

ASSAS project, Artificial intelligence for Simulation of Severe AccidentS; Simulator development and Isotopic Source Term proposals

Rafael J. Caro^{1,*} and Isabel Parrado²

¹ Radiation Engineering & Analysis, Westinghouse. Avda. Montes de Oca, 1, San Sebastián de los Reyes, 28703 Madrid, Spain

² Simulation and Modeling, Westinghouse. Avda. Montes de Oca, 1, San Sebastián de los Reyes, 28703 Madrid, Spain

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Abstract. Nuclear Power Plant simulators play a central role in the training of nuclear operators. However, most simulators worldwide only cover Design Basis Accident, excluding the management of Severe Accidents. The need for a realistic training on such situations has been strengthened by the deployment of post-Fukushima safety improvements, which include different improvements to better mitigate severe accidents. The European project ASSAS (Artificial intelligence for Simulation of Severe Accidents) aims to address this gap by developing a proof-of-concept for a severe accident simulator. The prototype will feature a basic principles generic Pressurized Water Reactor, whose Graphical User Interface will be developed by Tecnatom-Westinghouse.

In addition to being a demonstrator for more complex industrial simulators, this basic-principles simulator is intended to support education and training activities on severe accident phenomenology. Reaching this objective required to address several competing constraints: representing the complexity of severe accidents without overwhelming the user with information, showing a large variety of phenomenology and operating situations with a limited number of systems and scenarios, running the simulation accurately in real time, etc. The proposed characteristics of the simulator to reach a compromise are presented in the first part of the article.

Besides, the description of the Source Term (ST) released by the accident appeared to need special attention, because of the complexity of its chemical and isotopic composition, which can drastically influence the radiological consequences of the accident. The second part of the article proposes a synthetic description of the source term, considered appropriate for training but also for a fast and still accurate assessment of accident consequences. This last feature opens the way for the use of the simulator to support emergency preparedness and response, possibly with Artificial Intelligence models.

This paper summarizes the work developed by Tecnatom-Westinghouse as leading WP6: Interfacing ASTEC with the simulation environment, of Project ASSAS funded by EU-EURATOM (g. a. no. 101059682) along the first-year project. It includes the development of the Simulator Specifications and Interface, the selected systems included in the scope and the scenarios to be considered as well as the definition of the Graphical User Interface and the main criteria used to fit to the targets of the project. Then, the paper focuses on the discussion on the proposals made to define the potential isotopic composition for the source term estimates, fitting to the main objectives of the project, as they are the education, the training, or the training for the surrogate models defined by the IA methodology, and how these targets impose restrictions to the isotopic characteristics of the ST used but keeping the major simulator features. Even though it is out of the current scope of the project, it has also been considered the potential use of the simulator for emergency preparedness and response training and consequence assessments to be properly founded for the future evolution of the simulator.

1 Introduction

The ASSAS European project, Artificial intelligence for Simulation of Severe Accidents, began in 2022,

with the objective of developing a proof-of-concept Nuclear Power Plant Severe Accident (SA) simulator for education and training. The ASTEC (Accident Source Terms Evaluation Code) code developed by IRSN (FR) will be adapted and integrated into a commercial simulation environment based on TEAMSUITE®

* e-mail: rafaeljuan.carobenito@westinghouse.com

(Tecnatom-Westinghouse, Application for Modelling and Simulation Environment).

The project is being developed within the framework of the EURATOM Nuclear Safety program for the HORIZON-EURATOM-2021-NRT-01 call. IRSN coordinates the consortium formed by 14 European institutions (IRSN, IJS(SI), KIT(DE), KTH(SE), TECNATOM-WESTINGHOUSE (SP), ENEA (IT), TUD (NL), PHIMECA (FR), IVST (SK), CIEMAT (ES), ENERGORISK (UA), BELV (BE), CS-GROUP (FR), and PSI (CH)).

Tecnatom-Westinghouse provides a key contribution as a leader in simulators development and leads WP6. Simulator design, defines user functional expectations and provides experience and training in the response to SA and in the application of the Severe Accident Mitigation Guidelines (SAMG) in the nuclear industry.

The Proof-of-Concept Simulator will be able to show the main phenomena that occur during a severe accident and is intended for education and training activities for students, nuclear energy professionals (operators, Technical Scientific Support Organizations, TSOs, nuclear regulatory bodies, emergency responders) and non-specialists (decision makers, civil society). This target imposes the following specific characteristics:

- to count on a friendly graphical user interface that allows for the easy control of both the simulation and the evolution of the accidental scenarios,
- to show the main Severe Accident phenomena, and
- to run at real time or faster, and at the same time, to keep the simulation accurate.

To achieve these goals, the proof-of-concept simulator will be based on the capability of ASTEC (IRSN), which will need to be adapted, to run in real time with a high level of accuracy and to interact synchronously with an industrial simulation environment, TEAM.SUITE® (Tecnatom-Westinghouse).

The simulator prototype is going to be developed based on non-sensitive plant data for a generic and simplified 4-loop 1300 MWe PWR, with ASTEC as main simulation tool. However, the selected approach can be adapted to other severe accident codes like MELCOR, and other designs like Boiling Water Reactors, BWR. In the long run, the expectation is that the outcomes prove the interest and feasibility of including the severe accident phenomenology into the full-scope simulators used currently up to the design basis scenarios boundary.

A very relevant aspect of the project is the study of the application of Artificial Intelligence methodologies for the development of some physical or plant system models. Different machine learning methods will be tested to develop fast surrogate models, which could dramatically improve code performance. The specificities of these models must be considered for the design of the simulator. By essence, machine-learning models do not solve first-principles physical equations, but they learn correlations from training data. Therefore, they are computationally much more efficient. However, the complexity of AI models improves drastically with the dimensionality (number of degrees of freedom or input/output variables considered) of the problem considered, a phenomenon known as

“the curse of dimensionality”. Therefore, it is often necessary to reduce the dimensionality of the problem, which can be done thanks to statistical analysis (like principal component analysis or more advanced variational autoencoders) or thanks to expert assessment. Both approaches will be explored in ASSAS. The selection of a synthetic description of the source term is an example of dimension reduction based on expert knowledge. In this way, the surrogate model can directly map input data to the outputs of interest for the user, without computing intermediate species and isotopes as a physical model would do.

This article briefly describes the contributions made so far by Tecnatom-Westinghouse. In point 2, a summary of the development of the Simulator, its interface and its integration with the ASTEC severe accident code is provided, as well as the selection of the scenarios that will be considered in the project.

Point 3 develops the review of the different isotopic options of the source term that are proposed to give a synthetic description of the source term, which will notably simplify the development of Artificial Intelligence-based models.

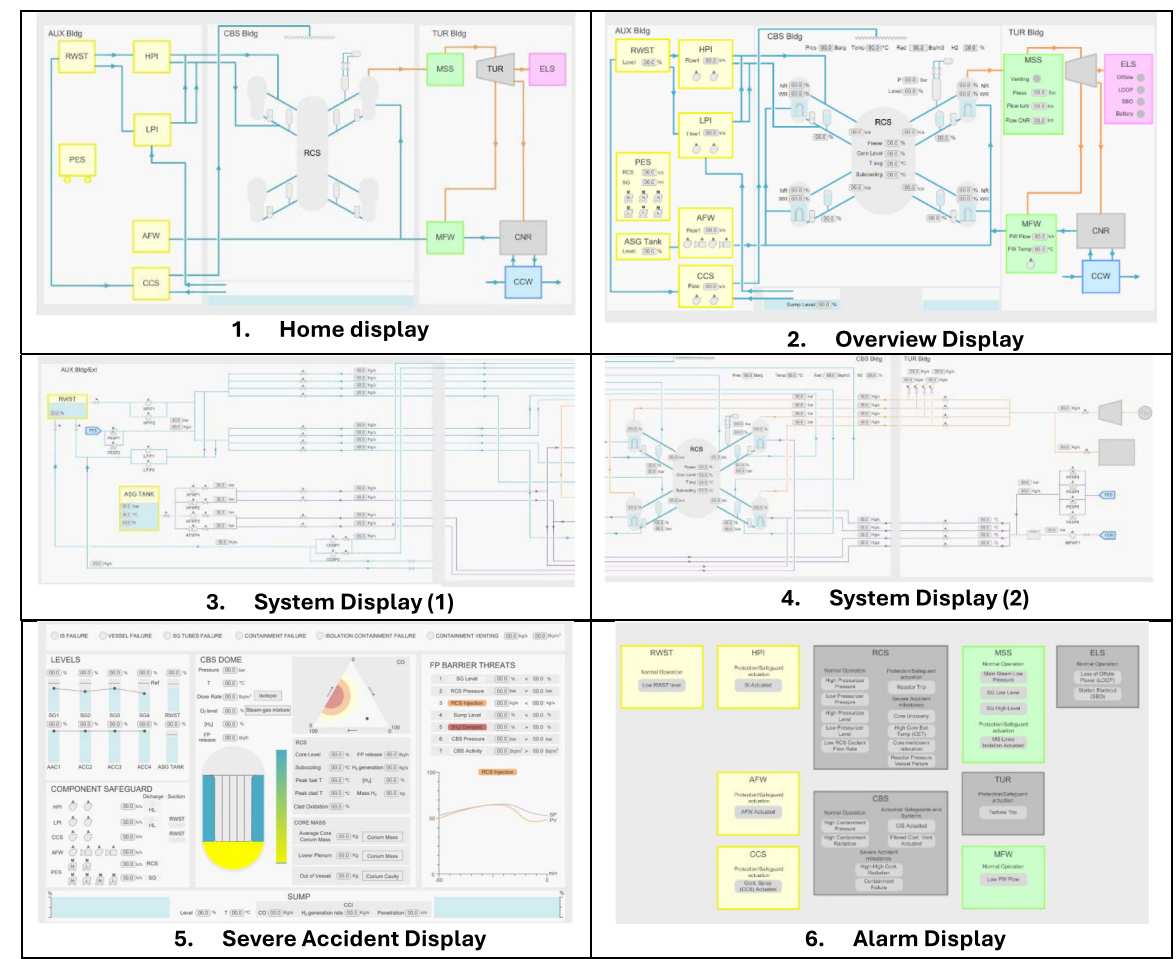
2 WP6: simulator specifications and interface

A NPP is a quite complex system which requires, among other aspects, well-trained personnel capable of facing normal operations as well as other more challenging scenarios like abnormal situations, or emergency scenarios. So far today, the common practice is to develop the so-called Full Scope Replica Simulators, that include mathematical models based on physical laws -or engineering approaches- for all the systems and components with any impact on the operation and including a Simulated Control Room which is exact replica of the Main Control Room of the reference NPP.

The scope for the conditions simulated historically has included operational states (normal operation and anticipated operational occurrences) and accident conditions including Design Basis Accidents but excluding Design Extension Conditions with core melting. This limitation was due to different reasons, only to mention some, the lack of knowledge or the complexity of the SA phenomena and the time consuming of the associated calculations, can be considered.

The enhanced knowledge on SA phenomenology, the improved capabilities of the technological system to speed up the required calculations, as well as the reinforced requirements for the conditions formerly called Beyond Design Accidents, nowadays called Design Extension Conditions, DEC, recommends including these scenarios into the scope of industrial training simulators. After the Fukushima-Daiichi accidents, new safety systems (including mobile systems) dedicated to severe accident management have been deployed, which requires adequate and realistic training for operators.

Therefore, to develop the Proof-of-Concept Simulator, so as to demonstrate the feasibility and the educational

Table 1. GUI Displays.

and training capabilities, some simplifications as selection of systems modeled, the operating scenarios to be considered, and the specific design for the interface are going to be briefly summarized below.

2.1 ASSAS simulator systems

The ASSAS simulator scope covers just the Design Basis Accident (DBA) and the Severe Accident (SA) and not the normal operation, so Turbine, Condenser, Condensate, Circulating water, Reactor Heat Removal and Chemical and Volumetric control systems are out of scope.

The systems that are to be modelled and present to be operated or monitored by the Graphical User Interface, GUI, are:

1. Reactor Coolant System (RCS).
2. Main Steam Supply System (MSS).
3. Containment Cooling Sprays (CCS).
4. Auxiliary Feedwater System (AFW).
5. High Pressure Injection System (HPI).
6. Low Pressure Injection System (LPI).
7. Accumulator Injection System (ACI).

8. Portable Equipment System (PES).
9. Containment venting.

2.2 ASSAS GUI

The selection of data displayed to the user is based on two type of parameters: first, the variables required for the operation of the scenarios defined, and second, those required to provide a good knowledge of the evolution of the different phenomena occurring during the evolution of a SA.

Selected variables can be divided into three groups according to the phase of the severe accident scenario.

- Typical instrumentation parameters for operation and transients.
- DBA associated variables.
- SA phase associated variables.

The GUI groups the different variables conceptually related (by system, alarms, SA) into a set of connected display screens organized into a top-down structure. The pictures in Table 1 show the 5 displays available in the ASSAS simulator GUI:

1. home display: it shows the layout of the Nuclear Power Plant (NPP). The user can navigate from Home to System displays clicking on each system box.
2. Overview display: it is the second display level, where most important variables of each system are shown.
3. Systems display: it is the third level. This display is the larger one showing all the systems. The user can move through it by moving the scroll. As this is a basic principles simulator, not an operator training one, this design will help users to better understand the functioning of the NPP.
4. SA display: it is the display showing all variables required for the tracking of main phenomena during the SA evolution from the point of view of the staff at the Main Control Room (MCR) or the Technical Support Center (TSC).
5. Alarm display: it shows the different warnings generated for the operation.

2.3 ASSAS simulator scenarios

In order to fulfill the project targets, the following two main accident scenarios have been considered to define the ASTEC and Team_SUITE® models' scope, the surrogate models and used also to validate the simulator:

- A. station Black-Out (SBO), with additional AFW Turbine Driven Pump (TDP) failure.
- B. Loss of Coolant Accident (LOCA), with additional Safety injection and Containment spray systems failure.

These scenarios have been chosen, one with high pressure (A) and the other with low pressure (B), to try to cover as much phenomenology as possible. These scenarios are used to validate the SAMG because they go through most of the guideline strategies.

These scenarios definition includes:

- the operator actions that must be considered.
- The transmitters that the final user must monitor, at least.
- The involved phenomena.

The specific evolution of the calculated variables will depend on the automatic orders issued by the simulated control system and operator actions taken by the user to face the situation (SA).

3 Isotopic ST proposal

One of the essential aims of the simulator is to show the effects of different mitigation actions as the containment spray system, or the filtered venting, on the radiological content of the containment and the releases to the environment, e.g., on the ST.

If the physical models of the simulator are run by ASTEC, a comprehensive list of radionuclides will be used. Even if only a short list will be displayed to the user, it will still be possible to retrieve the complete list from the regular savings of the simulator.

When the simulator is run with AI models, whether alone or hybridized with other ASTEC modules, only the shortlist of radionuclides will be estimated from the training data generated with ASTEC, performed with the comprehensive list of radionuclides, without computing intermediate species. AI models are expected to be much faster than physical models, which is of high interest in the context of a real emergency, to have an immediate answer and to evaluate a large variety of scenarios.

The target then is to develop a proposal for the radionuclide mix, for the ST estimate, to be considered for the first simulation model to be developed along the ASSAS Project. Therefore, the challenge is to provide a Source Term appropriate for the following two competing objectives. On the one hand, the ST should be detailed enough to be useful for potential training activities, for accident management, and for emergency preparedness and response, at least in a conceptual scope, considering first principles for a first prototype, that fits to the targets of the Project.

On the other hand, the ST should be simple enough to allow a simple visualization of results on the simulator interface without overwhelming the trainee, and to facilitate the development of AI surrogate models with a reduced number of degrees of freedom.

The simulator will also compute the total released activity, including all radionuclides of the ASTEC model. The different figures of merit will be calculated for the RCS, the containment, the sumps, and the environment. The dose rate in the containment will also be calculated.

3.1 Background

ST is, according to the IAEA glossary,

The amount and isotopic composition of radioactive material released (or postulated to be released) from a facility.

[It is] Used in modelling releases of radionuclides to the environment, in particular in the context of accidents at nuclear installations or releases from radioactive waste in repositories.

The number of isotopic components of a Light Water Reactor (LWR) core is very wide and is usually obtained from specific codes as ORIGEN (SCALE, ORNL), FISPIN (Fission Product INventory) or others.

Just from the beginning of the considerations on Radiological Consequences of Accidents at LWRs, it was clear that not all the radionuclides had the same relevance, and efforts were made to simplify the calculations. This way, Alpert (Ref. [1]) analyzed the 500 isotopes included in ORIGEN at that time, reducing the list to the 60 most important for radiological consequences assessment. Since then, further insights have led to the following Table 2 (Ref. [2]).

To consider the different phenomena that affect the isotopes that could be released by the fuel, along the different pathways up to the point they are released to the environment, it is common practice to use SA codes

Table 2. Adapted from Table 2-2 currently recommended radionuclide List for LWR Applications – NUREG/CR-7270.

Co-58	Y-90	Ru-103	Te-132	Ba-137m	Nd-147
Co-60	Y-91m	Ru-105	I-131	Ba-139	Np-239
Kr-85	Y-91	Ru-106	I-132	Ba-140	Pu-238
Kr-85m	Y-92	Rh-103m	I-133	La-140	Pu-239
Kr-87	Y-93	Rh-105	I-134	La-141	Pu-240
Kr-88	Zr-95	Rn-106	I-135	La-142	Pu-241
Rb-86	Zr-97	Te-127	Xe-133	Ce-141	Am-241
Rb-88	Nb-95	Te-127m	Xe-135	Ce-143	Cm-242
Sr-89	Nb-97	Te-129	Xe-135m	Ce-144	Cm-244
Sr-90	Nb-97m	Te-129m	Cs-134	Pr-143	Sb-127
Sr-91	Mo-99	Te-131	Cs-136	Pr-144	Sb-129
Sr-92	Tc-99m	Te-131m	Cs-137	Pr-144m	

Table 3. Adapted from Table 3.8 revised radionuclide groups – NUREG-1465.

Group	Title	Elements in Group
1	Noble Gases	Xe, Kr
2	Halogens	I, Br
3	Alkali Metals	Cs, Rb
4	Tellurium Group	Te, Sb, Se
5	Barium, strontium	Ba, Sr
6	Noble Metals	Ru, Rh, Pd, Mo, Tc, Co
7	Lanthanides	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am
8	Cerium Group	Ce, Pu, Np

(MELCOR, MAAP, ASTEC) to model the referred phenomena. Considering that the main phenomena relevant are driven by chemical characteristics of the radionuclides, the radionuclides have been classified in groups attending those aspects, and the codes track these groups instead of individual isotopes.

Initially the ST required by regulatory bodies, was derived from TID-14844 (1962) report (Ref. [3]) considering three groups. Thanks to the great progress in SA analyses and on calculation methods and systems, NUREG-1465¹ (1995) (Ref. [4]) proposed a classification into 8 groups which has been used in licensing many currently operating reactors and in a wide range of other applications and research activities and it is still used for differ-

ent kind of analyses. The following Table 3 provides the referred groups and radionuclides.

Most recently MACCS (Ref. [2]) (2020), proposed the latest improvements, considering the following groups and radioisotopes showed in Table 4. There are 71 radionuclides distributed into 10 groups in the latest MACCS approach, which is a good representative of the state of the art (used for example in SOARCA Project analyses).

3.2 Rationale

However, this number of radionuclides can be considered too high for a first principles prototype simulator and to simplify the AI surrogate models development, some additional reduction is going to be discussed.

Based on the capability of RASCAL tool (Ref. [5]) to establish the relative importance – for the consequence analyses – of isotopes of a specific Source Term of a particular scenario, and considering the most important contributions to dose for an accident in a PWR, including core melting with containment failure, it can be considered the following Table 5.

This selection would allow the prototype to perform some rough dose estimates for the phase before release as well as for the urgent phase, considering the major contributions to the three main pathways (Cloud shine, inhalation, and ground shine) for the urgent phase, up to the first day after the release, to assess the option on some precautionary protective actions and on urgent protective actions.

From the point of view of training, it can be considered,

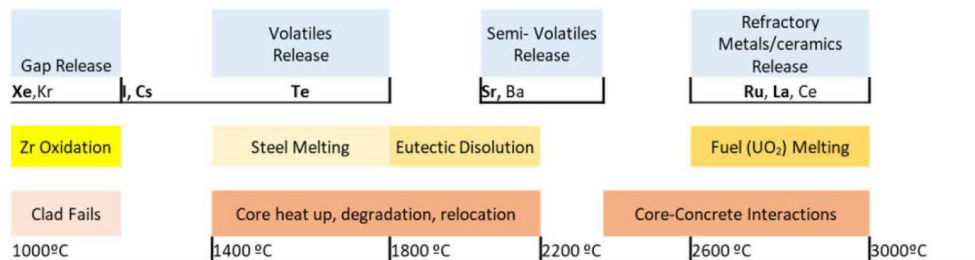
- the noble gases leak into the reactor coolant before cladding break,
- the gap release, considering Xe,
- in-vessel melting, considering I, Cs and Te-132, and
- some ex-vessel phenomena, considering La, Cm and Pu-241 as representative of Cerium Group, referring to NUREG-1465 groups, even though no model for releases from the corium are included in the first ASSAS prototype.

However, and still referring to NUREG-1465 classification, there is a lack of representatives for groups 5 Barium (Ba,

¹ More recently, NUREG-1.283 “Alternative radiological ST for evaluating DBA at NPPs” has proposed to split group 6 Noble metals, considering an additional group 9 Molybdenum group, including Mo, Tc, Nb. We refer to NUREG-1465 as most currently licensed NPPs used it for their licensing process.

Table 6. Proposal Option 2.

Isotopes Proposal Op. 2	NUREG-1465 Accident Source Terms for Light-Water Nuclear Power Plants (1995)			
	Table 3.8 Revised Radionuclide Groups			
	Nº G	Chemical Group	Isotopes Proposal	Nº I
	1	Noble Gas (Xe)	Xe-133	1
	2	Halogens (I)	I-131/2	2
	3	Alkali Metals (Cs, Rb)	Cs-134/6/7	3
	4	Tellurium Group (Te, Sb)	Te-132	1
	5	Barium, Strontium (Ba, Sr)	NO → Sr-90	1
	6	Noble Metals (Ru, Rh, Pd, Mo, Tc, Co)	NO → Mo-99	1
	7	Lanthanides (La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Cm, Am)	La-140, Cm-242	2
	8	Cerium Group (Ce, Pu, Np)	Pu-241	1
	Nº Isotopes			12

**Fig. 1.** Fission product release as function of temperature. (Adapted from Ref. [12]).

Sr) and 6 Noble Metals (Ru, Rh, Pd, Mo, Tc, Co), that can be solved by including two additional isotopes, e.g., Sr-90 (or Sr-89) and Mo-99 (because its relevance in Cs₂MoO₄ compounds), reaching to the Isotopes Proposal Option 2 in the in Table 6.

With Proposal 2, there are components to analyze/teach the main phenomena, as in the Figure 1.

In addition, it is proposed to include the lixiviation of the containment atmosphere by containment sprays and the trapping of aerosols by the containment venting system, as part of the accident management actions/strategies. Thus, it is required to consider at least the different forms of iodine in the gas phase (inorganic gas, organic gas, aerosols) in order the models to be able to simulate the following phenomena:

- inorganic iodine can be chemically dissolved thanks to the addition of caustic soda in the containment spray water.
- Iodine aerosols are lixiviated by the sprays and trapped by the sand filters of the containment venting system.
- Organic iodine is difficult to trap and has more affinity with biological systems.

Therefore, it is proposed to add 4 additional variables: 3 physical forms for each radioiodine instead of just the radionuclides.

Finally, by including just two additional isotopes, e.g., Ru-103 and Sb-127, it can be considered one representative of each group of radioisotopes recommended by the latest MACCS (MELCOR Accident Consequence Code System) classification, as Isotopes in the Proposal Option 3 in Table 7.

Even if the coupling with radiological consequence evaluation tools is out of the scope of ASSAS, reasonable provisions should be taken to facilitate this coupling after the end of the project. For example, IRSN emergency response department uses different sets of radionuclides to compute the radiological consequences of accidents. Detailed calculations extract approximately 200 radionuclides to evaluate radiological consequences from a list of 1000 radionuclides considered for source term evaluation. However, fast running tools consider the following minimal set of radionuclides: Xe-133, Cs-137, Te-132, I-131 (with physical-chemical form for iodine).

In the Report on the modelling strategy (D1.1: Report on the modelling strategy), Ciemat recommends consider-

Table 7. Proposal Option 3.

Isotopes Proposal Op. 3	NUREG/CR-7270 SAND2022-12166 Tech. Bases for Consequence Analyses Using MACCS 2022		
	Table 2.8 Recommended List of Radionuclides and Groupings for Consequence assessment MACCS		
	Nº G	Chemical Group	Isotopes Proposal
	1	Noble Gas (Xe)	Xe-133
	2	Alkali Metals (Cs)	Cs-134/6/7
	3	alkali Earths (Ba)	No → Sr-90
	4	Halogens (I)	I-131/2
	5	Chalcogens (Te)	Te-132
	6	Platinoids (Ru)	No → Ru-103
	7	Early Transition Elem. (Mo)	No → Mo-99
	8	Tetravalents (Ce)	Pu-241
	9	Trivalents (La)	La-140, Cm-242
	10	More volatile Metals (Cd)	No → Sb-127
	Nº Isotopes		
			14

Table 8. Comparative isotope magnitude of releases by Accident.

Isotope magnitude of releases by Accident		
Isotopes	Chernobyl	Fukushima Dai-Ichi
Te-132	1150 PBq	180 PBq
I-131	1760 PBq	150 PBq
Cs-137	85 PBq	12 PBq

ing at least the following elements for the degradation of the core and the dispersion of radionuclides: Xe, Te, Cs, I, Mo (due to its chemical reactivity with Cs).

Options 2 and 3 are compatible with these two complementary requirements.

3.3 Additional justification to the inclusion of Noble Gases (NG)

According to NUREG-1228 (Ref. [6]), based on the ranking in WASH-1400 (Ref. [7]),

Most of the noble gases (xenon, krypton) make a small contribution to health effects.

However, noble gases are the most likely group of fission products to be released following a severe accident because:

- they are chemically inert,
- they are available in large quantities, and
- they would not be affected by the reduction mechanisms that would remove other fission products before they could be released.

In addition, if all the noble gases in the core were released promptly, whole-body doses of about 100

Table 9. Comparative isotope D₂ values.

Isotopes	D ₂ -Value (TBq)
Te-132	8.E-01
I-131	2.E-01
Cs-137	1.E-01

rem (1Sv) are possible 1 mile (1.5 Km) from the NPP.

Therefore, noble gases should be included in the list of radionuclides to consider in source term estimation.

And, in particular Xe-133, according to TID-1488 and NUREG-1465, is the main contributor to the dose, among Xe isotopes.

3.4 Additional justification to the inclusion of Te-132

Together with NG, Cs and Iodine, different isotopes of Tellurium, and particularly Te-132, are released as high or medium volatiles mainly during the first and intermediate stages of the severe accident. Despite the fact that it has a short half-life, it has had a relevant impact in past accidents, as it can be seen in Table 8 that summarizes radiological releases from main past accidents (Ref. [8]).

And, according to IAEA (Ref. [9]), its dangerous values for dispersion are relevant enough (see Table 9).

Furthermore, it is relevant to consider that many tellurium isotopes decay to iodine, becoming a delayed source for iodine. This way, considering the magnitude of the releases and the radiological impact, it is recommended to be considered Te-132 in the proposal.

Additionally, it can be mentioned that due to its potential chemical interactions with Iodine, it might have an effect in the remobilization of Iodine (Ref. [10]).

3.5 Proposals recommendation

According for example with (Ref. [11]) fission product release due to containment failure:

- iodine content of the source term drives the “short-term” radioactive risk after release (half-life of I-131 is 8 days).
- Cesium content of the source term drives the “long-term” radioactive risk after release (half-life of Cs-137 is 30 years).

However, even though we could consider (Ref. [12]) the simplest proposal as Proposal 0 in Table 10, it is really not recommended.

The recommendation would be, in priority order:

1. proposal option 3.
2. Proposal option 2.
3. Proposal option 1.

Table 10. Proposal Option 0.

Isotopes Proposal Op. 0	State of the Art for SA ST Estimation. Fortum. (2013)	
	IAEA Technical Meeting on ST Evaluation for SA 2013	
	Short-term criteria	
	I-131	
	Long-term criteria	
	Cs-137	
	Option 0. Not recommended	
	Nº Isotopes	2

Therefore, the recommendation is to adopt proposal 3, considering proposal 2 the minimum enough. This way, it has been presented an spectra of proposals; considering the inclusion of the different forms of iodine, the activity, and the dose rate in containment it led to a maximum of 20 outputs for the most complete proposal.

4 Conclusions

Along the paper, different aspects to be balanced to achieve the goals of the project have been discussed, considering competing objectives such as, the definition of a prototype for a proof-of-concept simulator, that is simplistic by definition, which is expected to demonstrate the training of operation personnel feasibility, which means fidelity, precision and real-time, and for education in severe accident phenomenology, therefore, including the main phenomenology without overwhelming the user, and allowing to achieve the right balance between simplicity and complexity. This also simplifies the development of AI models.

Therefore, it has been introduced first of all which are the systems modeled to simulate the state conditions of a SA, which are the specific scenarios defined to consider the broader set of phenomena to be modeled and simulated and the definition of the GUI to allow an easy control of the simulation and operational aspects, providing the required information on the operational situation and on SA phenomenology and the impact of the different operational actions on the evolution of the scenarios in a simple but instructive way as well as rigorous enough.

Then, the article focused on the discussion of the proposals made to define the potential isotopic composition

for the estimates of the Source Terms. Different options have been provided, based on the development of knowledge of the Source Term and the associated SA phenomenology, as well as on the main references used for the licensing of most of the Western LWR currently in operation. The different options allow to scale the isotopic definition, with the same goal of achieving the right balance between simplicity and complexity while maintaining the desired features for the proof-of-concept and basic principles SA simulator.

The different isotopic proposals have been defined taking into account the considerations for the use of the results of ST estimates for emergency preparedness and response, even though it is outside the current scope of the project, in order to establish a solid basis for making some estimates on radiological consequence assessments – which are the main reason for all efforts – and to be adequately prepared for future developments of the SA simulator that the authors are convinced will take place.

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The authors declare that they have no competing interests to report.

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Author contribution statement

Conceptualization, methodology, writing and original draft preparation, Rafael J. Caro who is the corresponding author; writing, review and editing, Isabel Parrado and Rafael J. Caro. Both authors have read and agreed to the final version of the paper.

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