Annex II – Curricular Internship Report

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Introduction

After completing the first year of the master's in nuclear engineering, the next step was to obtain an internship and develop an advanced technical work. The project was to be based on the needs of the place where it was to be performed. During the first year of the master's program, I received the CATEDRA ARGOS scholarship given by the Consejo de Seguridad Nuclear (CSN). Through the efforts of the of the nuclear engineering program in UPC, Lluis Batet, and in communication with the CSN, I was able to perform my internship and develop my final master's project (TFM) in the CSN through the Catedra ARGOS.

Before beginning the internship, I had completed the first year of the master's program at UPC which involved taking the courses in nuclear engineering subjects. The courses taken ranged from thermal hydraulics in nuclear reactors to radiation detection and safety. Also, a lot of the course-work involved operation, safety, and regulations in nuclear power plants. This involved gaining and understanding a lot of the components of nuclear power plants, safety equipment and systems, and how these systems operated and reacted in case of accidents. I had some knowledge of accident phenomenology and severe accidents, but it was basic. Furthermore, through the completion of the courses at UPC and from my previous degree obtained at North Carolina State University in the USA, I gained interest and knowledge in some of the nuclear codes. Nuclear analysis codes are critical tools in the development of nuclear reactors and performing accident analyses.

For my undergraduate degree, I learned MCNP 5/X to create a simulation for a Deuterium-Tritium Accelerator and examine the neutron fluxes coming from the D-T reaction. This accelerator was contained in a room and the doses created from the reaction within the room were also examined and simulated using MCNP. At UPC, I learned 3 new codes: RELAP, PARCS, and PENELOPE. RELAP 5 is a thermal-hydraulics analysis code widely used in the nuclear industry, PARCS is a fuel analysis code used reactor fuel reloading analysis, and lastly PENELOPE which is mostly used for radiation and dose analyses given certain geometries.

Therefore, given my background, a project was started at the CSN that connected both my technical knowledge and expertise with nuclear codes with the needs and requirements of the CSN. The following excerpt from my final master thesis (TFM) outlines the objectives and motivation behind the project:

"During severe accident conditions at a nuclear power plant (NPP), it is of utmost importance to maintain the structural integrity of the containment building. The containment building prevents the escape of harmful radiation to the environment in case of a severe accident. Any ruptures that lead to radioactive gas leakage from it pose a potentially serious threat to the well-being of surrounding populations.

The severe accident that occurred in Fukushima- Daichi in March 2011 had a significant impact on the safety of operational light water reactors (LWRs). This accident highlighted the need for implementation of additional safety systems in present LWRs to provide additional protection to the integrity of the containment building against the threat of a severe accident.

As a result, regulatory authorities (including the Consejo de Seguridad Nuclear [CSN]) require the implementation of safety enhancements which must be licensed for NPPs to operate. These severe accidents and containment building severe accident management strategies (SAMG) have increased in importance for the licensing process after Fukushima-Daiichi. Among the many safety enhancements required by the regulatory authorities, two are specifically relevant for this study: the implementation of Passive Auto-catalytic Recombiners (PARs) and Filtered Containment Venting Systems (FCVS) in all the Spanish Nuclear Plants.

These new safety requirements led the proposal and execution of a severe accident study using PARs, the FCV and the containment heat removal systems (CHR). This study was inspired and motivated by a previous study performed by the United States Nuclear Regulatory Commission [NRC]. The NUREG/CR-5567 "PWR Dry Containment Characterization Study" is a "review and discussions of early containment failure due to direct containment heating (DCH), in-vessel steam explosions, hydrogen burns and steam spikes, late containment failure due to gradual over-pressurization and baseman melt-through, and containment bypass (interfacing systems LOCA) events are included. An assessment of potential improvements such as RCS depressurization, reactor cavity reflooding, hydrogen control, containment venting and accident management strategy is presented. containment behavior during severe accidents." [NUREG 5567, Yang]

Based on the findings of the report, it was decided to follow a similar path analyzing the evolution of containment conditions using the new safety implementations (PARs and FCVs) and the nuclear power plants containment heat removal systems. Specifically, analyzing how CHR systems could be used to forego opening the CFVS and thus preventing release of gases from inside the containment.

Furthermore, the activation of the different CHR systems lead to scenarios where the hydrogen and carbon monoxide concentrations were high enough to cause a combustion event. This led to the questions of how effective are PARs in removing hydrogen from the containment atmosphere? How does the initiation of fan coolers or the containment spray system affect the containment atmosphere? What would the effects be on the containment building if there is a combustion scenario?

To be able to properly answer these questions, proper knowledge of severe accidents and their phenomenology is required along with a great amount of knowledge of severe accident codes. Severe accident codes are fundamental to perform safety assessments and study of the efficiency of different severe accident management actions. CSN has the nuclear code MELCOR for its independent safety evaluations so it was the code of choice to perform the analysis.

Based on the motivation above, 3 main objectives were placed for this project. The first one was to be able to run and execute MELCOR and provide technical assistance to the CSN staff. With time, some of the expertise within the CSN was lost with this code and re-familiarization was necessary to be able to carry on the project. This requires learning how the code worked, its structure, how to utilize the different code packages and their implementation into the input deck as well as executing it and performing troubleshooting operations when needed. It also involved learning and using all the tools required to execute MELCOR and analyze the results.

The second objective was to try and implement improvements in the MELCOR inputs for Spanish nuclear power plants. The form of these improvements could be upgrades in some of the packages to make the code run smoother or more accurate, update the input deck to run with the latest version as MELCOR is currently in version 2.X with the latest build being 2.2.94, and optimize other places.

The third and last objective of this project was to provide insights into heat removal strategies that preclude opening the filtered vent system and utilizing instead containment heat removal systems such as fan coolers and the containment spray along with the implementation of passive autocatalytic recombiners (PARs) in large dry containments. The objective was also expanded to analyze the performance of (PARs) and investigate the amount of hydrogen removed from the containment due to their effect.

Using the NUREG/CR-5567 report as an idea mat and with these 3 objectives, the project was started.

Work Environment and Responsibilities

a. Work Environment

The Consejo de Seguridad Nuclear is the governmental regulatory body for radiation protection and nuclear safety in Spain. It is in Madrid, Spain. The mission of the CSN is to protect workers, the public and the environment from the harmful effect of ionizing radiation, ensuring that nuclear installations are operated by their owners in a safe manner and establishing prevention plans and guidelines in case of radiological emergencies, regardless of their origin.

The main functions of this governmental entity are to:

- Regulate the operation of nuclear and radioactive facilities.
- Propose guidelines and regulations for nuclear safety and radiological protection.
- Monitor the environmental and its radiation levels through an established network of stations spread throughout the country.
- Approve licenses for workers in nuclear facilities.
- Approves permits for nuclear facilities.
- Controls doses received by workers in nuclear facilities.
- Suggests corrective actions for facilities not obeying nuclear safety standards.
- Create and promote research projects.
- Informs the public and the courts of its activities.
- Maintains relationships and collaborations the state with other similar organisms.

Given the description and functions above, I was involved in a research project for the modeling and simulation department of the CSN. As mentioned above, the main goals were to learn MELCOR, be able to execute simulations and pass on the knowledge I had gained to other members of the CSN as well as examine the results from a severe accident scenario. The head of this department is Miguel Sanchez Perea.

Miguel was the main motivator behind the project as he recognized a need to recover know-how in nuclear codes. In this case specifically, MELCOR; a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactors. His role in this project became that of a type of overseer. There were bi-monthly progress meetings where the status of the project was discussed. Miguel would contribute by giving his opinions on the current project status as well as providing insight into the project suggesting areas of improvement, other possible methods of analysis and possible areas of expansion in the project.

Along with Miguel, I also collaborated highly with Fernando Robledo Sanz. Fernando is the CSN expert in severe accidents and works in the modeling and simulation department. He and I worked alongside each other daily throughout the project. Fernando was instrumental in developing the project's purpose and aim based om his expertise in severe accidents. He was the person whom I would teach and transfer my knowledge gained in MELCOR to.

The general work environment at CSN was excellent. Everyone was very friendly and willing to help if needed. Throughout the stay, whenever there was a technical problem related to something outside of nuclear engineering, the IT team was readily available to fix my problem and provided whatever tools I might need to be able to work properly. The work atmosphere was also very relaxed which allowed me to work freely and comfortably.

b. Work Responsibilities

Throughout the project, various responsibilities were assigned to me linked to the objectives. The first and foremost important responsibility was learning and executing MELCOR and passing on the knowledge acquired to Fernando. While a lot of work from my side was required, the appropriate help was also given to be able to accomplish this. Miguel provided sources from where I could learn all the tools needed to properly execute MELCOR and accompanying software required for analysis. Fernando on the other hand was helpful so I could obtain the MELCOR license and software.

The second responsibility involved modifying the input deck received from CIEMAT to be able to execute our needs and that of the project. There were several test cases ran, with several of these cases causing errors that would terminate the execution of the program. For some I was able to find solutions and others not. CIEMAT in this case was very helpful in guiding us towards the right solution to be able to successfully execute these cases.

Other responsibilities involved creating manuals for the use of the CSN in setting up and executing MELCOR as well as leaving behind documentation useful in generating graphs and analyzing the data.

Technical Aspects of the internship

a. Tasks Assigned, Problems faced and Resolutions

Considering the responsibilities mentioned above, the first and foremost important task that undertook was learning the nuclear engineering code MELCOR. This was a very time consuming and tedious process considering the complexity of the code. To learn MELCOR, I started off by reading the user and reference manuals that come with the code. This involved reading through over 1500 pages of material related to the code and phenomenology. This served two critical purposes. One was learning all the packages and inputs in MELCOR to be able to create, modify and execute the code. Two, understand the phenomenology behind severe accidents and how MELCOR calculates the evolution of these during execution.

MELCOR is a fully integrated, engineering-level computer code that models the progression of severe accidents in light water reactor nuclear power plants. MELCOR is being developed at Sandia National Laboratories for the U.S. Nuclear Regulatory Commission as a second-generation plant risk assessment tool and the successor to the Source Term Code Package. A broad spectrum of severe accident phenomena in both boiling and pressurized water reactors is treated in MELCOR in a unified framework. These include thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings; core heat-up, degradation, and relocation; core-concrete attack; hydrogen production, transport, and combustion; fission product release and transport behavior. Current uses of MELCOR include estimation of severe accident source terms and their sensitivities and uncertainties in a variety of applications. (L.L Humphries, 1)

MELCOR functions by executing an input file in MELGEN which then creates a restart file that is executed by MELCOR. The figure below is representative of the input-output mechanism of MELCOR.

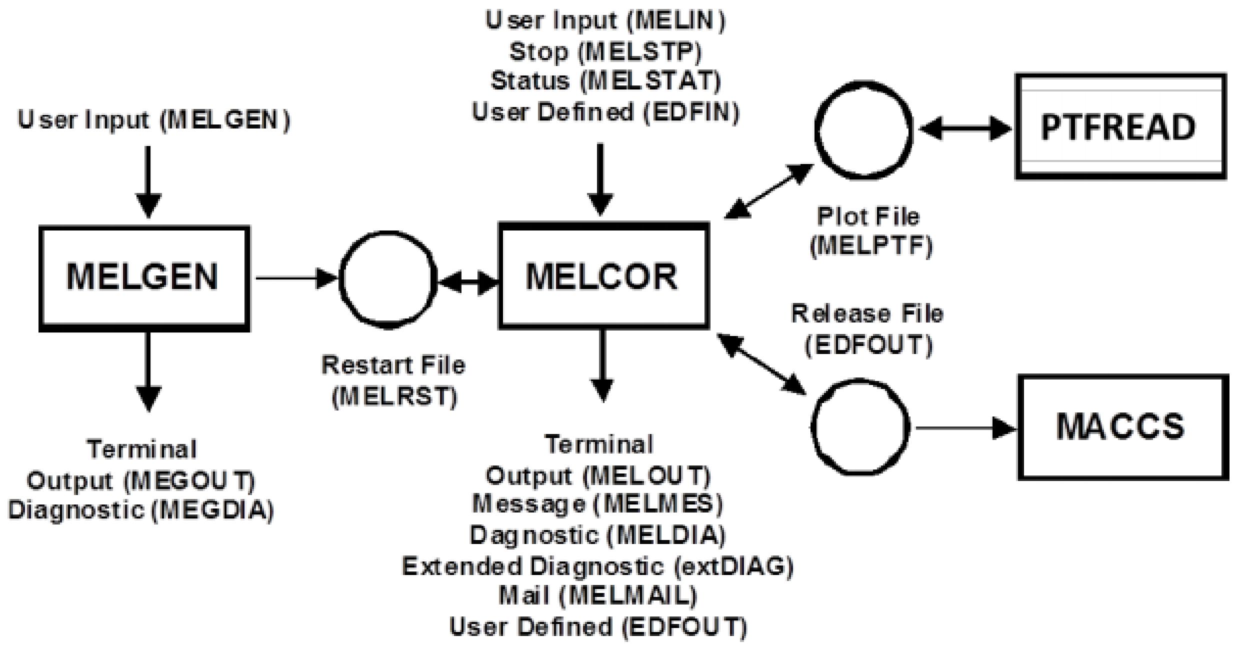

Figure 1 – MELCOR Code and File Relations

Learning the file relations and input-output mechanisms was quintessential to effectively be able to run and troubleshoot MELCOR.

Initially, there were many problems faced when executing MELCOR either in the execution of MELCOR where the execution would end due to a terminal error in the calculation or just an input error in MELGEN. The main methodology for problem resolution when an execution failure occurred would be the open the diagnostic file that would either come from MELGEN or MELCOR, depending where the error was, and examine what caused the failure. I would then go back into the input code and modify the part that caused the failure.

However, as it is the case with many of these engineering codes, the modification would not resolve the error and more troubleshooting was required, which could range from formatting errors in a different part of the code to changing whole package sections that were causing calculation errors in a different package. As experienced was gained, there was less application of trial and error to resolve these problems.

Once the main task of learning and correctly executing MELCOR was finished, the next task was modifying the existing input obtained from CIEMAT. This involved modifying and creating new control functions in the MELCOR input deck, changing and adding functions in the Engineering Safety Functions and containment Spray package.

Below is a small sample of changes performed.

```
!          cfname       icfnum       cftype
CF_ID     'SPRAY-ON'         9001       L-AND
!
!CF_SAI              1.0                              0.0
!
CF_CLS   'LATCH'
!
CF_MSG              2          'SRAYS ACTIVATED'
!
CF_ARG    2 !n            cfarg       arscal       aradcn
          1  CF-VALU('SPR-ON-P')
          2  CF-VALU('SPRAY-ON-TIME')
!
!          cfname       icfnum       cftype
CF_ID     'SPRAY-ON-TIME'         9002      L-GE
!
CF_CLS   'LATCH'
!
CF_ARG    2 !n            cfarg       arscal       aradcn
          1  EXEC-TIME       1.0                        0.0
          2  EXEC-TIME       0.0                        2.88E4  !8 HOURS
!          2 EXEC-TIME     0.0                        2.52E4   !7 HOURS
!          2 EXEC-TIME     0.0                        3.24E4   !9 HOURS
!          2 EXEC-TIME     0.0                        3.60E4   !10 HOURS
!
!          cfname       icfnum       cftype
CF_ID     'SPR-ON-P'         9003       L-GE
!
CF_CLS   'LATCH'
!
CF_ARG    2 !n            cfarg       arscal       aradcn
          1  CVH-P('DOM-COMP')        1.0
          2  EXEC-TIME       0.0       3.99E5
```

The creation of these control functions led to some errors in the MELGEN check and MELCOR execution. While some errors were able to be corrected through trial and error, there were a couple of other problems where the expertise of CIEMAT was required to solve the issue. These types of problems were caused by conflicting settings in packages. Their recommendations to fix these problems generally involved changing options were turned on or off by commenting out the conflicting option.

The tasks involved in completing the project were mostly analyzing the results using various graphing tools to examine the evolution of the different factors and variables in the containment building given the systems and the times activated. Given the large number of variables and graphs that needed to be made, APT Plot scripts were created to more quickly and efficiently generate the graphs needed for the analysis. A preliminary template was obtained from Miguel which gave me a basic idea of how the scripting worked in APT Plot and then the short reference manual was read to quickly learn all the other functions that were necessary to produce the required graphs. As the scripts are all text based, the software Notepad++ was used to write them.

b. Professional Challenges

The biggest professional challenge was adapting to the new workplace. This meant learning the how the CSN functioned internally, who were the people to go to when there were technical problems non-engineering related and what their assignments and roles were in the company. Thankfully, I had a great introduction initially and my office-mate was very helpful in helping me learn the dynamics of the CSN.

I also think that getting into a work routine deserves a mention as a challenge as it is not easy to quickly adapt. Beginning such a job means waking up early and possibly working until late hours until the tasks are completed which is not easy for everyone to do. A challenge for me was waking up early every morning as I tend to be a night person, which means during school, studying and projects would get accomplished during the night.

Formation and Experience Acquired

a. Knowledge gained during Internship

There was a lot of material to cover during the 6 months that the internship lasted which also meant that much knowledge was gained. I can confidently say that I have become a moderately experienced user of MELCOR, to the point where I could create a nuclear power plant model given the reactor and plant characteristics. More importantly, learning MELCOR and analyzing the results required learning severe accident phenomenology in-depth. I feel this knowledge gained makes me a better nuclear engineer since a broader understanding of the phenomenology, how the transient develops based on the type of accident, and the effect that the activation of different safety systems has on conditions can make a big difference in the severity of the accident.

From a personal perspective, I learned a lot about teamwork and how important it is in a project such as the one that was undertaken. I personally like to collaborate and work in groups where responsibilities are shared. In this internship, I felt that it was more of a mentorship both ways with Fernando, the person whom I worked with most closely. As I learned and gained knowledge in MELCOR, I would pass all of that to him. In return, we would sit together and examine the results from test cases and the ones performed and he explained the phenomenology and why certain events would occur as other possible ones during severe accidents. Sharing knowledge this way was very enjoyable and set a standard for how collaborative projects like this should be.

Time management and effective work skills were also learned and polish during this internship which will translate well into future jobs. The connections made, and the broader reach of my personal network is also very gratifying knowing that I have made good new colleagues as well as a couple of new personal friends.

b. Valuation of tasks developed in the internship in relation to studies

I think that the knowledge gained during the coursework performed before the internship was appropriate in preparing me. Given that in the year of courses I had learned 3 new nuclear engineering codes, I was able to quickly learn a new one since they are all formed in similar ways since they are all coded in the same computer language, FORTRAN

95. Furthermore, accidents, their causes, the systems involved, and their development were also thoroughly studied and learned during classes. This helped understand what was happening from a systems point of view during the accident.

However, there was little mention of the phenomenology and physics behind these accidents. To be able to properly understand and analyze the development of the accident as well as the evolution of the atmosphere based on the initiation of the different safety systems that were being activated, I had to learn about the phenomenology during severe accidents and the physics and to a certain degree the math behind it. These topics were covered very briefly or not at all during the coursework. This meant that I had a very broad and unclear idea of all the phenomena occurring during the accident such as molten core concrete interaction scenarios, evolution of combustible gases in a severe accident scenario, effect of initiation of safety systems on containment atmosphere molar mass concentrations. The phenomenology behind these topics were critical in the analysis of the project.

Conclusion

At the end of the internship, I was very satisfied with the work I had performed, with the knowledge gained, and the experience as a whole; both from a personal and a professional point of view. I learned many things about workplace environment and work ethics as well as made new connections that may be helpful for the future.

With regards to the final result of the project performed, I think it was a success for both myself and the CSN as I was the first student from UPC to perform an internship there. The results obtained were an important source of discussion as a final presentation was made and a group of MELCOR users and severe accident analysts gathered for the revealing of the work performed by Fernando and me. The counselor valued greatly the results of the project but more importantly the exchange of knowledge between myself and Fernando as both parties came out winning. He called the result of the project "an outstanding win-win for everyone." Overall, the internship and the project at the CSN was an incredibly positive experience.

In general, I do consider that I was adequately prepared for the internship. The times where I did not feel prepared to perform a task was due to the specificity of the task and required level of detail rather than a deficiency in my academic formation. The project that I performed was in an area (severe accidents) where a lot of time must be spent to develop the expertise needed to tackle the topic.

References

1. Unites States NRC. L.L Humpries. MELCOR Computer Code Manual Vol.1: Primer and Users' Guide. United States. 2017