FRACTIONATED DOSAGE OF HYDROGENATED ADDITIVES IN UO_2 POWDER BLENDING PROCESS

O. ZURRÓN-CIFUENTES, J. LÓPEZ-MÁRQUEZ, E. ESCANDÓN-ORTIZ
Juzbado Fuel Fabrication Plant, ENUSA Industrias Avanzadas S.A.
Ctra. Salamanca-Ledesma, Km. 26; 37115 Juzbado (Salamanca) – Spain

ABSTRACT

The Juzbado Fuel Fabrication Facility has recently completed the implementation phase of the Integrated Safety Analysis (ISA) project. This project aims to identify all the potential accident sequences during the operation of the facility as well as the items upon which the safety to prevent such accidents or mitigate their consequences to an acceptable level relies on (IROFS, Items Relied On For Safety), and to establish management measures to provide acceptable availability and reliability of these safety features. The ISA evaluation carried out on the manufacturing process of green pellets, and particularly on the blending and homogenization nodes where hydrogenated additive is involved, has identified potential accident sequences affecting the control of nuclear material internal moderation, for both uniform and non-uniform over-moderation. Therefore, it has become necessary to implement IROFS. ENUSA has developed a device for the fractionated dosage of hydrogenated additive that acts as a barrier to prevent the occurrence of these sequences. This system acts over the accident uniform over-moderation sequence, first by limiting the additive poured amount by a passive engineering control (pre-set volume container), and second, by limiting the pouring to one single container through an active engineering control. Regarding the sequence of non-uniform over-moderation, the device implements an alveolar valve, providing additive pouring fractionation through a dosage/time pre-set program.

1. Introduction

The ceramic fabrication process begins with the powder preparation and green pellets manufacturing process, which is performed in the PWR, BWR and Gadolinium ceramic areas. This step starts with the uranium dioxide UO_2 reception and its storage in the powder store. The most important criticality control applied on this process is the nuclear material internal moderation, which is controlled even before the uranium powder leaves the shipper facility. It is only allowed to leave the shipper facility if its moisture weight percentage is below 0.40%. This UO_2 powder, U_3O_8 powder (this one is produced at the Juzbado facility by UO_2 oxidation) and a pore forming additive are then mixed and blended. The last one is a hydrogenated additive, so, from the criticality safety point of view, it acts as a neutron moderator. The pore forming additive weight is determined depending on the target pellet density. The blending process is performed in a 600 litre hopper shaped blender, where the and a uniform blend is obtained by means of a rotating and translating worm gear.

The next stage is the pre-press and coarse graining process. The material coming from the blender is poured in a press machine and fashioned into low density pellets that are easily crumbled by a small grinder. The uranium powder so obtained has higher density than the one coming from the shipper and suitable for the next step of the process.

This grained powder is then poured in a homogenization machine, where it is mixed with a lubricant additive and, by a vibration motion, blended homogeneously. This second additive is made of hydrogen and therefore, is a neutron moderator.

The homogenized powder is pressed in a high density press machine, obtaining the so called green pellets. Their density is double the grained powder density. Finally, these pellets are sintered, reaching the target density, passed through a grinder to give them the appropriate diameter, checked and loaded into zirconium tubes.

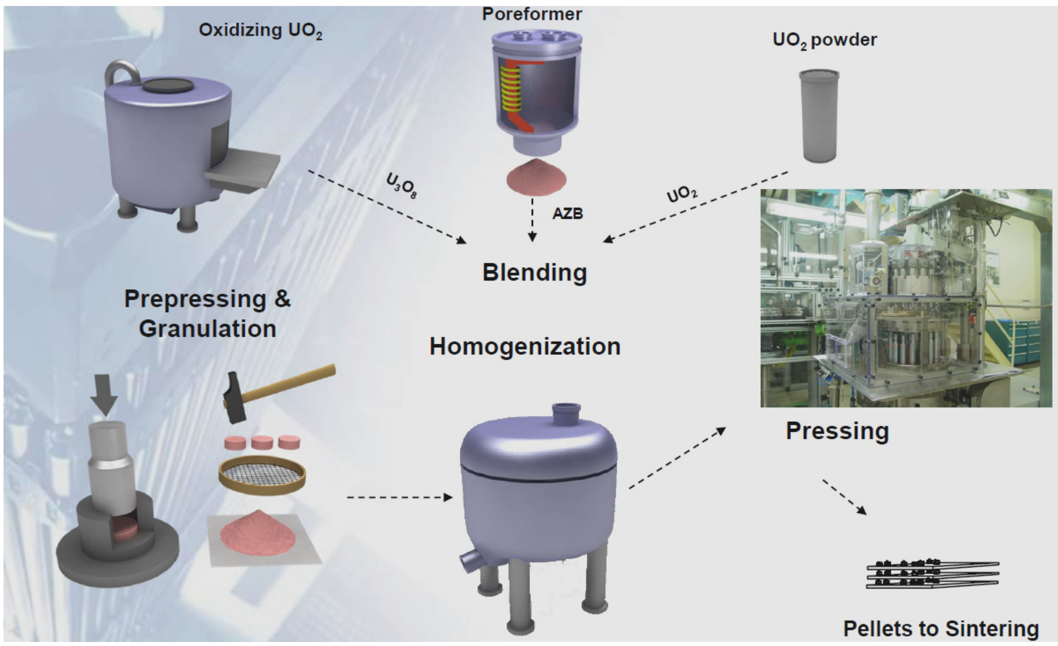

Fig. 1 Pellet Fabrication Ceramic Process

2. Criticality safety controls applicable to the preparation of uranium powder and pellet pressing processes

The criticality safety parameters that are controlled in these processes are **geometry**, **mass** and **neutron moderation**. The geometry parameter is controlled by a passive engineering control given by equipment's geometrical characteristics; in case of the blender, this means the hopper height and its upper and lower diameters. Mass and neutron moderation are limited by administrative controls. The maximum hydrogen content in this stage is given by the total hydrogen-to-uranium atomic ratio $H/U < 0.41$.

Before performing the blending process, a Blending Process Sheet (BPS) is prepared, taking into account the weight of all ingredients (UO_2, U_3O_8, pore former and lubricant additives). A computer software, called MEDEA, computes the H/U given by each one of these ingredients and checks that the total H/U is below the limit. The BPS can only be released if the H/U limit is accomplished. Before taking the uranium powder drums from the powder store, it shall be checked that they are included in the defined BPS. At the time the pore former is weighted, it shall be verified that it weights as defined by the BPS. Furthermore, before pouring the uranium powder and the pore former in the blender, it shall be verified again that the items are the ones defined in the BPS. In case an item is not included in the BPS or the H/U limit is exceeded, the software shows a warning message and terminates the process.

The criticality safety controls applied in the homogenization process are analogous to the blending process. In this case a so-called Homogenization Process Sheet is defined, including all the material involved in the process.

2.1 Neutron moderation accident sequence

Basically, there are three different pathways leading to a loss of the neutron moderation control, which means exceeding the H/U limit value. These are analysed in terms of ISA as the following sequences:

- Mixing process improperly done
- More hydrogenated additive
- Less uranium powder

2.1.1 Mixing process improperly done

Once all the ingredients are poured in the blender (or in the homogenization equipment), the homogeneous mixture (H/U < 0.41 in all the blender volume) is assured only if the mixing process starts immediately and is properly performed. In this case, an improperly performed mixing process could result in the creation of an over-moderated region where H/U limit is not accomplished (see Figure 2). This situation is called **non-uniform over-moderation**.

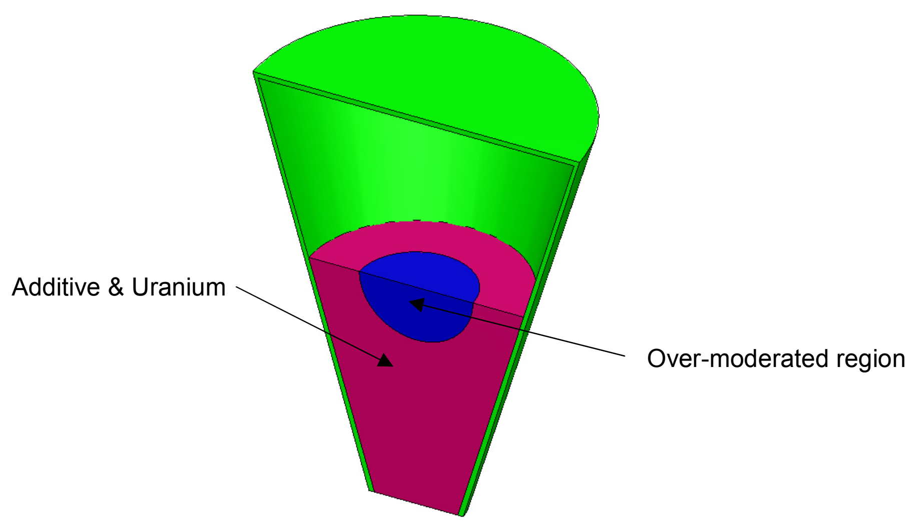

Fig. 2 Non-uniform over-moderation (blender)

Next figure shows the behaviour of k_{eff} during the blending process, starting from the moment all the uranium and additive have been poured into the blender and finishing when the homogeneous mixture is achieved. The over-moderated region (H/U > 0.41) has been modelled as a hemisphere, initially formed only by the additive, which incorporates nuclear material as the blending process advances.

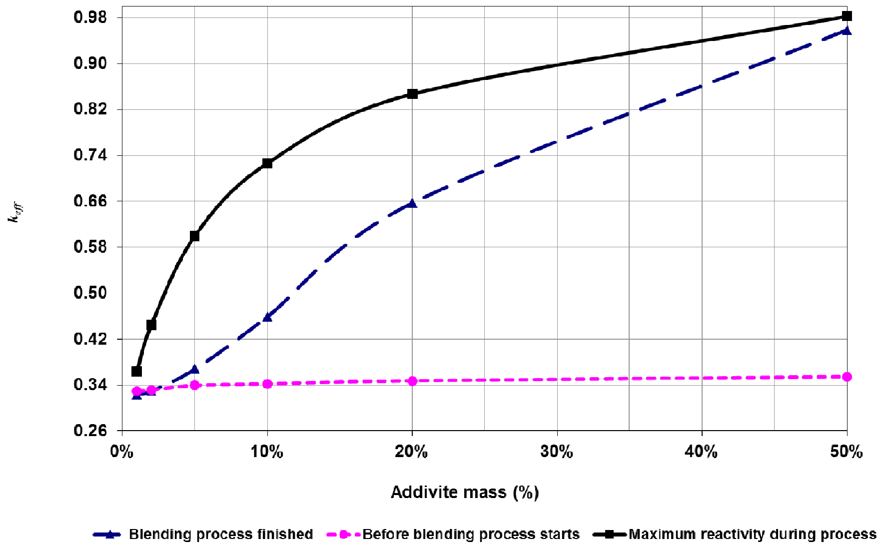

Fig. 3 k_{eff} Vs. Additive mass. Non-uniform over-moderation (blender)

As Figure 3 shows, the reactivity value increases from the curve “Before blending process starts” up to the curve “Maximum reactivity during process” as the process advances, and then retreats to the curve “Blending process finished”. This result made us realize that the fractionated dosage process must ensure that the reactivity value during the process is below the curve “Blending process finished”, thus assuring a large safety margin.

2.1.2 More hydrogenated additive

The second way to lose the neutron moderation control comes from pouring an amount of additives greater than that included in the BPS. This case is named **uniform over-moderation**. Figure 4 shows how reactivity goes up as the added additive weight increases (expressed in weight percentage). Obviously, the second important factor that must be controlled by the fractionated additive dosage is the additive amount poured into the blender. As can be seen, this sequence could end up in k_{eff} > 0.98.

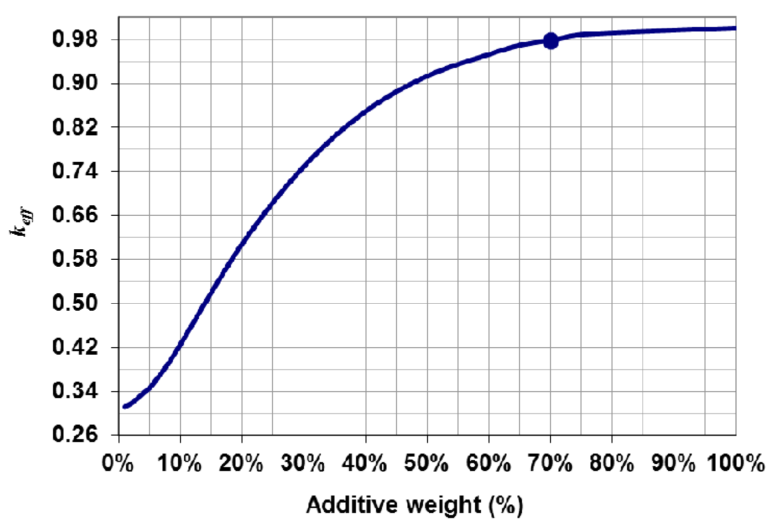

Fig. 4 More hydrogenated additive sequence

These results lead to the maximum severity from the Integrated Safety Analysis point of view, whose methodology compelled us to design and establish IROFs in order to avoid such sequences. Thus, the Juzbado Facility has developed a fractionated dosage device for the hydrogenated additives, not only in the blending but also in the homogenization process. Section 2.2 is devoted to describe how this fractionated dosage system works. Although focus is set in the blending process because of the higher amount of uranium involved, the functional properties are analogous for the homogenization process.

2.1.3 Less uranium powder

This sequence could happen in case all the additive is poured into the blender and the uranium mass is less than the established in the BPS, so the H/U ratio could increase over the limit value. It is considered that the blending process is properly performed and thus uniform mix conditions are achieved. Figure 5 shows the reactivity values for different uranium masses and also several additive weight percentages. A typical additive weight percentage is 1% of the uranium weight.

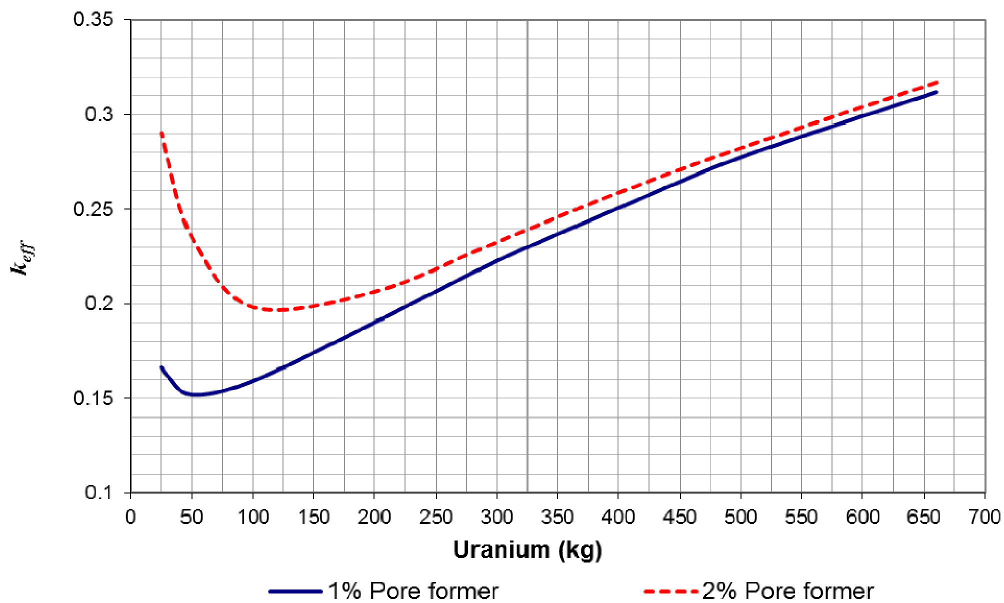

Fig. 5 Less uranium sequence

As it can be seen, less uranium than established in the BPS makes k_{eff} to decrease, although the H/U ratio increases and exceeds its limit value. The maximum k_{eff} value is reached in case all the uranium cans have been poured into the blender, so the H/U is less than 0.41. Minimum k_{eff} values are reached at H/U = 2.0. These results show that the less uranium sequence, although exceeding the H/U limit values, does not increase the process reactivity and thus, the safety margin is not affected. Therefore, this sequence has no effect from the criticality safety point of view and, considering the ISA methodology, its severity is null. Thus, there is no need to implement IROFs as barriers against this sequence.

2.2 Fractionated dosage of hydrogenated additives

The uranium cans are emptied trough the blender upper cabinet. Before the ISA conclusions, all the additive was poured directly into the blender through this cabinet too. Figure 6 shows the designed fractionated dosage equipment. It is placed on the blender upper side, and it is mainly formed by an additive container and an alveolar valve. The equipment designed by ENUSA acts avoiding both non-uniform and uniform over-moderation.

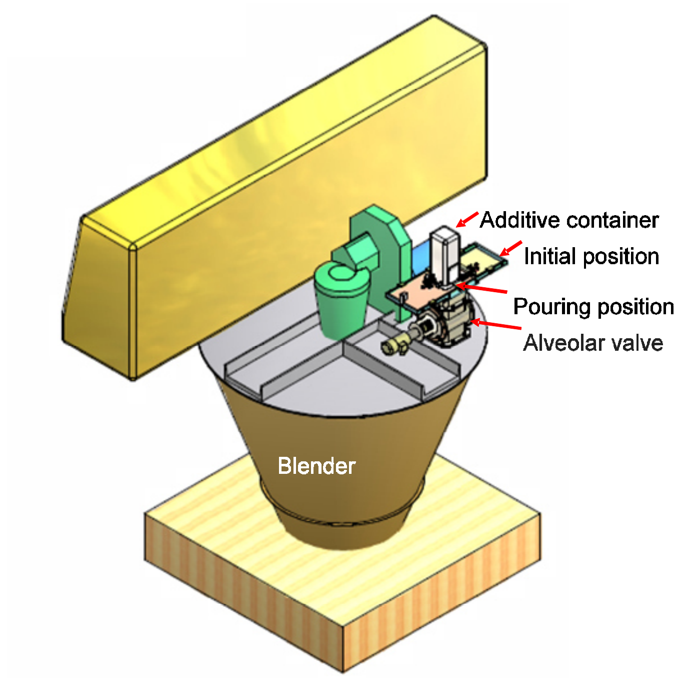

Fig. 6 Fractionated dosage device

2.2.1 Uniform over-moderation

The additive container has a pre-set volume such that, even in case of exceeding the additive weight established in the BPS, the moderation of the resulting mixture is below the limit H/U < 0.41. This container is filled with the pore former in a separate area and taken to the blending area just before the process starts: it is not allowed to store hydrogenated additives in this area. The additive container is placed on the "Initial position", and remains there until all the uranium cans have been emptied into the blender. After verifying that all the right cans have been poured into the blender, it is allowed to move the additive container to the "Pouring position" and over the alveolar valve. This requirement avoids the additive to be mixed with less uranium than established in the BPS, so H/U value is kept below the limit.

As soon as the blending process starts, the additive container is kept blocked in the pouring position. A material detector at the blender bottom avoids to remove the additive container unless the blender is empty. In case of unexpected blender shutdown during the process, such as power failure, the additive container remains blocked. These requirements guarantee that the additive container is removed from the blender only if the blending process has been finished properly, and only once the blender is empty. Therefore, it is not possible to place more than one additive container on the same blending process.

Additionally, there is an additive detector between the alveolar valve and the additive container. If it is still activated once the blending process is finished, which could mean that some additive has not been poured into the blender, it avoids both to finalize the blender and to remove the additive container. In such case it is only possible to re-start the mixing process. This requirement avoids that an additive amount coming from the previous process could be poured in the next process.

2.2.2 Non-uniform over-moderation

The alveolar valve acts as a stopple, so there is not straight way from the additive container into the blender. The alveolar valve only starts working if the mixing process has already begun. The alveolus volume is very small, so every time the valve spins, the additive amount poured over the uranium is also small, and furthermore, as the blender is in process, the additive is quickly mixed. Therefore, the additive and uranium are always mixed uniformly, avoiding thus the creation of an over-moderated region during the mixing process. As it was said before, if the mixing process is unexpectedly cancelled, the alveolar valve stops spinning and no more additive is poured.

Finally, taking into account the calculations performed on k_{eff} behaviour during the mixing process, it is found out that the maximum k_{eff} value is reached within the first and fourth minute, depending on whether the process is performed in the homogenization or in the blender machine. Thus, in order to avoid this maximum k_{eff} condition, the additive addition lasts at least six minutes since the mixing process starts.

3. Conclusions

Considering the high k_{eff} values and the fact that the safety margin for these processes could be challenged, and applying the Integrated Safety Analysis methodology, we are compelled to implement IROFs on the ceramic pellets fabrication process.

This hydrogenated additives dosage process, developed by ENUSA-Juzbado, works as a barrier against the non-uniform and uniform over-moderation, firstly, by limiting the additive mass and, secondly, by spreading it along the mixing process.