Vulnerability of Critical Infrastructures Exposed to Technical Failures or Natural Hazards
Chernobyl and Katrina: two Names to make History

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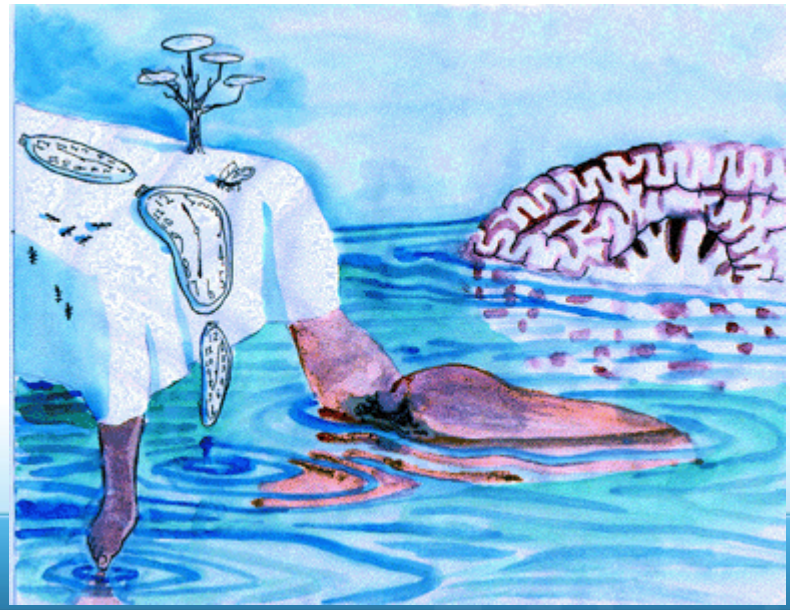
Issues

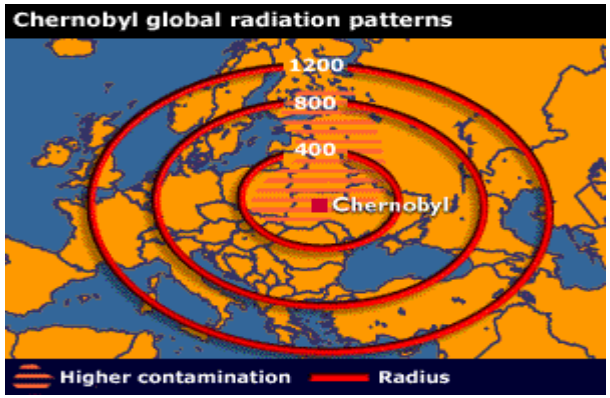
- If one looks into the history of large scale disasters, definitely Chernobyl and Katrina are on the top of the list. Do they have ***commonalities when it comes to the vulnerability assessment of complex systems*** with reference, either to technical / human or to natural hazards initiation?
- A ***generic model*** developed recently for quantitative vulnerability assessment of complex system (e.g. system of systems), has been proved to have a robust structure in order to assess and quantify a vulnerability related indicator for a variety of threats (induced by either technical or natural events), for critical infrastructures such as petrochemical and refineries.
- A sequence of examples is prepared by the authors, in order to acquire a consolidated system vulnerability metric, leading to a ***vulnerability associated number and a acceptance matrix***. It is argued that this , irrespective that one addresses technical systems e.g. a nuclear reactor exposed to undesired events which could change its operational stability, or societal related vulnerabilities to critical infrastructures, induced by natural hazards with potentially large and devastating consequences on the ***operability of critical infrastructures at regional level*** e.g. the case of New Orleans and its vicinities.
- An open debate is proposed in order to achieve what one could call ***vulnerability governance***, as a complementary concept to recently lunched concept of risk governance, in order to assess the overall technical and management performance of single or interdependent critical infrastructures.

Vulnerability Analysis

- The general QVA approach (see the introductory module) postulates that system's monitored parameters may be aggregated such that the control variables U and V of the cuspidal stability model for vulnerability analysis be obtained. Also in the general approach, one submits that U and V are membership functions of the fuzzy theory of impact indicators.
- When a QVA concept is tempted in relation to a specific system - such as a coherently functioning industrial installation, the U and V parameters of the QVA theory should naturally emerge from the physical laws governing the processes that the system hosts. The difference between the 'fast variables' and the 'slow variables' is maintained. However, the actual U and V parameters of the equation of state may depend on ALL input variables, whether fast or slow, in intricate fashions.
- The most general criterion of feasibility of a QVA approach to a specific (as opposed to 'general') system may read:
- ***A SYSTEM MAY BECOME A SUBJECT OF A QVA - IN THE SENSE ADOPTED IN THIS WORK - IF ITS PROCESS EQUATIONS ARE AMENABLE TO AN EQUATION OF STATE Z = Z(U, V) HAVING AS SPACE OF STATIONARY SOLUTIONS A CUSPIDAL FOIL FEATURING STABILITY AND INSTABILITY REGIONS.***
- Since the process equations may wildly vary from system to system, it becomes virtually impossible to design a universal interface for a QVA code. On the other hand, however, the general framework observed with the 'generic', and 'territorial', vulnerability machines still stands valid.

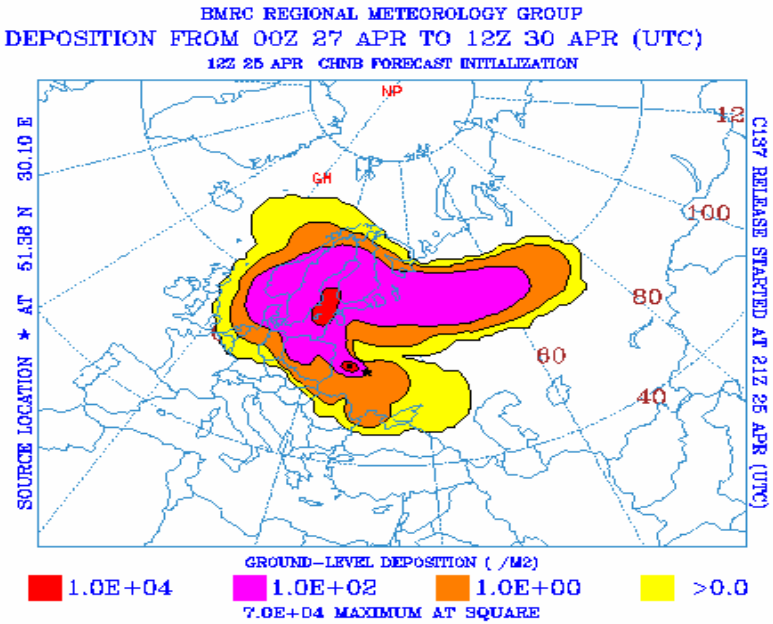


Chernobyl


Chernobyl global radiation patterns
1200
800
400
Chernobyl
Higher contamination
Radius

Chernobyl


MAY 12, 1986
$1.95
TIME
Reagan On the Road
MELTDOWN
Chernobyl Reactor


BMRC REGIONAL METEOROLOGY GROUP
DEPOSITION FROM 00Z 27 APR TO 12Z 30 APR (UTC)
12Z 25 APR CHNB FORECAST INITIALIZATION
SOURCE LOCATION ★ AT 51.38 N 30.10 E
C137 RELEASE STARTED AT 21Z 25 APR (UTC)
NP
GM
12
100
80
60
40
GROUND-LEVEL DEPOSITION (/M2)
1.0E+04
1.0E+02
1.0E+00
>0.0
7.0E+04 MAXIMUM AT SQUARE

STEPS/CONTAINMENT New Input File

File Edit

01. Unit Name
02. Power (MWe
03. Builder
04. Reactor Ty
05. Containmer

Containment S:

06. Free Volu

SOURCE TERM Nu

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to account fo:
the edited va.

Nuclide

07 72. I-129
07 73. I-131
07 74. I-132

Close Help

05. Containment Class ?

File Edit

CONTAINMENT TYPE

To visualize a c
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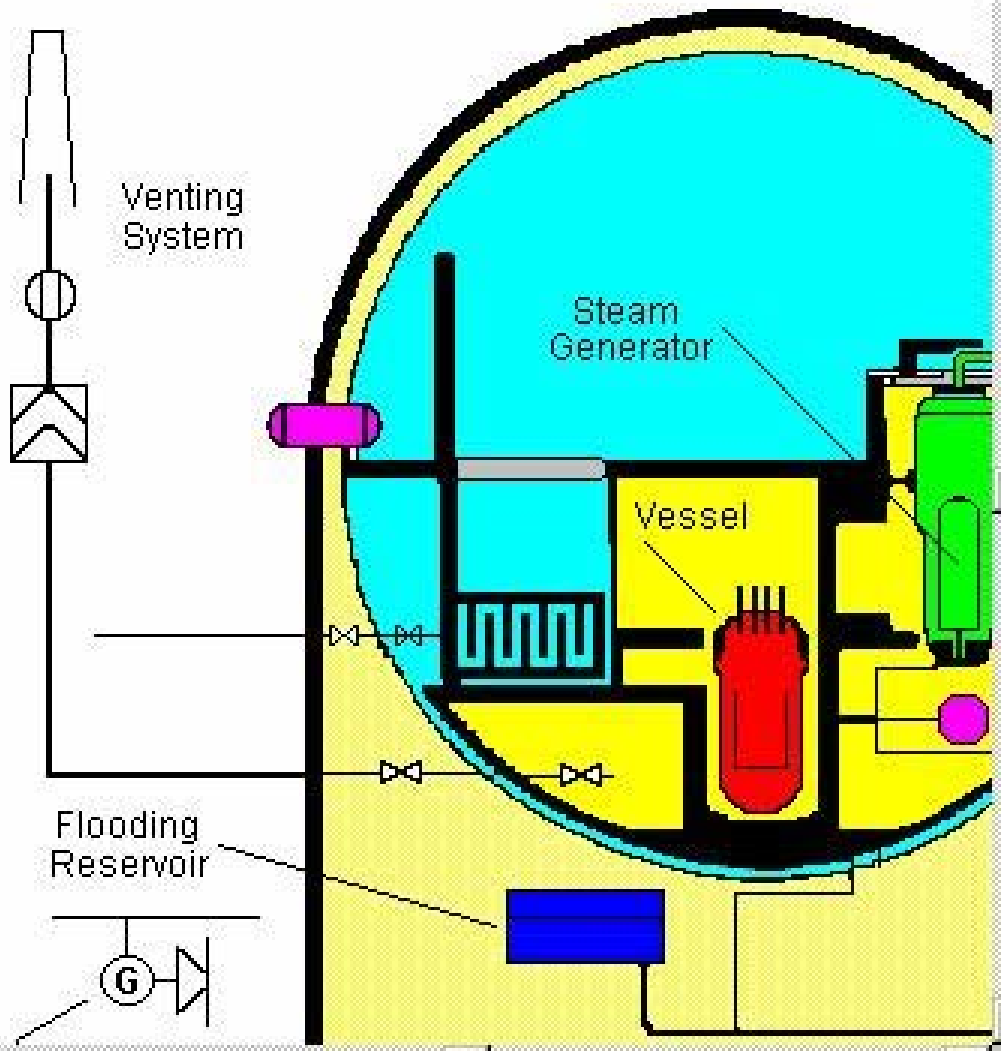
is the closest t

01. REP/900
02. REP/1300
03. PWR/LD/SA
04. PWR/I
05. BWR/M1
06. BWR/M2
07. BWR/M3
08. KONVOI
09. VVER/213
10. VVER/230
11. VVER/1000
12. Other

Close Help

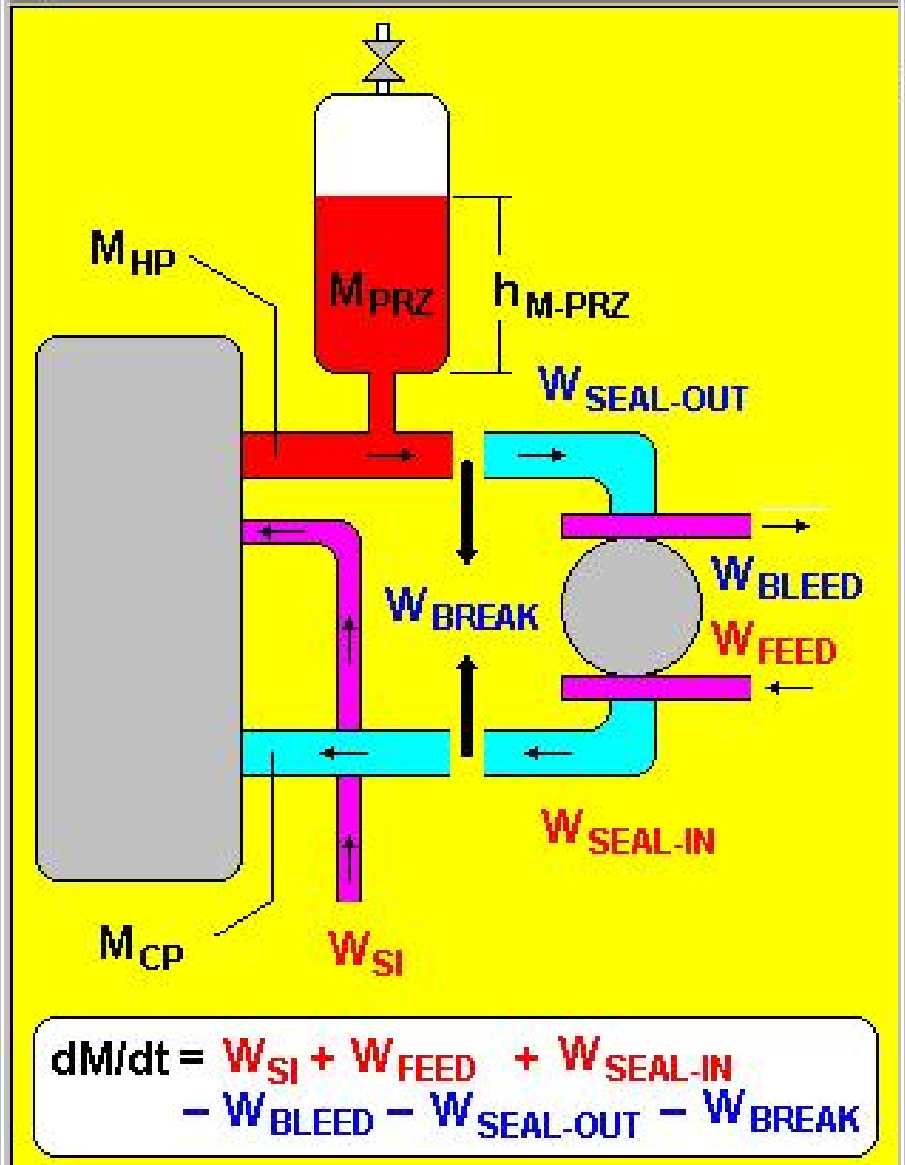
08. KONVOI PWR, Dual Containment

Windows



STEPS/CONTAINMENT: MASSIC INFLOW SIMULATOR

INPUT SCHEMATICS



INPUT DATA

File Edit

INPUT DATA

Maximize this window.
Edit 'static' data, directly.
To provide 'dynamic' data, select t
(double-click line inception or dep
and brush over line), then click bu
Use visual aid in the background wi

A. Static

These are static data.
Please change defaults as appropria

01. Inflow Duration (from initiator
02. PC Cold Leg Volume, Vcp
03. PC Hot Leg Volume, Vhp
04. Pressurizer Cross Section Area,
05. Pressurizer Effective Height, H
06. Normal Liquid Phase Level in Pr

Close Selected

The Model

THE MODEL-SYSTEM is a nuclear reactor with two temperature zones and with delayed neutrons neglected.
The model equations are:

$$\frac{dQ}{dt} = \left(\frac{Rc}{L}\right)Q \qquad (1)$$

$$(RoF.VF.CpF)\frac{dTF}{dt} = VF.Q - kS.S.(TF - TC) \qquad (2)$$

$$(RoC.VC.CpC)\frac{dTC}{dt} = kS.S.(TF - TC) - G.CpC.TC.phi \qquad (3)$$

- where:
- *Q* (W/m3) is the core power density;
- *TF* (K) is the temperature in the zone 1 (fuel+clad);
- *TC* (K) is the temperature in the zone 2 (primary coolant);
- *VF* (m3) is the fuel volume;
- *VC* (m3) is the primary coolant volume;
- *CpF* (J/(kg.K)) is the specific heat of fuel;
- *CpC* (J/(kg.K)) is the specific heat of primary coolant;
- *RoF* (kg/m3) is the fuel density;
- *RoC* (kg/m3)) is the primary coolant density;
- *kS* (W/(m2.K)) is the global coefficient of heat transfer, and
- *S* (m2) is the surface of heat transfer between zones 1 and 2;
- *G* (kg/s) is the coolant massic flow;
- *Rc* (1.0e-5 *dk*/*k*) is the total reactivity;
- *L* is of the order of 1.0e-4 s, for thermal neutrons;
- *phi* is a scaling constant.

The Model

- With the adiabatic approximation one has:
- $dTF/dt = 0$ (4)
- $dTC/dt = 0$,
- which makes Eqs.(2), (3) read:
- $VF.Q - kS.S.(TF - TC) = 0$ (5)
- $kS.S.(TF - TC) - G.CpC.TC.phi = 0$.
- Solving the system (5) one obtains:
- $TF = A.Q$ (6)
- $TC = B.Q$,
- with
- $A = VF(1/(kS.S) + 1/W)$ (7)
- $B = VF(1/W)$
- $W = G.CpC.phi.$

The Model

The total reactivity *Rc* is composed of the reactivity from the control rods, *Rc0*, which includes the effect of the fuel burnup, and two temperature-feedback terms relating to fuel and primary coolant, respectively:

$$Rc = Rc0 + alphaF.TF + alphaC.TC \quad (8)$$

- In turn, it is generally admitted that
- $alphaC = a + b.TC$ (9)
- $alphaF = c + d.TF$
- Introducing Eq.(9) and Eqs.(6,7) into Eq.(8), and then the resulting Eq.(8) into Eq.(1) one obtains:
- $L.dQ/dt = Rc0.Q + n.Q^2 + m.Q^3$ (10)
- with
- $n = c.A + a.B$ (11)
- $m = d.A^2 + b.B^2$
- The change of variable
- $q = Q - epsilon$ (12)
- transforms Eq.(10, 11) into:
- $L.dq/dt = q^3 + U.q + V$ (13)
- where
- $U = Rc0/m - n^3/(3\ m^2)$ (14)
- $V = 2(n/(3m))^3 - n.Rc0/(3\ m^2)$
- and
- $epsilon = -n/(3m)$. (15)
- The stationary solution is obtain taking in Eq.(13)
- $dq/dt = 0$,

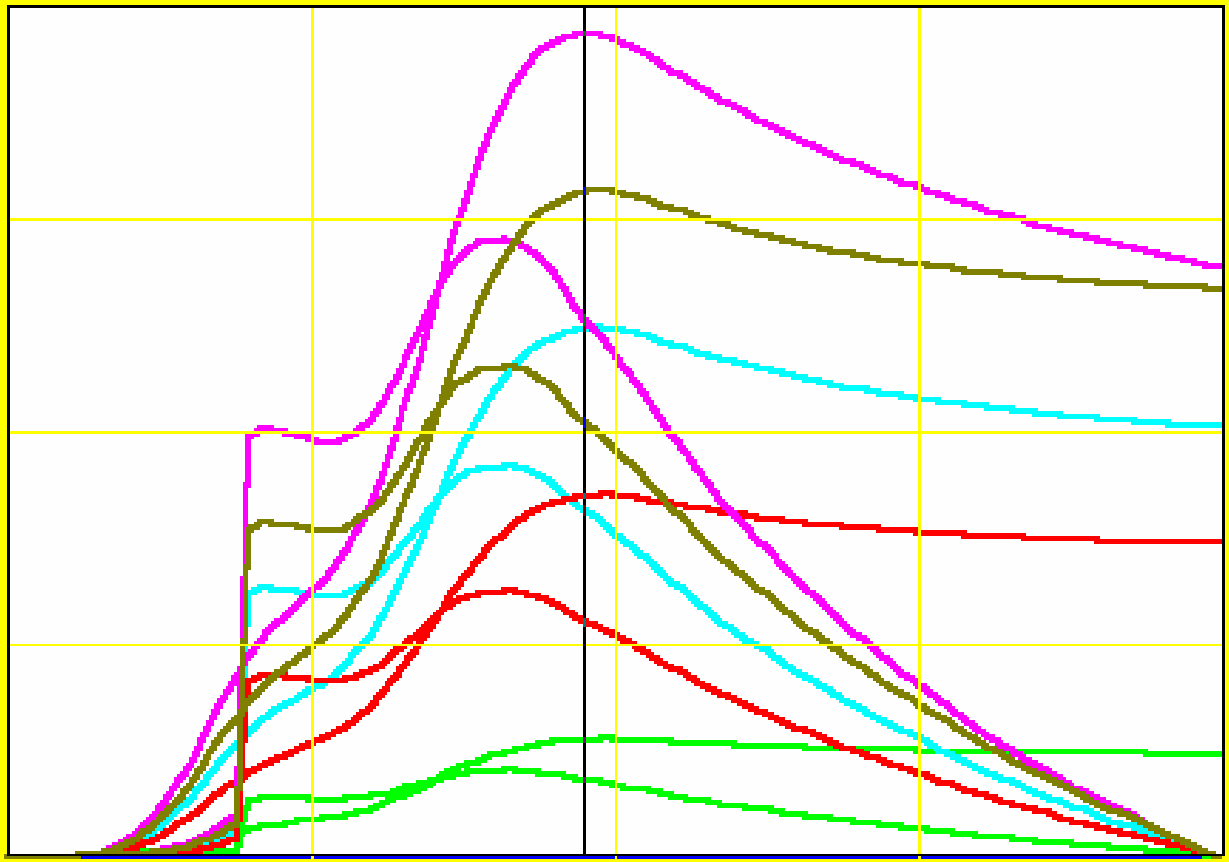
That is:

- $q^3 + U.q + V = 0.$ (16)
-
- ***Equation (16) is the 'equation of state' of the system, in the sense of the model, providing a space of states (also known as system's 'characteristic') in the form of a cuspidal foil,***
- $q = q(U, V).$ ***(17)***

STEPS - CONTAINMENT: OUTPUTS

CONTAINMENT DIRECT OUTPUTS Listing

Source Term OUTPUTS Graphics



NUKE	Bq/m3	Bq/s
I-129		
I-131		
I-132		
I-133		
I-134	6.9590e10	1.0779e11
I-135		

Time (s): 856

Click NUKE and scan data field,
for Bq/m3 IN containment
and Bq/s OUT of containment.

Unit: Fictplant-x
Power: 1000
Builder: FICT
Containment: PWR/LD/SA

Time Sprays On (s): 300
Time Sprays On (s): 1200
Time Ice Bed Exhaustion (s): ?
Time Pool Out (s): ?

OK

QVA - QUANTITATIVE VULNERAB

CONTINUE Data Library File Edit

VULNERABILITY ANALYSIS

The general QVA approach (
that system's monitored pa
the control variables U an
for vulnerability analysis
one submits that U and V a
of impact indicators.

When a QVA concept is temp
such as a coherently funct
U and V parameters of the
the physical laws governin
The difference between the
variables' is maitained. H
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The most general criterion
a specific (as opposed to

A SYSTEM MAY BECOME A SUBJ
IN THIS WORK - IF ITS PROC
AN EQUATION OF STATE Z = Z
SOLUTIONS A CUSPIDAL FOIL
REGIONS.

Since the process equation
it becomes virtually impos
for a QVA code. On the oth
observed with the 'generic
machines still stands vali

The physical indicator val
interface via their relati
from Yi as:

Xi = A.Yi + B, i = 1, 2

The constants A and B are,
knowledge of pairs of valu
physical (Y) and normalize

A.Yi1 + B = Xi1
B.Yi2 + B = Xi2

wherefrom

A = (Xi2 - Xi1)/(Yi2 - Yi1

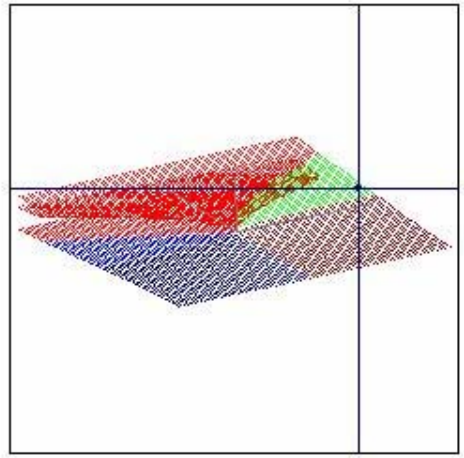
VULNERABILITY - Sensitivity Analysis

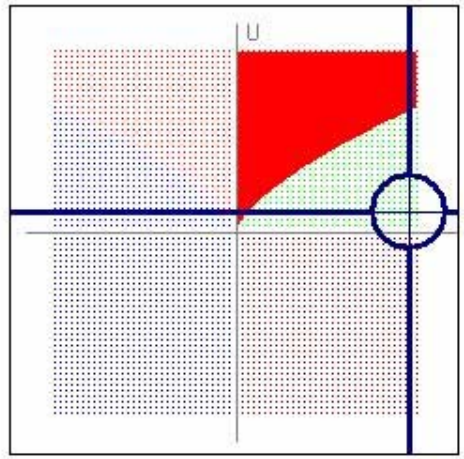
Files Settings

SYSTEM INDICATORS

Baseline Reactivity (1/s)	0.2
Coolant Flow Rate (kg/s)	0.2
Heat Exchange Coefficient (W/(m2....	0.2
Fuel Temp.Reactivity Coeff.#1 (1/...	0.2
Fuel Temp.Reactivity Coeff.#2 (1/...	0.2
Coolant Temp.Reactivity Coeff.#1 ...	0.2
Coolant Temp.Reactivity Coeff.#2 ...	0.2
Coolant Specific Heat (J/(kg.K))	0.68
Heat Exchange Area (m2)	0.6
Fuel Volume (m3)	0.2

Heat Exchange Area (m2)...: 20.0





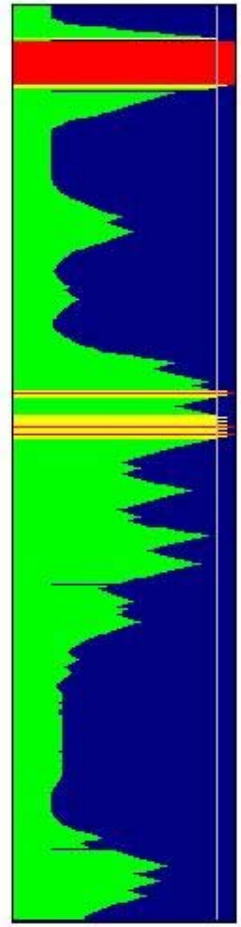
SYSTEM TEMPERATURE (K): 273:

U = 0.11093822 V = 0.96303264

SYSTEM STABLE. LOW VULNERABILITY

VULNERABILITY SCALE INDEX (1-100): 32.602

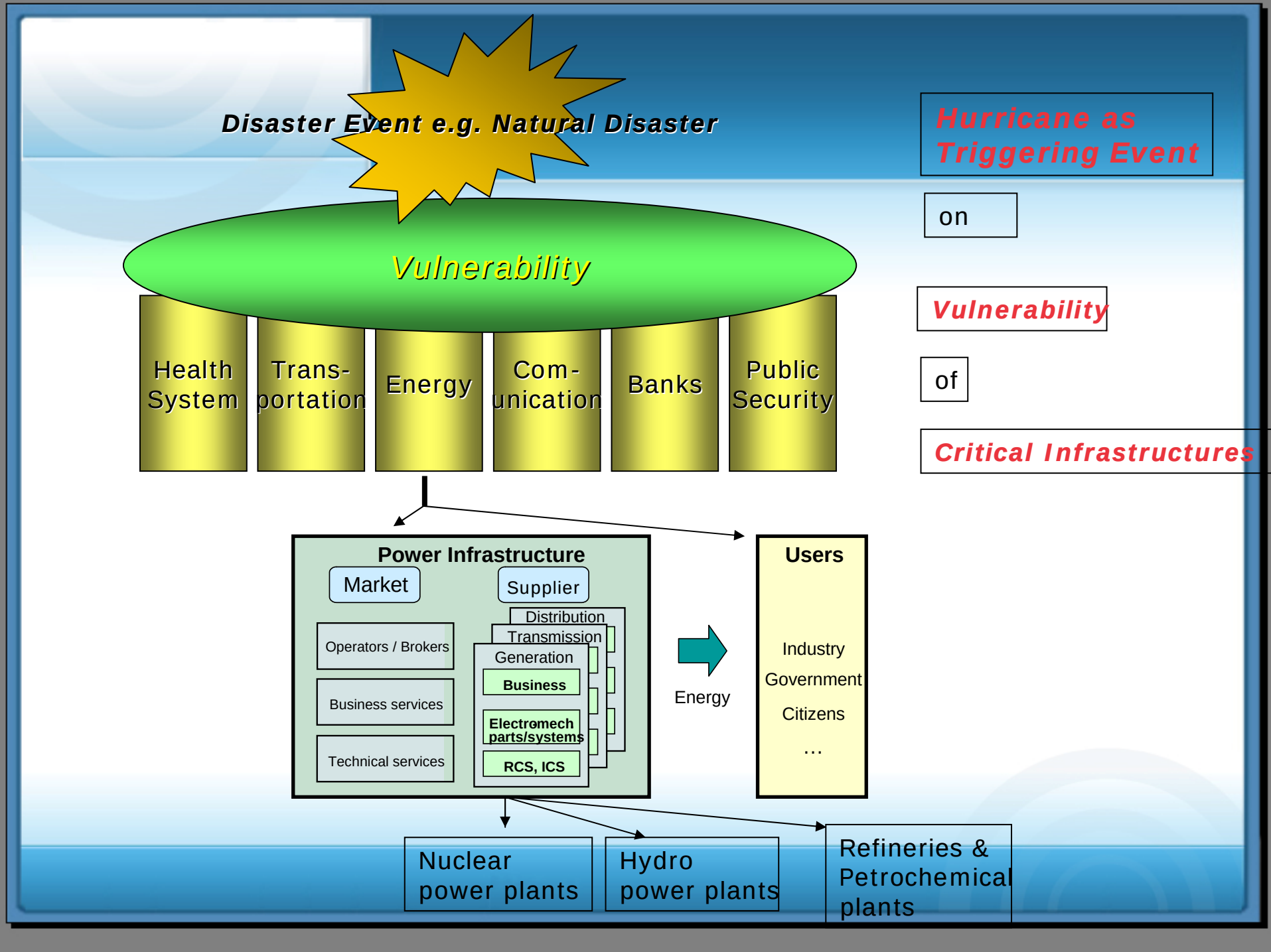
0 V-Scale 100

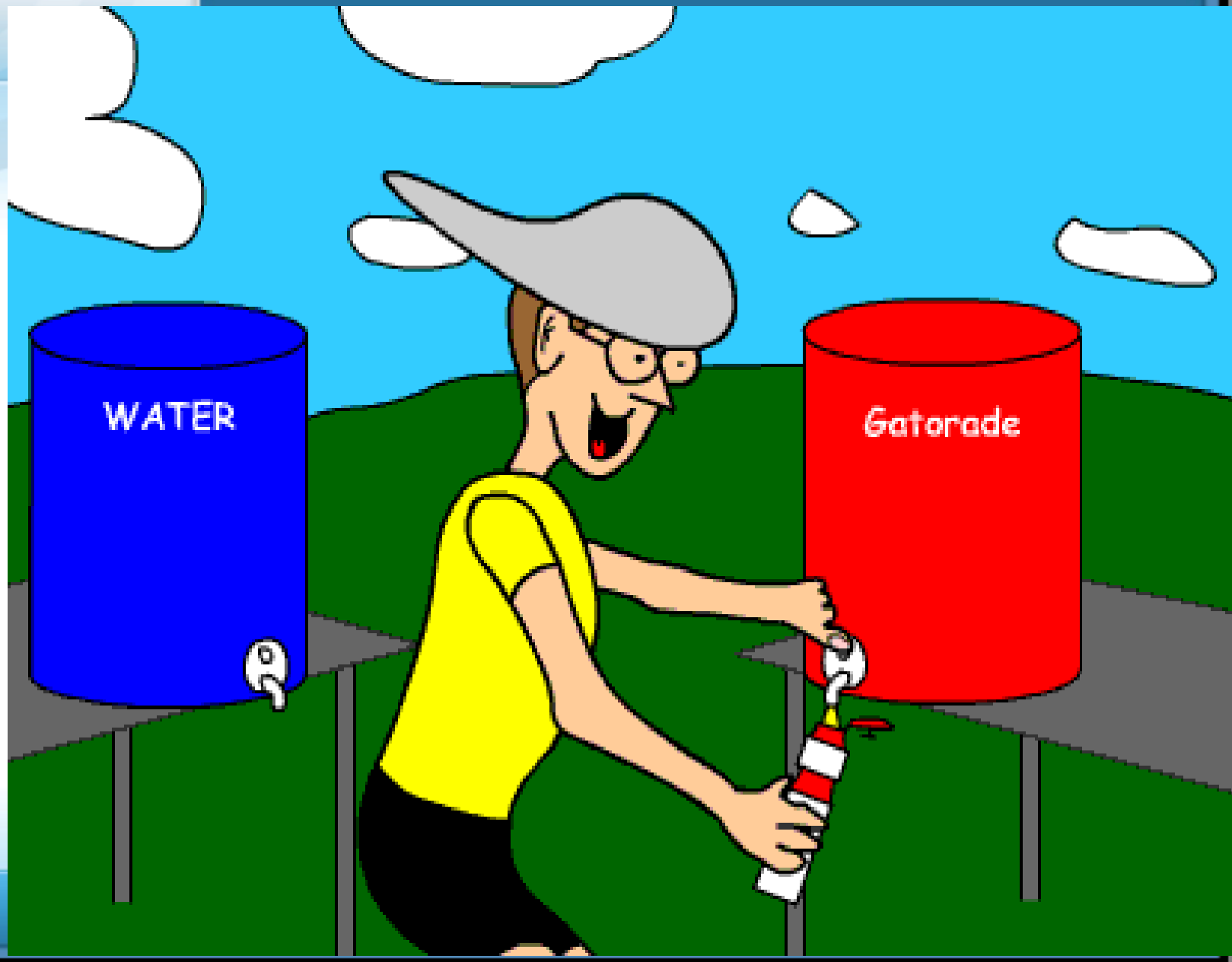


U - GRAM

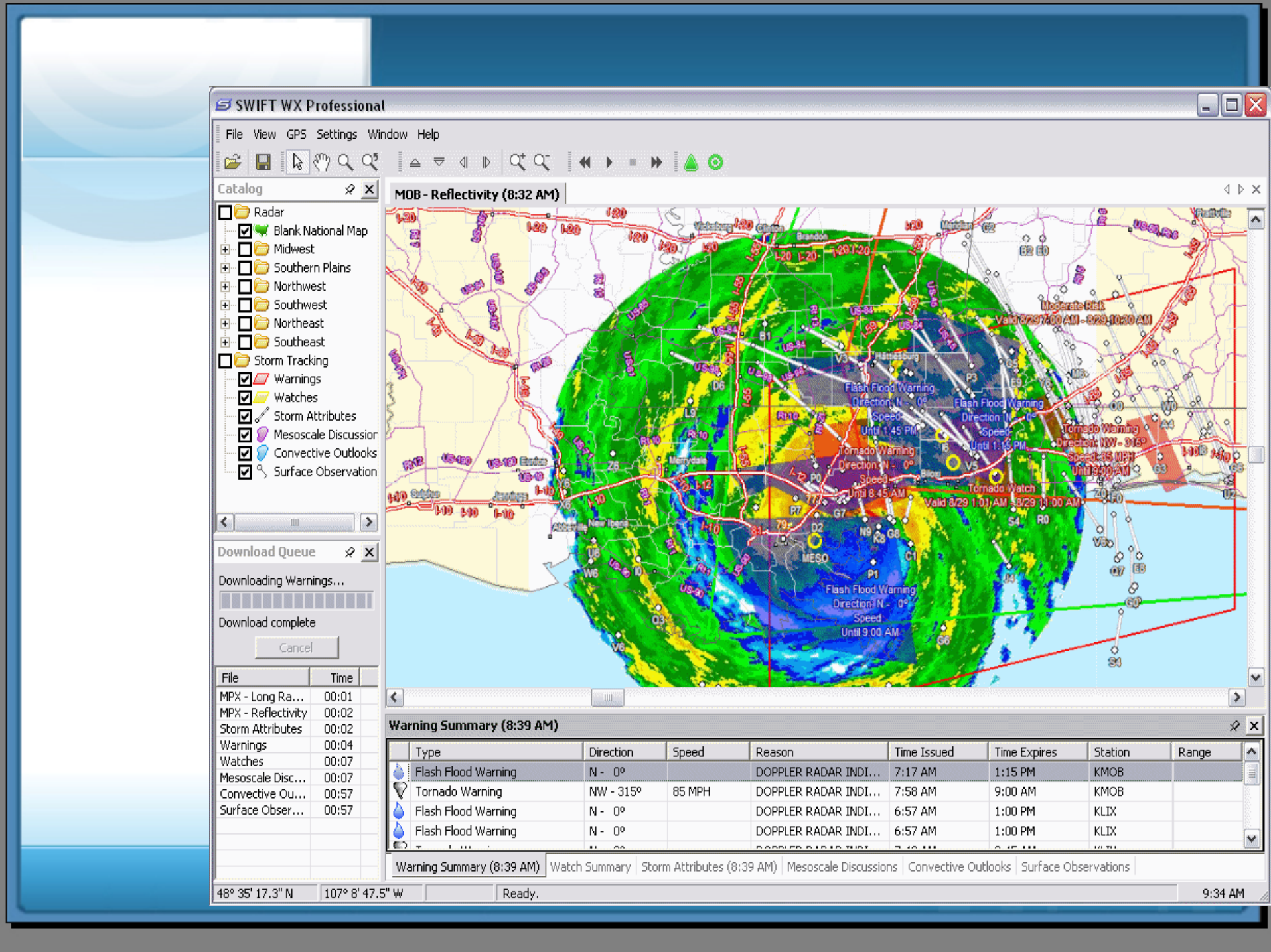
Critical Vulnerability Level
currently set to 90.
on the 0 - 100 scale.
Use the menu to change.

start SOFT SURE... SOFT SURE... STRUCTURA... QVA - QUAN... VULNERABIL... 2:12 PM


Disaster Event e.g. Natural Disaster
Hurricane as Triggering Event
on
Vulnerability
Vulnerability
of
Critical Infrastructures
Health System
Trans-portation
Energy
Com-unication
Banks
Public Security
Power Infrastructure
Market
Supplier
Distribution
Transmission
Generation
Business
Electromech parts/systems
RCS, ICS
Operators / Brokers
Business services
Technical services
Energy
Users
Industry
Government
Citizens
...
Nuclear power plants
Hydro power plants
Refineries & Petrochemical plants


WATER
Gatorade


LIVE
CNN
4:32a ET
DAYBREAK
NT QUADRANT, CUR
AST TO HIT THE COAST OF
M Tue
MS
AL
LA
2 AM
M Mon
Hmmm....
5 AM Sat

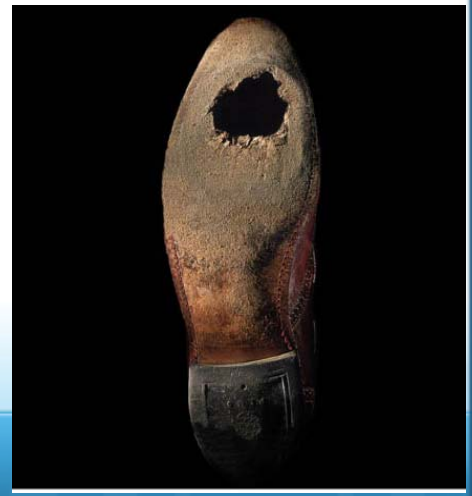

SWIFT WX Professional
File View GPS Settings Window Help
Catalog
Radar
Blank National Map
Midwest
Southern Plains
Northwest
Southwest
Northeast
Southeast
Storm Tracking
Warnings
Watches
Storm Attributes
Mesoscale Discussion
Convective Outlooks
Surface Observation
Download Queue
Downloading Warnings...
Download complete
Cancel
File Time
MPX - Long Ra... 00:01
MPX - Reflectivity 00:02
Storm Attributes 00:02
Warnings 00:04
Watches 00:07
Mesoscale Disc... 00:07
Convective Ou... 00:57
Surface Obser... 00:57
MOB - Reflectivity (8:32 AM)
Flash Flood Warning
Direction: N - 0°
Speed:
Until 1:45 PM
Tornado Warning
Direction: N - 0°
Speed:
Until 8:45 AM
Tornado Warning
Direction: NW - 315°
Speed: 85 MPH
Tornado Watch
Valid 8/29 1:01 AM - 8/29 11:00 AM
MESO
Flash Flood Warning
Direction: N - 0°
Speed:
Until 9:00 AM
Warning Summary (8:39 AM)
Type Direction Speed Reason Time Issued Time Expires Station Range
Flash Flood Warning N - 0° DOPPLER RADAR INDI... 7:17 AM 1:15 PM KMOB
Tornado Warning NW - 315° 85 MPH DOPPLER RADAR INDI... 7:58 AM 9:00 AM KMOB
Flash Flood Warning N - 0° DOPPLER RADAR INDI... 6:57 AM 1:00 PM KLIX
Flash Flood Warning N - 0° DOPPLER RADAR INDI... 6:57 AM 1:00 PM KLIX
Warning Summary (8:39 AM)
Watch Summary
Storm Attributes (8:39 AM)
Mesoscale Discussions
Convective Outlooks
Surface Observations
48° 35' 17.3" N
107° 8' 47.5" W
Ready.
9:34 AM


HURRICANE
KATRINA
DISASTER
RELIEF

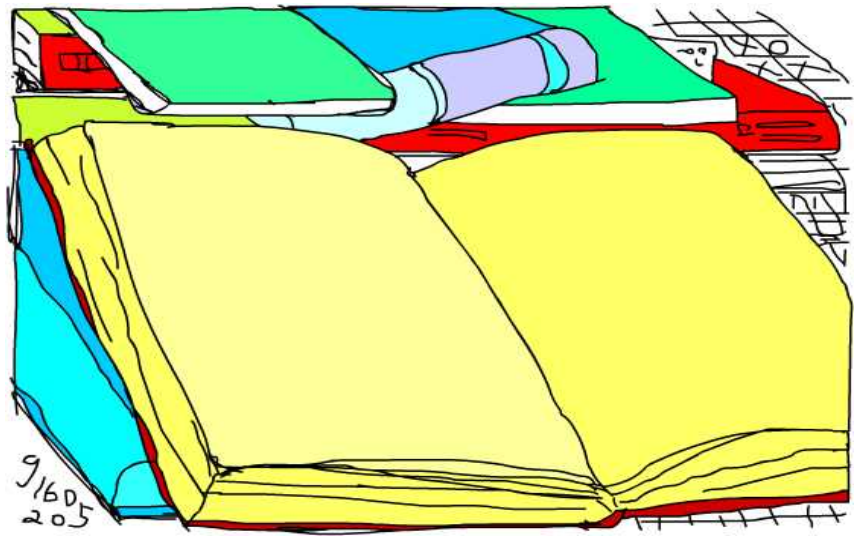
Katrina

"I remember reading that civilization is only ever three missed meals away from anarchy"

James MacMillan, Glasgow, UK
BBC News

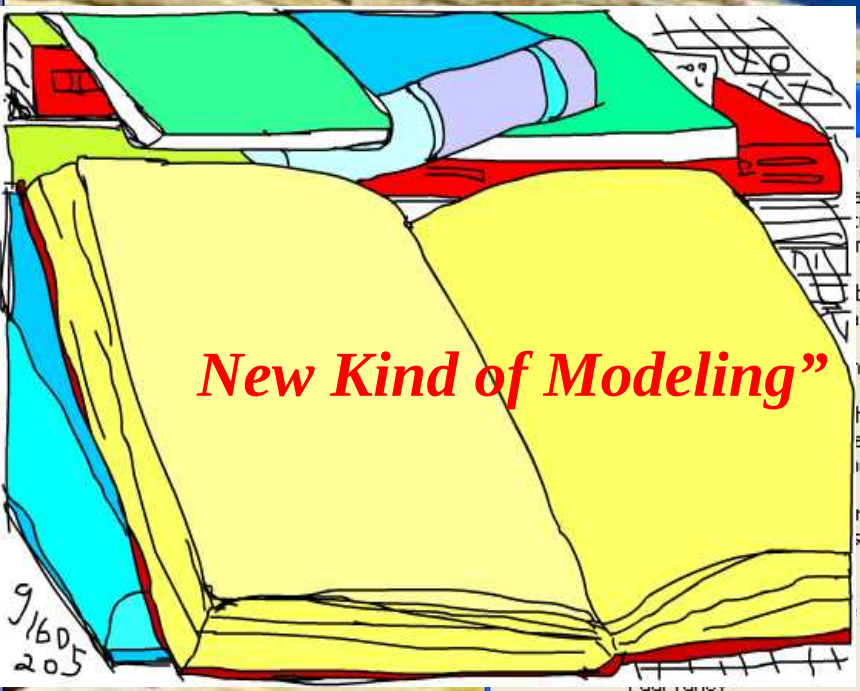


Katrina



V - M A T R I X - INFERRING VULNERABILITIES FROM NUMBERS AND WORDS

Files Data Utilities About



decision support.
ata libraries and web resources in an attempt to
rinsically and comparatively assess the vulnerability
n of their structural, and governance deficiencies.

be considered a concept proof only.
number of limitations, bearing, inter alia, upon

dicators in the U (governance deficiency) and V (structural

he indicator rating; and
er plausible and convenient - manner of quantifying
dicators.

rcise by KOVERS - KT, a knowledge transfer unit within the
is of the the Swiss Federal Institute of Technology ETH-Zurich.

especially recognized:

Alyce Watson
Robert Jung
Bogdan Vamanu

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FEEDBACK AND COMMENTS ARE WELCOME.
Please contact: Adrian GHEORGHE,
gheorghe@mavt.iet.ch

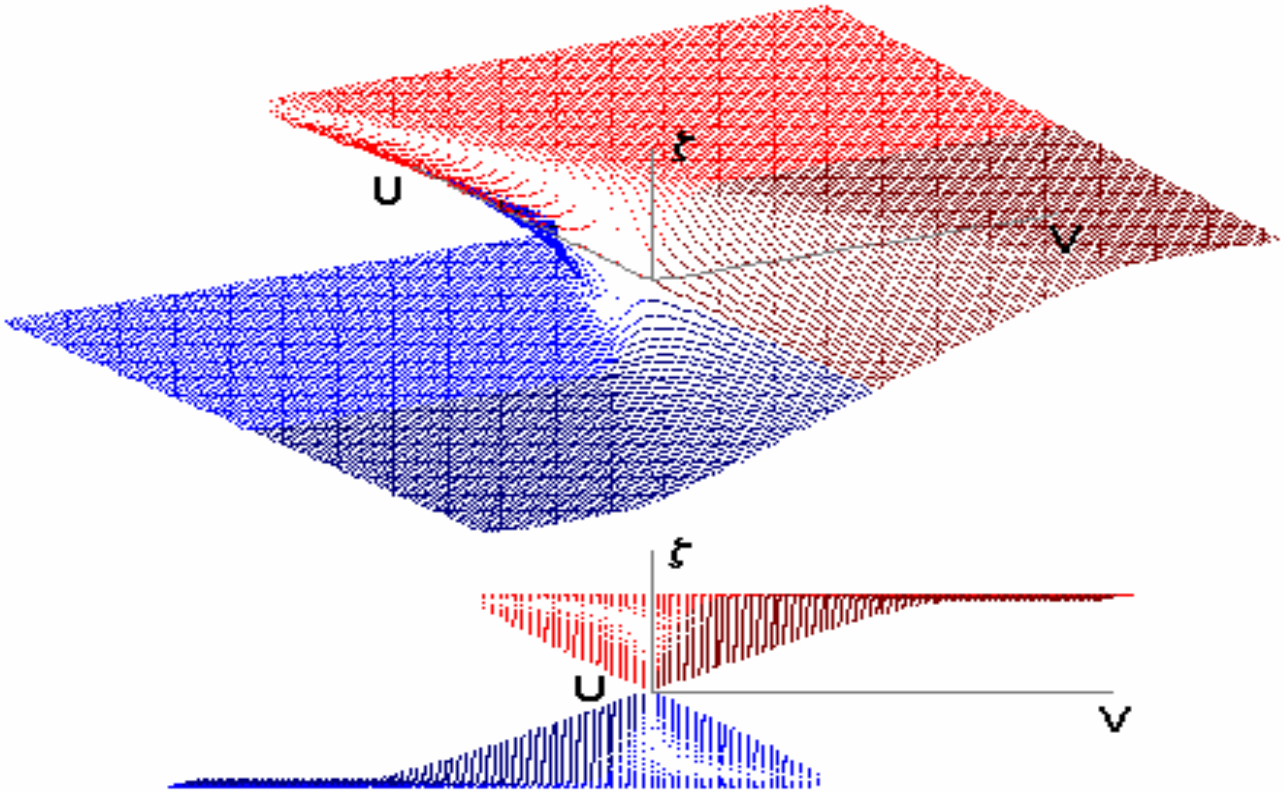
OK

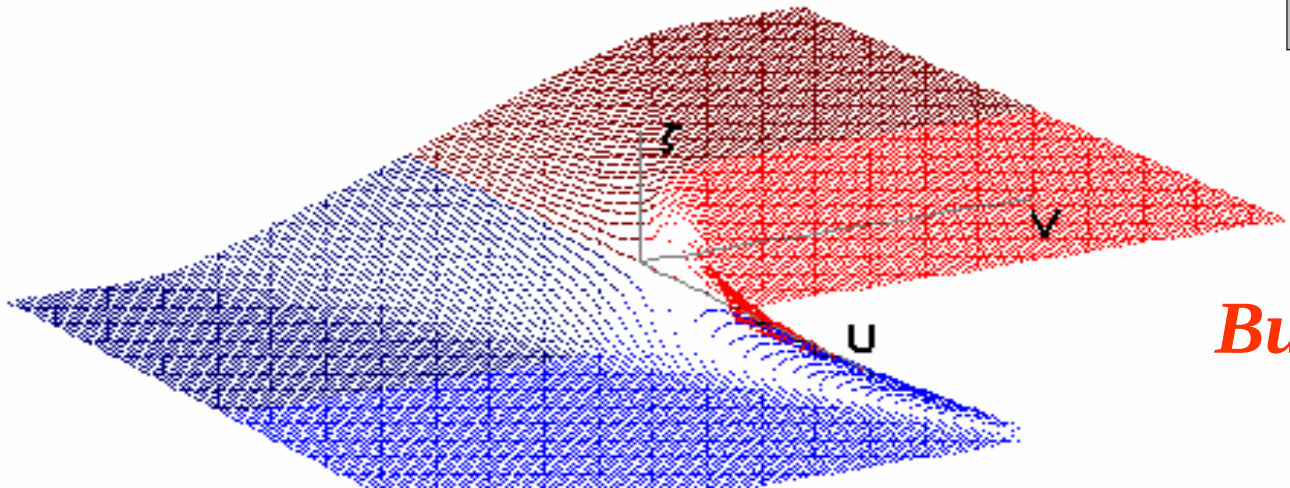
The KOVERS Soft Library

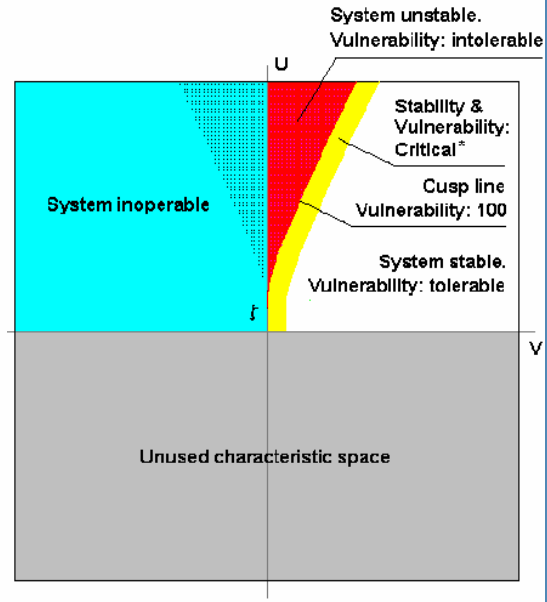
ETH KRS

start Inbox - Microsoft Out... V - M A T R I X - IN... 11:31 AM

SYSTEM TEMPERATURE (K): 273

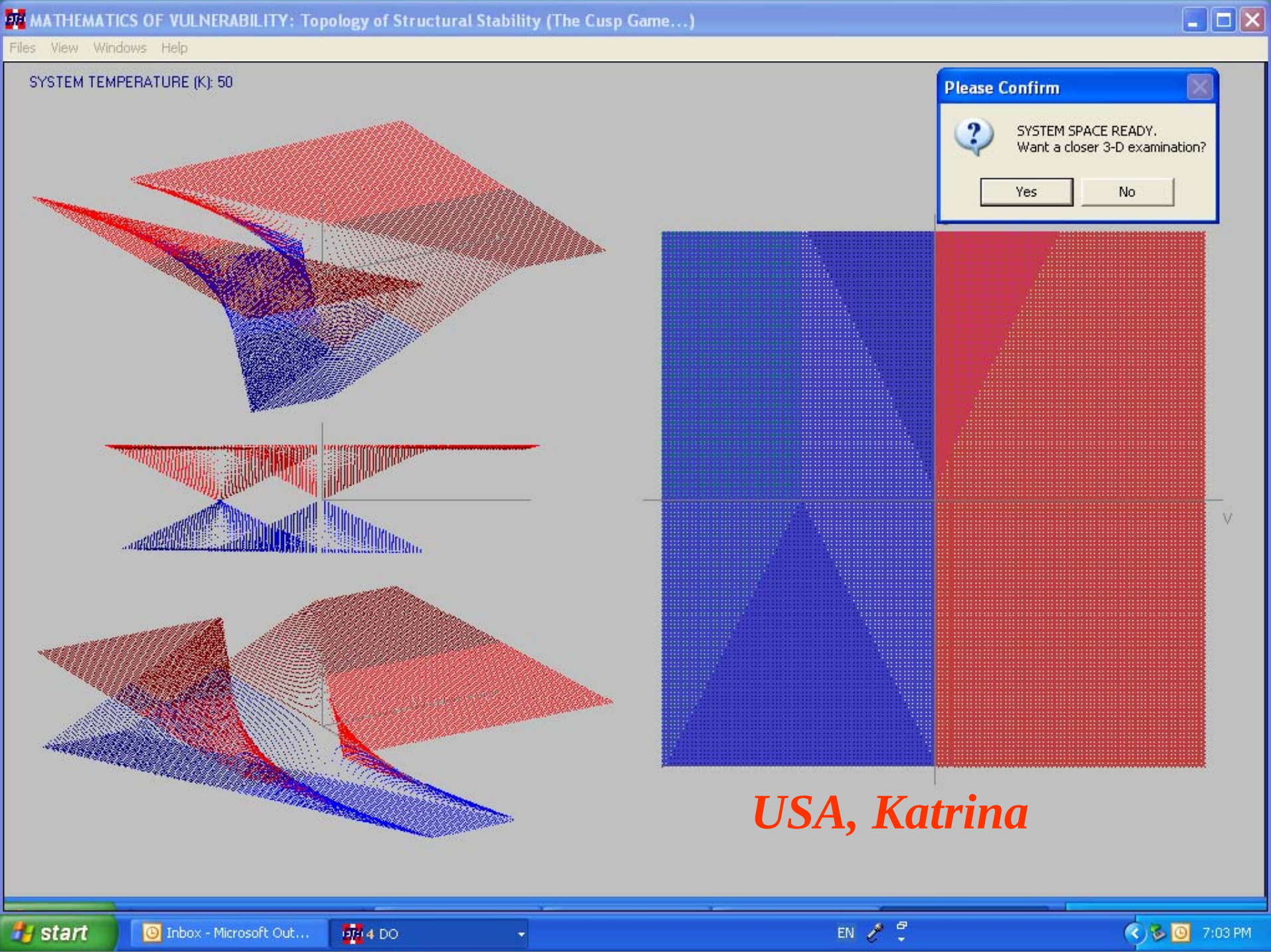






* Critical Vulnerability Level to be set by the analyst, between 0 and 100.

Business as usual


MATHEMATICS OF VULNERABILITY: Topology of Structural Stability (The Cusp Game...)
Files View Windows Help
SYSTEM TEMPERATURE (K): 50
Please Confirm
SYSTEM SPACE READY.
Want a closer 3-D examination?
Yes
No
V
USA, Katrina
start
Inbox - Microsoft Out...
4 DO
EN
7:03 PM

Backbone

- 'Society' as a collection of many, M, interacting individuals, of which M_1 are law-abiding, and M_2 are not.
- The 'Normal' condition of a 'law-and-order-patterned, functional' society/community implies $M_1 >> M_2$.
- A Katrina-scale event:
  - disrupts the critical infrastructures (CI - power, sewage, drinking water, health services, police, firefight etc.) in an time-evolving aggravating sequence;
- As a certain 'unpredictable' limit in CI degrading is crossed, the law-and-order society collapses into an anarchic, lawless society, featuring $M_2 >> M_1$.
- The Gheorghe-Vamanu QVA model comes in:
- Model's main task is *to reveal where the hidden fault which, if crossed, makes the lawful society collapse into a lawless society is, and how could it be hopefully detected in advance*.

The task translates into a typical application of the QVA model :

- **Use V-MATRIX!**
- **Define the U-class as '*Critical Infrastructure (CI) Dependency Index*' and the V-class as '*CI Management Capability and Availability*'.**
- **Identify a sufficient number of U-class indicators among those offered by *V-MATRIX* – typically indicators qualifying welfare (from GDP/capita to number of Internet users…).**
- **Identify a sufficient number of V-class indicators among those offered by *V-MATRIX* – typically indicators qualifying infrastructure availability and management (from electricity generation capability to radios and TV sets per cap etc) – needs careful consideration, of course.**
- **Conduct Quantitative Vulnerability Assessment:**
  - ***for U.S.***
  - ***for New Orleans – if feasible (indicators?)***
  - ***for other catastrophe-struck countries (South-East Asia, Japan etc.)***
- **Discuss calibration via model's 'temperature' and 'tolerability offset', and use/suggest Katrina as calibration case!**

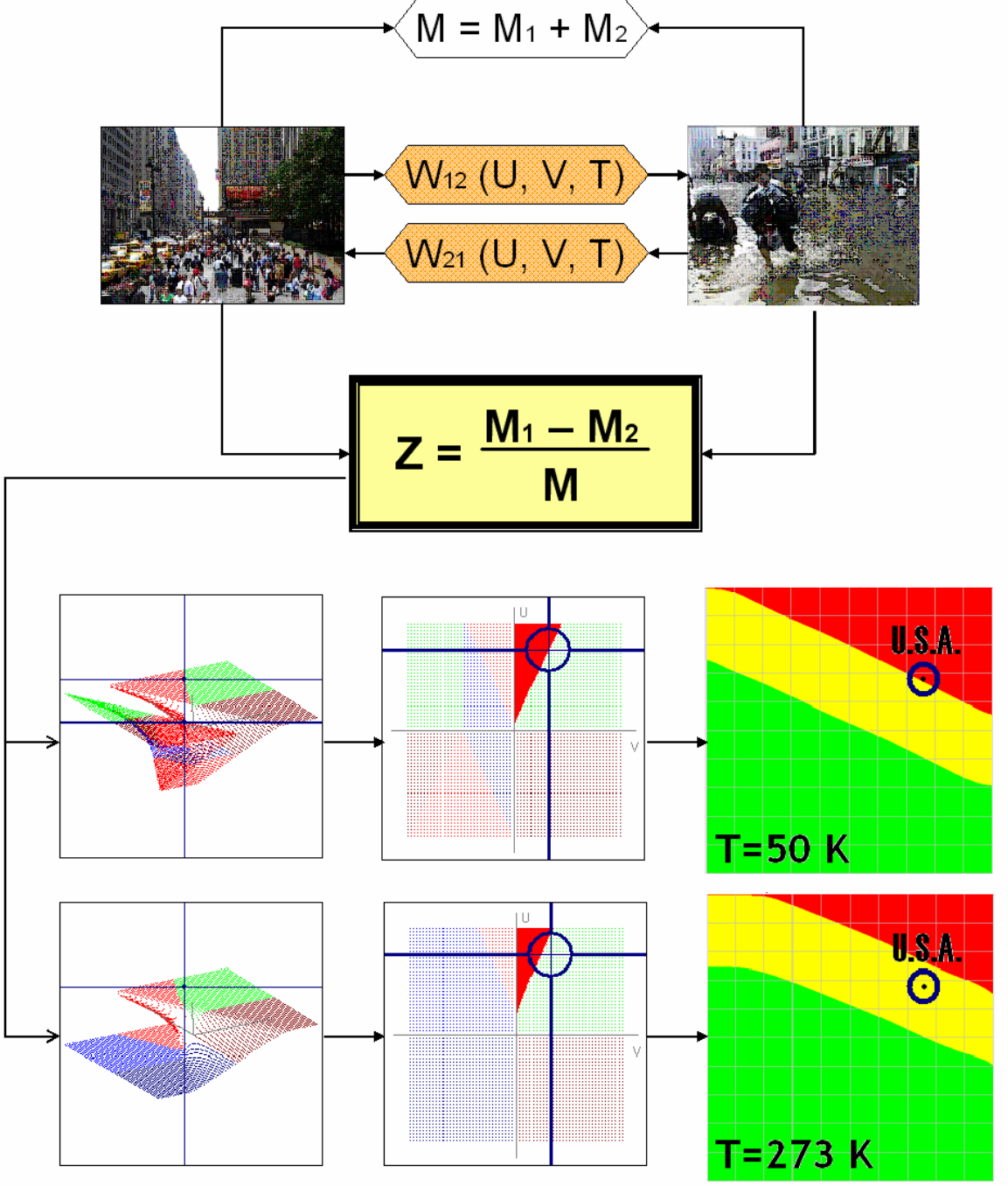
DISASTERS: FROM CROWDS TO MOBS

?

WHY?
WHEN?

M1 + M2 = M

THE MODEL



M_1 – Law-Abiding Citizens
M_2 – Law-Breaching Citizens
M – Total Constituents
W – Transition Probabilities
Z – Governability Fraction
U – Infrastructural Services Addiction Index
V – Societal Management Issues and Deficiencies Index
T – System 'Temperature'

Theme: Societal Governability Collapse Under Disaster

WORKFLOW

Indicators

SOCIETAL GOVERNABILITY. MINIMAL SET.

1. DEMOGRAPHY
   - 1-1-1. Religions
   - 1-1-2. Literacy total population
2. ECONOMY
   - 2-1-1. GDP - per capita purchasing power parity - $
   - 2-1-2. Services
   - 2-1-3. Unemployment rate
3. OTHER GOVERNABILITY RESOURCES
   - 3-1-1. Military expenditures - percent of GDP

SOCIETAL GOVERNABILITY. THE EXTREME ASSUMPTION.

1. DEMOGRAPHY
   - 1-1-1. Religions
2. ECONOMY
   - 2-1-1. GDP - per capita purchasing power parity - $

U: Integrates dependence on infrastructural services; loosely relating to standards of living and affluence.
V: Integrates societal issues and capability to manage these.
S: Increases vulnerability when incremented.
I: Decreases vulnerability when incremented.

U / *V* Allocation

1-1-1. Religions	V
1-1-2. Literacy total population	U
2-1-1. GDP - per capita purchasing power parity - $	U
2-1-2. Services	U
2-1-3. Unemployment rate	V
3-1-1. Military expenditures - percent of GDP	V

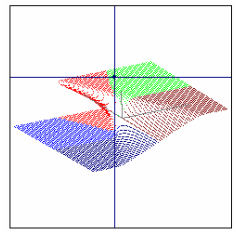
Indicator Interdependence Matrix

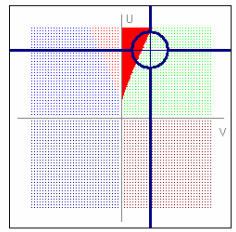
	1-1-1	1-1-2	.....	3-1-1
1-1-1. Religions	1	0	.....	0
1-1-2. Literacy total population	0	1	.....	0
2-1-1. GDP - per capita purchasing power parity - $	0	0	.....	0
2-1-2. Services	0	0	.....	0
2-1-3. Unemployment rate	0	0	.....	0
3-1-1. Military expenditures - percent of GDP	0	0	.....	1

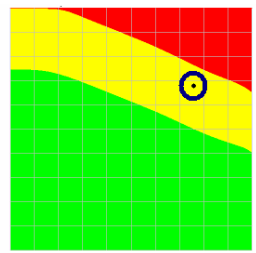
Stimulator (S) / Inhibitor (I) Allocation

1-1-1. Religions	S
1-1-2. Literacy total population	I
2-1-1. GDP - per capita purchasing power parity - $	S
2-1-2. Services	S
2-1-3. Unemployment rate	S
3-1-1. Military expenditures - percent of GDP	I

Assessment





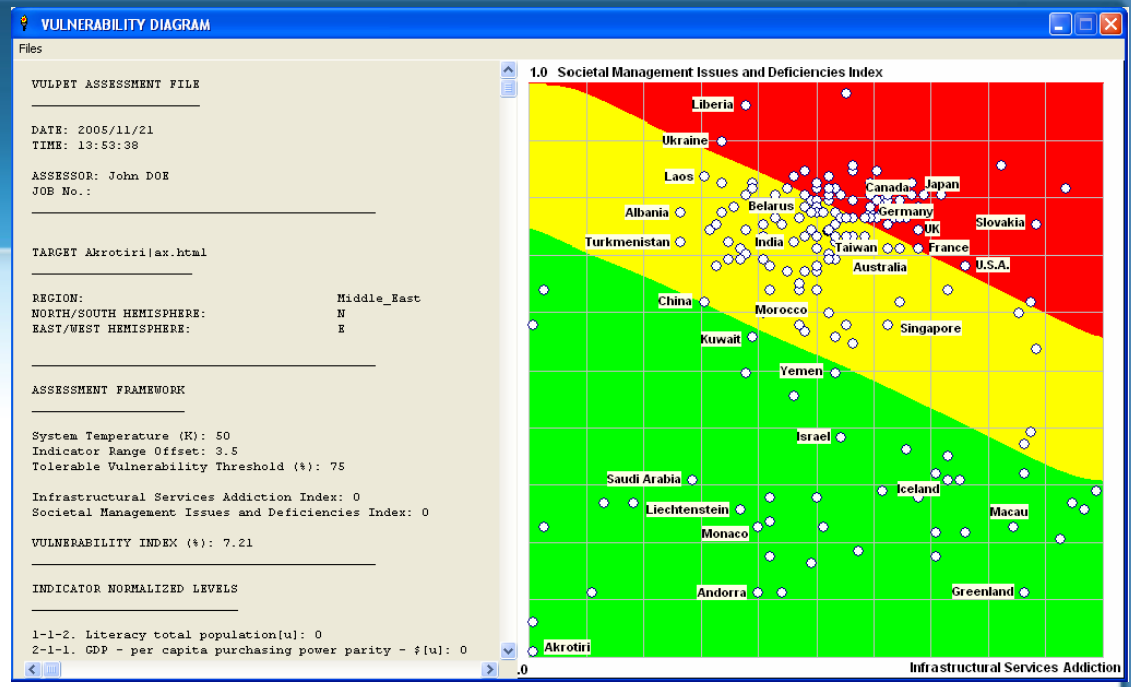


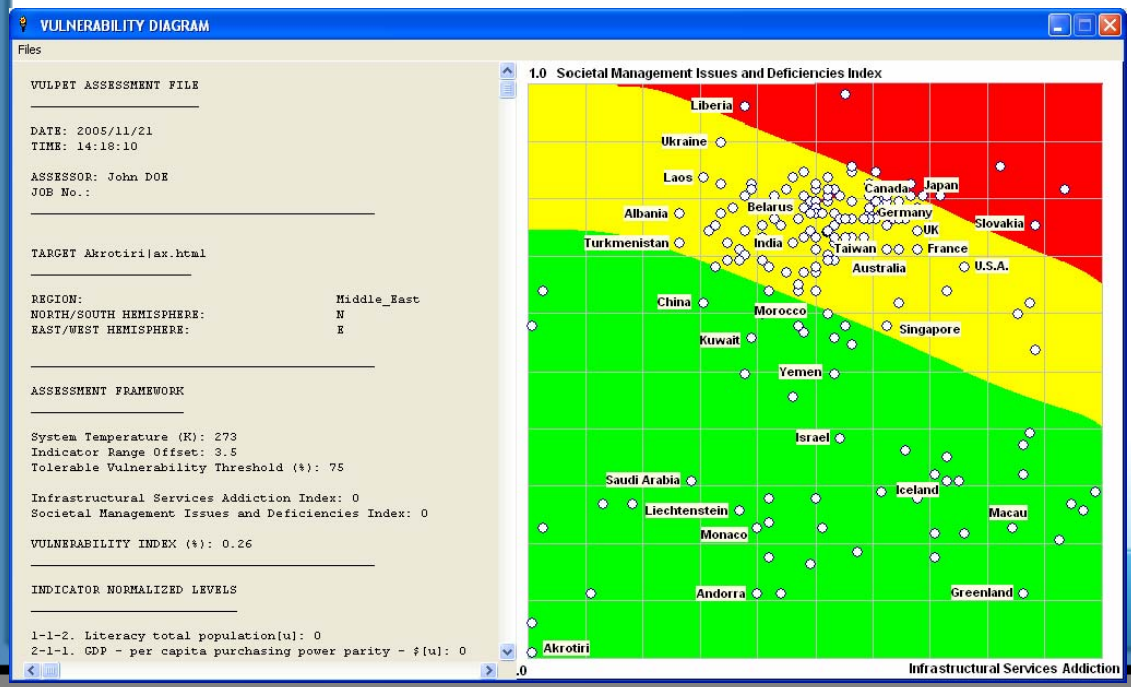
Country Ranking by Vulnerability of Social Order to Disasters I*

Model CALIBRATION:

Reference: USA, Katrina

- System at 50 K
- Indicator range offset 3.5





Model APPLICATION:

USA, Business as usual

System at 273 K

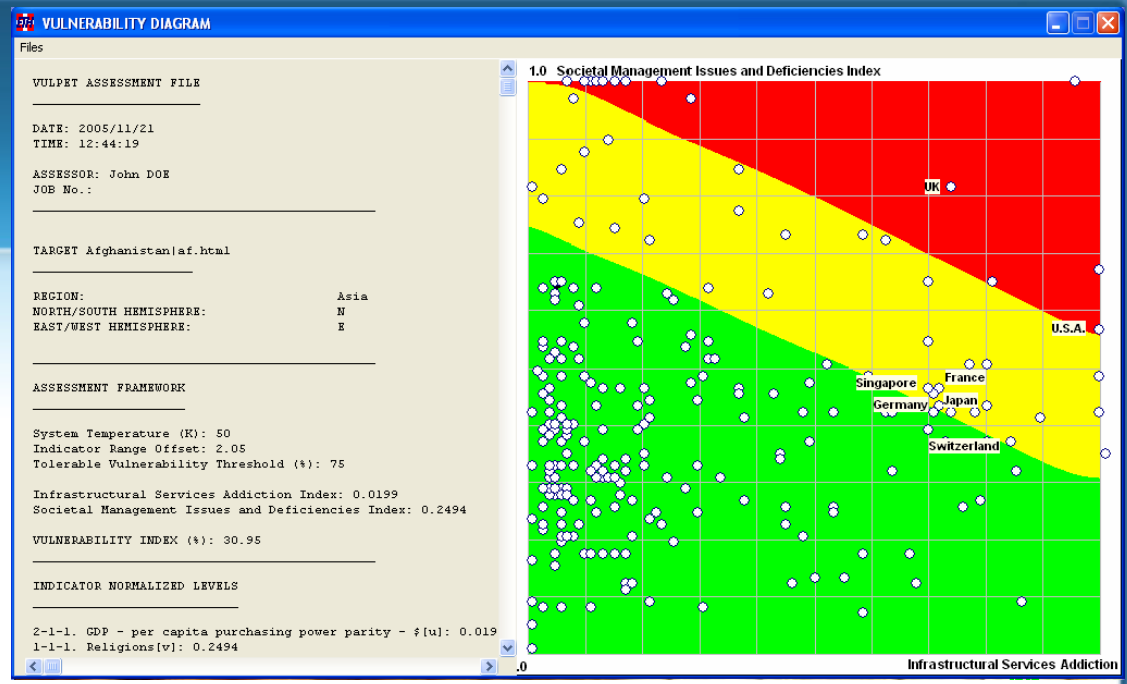
* Minimal indicator set

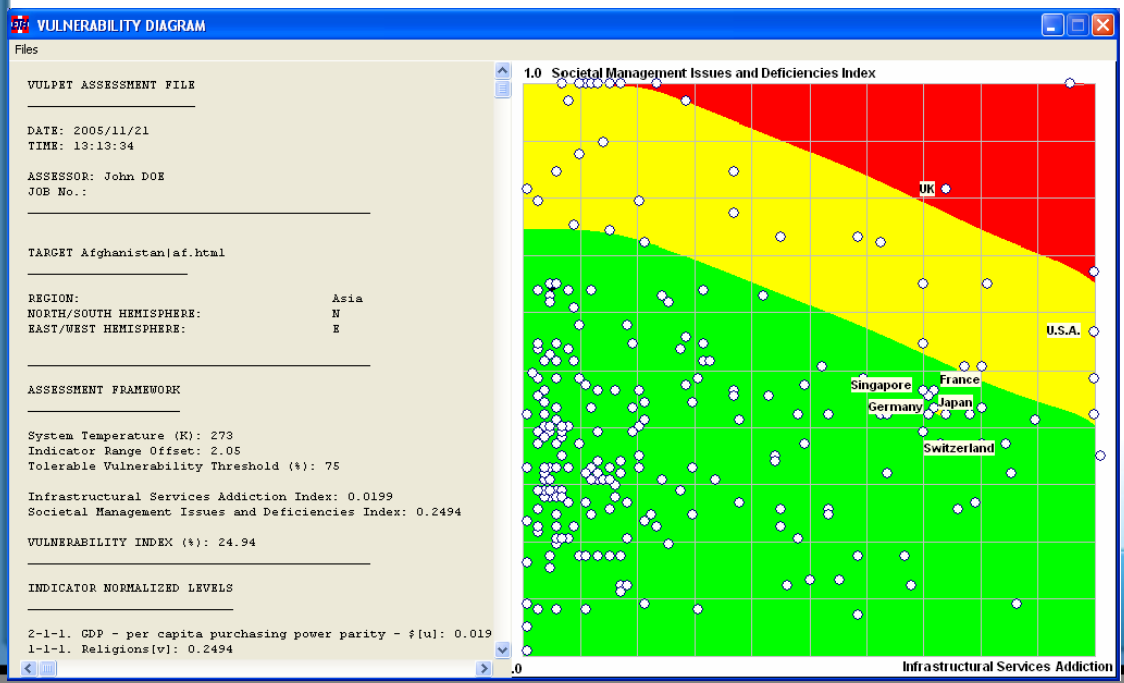
Country Ranking by Vulnerability of Social Order to Disasters, I**

Model CALIBRATION:

Reference: USA, Katrina

- System at 50 K
- Indicator range offset 3.5





Model APPLICATION:

USA, Business as usual

System at 273 K

** The extreme assumption: only two indicators

Approaching Resilient Critical Infrastructures