Knowledge-based Education and Awareness about the Radiological and Nuclear Hazards

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Abstract: There are multiple approaches to organize and formalize the knowledge related to nuclear accidents, emergency situations and management of hazards. However, in general, the materials available for educational and awareness purposes are not directly linked to an organized knowledge base. This paper shows our studies on representing and using the experts' knowledge on radiological and nuclear risks, with the purpose of making it more accessible to junior students and to other interested stakeholders. This effort resulted in an ontology of nuclear vulnerabilities, a set of rules, and processes for prevention, protection and emergency response, useful for understanding the decisions made by responsible institutions. These representations were applied in the development of a platform for informal education and awareness.

1 INTRODUCTION

All over the world, government agencies, local officials, nuclear plant owners and other stakeholders are directly interested in creating education and awareness about the radiological and nuclear hazards. This concern was also present in the key messages launched in 2013 by the International Federation of Red Cross and Red Crescent Societies (IFRCRCS) to increase public awareness and public education for disaster risk reduction.

The occurrence of severe nuclear accidents in Eastern Europe and Asia, as well as the problems raised by radioactive waste, have increased the general concern on nuclear power plants safety, up to discussing the acceptance by the large public of this form of producing energy (Bing et al., 2013). Apart from establishing and maintaining radiation protection measures in nuclear power plants, there are also issues like environment protection, climate change and potential conflicts between technological and social development, leading to the analysis of the people's risk awareness. Thus, the studies show that safety goals and public acceptance have a direct impact on each other (Li et al, 2012). Whereas the geographic proximity to a nuclear facility influences the interest towards the nuclear energy and the awareness of the induced vulnerabilities, it has not been proven to be an important factor in the acceptance of its usage (Cale and Kromer, 2015). However, the attitude changes for the population living in the vulnerability area of a former nuclear accident. Kitada (2016) analysed the results of multiple surveys realized in Japan, before and after the Fukushima Daiichi Nuclear Power Plant accident. After the event, the negative opinions about nuclear power increased; people were discussing more about renewable energies and tended to focus on the accident risks. The perception of nuclear energy risks in Taiwan and Hong Kong were also studied in (Grano, 2014). Similarly to Japan, they are seismic countries, densely populated and with nuclear power plants located side by side to urban centres, or in close proximity to numerous underwater volcanoes. The paper presents the implication of the government and media in disseminating crucial information and influencing public opinion and perception of risk. Education on natural disasters in general also has its impact in this respect (Smawfield and Ed, 2013).

The idea supported in this paper is that education and awareness can also be created in correlation with formalized knowledge regarding the management of

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hazards, crisis situations, and disasters, currently existing in a multitude of representations, or newly created for education and awareness purposes. Section 2 summarizes the existing background and related work, Section 3 presents the knowledge representations, composed of: an ontology, a set of rules, and processes regarding the management of radiological and nuclear hazards. Section 4 shows the application of the formalized knowledge in the development of a platform for education and awareness concerns.

2 BACKGROUND AND RELATED WORK

For the knowledge of our domain of interest, a major contribution comes from the International Atomic Energy Agency (IAEA), who also published a "Nuclear Accident Knowledge Taxonomy" (IAEA, 2016), along with many other reports, recommendations and guides. Other research-oriented approaches also exist, like the nuclear or radiological emergency ontology presented in (Konstantopoulos and Ikonomopoulos, 2015).

Due to the increasing role of social media in any crisis situation, including those related to natural hazards, one also proposed an ontology to help dealing with the exceeding media content and extracting situational information (Moi et al, 2016). A comprehensive review of the state of the art in crisis management ontologies is given in (Liu et al., 2013), identifying a set of critical subject areas that cover the information concepts involved in crisis management, such as resources, processes, people, organizations, damage, disasters, infrastructure and geography.

The knowledge bases used in disaster situations were studied in (Hristidis et al., 2010), based on an analysis that goes across several Information Technology areas: data integration and ingestion, information extraction, information retrieval, information filtering, data mining and decision support. Based on the integration of seven existing vocabularies or ontologies, Gaur et al. (2019) proposed an ontology relevant for hazard situational awareness and emergency management, interlinked with other nine external vocabularies.

A milestone in the European Union was the development of RODOS (Real-time Online DecisiOn Support) system for nuclear emergency management (Bartzis et al., 2000). Its main objectives are to provide integrated methodological bases, develop models and databases, and install common hardware and software frameworks for forecasting the consequences of an accident and supporting decisions. The role of multi-criterion analysis to ensure transparency of the decision-making process in the management of emergency situations was described in (Geldermann et al., 2009).

There have also been efforts towards an integrated approach of hazards, including Chemical, Biological, Radiological and Nuclear (CBRN), with integrated monitoring, warning and alerting solutions. Sentinel Asia is such an example, functioning since 2005, sharing data from earth observations and in-situ measurements, and creating a link between the space and the disaster reduction communities, at international level (Kaku and Held, 2013). The European Commission also supported multiple projects for an integrated management of crisis situations and for correlated responses in case of disasters (2017). Such efforts are also related to another concern at the international level - the creation of situation awareness tools, to provide a clear perception of a disaster scenario, and to improve decision support and the relations between the involved actors and the environmental factors (Pavković et al., 2014).

Knowledge engineering was also used in developing software related to the nuclear energy. Applications where ontologies were used to significantly increase the number and the variety of scenarios for detecting special nuclear materials, based on a set of initial descriptions, were presented in (Ward et al., 2011) and (Sorokine et al., 2015). A web portal for sharing knowledge about nuclear reactors was described in (Madurai Meenachi and Sai Baba, 2014); the ontology, represented with Protégé in OWL, includes concepts about neutron energy, steam generator detection and protection, control rod drive mechanisms etc. Furthermore, the design of nuclear power plants is governed by rules that may be expressed in ontological models, using for instance the Semantic Web Rule Language (SWRL) as a standard language (Fortineau et al., 2012).

3 KNOWLEDGE ON RADIOLOGICAL AND NUCLEAR HAZARDS

3.1 Methodology

Our work was performed with the purpose to share knowledge on radiological and nuclear hazards with stakeholders concerned of these risks but having medium to zero scientific background on such topics. In our collaboration with professors teaching nuclear technology and with researchers from a physics and nuclear engineering institute, we first played the part of software engineers for developing an educational and awareness platform, but soon discovered that we were also among the potential users of such a platform. It was challenging for them to select which were the basic concepts to be explained and what was important from the point of view of people who may have a technical background but are not accustomed with the specificities of this domain. Our task consisted in organising the relevant knowledge that was selected by our partners, and of identifying the connections between concepts that would help for an easier understanding and then for a better navigability within the platform. Furthermore, we wanted to go beyond getting accustomed to a basic terminology and to introduce some insights into the judgement criteria of the relevant authorities, because this might increase the population cooperativeness and trust, and might also offer the possibility to check the validity of some decisions one may be directly affected by. This is particularly important in our country, due to the operation of a nuclear power plant and the proximity of other nuclear facilities that may induce further territorial vulnerabilities (Lazaro et al., 2017).

The work resulted in: a) an ontology to organize the resources for informal education and awareness about the radiological and nuclear hazards; b) the design of a rule-based simulator dedicated to non-specialists, based on criteria, activities and threshold levels conforming to the reccomendations of IAEA (International Atomic Energy Agency); c) the formal representation of processes to be followed for prevention, protection and emergency response situations.

The knowledge representation was realized in multiple languages, including: UML (Unified Modeling Language), OWL (Web Ontology Language), XML (Extensible Markup Language) and BPMN (Business Process Model and Notation). They were then applied for realizing a TikiWiki platform, including semantic links, and a tool to simulate the authorities' decisions in a variety of situations related to radiological and nuclear vulnerabilities. The platform was also used by students in Power Engineering who chose the Nuclear Power Plant program (Ionita et al., 2016).

3.2 The Nuclear-Watch Ontology

Based on the selection made by specialists in nuclear engineering and physics, we represented a set of concepts that are relevant for understanding the nuclear and radiological vulnerabilities and for creating awareness. The work was part of a project developing prediction tools for the influence of radioactive clouds on the territory situated in the near and far field of a nuclear facility (N-WATCHDOG, 2017). Thus, our aim was to offer support for education and awareness, necessary for understating and testing the project results, and not to elaborate an exhaustive ontology, because, this would have to cover multiple domains that are already characterized by a very detailed terminology. We worked on the basis of a glossary with four categories of concepts:

- Hazard Management
- Emergency management
- Organizational structure and
- Nuclear and radiological reference terms.

This knowledge was structured in the Nuclear-Watch ontology, covering the scope of education and awareness (see Figure 1). We added two kinds of relationships: on the one hand, there are the relationships between the Nuclear-Watch concepts, on the other hand, there are correspondences to concepts from other ontologies representing knowledge from related domains, for validation purposes. One of them is VuWiki (Vulnerability Ontology 1.0) (Khazai et al., 2014) - a selection of concepts to which we identified correspondences is light-coloured represented in Figure 1, as opposed to our coloured concepts. The Nuclear-Watch ontology was also represented in OWL, using Protégé.

The concepts selected in the representation from Figure 1 and pertaining to the first three categories – Emergency management, Hazard management and Organizational structure – are explained below.

For the Hazard category we selected the following concepts relevant for awareness:

- Hazard management system – represents an assembly of physical, software and human components for monitoring, processing and visualization of specific hazards;
- Alert system – supports the decision and communication of alerts in case of disastrous events having happened;
- Early warning system – covers strategic, technical and operational aspects, with the purpose of avoiding or reducing the disastrous effects; its conception and realization considerably depends on the type of hazard, with a clear differentiation between rapid-onset threats, like nuclear plant failures, and slow-onset threats, like climate change (UNEP, 2012);

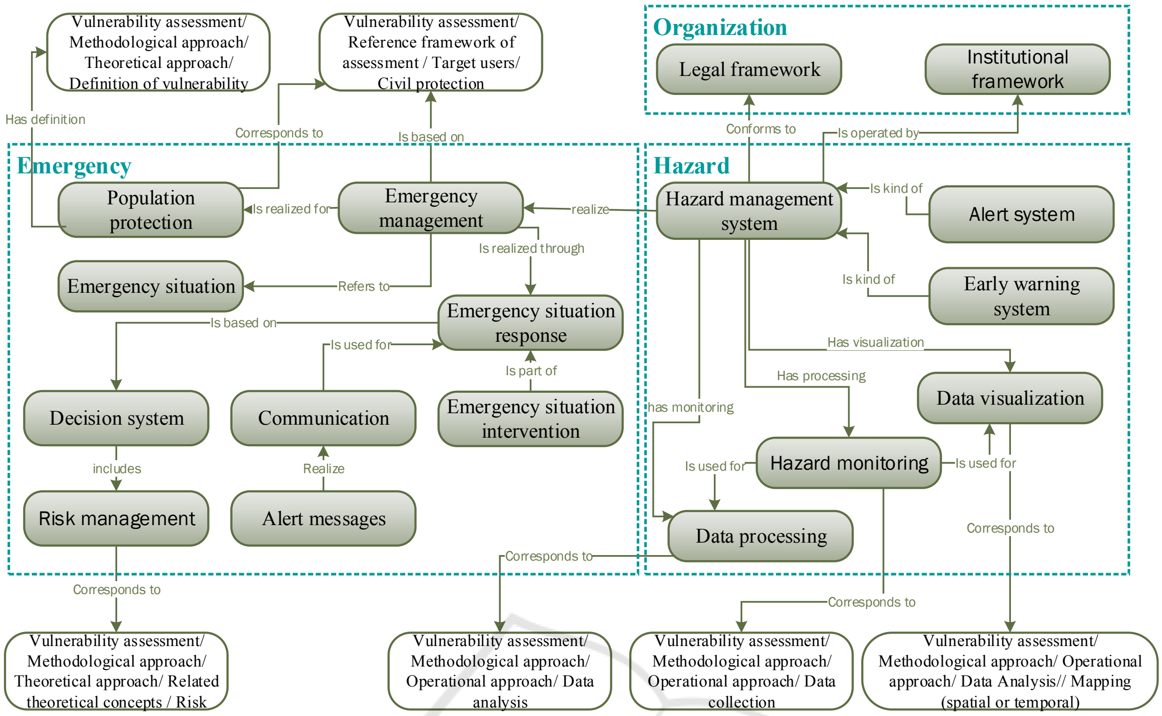

Figure 1: Selection of concepts from the Nuclear-Watch ontology.

- Hazard monitoring – is specific to the type of hazard and may be realized with diverse measuring instruments, like sensors, satellites, spectrometers, thermometers etc.);
- Data processing – is performed for a variety of goals: estimation of derived physical quantities, prediction, risk assessment, risk mitigation, organizing and storing data for historical purposes, transforming data for communication purposes (Ionita and Olteanu, 2014);
- Data visualization – uses data acquired at hazard monitoring and includes maps, graphs, tables, color-coded advisories, video images.

For the Emergency category, the concepts considered are:

- Emergency management – represents the overall organization of resources for dealing with emergency situations, possibly realized by existing hazard management systems; a collection of twenty-six definitions of emergency management, along with a comprehensive presentation of the related terminology, are given in (Wayne Blanchard, 2008) and (Khorram-Manesh, 2017);
- Population protection – is performed when a hazard-related event happened, but the effects do not require emergency reactions; in the case of nuclear vulnerabilities, the protection may consist in sheltering, iodine administration, or temporary relocation;
- Emergency situation – is characterized of a significant augmentation of the risks to which the population and the personnel working in the affected facility are exposed to;
- Emergency situation response – stands in the identification and classification of an emergency, followed by alert and activation of the authorities responsible with emergency management;
- Emergency situation intervention – includes concrete actions performed by emergency professionals and other organizations, like national, regional and local authorities;
- Decision system – offers a computerized support for decision making, based on risk management, models and collections of data;
- Risk management – is realized by identification, evaluation and mitigation of risks concerning the hazard of interest;
- Communication – is used for emergency situation response, to transmit alert messages to authorities and other stakeholders, like economic players in the affected territory, subscribers or the large public;
- Alert messages – realize the communication in a form that is approved and well-formatted.

For the organization category, the concepts introduced in the ontology are:

- Legal framework - consists of the main laws and government orders to which the emergency management and a hazard management system must conform to;
- Institutional framework – is an assembly of resources and organizations created for managing emergencies at regional, national or international levels.

The fourth category, nuclear and radiological reference terms, includes concepts related to radiations, environment radioactivity and nuclear security, accessible to people having a technical background (high school level); a presentation of more advanced terms about nuclear emergencies is given in (Vamanu and Acasandrei, 2014).

3.3 Rules for Prevention, Protection and Emergency Response

This section describes the knowledge of a rule-based system (Nowak-Brzezińska and Wakulicz-Deja, 2019) to simulate the decisions to be taken by responsible authorities and to create awareness on the nuclear vulnerabilities. We extracted what can be expressed as a set of rules from the criteria defined for preparedness and response for a nuclear or radiological emergency. They were identified based on reports of the International Atomic Energy Agency (IAEA, 2005) (IAEA, 2011).

Figure 2 represents concepts identified in the nuclear and radiological emergency domain that can be used for defining rules, represented as a UML (Unified Modeling Language) class diagram. The rules belong to six categories that depend on the dose of radiation, which decreases from A (when "urgent actions are always justified") to F (when there are no "generically justified actions").

The rules depend on three types of risks, with the meaning explained below:

- R1 – concerning avertable doses that do not affect population's health, hence it is necessary to take *prevention* measures;
- R2 – when the population *protection* is required due to larger values of projected doses;
- R3 – when the dose has already been received and internal / external exposures are high, so *emergency response* actions are necessary.

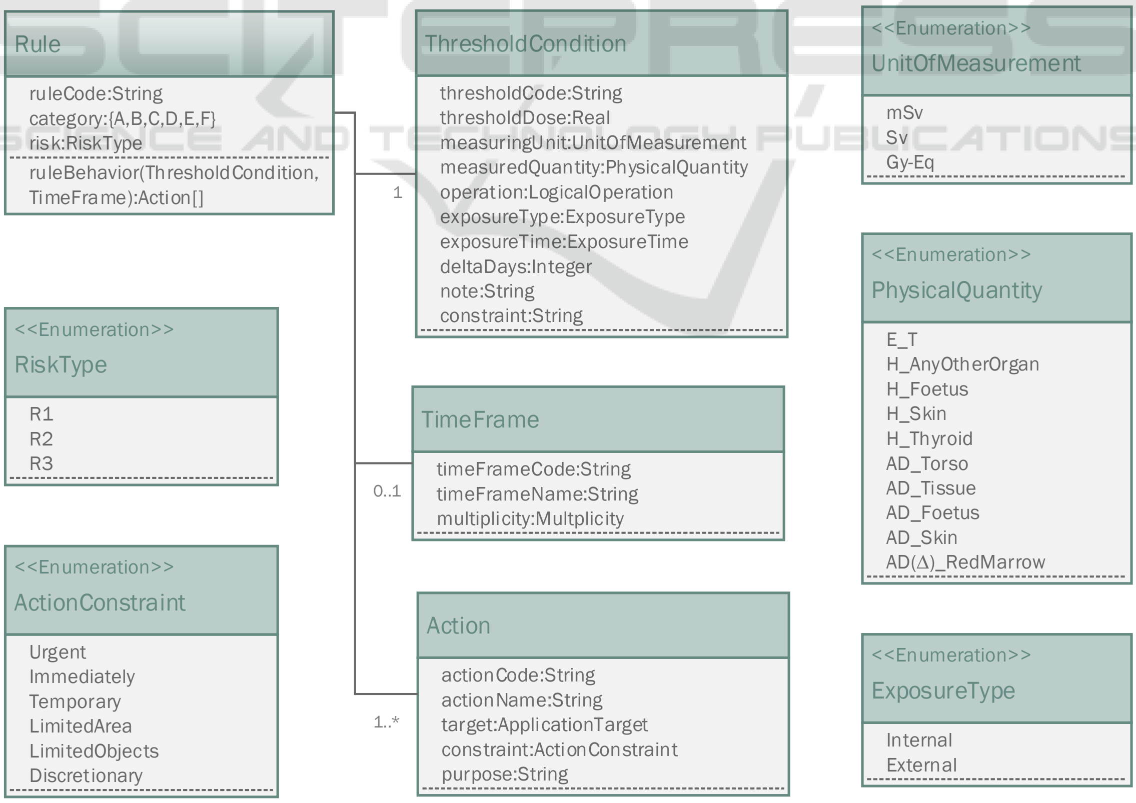

Figure 2: Object-oriented representation of the concepts used in the rule-based system.

Table 1: Part of the knowledge base for the rule-based system.

Rule Code	**"If-then" clauses**	**Premises**		**Conclusion: Recommended Actions**
		Threshold Conditions Time frame	**Risk type**	
Rule_1	IF (Timeframe_1 AND Threshold_1) THEN (Action_14)	$E_T \approx 5$ mSv 1 year	R1	*Action_14*. Replacement of food, milk and water
Rule_2	IF (Timeframe_1 AND Threshold_2) THEN (Action_6 AND Action_16 AND Action_11)	$E_T >= 10$ mSv 1 year	R3 OR R2	*Action_6*. Limited area/object decontamination *Action_16*. Limited restriction of food, milk and water consumption *Action_11*. Public information
Rule_3	IF (Timeframe_8 AND Threshold_2) THEN (Action_19)	$E_T >= 10$mSv 2days	R1	*Action_19*. Sheltering
Rule_4	IF (Timeframe_3 AND Threshold_3) THEN (Action_13 AND Action_7)	$E_T >= 30$mSv 1month	R1	*Action_13*. Temporary relocation *Action_7*. Discretionary decontamination
Rule_5	IF (Timeframe_5 AND Threshold_4) THEN (Action_8 AND Action_5 AND Action_15)	$E_T >= 50$mSv 1 week	R1	*Action_8*. Evacuation *Action_5*. Urgent decontamination *Action_15*. Restriction of food, milk and water consumption
Rule_6	IF (Timeframe_3 AND (Threshold_5 OR Threashold_11)) THEN (Action_18 AND Action_1)	$E_T >= 0.1$Sv $H_{Thyroid} >= 50$mSv 1 month	R3	*Action_18*. Screening based on individual dose, to determine need for registration for long term medical follow-up *Action_1*. Advice and basic counseling
Rule_7	IF (Timeframe_10 AND Threshold_6) THEN (Action_10)	$E_T >= 1$ Sv lifetime	R1	*Action_10*. Permanent resettlement
Rule_8	IF (Timeframe_1 AND Threshold_7) THEN (Action_6 AND Action_16 AND Action_11)	$H_{AnyOtherOrgan} >= 0.1$ Sv 1 year	R3 OR R2	*Action_6*. Limited area/object decontamination *Action_16*. Limited restriction of food, milk and water consumption *Action_11*. Public information
Rule_9	IF (Timeframe_4 AND Threshold_9) THEN (Action_2)	$H_{Foetus} >= 0.1$ Sv Time frame = months	R3	*Action 2*. Basic counselling to allow informed decisions to be made in individual circumstances
Rule_10	IF (Timeframe_4 AND Threshold_9) THEN (Action_6 AND Action_16 AND Action_11)	$H_{Foetus} >= 0.1$ Sv Time frame = months	R3 OR R2	*Action 6*. Limited area/object decontamination *Action 16*. Limited restriction of food, milk and water consumption *Action 11*. Public information
Rule 11	IF (Timeframe_9 AND Threshold_10) THEN (Action_3 AND Action_5)	$H_{Skin} >= 0.1$Sv Time frame = days	R1	*Action3*. Contamination control *Action 5*. Urgent decontamination

A rule behaviour depends on a threshold value for the radiation dose, in respect with the generic reference levels adopted by IAEA, and the time frame elapsed from the moment of the nuclear incident. Thus, the premises of the rules are: a) the threshold conditions regarding the radiation doses compared to the specified reference levels, b) the time frames, and c) the risk types.

The conclusion resulted from applying these rules is a set of actions recommended by IAEA, which are supposed to be applied by the organizational structures responsible with emergency management.

The rules are further defined as "if-then" clauses and their codes have the form *Rule_i*, where *i* is the index, as seen in the examples from Table 1. From the analysis of IAEA specifications, we identified 25 rules that were included into the knowledge base.

There are 22 threshold conditions identified from the studied IAEA specifications and we assigned each of them a code having the form *Threshold_i*, where *i* is the index. A threshold condition represents one of the rule premises and is assigned with a logical operation for checking the condition, and a threshold dose, which is a reference value for a given physical quantity. The physical quantities that are relevant for the purpose of the nuclear and radiological verifications are:

- *E* (Effective dose) – measured for the entire organism or for *T* (the tissue or organ of interest),
- *H* (Equivalent dose) – to express the stochastic health effects on the foetus, thyroid or any other organ, and
- *AD* (Absorbed dose) – due to the external exposure of torso, skin, tissue and foetus, or due to the internal exposure of red marrow, thyroid, lung, colon and foetus.

An action has a name that indicates what are the measures to be taken by the emergency personnel, domain specialists and various responsible authorities, to avoid or reduce the effects of a presumable disaster. See several examples in the last column from Table 1. From the IAEA reports we extracted 25 possible actions, assigned with a code *Action_i*; the conclusion / decision of a rule may reunite several such actions. A constraint for the time or space to apply each action may exist, to specify that it has to be performed urgently or immediately, to certain objects, or to an entire area.

Based on this knowledge base, we defined the decision tree from Figure 3, where the decisions were organized in respect with the types of risks (R1, R2 and R3) correspondent to prevention, protection and emergency response to nuclear and radiological situations.

3.4 Processes

The IAEA reports studied for obtaining the knowledge base of rules include the representation of several processes, like the situation assessment in the contamination of large or moderate areas (IAEA, 2011). However, for awareness purposes, we needed to show the big picture and not only details for specific procedures to be followed by specialists. For this purpose, we distributed the threshold conditions, rules and activities into three groups, in respect with the type of risk they are recommended for, and we represented three processes, for prevention (risk type R1), population protection (risk type R2) and emergency response (risk type R3).

Figure 4 illustrates the prevention process represented in BPMN. The tasks, notated as rectangles with rounded corners, correspond to the measurements of physical quantities necessary in decision making and to the actions recommended by IAEA (previously explained in Section 3.2).

The decisions, represented as diamonds in BPMN, verify whether the threshold conditions are met, by comparing the measured values with the reference levels from the IAEA safety guides. In respect with the threshold conditions fulfilled or not, the sequence flow advances to the actions recommended in that situation.

The timer intermediate events, represented with the clock icon, correspond to the time frames mentioned in Section 3.3. For example, two days after the incident, if the effective dose measured in tissues is greater or equal to 10 Sv, it is recommended to shelter, in order to reduce the exposure to radiation.

4 APPLICATION

The knowledge described in Section 3 was applied for the development of an educational and awareness platform with Tiki Wiki, creating wiki pages correspondent to the Nuclear-Watch ontology concepts and capitalizing the Semantic Links functionality to define relations between them. Thus, we introduced new link types that are mutually inverted, to improve the navigability and the search capabilities.

The platform also contains a simulator of the rule-based system where it is possible to introduce the date of the presumable nuclear incident, a set of values for the relevant physical quantities presented in Section 3.2 and the date when the measurements were taken. Based on these inputs, an inference engine is run, and the recommended actions are displayed to the user. For the purpose of this simulator, the representation of knowledge was done in Extensible Markup Language (XML), based on an appropriate schema for creating a unitary structure and a specific content. The knowledge base has specific files for each concept necessary for executing the rule behaviour, with child elements that correspond to the class

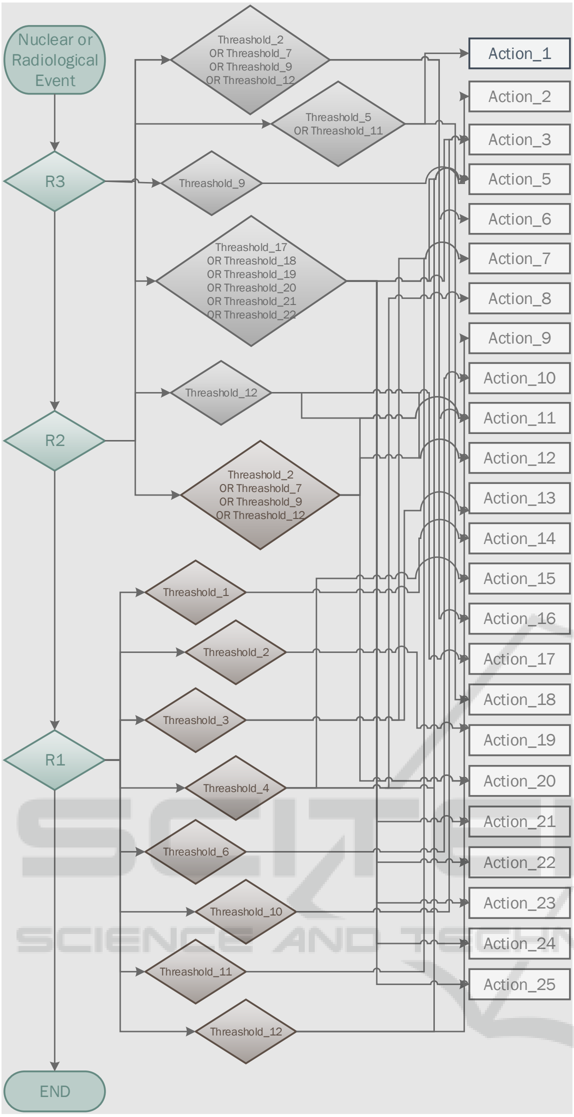

Figure 3: Decision tree for prevention, protection and emergency response.

attributes from Figure 2, e.g.:

- the representation of actions, having five child elements: *actionCode, actionName, target, constraint* and *purpose*;
- the representation of timeframes, with three child elements: *timeFrameCode, timeFrameName* and *multiplicity*;
- the representation of threshold conditions, with ten child elements: *thresholdCode, thresholdDose, measuringUnit, measuredQuantity, operation, exposureType, exposureTime, deltaDays, note* and *constraint*.

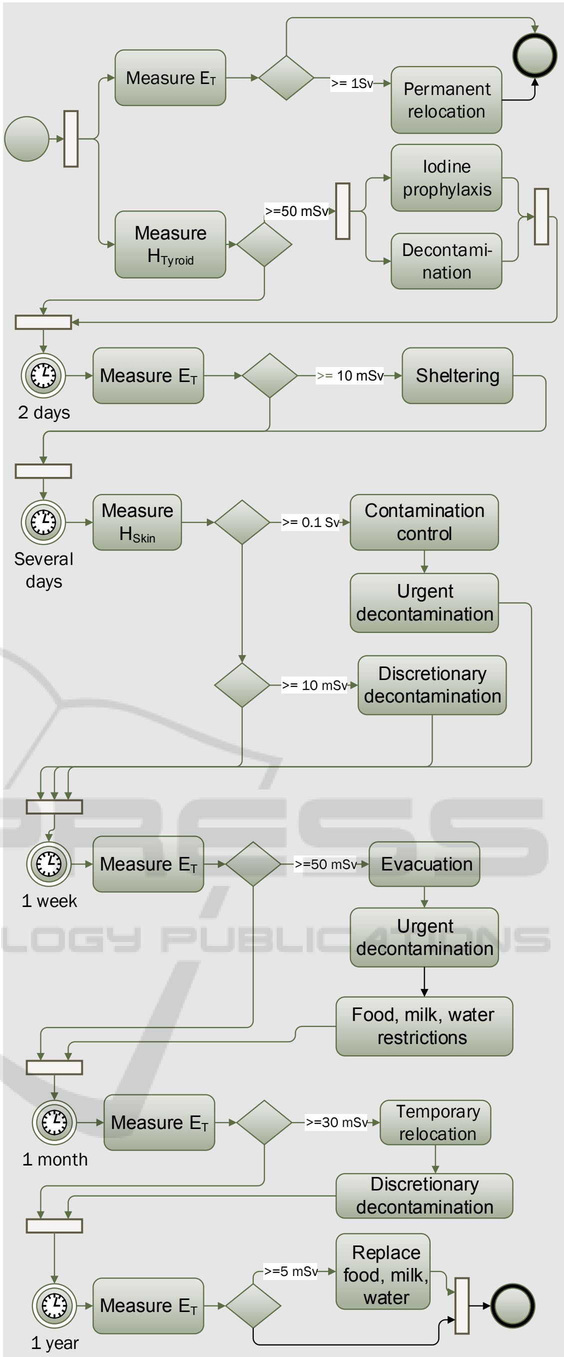

Figure 4: Prevention process.

Although its main purpose was to create awareness in general, the platform was also used in educational settings, for junior students in power engineering, who can visualize fundamental notions about the physical phenomena related to nuclear facilities, understand the alert and early warning systems, study legal aspects and learn more about the organizational framework responsible of emergency situations. Moreover, the teachers were allowed to define new wiki pages, edit the existing content, and introduce new navigation links based on semantics. More details on the educational aspects and the tests performed were given in (Ionita et al., 2016).

5 CONCLUSIONS

The paper presented several representations of knowledge for education and awareness about nuclear and radiological vulnerabilities, applied for the development of a platform with semantic functionality. First, we introduced the Nuclear-Watch ontology, based on a selection of concepts made by specialists with academic and research profiles, which was represented in OWL and linked with other existing ontologies with a larger scope, i.e. vulnerability assessment and disaster management. The ontology was then used for organizing the Tiki Wiki platform and for introducing semantic links.

Then, we defined a set of rules for assessing a situation related to a nuclear or radiological risk and offering information about the recommended actions to be taken by authorities responsible with emergency management. The premises are the measurements taken for radiation doses, the timeframe from the presumable accident, and the type of risk. All the rules conform to the specifications of the International Atomic Energy Agency and are applied within a simulator accessible from the platform, with educational scope.

Finally, for awareness purposes, we grouped the rules into three categories in respect with the type of risk, and we represented business processes correspondent to prevention, protection and emergency response.

Future work should also include cooperation with experts from social sciences and humanities, to investigate how such a platform would be perceived by the large public, and what are the elements to be adapted. This might concern the ontology concepts for awareness purposes, the level of detail of their descriptions in the wiki pages, the semantic links, and the look-and-feel of the rule-based simulator.

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