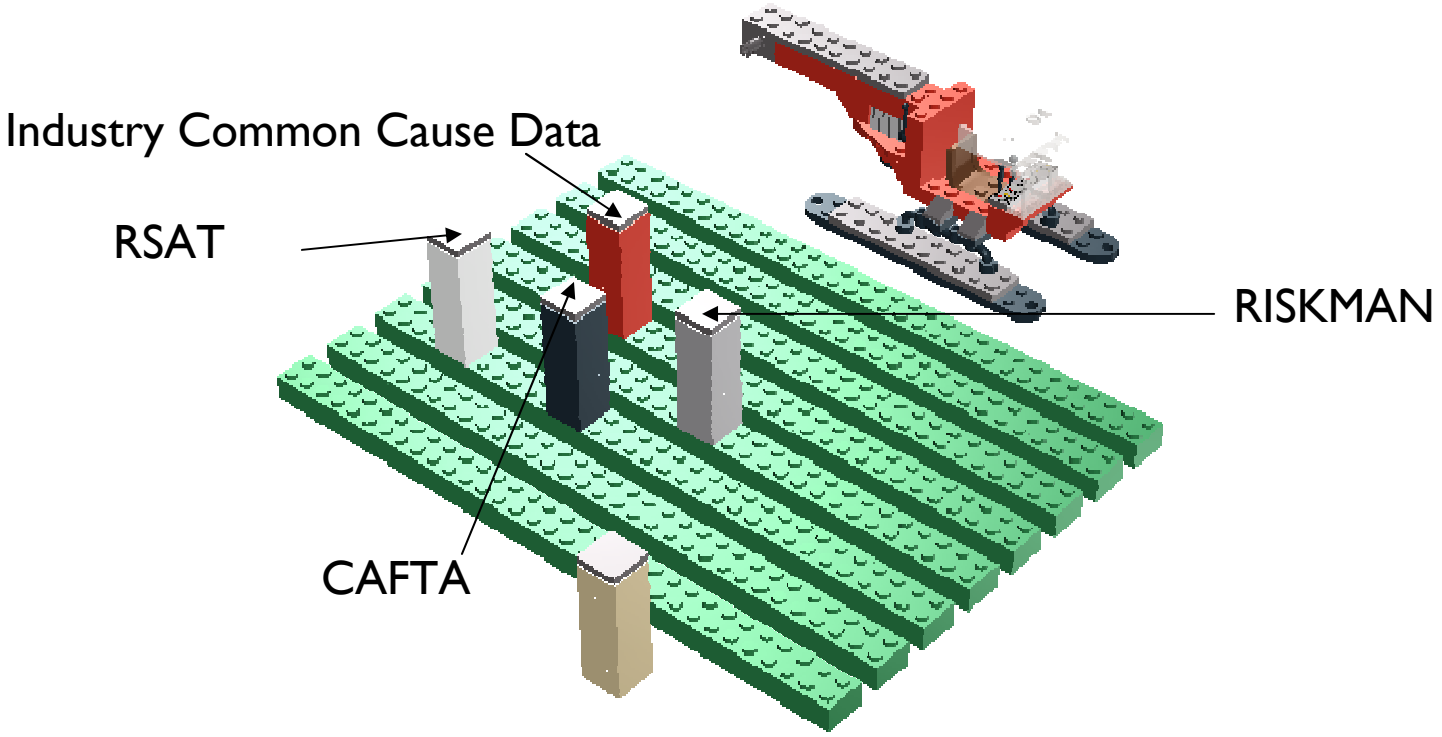
# … and then build upon the foundation …



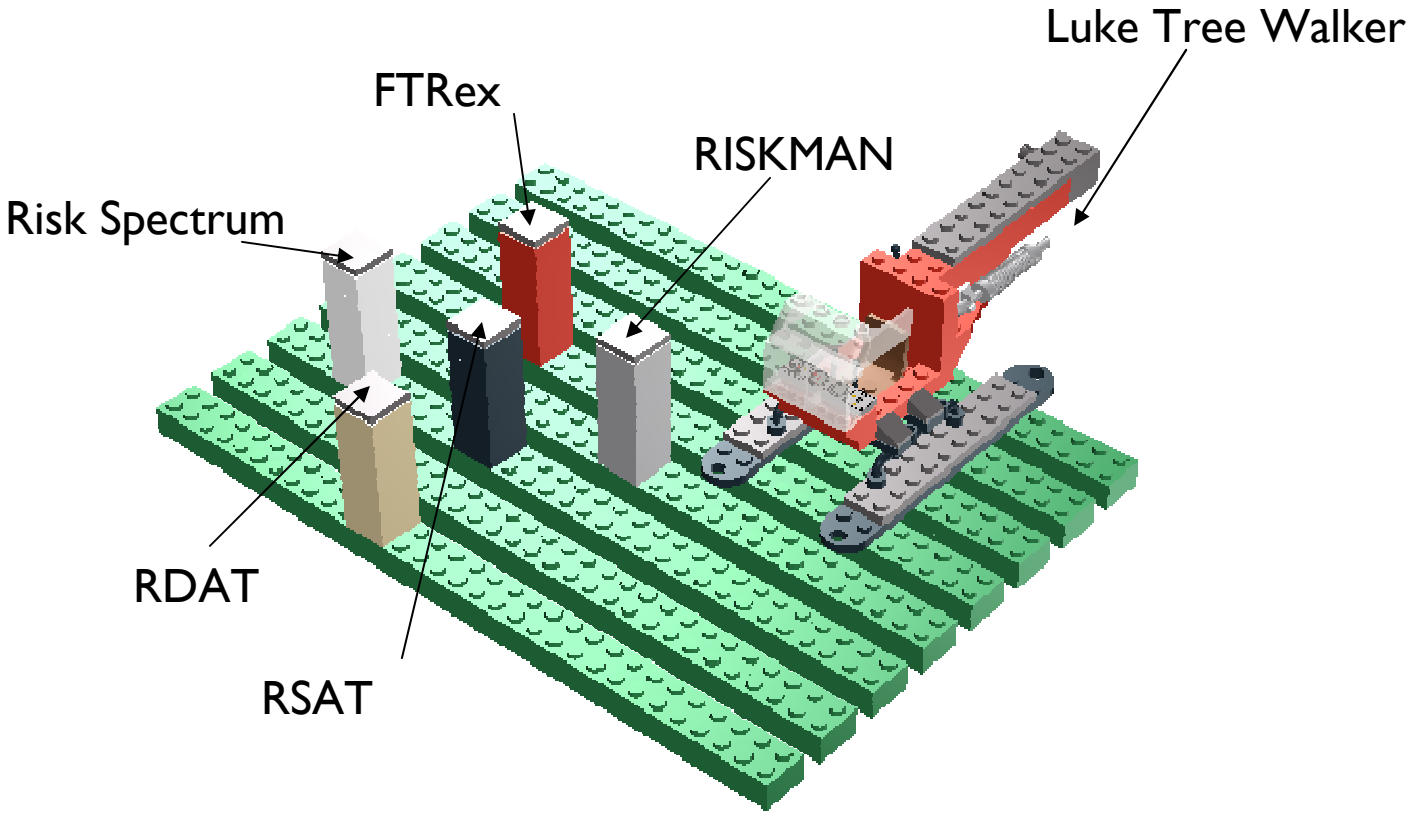
# … for example …



# … or this …



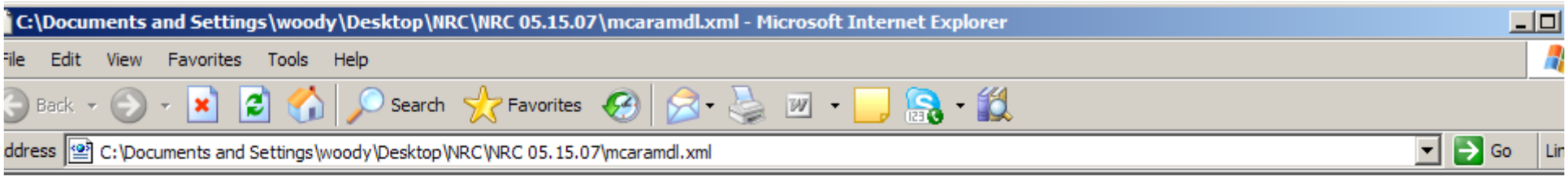
# … or even this …



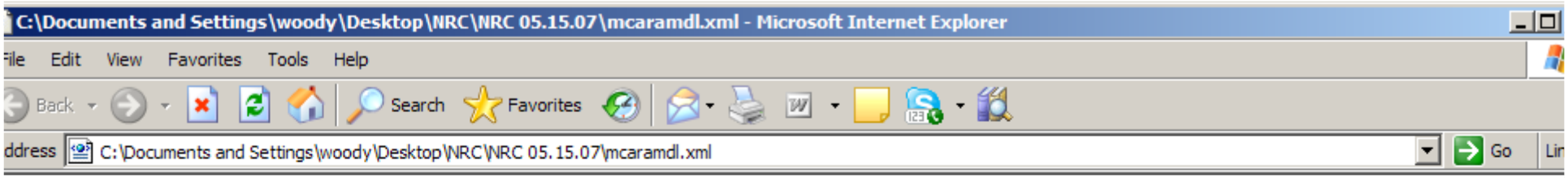

… all interconnected through the foundation: a Standard Representation Format.

This is not just imagination.

We have actually used a prototype format like this in research and production.




```
<?xml version="1.0" ?>
<!DOCTYPE riskman (View Source for full doctype...)>
- <riskman name="BU">
  - <faulttree topevent="BU">
      <!-- The Fault Tree -->
    - <gate name="BU" type="or">
        <fanin name="G00MAB" />
        <fanin name="G00MDB" />
        <fanin name="CHECKV4FTO" />
      </gate>
    - <gate name="G00MAB" type="or">
        <fanin name="TANKRUP" />
        <fanin name="MANUALVTC" />
        <fanin name="CHECKV3FTO" />
      </gate>
    - <gate name="G00MDB" type="and">
        <fanin name="G00MDC" />
        <fanin name="G00MJC" />
      </gate>
    - <gate name="G00MDC" type="or">
        <fanin name="MDPUMP1FTR" />
        <fanin name="MDPUMP1FTS" />
        <fanin name="CHECKV1FTO" />
        <fanin name="MOVALVE1FTO" />
        <fanin name="HETEST1" />
        <fanin name="G00MGD" />
      </gate>
    - <gate name="G00MGD" type="and">
        <fanin name="G00MGE" />
        <fanin name="CHECKV2FTR" />
      </gate>
    - <gate name="G00MGE" type="or">
        <fanin name="MDPUMP2FTR" />
        <fanin name="MDPUMP2FTS" />
      </gate>
    - <gate name="G00MJC" type="or">
        <fanin name="MDPUMP2FTR" />
```





```
<?xml version="1.0" ?>
<!DOCTYPE riskman (View Source for full doctype...)>
- <riskman name="BU">
```


XML (Extensible Markup Language) is a public-domain, flexible way to create common information formats and share both the formats and the data on the World Wide Web, intranets, and between computer programs.

For example, software makers might agree on a standard or common way to describe and exchange data and then describe the data format with XML. Such a standard way of describing data would enable users to make valid comparisons.

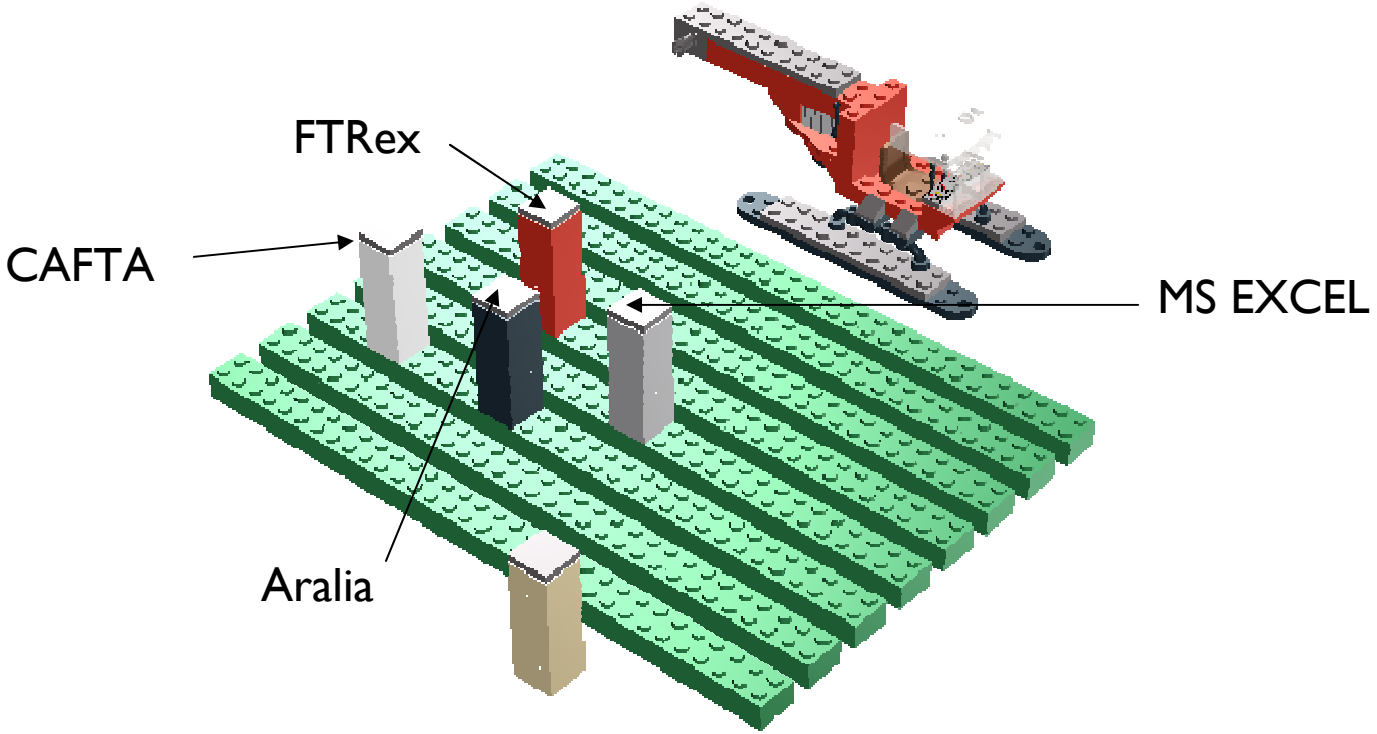
XML, a formal recommendation from the World Wide Web Consortium (W3C), is similar to the language of today's Web pages, the Hypertext Markup Language (HTML). An XML file can be processed purely as data by a program or it can be stored with similar data on another computer or, like an HTML file, that it can be displayed. Each application can decide how to handle the incoming data; it could be calculated, displayed, or inform the user that this type of data cannot be used.

XML is "extensible" because the markup symbols are unlimited and self-defining. XML is actually a simpler and easier-to-use subset of the Standard Generalized Markup Language (SGML), the standard for how to create a document structure.

It is now the case that XML is used in many Next Generation applications.

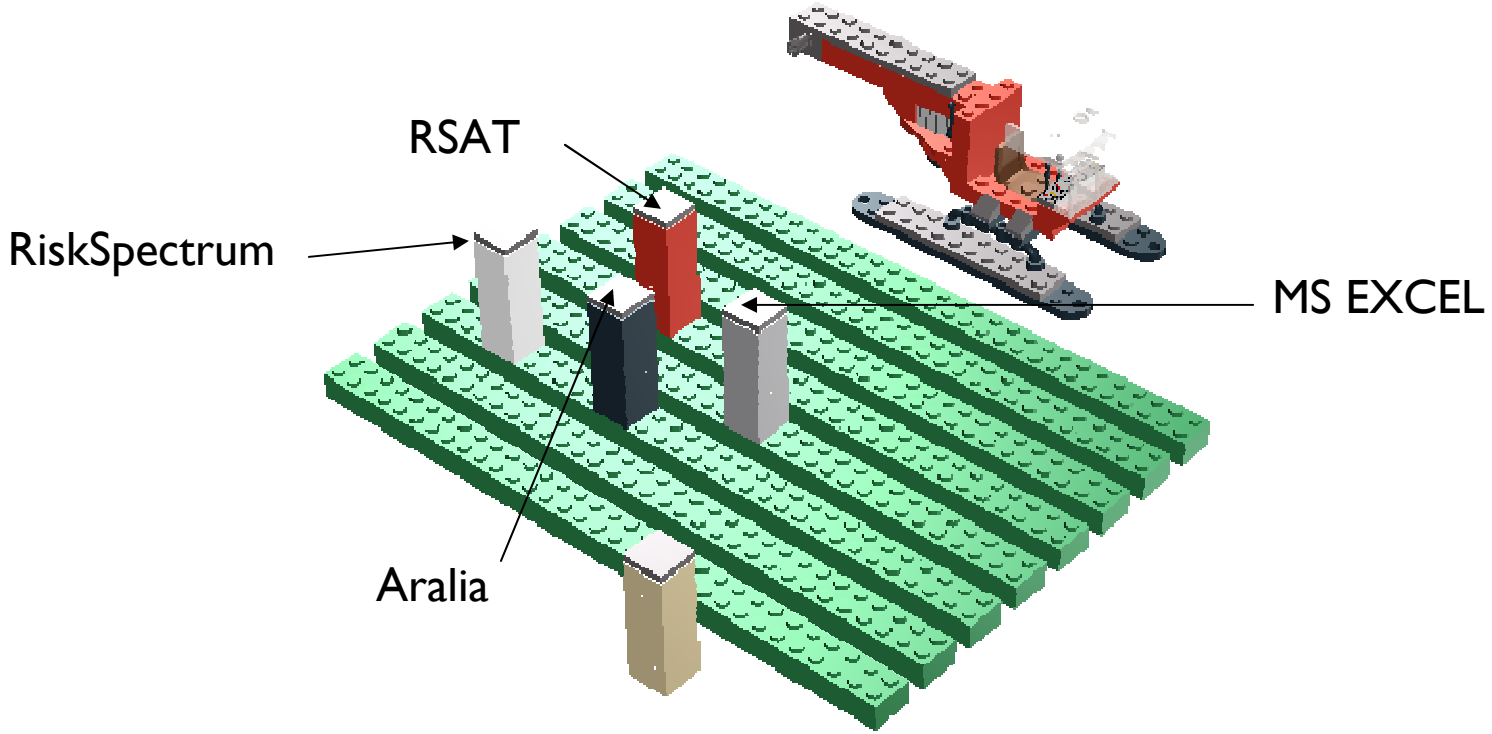

```
<fanin name="MDPUMP2FTR" />
```

# Example #1



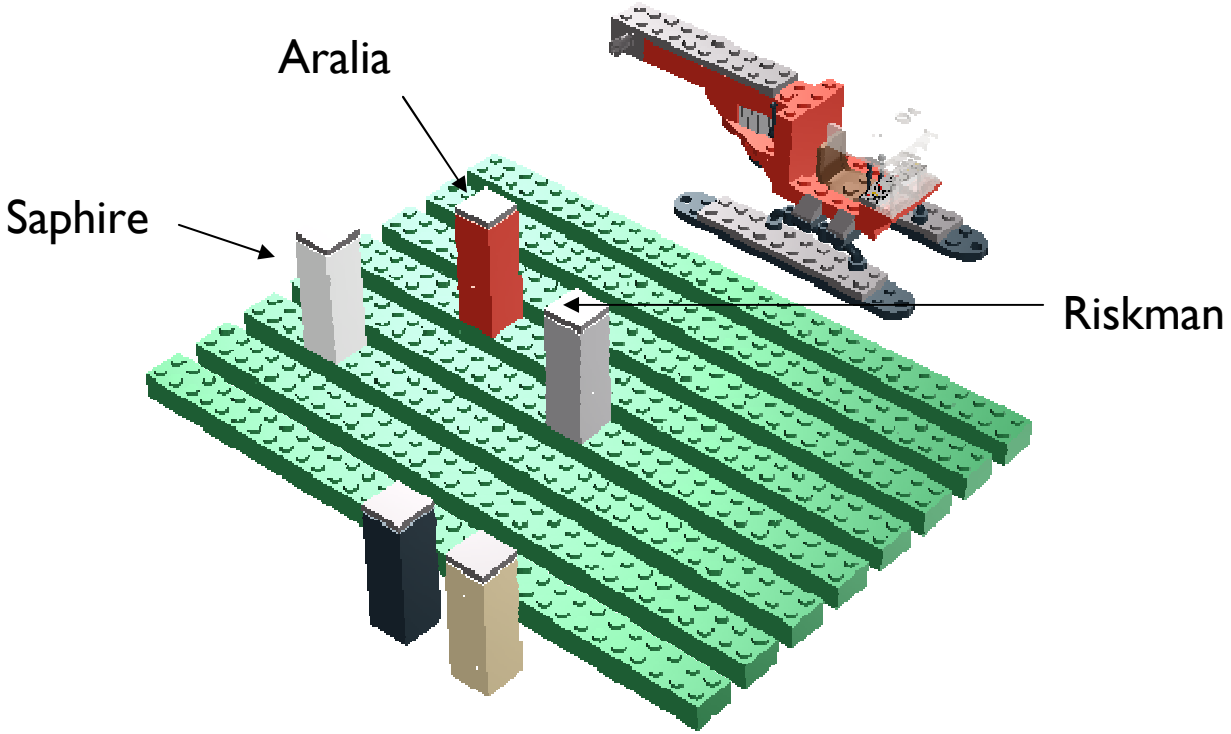

Three different FTL models from three different US organizations.

# Example #2



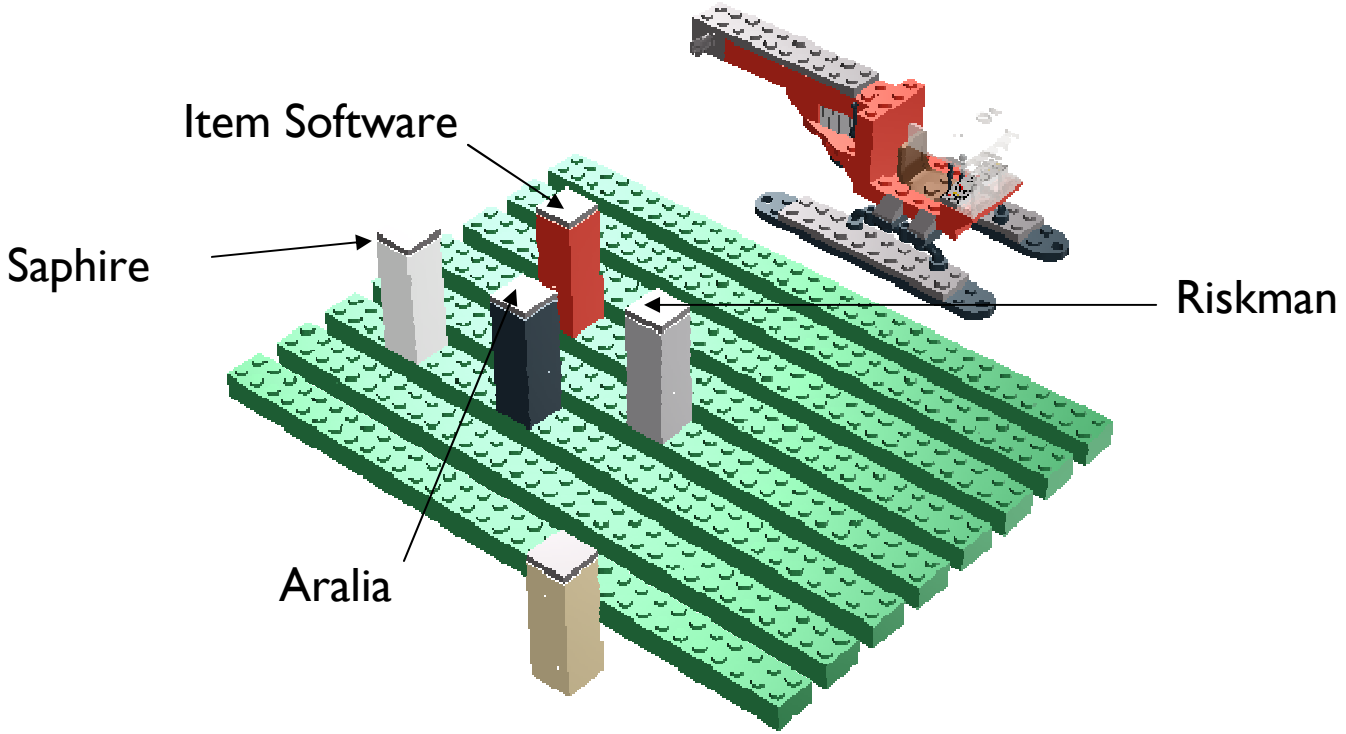

A Japanese core damage model solved exactly with BDD.

# Example #3




An investigation of a SPAR model.

# Example #4




A sanity check on the MER PRA done by NASA.



# Open Initiative for Next Generation PSA Software



ABS Consulting

## Technical Working Group Meeting #1
## Standard Representation Format for PSA Models

July 19th, 2007
Electricité de France
département Management du Risque Industriel, Paris

**Call for Participation:** In response to the "next steps forward" charge given by the Open Initiative, the first working group meeting for the Standard Representation Format for PSA Models will begin discussions. Dr. Antoine Rauzy will be the session chairman. Participation is open to anyone in the international PSA community.

**How to Participate:** Please fill out the attached form and eMail to Antoine Rauzy at antoine.rauzy@arboost.com as soon as possible. Please put the word "Working Group" in the subject line. We will make every effort to make room for anyone who wants to participate. This is an open technical forum for the exchange of ideas.

**Meeting Location:** The workshop will be held at Electricité de France, at the département Management du Risque Industriel, which is located in Clamart, a banlieu (suburb) of Paris, about 25 minutes from Porte d'Orléans, the terminus of Metro line #4. For location information: http://www.edf.fr/41341i/Home-fr/Research--Development/The-scientific-community/Access-to-EDF-RD-sites.html. If you do not know Paris well, there will be a meeting place in Montparnasse at the café of the restaurant Le Dôme (Metro Vavin) at 08h30, and at Porte d'Orléans at 09h15.

# 弹 Resilience Engineering

Introduction :: Network :: Case Studies :: Projects :: Events :: Proceedings :: Forum :: Links :: F.A.Q. :: Poetry and Art

## Welcome to the Resilience Engineering Network

- Welcome
- Purpose of the R.E.N.
- How to Register a Node
- Registration Form

### Resilience Engineering

The term Resilience Engineering represents a new way of thinking about safety. Whereas conventional risk management approaches are based on hindsight and emphasise error tabulation and calculation of failure probabilities, Resilience Engineering looks for ways to enhance the ability of organisations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures. In Resilience Engineering failures do not stand for a breakdown or malfunctioning of normal system functions, but rather represent the converse of the adaptations necessary to cope with the real world complexity. Individuals and organisations must always adjust their performance to the current conditions; and because resources and time are finite it is inevitable that such adjustments are approximate. Success has been ascribed to the ability of groups, individuals, and organisations to anticipate the changing shape of risk before damage occurs; failure is simply the temporary or permanent absence of that.

### The Resilience Engineering Network

The Resilience Engineering Network (R.E.N.) is an open organisation of people and places that are engaged in the development and application of Resilience Engineering. Any dedicated activity on resilience engineering can join the network, as a resilience engineering node (see below). While it is in the nature of a network, that there is no center and that all nodes are equally important, the node in Sophia Antipolis will for practical reasons serve as a host node for information about the network and also provide the basic administration facilities. The URL for the Sophia Antipolis node is <www.resilience-engineering.org>.

# A Standard PSA Model Representation Format
## Scope and Needs Statement for ASME

**Scope:** We propose that an independent international standard format be created to represent computerized PSA models and industry data in digital fiorm. We propose that an ASME subgroup be created to (1) create a prototype Standard Model Representation Format (**SMRF**), (2) present examples in the prototype format, and (3) deliver a report as to the efficacy of the prototype in addressing the "Needs" statement, below.

**Needs:** Over the last 5 years, new calculation techniques, such as BDD, have been extensively studied in nuclear PSA, and research efforts made in the direction of "next generation" PSA software and "declarative modeling", which try to present a more informative view of the actual systems, components, and interactions which the model represents.

The concern of these studies has been to end the use of approximations: numerical approximations for which we do not know the error factors, and modeling approximations which leave out perhaps critical elements of the actual plant.

From all these investigations, some alarming issues related to large nuclear PSA models have been raised, which we feel need to be addressed before we put new calculation engines or next generation user interfaces into place. We believe that to address these issues enumerated below, a **SMRF** for PSA models, a representation which is independent of all PSA software, must be in place. Each software would retain their own internal representation for a model; but each software would also be able to share models and industry data by means of the SMRF.

1. **Quality assurance of calculations:** at the moment, a model built with one software, such as CAFTA, cannot be simply quantified with another software, such as SAPHIRE or RiskSpectrum, and visa versa; there are too many software dependent features used by modelers to make inter-calculation comparisons a one-step process. A standard representation will allow models to be quantified by several calculation engines, therefore quality assuring results in a strong way.

2. **Over reliance on numerical approximations and truncation:** while this cannot be solved directly by a standard representation, as new calculation engines are completed, a standard representation will allow new engines to be snapped into new (or existing) user interfaces without changing the model or user interface software.

3. **Portability of the models between different software:** at the moment, models are essentially non-portable between calculation engines, as pointed out above. We would like to emphasize here that a standard representation would allow complete, whole models to be shared right now between software; the onus will be on each software to correctly interpret the model representation. We have


NUREG-1635, Vol. 8
DRAFT FINAL March 5, 2008

# Review and Evaluation of the Nuclear Regulatory Commission Safety Research Program

**A Report to the**
**U.S. Nuclear Regulatory Commission**

**ADVISORY COMMITTEE ON REACTOR SAFEGUARDS**
**U.S. Nuclear Regulatory Commission**
**Washington, D.C. 20555-0001**

From the report ...

- *Next Generation of PRA Software*

The agency's main PRA tool is the SAPHIRE code that has been developed in the last twenty years and is the basis for the Standardized Plant Analysis Risk (SPAR) models that are used extensively in the Reactor Oversight Process. The ACRS Subcommittee on Reliability and Probabilistic Risk Assessment was briefed recently by representatives from EPRI and an international group of researchers that have formed the Open PSA Initiative. Two issues with the present state of PRA software were identified. First, it is hard to check the completeness and correctness of the logic of the PRA models produced using current PRA codes because these models are code dependent. Second, there is disturbing evidence that, under certain circumstances, the probabilistic calculations may be flawed.

There are efforts under way to develop a standard PRA representation format that would promote independence between the logic models and the individual codes. Such a standard would facilitate significantly the review of the PRA logic, a benefit of great value to the agency. The staff should participate actively in the international activities related to the development of the next generation of PRA software.

In its 2006 report to the Commission on the NRC Safety Research Program (NUREG-1635, Vol. 7), the ACRS stated that "the staff needs to review the literature concerning Binary Decision Diagrams and

such an investigation." The ACRS continues to believe that the staff should undertake such an investigation and participate actively in the international activities related to the development of the next generation of PRA software. A short-term product could be an evaluation of the potential impact of the new software on regulatory decisionmaking. The results of such an evaluation would guide the establishment of a longer-term research project in this area.

**Development of a Regulatory Infrastructure for Much More Efficient and Effective Regulatory Work**

The second theme within the general topic of long-term research at NRC deals with the productivity of the line organizations handling regulatory issues and the growth of nuclear power in the U.S.

The growth of nuclear power seems inevitable at this juncture based on applications for early site permits and the recent submittal of several COL applications. This presumes, however, that no major reactor accident occurs in this Country or pertinent accidents occur in other countries with well developed nuclear energy capabilities. A focus on LWR technologies also seems likely, since alternative technologies have not yet been demonstrated adequately and several modern LWR designs have been certified. More certifications of advanced LWRs are anticipated. However, the NRC will likely need to develop safety requirements and an infrastructure to deal with safety matters relating to certain non-LWR designs (e.g., LMR, HTGR) and unique LWR designs (e.g., IRIS). Constraints on the growth of the size of the NRC staff seem likely based on the

# Open Initiative for Next Generation PSA

arboost EPRI ELECTRIC POWER RESEARCH INSTITUTE ABS Consulting

## Workshop Announcement
## Next Generation PSA Software and Model Representation Standards

October 3rd, 2007
EPRI, Washington D.C., USA

**Call for Participation:** To meet and discuss efforts, visions, and future needs with regards to software, PSA analysts, and model representations in large, safety critical PSA. All attendees are encouraged to present ideas, work-in-progress, research, and production systems, especially in the following areas:

- Quantification Methods and Algorithms;
- User Interfaces and results presentation;
- Declarative Modeling;
- Standard Model Representations;
- Data and Results Visualization;
- PSA Software Architectures;
- Risk Assessment of Human Actions;
- Modeling Styles and their Effects on Clarity and Quantification;
- Uncertainty and Importance
- PSA Software Verification, Benchmarks, and Quality Assurance.

**How to Participate:** Registration must be done on the EPRI website (www.epri.com). As well, please fill out the attached Intention to Participate form and eMail to Steve Epstein at sepstein@absconsulting.com as soon as possible. Please put the word "EPRI Workshop" in the subject line. We will make every effort to make room for anyone who wants to talk, make a presentation, or make a demonstration. This is an open forum for the exchange of ideas.

**Organizers:** This workshop is organized by ABS Consulting, ARBoost Technologies, and EPRI, the Electrical Power Research Institute. Please do not hesitate to contact any of the following members of the organizing committee if you have any questions:


Steve Epstein sepstein@absconsulting.com
Antoine Ranzy Antoine.ranzy@arboost.com
Ken Canavan kcanavan@epri.com

# 次世代 PSA ソフトウェア オープンイニシアチブ
# ワークショップ開催のお知らせ

arboost TECHNOLOGIES　nel　ABS Consulting

## 主テーマ： 次世代 PSA ソフトウェア、共有可能なモデル標準
## 2007 年 11 月 13 日・14 日
## 於： ㈱原子力エンジニアリング（NEL）、大阪

**本ワークショップの主旨：**

- 原子力施設等の確率論的安全評価（PSA）での、ソフトウェア開発、PSA 実施状況、モデル標準化といったトピックスにおける、最新の取り組み状況、ニーズや将来ビジョン等に関して、インターナショナルな動向を紹介する事を中心に、ワークショップ御参加者において、オープンな御議論を実施いただく。
- 下記の様な PSA 分野について、ワークショップ御参加のそれぞれの機関から、所有ソフトウェア、評価実施例、調査研究の成果、等のプレゼンテーションも行っていただき、諸問題の御議論も実施いただく。
  - モデリング手法（明瞭さ、定量化方法等）
  - 定量化手法およびアルゴリズム
  - ユーザインターフェース
  - データおよび結果の視覚化
  - 地震 PSA
  - リスクモニター
  - 人間信頼性評価
  - PSA ソフトウェアの検証、ベンチマーク、品質保証
  - （異なるソフトウェア・ツールで）共有可能なモデル標準
- 今回と同様のワークショップは、これまでに、スイス Gösgen 発電所（2007 年 6 月）、EdF（2007 年 7 月）で開催しており（米国 EPRI でも 2007 年 10 月に開催予定です）、それらのワークショップでの結果等を御紹介いたします。
  また、次世代 PSA ソフトウェアや異なるソフトウェアで共有可能なモデル標準の原案等も、御説明いたします。

**参加申込要領：**

- 添付の申込用紙にご記入の上、Woody Epstein (sepstein@absconsulting.com)宛に、電子メールにて御送付ください。（締め切り： 2007 年 10 月 15 日）
- 電子メールの件名は、「NEL Workshop」としてください。
- 本ワークショップは、ご参加いただく皆様のオープンな意見交換の場となっております。
  ご参加いただく皆様にも、プレゼンテーション・デモンストレーションの機会などを設定させていただきますので、ご希望などございましたらお伝えください。

**事務局：**

本ワークショップは、ABS Consulting, ARBoost Technologies, ㈱原子力エンジニアリングが開催するものです。御質問等ございましたら、御遠慮なく下記メンバーにご連絡ください。


| | |
|---|---|
| Woody Epstein | sepstein@absconsulting.com |
| Antoine Rauzy | Antoine.rauzy@arboost.com |
| Takahiro Kuramoto | tkuramoto@neltd.co.jp |

www.open-psa.org

# Open Initiative for Next Generation PSA

## Workshop Announcement

## Next Generation Probabilistic Safety Assessment

December 6th and 7th, 2007

IAEA, Vienna

**Call for Participation:** To meet and discuss efforts, visions, and future needs in large, safety critical PSA. PSA analysts, software companies, regulators, managers, and policy makers are especially encouraged to attend and to present ideas, work-in-progress, research, and production systems, especially in the following areas:

- Quantification Methods and Algorithms;
- User Interfaces;
- Future Needs of Regulators;
- Standard Model Representations;
- Data and Results Visualization;
- PSA Software Architectures;
- Risk Assessment of Human Actions;
- Modeling Styles and their Effects on Clarity and Quantification;
- PSA Software Verification, Benchmarks, and Quality Assurance.

**How to Participate:** Please fill out the attached Registration Form and eMail to Steve Epstein at sepstein@absconsulting.com as soon as possible. Please put the word "IAEA Workshop" in the subject line. We will make every effort to make room for anyone who wants to talk, make a presentation, or make a demonstration. This is an open forum for the exchange of ideas.

**Organizers:** This workshop is organized by ABS Consulting, ARBoost Technologies, and the IAEA, the International Atomic Energy Agency. Please do not hesitate to contact any of the following members of the organizing committee if you have any questions:


| | |
|---|---|
| Steve Epstein | sepstein@absconsulting.com |
| Antoine Ranzy | Antoine.ranzy@arboost.com |
| Mark Reinhart | F.Reinhart@iaea.org |


Robertas Alzbutas
J.D. Andrews
George Apostalakis
Julian Argirov
Richard Attinger
Ali Azaram
Ola Backstrom
Amedee Barre
Guenter Becker
Dennis Bley
Jorg Bohm
Roger Boyer
Vicki Buchanan
Ken Canavan
Jose Carretero
Marko Cepin
James Chang
Simone Colombo
Sergio Contini
Vinh Dang
Nicolas deVictor
Eiji Doi
Francois Ducamp
Nicolas Duflot
Dat Duthinh
Steve Epstein
Irene Eusgeld
Kazuhito Fujita
Alain Gauvin
Tina Ghosh
Sergio Guarro
Tadakuni Hakata
Hossein Hamzehee
Joachim Herb
Roberto Herrero Santos
Mohamed Hibti
Erik Hollnagel
Elod Hollo
Feng Hsu
Göran Hultqvist
Ulrich Hussels
Cristina Ibanez
Masanobu Ijiri
Teruo Ishii
Moosung Jae
Karel Jung
Dionisis Kampranis
Reza Kazemi
Myung-ro Kim
Ken Kiper
Bob Kirschner
Toivio Kivirinta
Ulrich Klapp
Christine Klatt-Preyssl
Jens Klugel
Takehisa Kohda
Yuji Komori
Zolton Kovacs
Wolfgang Kroger
Takahiro Kuramoto

Pierre Labeau
Jeffery LaChance
Virgile Lalumia
Qiao Liu
WeeTee Loh
Erasmia Lois
Diego Mandelli
José María Izquierdo Rocha
Marius Marian Lontos
Jana Markova
Satoshi Matsumoto
Enrique Melendez
Davide Mercurio
Bobby Middleton
Zahra Mohaghegh
Ali Mosleh
Allen Muldenhauer
Ken Muramatsu
Bill Nelson
Shoichi Nose
Olivier Nusbaumer
Kouichi Ohta
Arturo Perez Mulas
Serge Perrot
Gueorgui Petkov
Luca Podofillini
Andre Poucet
Christian Preyssl
Jean Primet
Pekka Pyy
Richard Quatrain
Shoba Rao
Antoine Rauzy
Peter Rawson
Mark Reinhart
Martin Richner
Junichi Sakaguchi
Isao Sakaki
Kauru Sakata
Osamu Saramoto
Chikahiro Satoh
Owen Scott
Ho Seok
Yoshio Shimada
Woo Sik Jung
Nathan Siu
Curtis Smith
Johan Sorman
Kurokawa Takamasa
Hitoshi Tamaki
Piia Tint
Gennady Tokmachev
Takashi Tomozawa
Homma Toshimitsu
Kensuke Toyoshima
Jussi Vaurio
Paolo Vestrucci
Sigrid Wagner
Don Wakefield
Takashi Watanabe

Andreas Wielenberg
John Wreathall
Masaru Yamanaka
Liao Yehong
Mitsuru Yoneyama
Olivier Zuchuat

ABS
ARBoost Technologies
AREVA NP Fr
Areva NP GmbH
AREVA TA
ASCA Inc.
Atomenergoproekt
AXPO/NOK
BKW FMB Energie AG
CEA (French Atomic Energy Commission)
CSN, Spanish Regulatory Authority
CTI
DNV
Dominion
EdF
Empresarios Agrupados
EPRI
ERRA
ESA
ETH Zurich
European Commission - JRC
Forsmark Nuclear Power
FPL
Genden Info Systems
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
Hanyang University
IAEA
IJS
INEL
INRE
INSS
Instituto de Investigacion Tecnologica.Universidad Comillas Madrid
IRSN
ISL, Inc.
JAEA
Kernkraftwerk Gösgen-Däniken AG
KKL
Klokner Institute
KOPEC
Korean Atomic Energy Research Institute
Kyoto U.
LEI
Loughborough University
Loviisa Power Plant
MHI

NASA
NEL
Nishimu
NIST
NRC
OECD/TVO
OSU
Paul Scherrer Institut
Politecnico di Milano
Preventor Inc.
Relcon Scandpower
RELKO
RFK Dynamics
RISA
Sandia
Scientech
Shikoku-Electric
Southern Nuclear
Tallinn University of Technology
Technical University of Sofia
TEPSYS
TH Consulting
Toshiba
TuV
TVO
U of M
Universita di Pisa
Universite Libre de Bruxelles
University of Bolonge
UTT
Vattenfall
VEIKI
Wreathwood Group
Yonden-Engineering

# Open PSA Participants 2007

# eMocus

## Enumerative Algorithms to Assess Boolean Models

Antoine Rauzy
IML/CNRS
163, Avenue de Luminy
13288 Marseille Cedex 9
FRANCE
arauzy@iml.univ-mrs.fr

Christmas '07

**Abstract:** this article proposes an enumerative algorithmic scheme to build a sum of disjoint products equivalent to a fault tree, to assess the probability of its top event and to build its minimal cutsets. These algorithms work both on coherent and non coherent models. It turns out that the MOCUS algorithm, which is considered as one of the most efficient methods to compute minimal cutsets, is just a specific variation of the proposed algorithm. This article opens new perspectives for the development of efficient algorithms to assess Boolean models.

### 1. Introduction

Algorithms to assess Boolean models of the risk (Fault Trees, Event Trees, Block Diagrams) range mainly into two categories: bottom-up algorithms that aim to calculate either the minimal cutsets of the model (see e.g. [JK98, JHH04]) or its truth table (see e.g. [Rau93]) and top down algorithms to compute minimal cutsets like MOCUS [FV92, Ber94, Rau03]. Monte-Carlo simulation and other methods are also regularly proposed, but with less success due to their computational cost. Top down algorithms have shown to be very effective to assess large models like those issued from probabilistic safety analyses of nuclear power plants. These models embed thousands of gates and basic events, but in general a relatively small number of minimal cutsets concentrates the risk (see e.g. [ERW06]). Therefore, efficient algorithms are those able to prune the model under study as much and as fast as possible, focusing on its relevant parts (minimal cutsets of highest probabilities).

This article proposes an enumerative algorithmic scheme to build a sum of disjoint products equivalent to a fault tree, to assess the probability of its top event and to build its minimal cutsets. Enumerative algorithms, such as the well known Davis-Putnam's procedure [DLL62], are widely used in Artificial Intelligence, Automated Reasoning or Model Checking. Nevertheless, they attracted so far only very little attention in the reliability engineering framework (see however [RCDB03]), probably because in the former fields one is interested in finding one solution of the formula under study, while in the latter one is interested (mainly) in evaluating the probability of the formula. From a theoretical view point, the problem at hand jumps from the NP-complete to #P, at complexity class which is believed to be much more difficult than NP (see e.g. [Pap94] for a survey of computational complexity theory).

The principle of enumerative algorithms consists in selecting a pivot variable and in decomposing the problem under study into two sub problems: the case where the variable takes the value true and the case it takes the value false. In other words, enumerative algorithms traverse implicitly a binary search tree. The novelty introduced in this article consists in selecting the pivot variable not only among the basic events (as done by the Davis-Putnam's procedure), but also possibly among gates. A four-valued logic makes it possible to propagate variable assignments and to determine efficiently which branches of the binary tree is a candidate minimal cutset. It turns out that the MOCUS algorithm, which is considered as one

**Open PSA Meeting. CSN, Madrid 24-25 January 2008**

The meeting will take place at the CSN headquarters, Calle Justo Dorado, 11, Madrid. See Map1, Map2 and Map3. (Press Crtl+clic on each web address).

Map. ***Calle Justo Dorado*** on top-left

http://maps.google.es/?ie=UTF8&om=1&z=16&ll=40.446686,-3.709087&spn=0.006679,0.013647

The nearest underground station is ***Guzmán el Bueno (line 6)***, just a five minutes walk. Another underground station very close, a ten minutes walk, is ***Cuatro Caminos (lines 1, 2 and 6)***.

Two hotels are nearby, ***Jardin Metropolitano*** and ***AC Los Vascos***, at ten and five minutes walk, respectively, from CSN premises.

The hotel ***Jardin Metropolitano*** is between CSN and *Cuatro Caminos* underground station, closer to *Cuatro Caminos*. This underground station is very well placed as lines 1 and 2 go lead you directly to downtown Madrid (Puerta del Sol, Gran Via, Callao, Plaza Mayor, Palacio Real, Teatro Real, Plaza de España, etc.)

The hotel ***AC Los Vascos*** is very close to CSN premises, near *Guzmán el Bueno* metro station and fifteen minutes walk from *Cuatro Caminos* underground station. See accompanying file for details

Best regards and hoping to see you soon in Madrid.

| Name | Telephone | Email |
|---|---|---|
| Arturo Pérez | +34 913460262 | apm@csn.es |
| Roberto Herrero | +34 913460262 | rhs@csn.es |
| Enrique Meléndez | +34 913460633 | ema@csn.es |

Consejo de Seguridad Nuclear
C/ Justo Dorado, 11
28040 Madrid
Fax: + 34 913460496

# The Madrid Meeting

The Open-PSA Initiative

# Open-PSA Model Exchange Format


Open PSA Work Packages

Work Package Proposal

# Translation of Risk Spectrum models into Open-PSA International Standard Representation Format


| | |
|---|---|
| Reference: | Open-PSA Work Package RS32-SuRF |
| Version: | 2.0 |
| Creation Date: | 03/12/2007 |
| Last Modification Date: | 07/12/2007 |
| Authors: | S. Epstein, J. Sörman & A. Rauzy |


Pledges of Participation

| Organization | Participation in Euro |
|---|---|
| KKG | 7500 |
| KKL | 7500 |
| NoK | 7500 |
| Tractebel | 7500 |
| AREVA | 7500 |
| KKB | 5000 |
| CSN | 3000 |
| EdF | 7500 |
| IRNS | 7500 |
| **TOTAL** | **53,500** |

# Work Package #1

EPRI and the Open PSA Initiative Workshop

ABS Consulting

# Workshop Announcement

## Open Probabilistic Safety Assessment (PSA) Architecture Workshop

May 1st and 2nd, 2008

EPRI, Charlotte N.C., USA

**Call for Participation:** The purpose of the Open Probabilistic Safety Assessment (PSA) Architecture Workshop is to meet and continue to discuss efforts, visions, and future needs with regards to software, PSA analysts, and model representations in large, safety critical PSA. All attendees are encouraged to present ideas, work-in-progress, research, and production systems, especially in the following areas:

- Quantification Methods and Algorithms;
- User Interfaces;
- Declarative Modeling;
- Model Exchange Formats;
- Data and Results Visualization;
- PSA Software Architectures;
- Risk Assessment of Human Actions;
- Modeling Styles and their Effects on Clarity and Quantification;
- PSA Software Verification, Benchmarks, and Quality Assurance.

**How to Participate:** Registration for this workshop must be done on the EPRI website: http://guest.cvent.com/EVENTS/info/summary.aspx?e=16bd28f9-7ba6-4f44-9ac5-4715fdd025e0. You do not have to be an EPRI member to participate, but you must register via the above link.

**Organizers:** This workshop is organized by EPRI, the Electrical Power Research Institute, the Open PSA Initiative, with support from ARBoost Technologies and ABS Consulting. Please do not hesitate to contact any of the following members of the organizing committee if you have any questions:


Steve Epstein sepstein@absconsulting.com
Antoine Rauzy Antoine.rauzy@arboost.com
Ken Canavan kcanavan@epri.com


# The Open-PSA Initiative
# Dassault Systèmes
# Paris 10/21/2008

The Open PSA Initiative
sepstein@absconsulting.com
benoit.perrot@3ds.com
antoine.rauzy@3ds.com
parsec@chello.at
www.open-psa.org

# Today's Participants

| Organisme | Contact |
|---|---|
| EDF (FRANCE) | mohamed.hibti@edf.fr |
| KKL (SUISSE) | olivier.nusbaumer@kkl.ch |
| KKG (SUISSE) | jkluegel@kkg.ch |
| IRSN (FRANCE) | francois.ducamp@irsn.fr |
| RISA (ALLEMAGNE) | guenter.becker@risa.de |
| TRACTEBEL (BELGIQUE) | francoise.dassy@tractebel.com |
| CSN (ESPAGNE) | ema@csn.es |
| NOK (SUISSE) | Martin.Richner@nok.ch |
| JRC (ITALIE) | sergio.contini@jrc.it |
| AREVA NP ?? | aline.elliahervy@areva.com |
| AREVA TA ?? | virgile.la_lumia@areva.com |
| Relcon Scandpower (SUEDE) | johan.sorman@relconscandpower.com |
| Interaction Internationale | parsec@chello.at |
| André | andre.lannoy@orange.fr |
| Antoine | Antoine.RAUZY@3ds.com |
| Woody | SEpstein@absconsulting.com |
| Leïla | leila.marle@imdr.eu |

# Agenda

| Time | Subject | Discussion Leader |
|---|---|---|
| 10h30-10h45 | Presentation of the participants | |
| 10h45 - 11h00 | Introduction of IMdR | Leila Marle |
| 11h00 – 12h00 | Update on Open PSA | Mark ¾ & Johan Sörman ¼ |
| 12h00 – | Overview of the Technical Goals | Antoine |
| - 12h30 | Management Overview | Antoine |
| 12h30 – 13h30 | Lunch and Continuing Discussions | |
| 13h30 – 16h00 | Clarification and discussion about all issues by participants | Mark |

Institut pour la Maîtrise des Risques
Sûreté de Fonctionnement - Management - Qindynics

Open PSA Work Package

# Project P08-4: «Validation of Open-PSA Model Exchange Format for Probabilistic Safety Analyses»

## Project Specifications

November, 28th, 2008

Participants

| | |
|---|---|
| Mohamed HIBTI | EDF (FRANCE) |
| OLIVIER NUSBAUMER | KKL (SUISSE) |
| Jens-Uwe Klügel | KKG (SUISSE) |
| François DUCAMP | IRSN (FRANCE) |
| Guenter BECKER | RISA (ALLEMAGNE) |
| Isabelle HENDRICKX | TRACTEBEL (BELGIQUE) |
| Enrique Meléndez Asensio | CSN (ESPAGNE) |
| Martin RICHNER | NOK (SUISSE) |
| Sergio CONTINI | JRC (ITALIE) |

Project Manager

| | |
|---|---|
| Antoine Rauzy | Dassault Systèmes |

IMdR Representative

| | |
|---|---|
| André LANNOY | IMdR |
| Leïla MARLE | IMdR |

IMdR - 12, Avenue RASPAIL – 94250 GENTILLY Imdr@orange.fr www.imdr.eu

# EdF Open PSA Review of the OPSAMEF

**Open PSA Initiative**
**EdF Paris, France**
**28 & 29 September 2009**

Monday 28 September 2009

| Time | Item | Discussion Lead |
|---|---|---|
| 0900 | Welcome & Introduction | Mark |
| 0905 | Introduce Participants & Sign In List & Review Agenda | Mark |
| 0915 | Open PSA Initiative | Woody |
| 0945 | Overall OPSA enhancements<br>• OPSAMEF<br>• Other | Antoine |
| 1015 | RIDM: Destination & OPSA | Mark |
| 1045 | Break | |
| 1100 | OPSAMEF | Antoine |
| 1145 | KKB PSA Model<br>• Description of Model<br>• Features of Model outside OPSAMEF<br>• Aspects of OPSAMEF not tested with Model | Günther |
| 1230 | Lunch | |
| 1315 | (For CAFTA) PSA Model<br>• Description of Model<br>• Features of Model outside OPSAMEF<br>• Aspects of OPSAMEF not tested with Model | Woody |
| 1400 | Comments From Robert CSN: Advance by e-mail to the group.<br><br>As a result of CSN experience converting PSA models from Cafta to RiskSpectrum, they have found some interesting hints that deserve special attention | Enrique |
| 1445 | (For Risk Man) PSA Model<br>• Description of Model<br>• Features of Model outside OPSAMEF<br>• Aspects of OPSAMEF not tested with Model | Woody |
| 1530 | Break | |
| 1545 | RiskSpectrum Plugin<br>• Description<br>  ○ 32 bit versus 16 bit<br>• User Manual<br>• Relcon Alpha Testing | Johan |
| 1630 | Place Holder: End of 1st Day Summary. Plan for 2nd Day. | Mark |
| 1700 | End of Day | |

# How we will go forward:

- Help software vendors and PSA modelers investigate their models (Model Triage).
- Creation of Work Packages in the USA and Japan
- Creation/Continuation of Working Groups
  - Standard Format
  - Seismic Quantification
  - Benchmarking
  - Dynamic PSA
- Creation of Short Courses from Open PSA Experts
- Internships for personnel from other companies to learn about good PSA practices and PSA software.

# In this context, items needing discussion …

- International Group
- Alliance/Consortium
- Manpower
- Financial Support
- Research and Development Work Packages
- Administrate Work Packages and Short Courses
- Administrate Working Groups
- Make Translators for MEF
- Board of Directors
- Owned by Members (??)
- Not-for-Profit (??)