XA9948977

EXAMPLES OF REMOTE HANDLING OF IRRADIATED FUEL ASSEMBLIES IN GERMANY

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Abstract:

Examples for the remote handling of irradiated fuel in Germany are presented in the following areas:

- fuel assembling pool service activities;
- early encapsulation of spent fuel in the pool of a nuclear power plant (NPP) at the end of the wet storage period.

All development in remote fuel assembly handling envisages minimization of the radioactive dose applied to the operating staff. In the service area a further key objective for applying advanced methods is to perform the work faster and at a higher quality standard. The early encapsulation is a new technology to provide the final packaging of spent fuel already in the pool of a NPP to ensure reliable handling for all further back end processes.

1. INTRODUCTION

Spent fuel assemblies (SFAs) need to be handled remotely in order to protect the operating personnel from the radioactive radiation originating from the fission products contained in the fuel. In the beginning of nuclear technology, remote handling occurred mostly manually from behind a shielding placed between the irradiated fuel and the operators. Shielding is provided either by water of the spent fuel (SF) pool or by the structure of the hot cells in which the irradiated fuel is handled. Handling of irradiated fuel has been improved considerably by applying computer controlled automation of the processes. This results not only in a more reliable performance of the handling processes, but also in much shorter process time and in a considerable reduction of the radioactive doses applied to the operating staff. In the paper examples of advanced remote fuel handling from the following two areas are presented:

- fuel services in the pool of a NPP;
- preparation of SF for long-term interim storage in the pool at reactor site.

2. EXAMPLES OF REMOTE HANDLING IN FUEL ASSEMBLY SERVICES

2.1. The MULTI-INSPECTION system

The MULTI-INSPECTION system has been developed by Siemens to minimize time and expense of the visual inspections of fuel and control assemblies required during the course of a refueling outage. In the past, these components were held in the refueling machine for the duration of the inspection and inspected in a temporally installed system. With the new system, the components are placed in receptacles located in the SF pool so that the refueling machine is only required for a short time to position components.

While the inspections are being conducted, the refueling machine can be used to insert and remove SFAs, to perform a mast sipping test or to shuffle control assemblies and flow restrictors. This cuts the time required for refueling activities by as much as three days, as was confirmed during two refueling outages at the Gösgen PWR plant in Switzerland, in which this kind of inspection system was first installed (Figures 1 and 2).

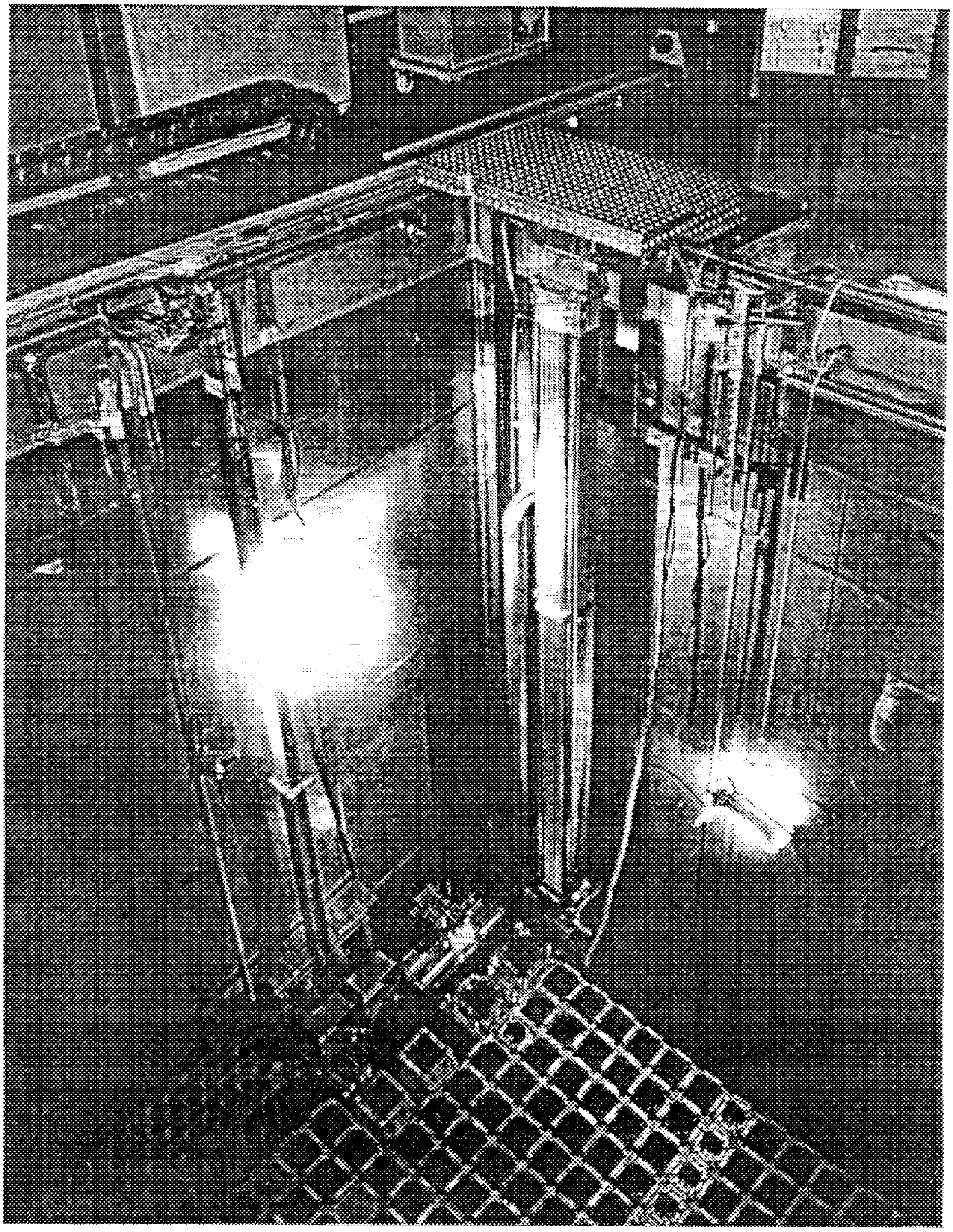


FIG. 1. MULTI-INSPECTION at Gösgen

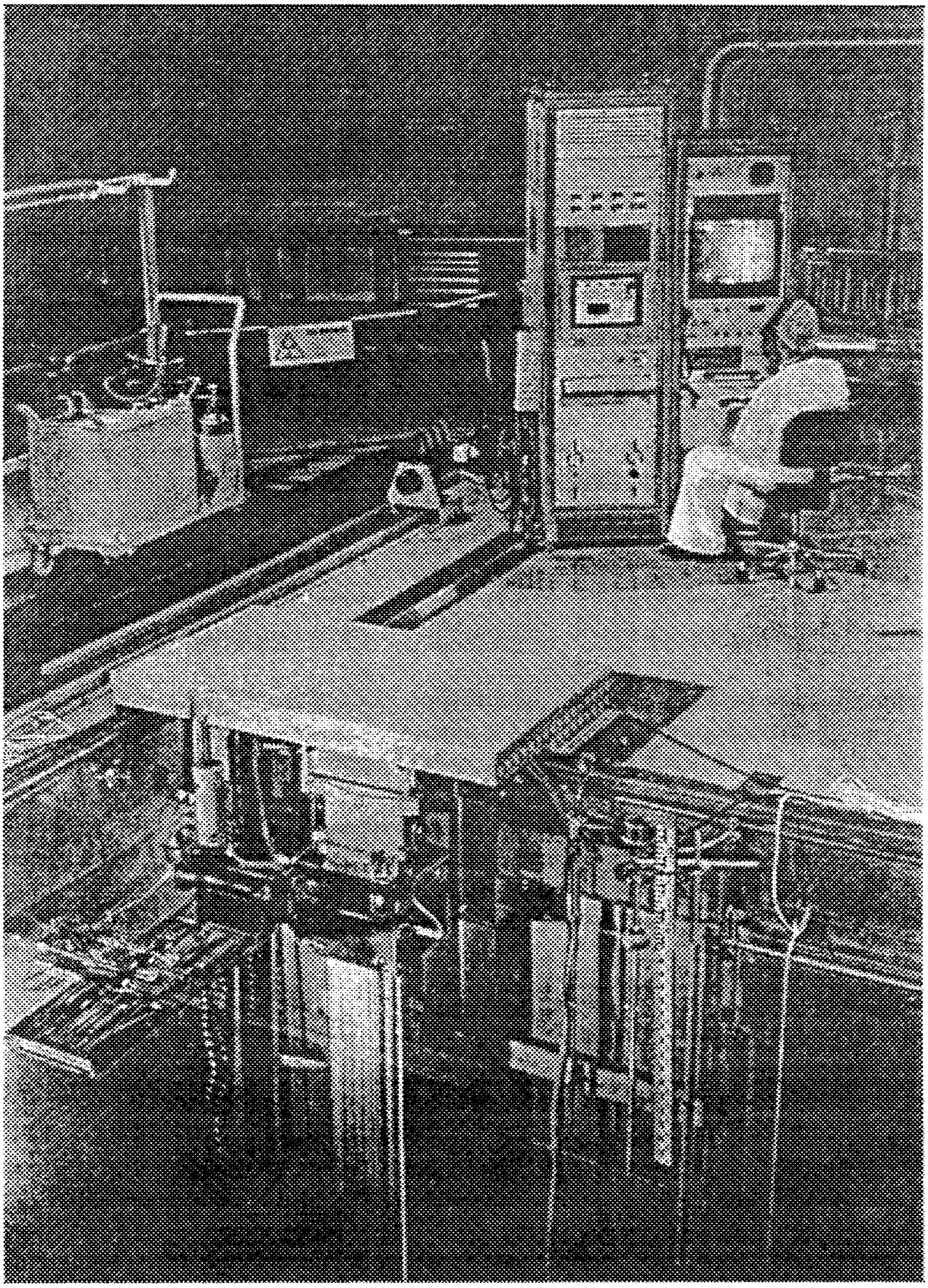


FIG. 2. Visual inspection systems

The MULTI-INSPECTION system installed at the Gösgen plant consists of an inspection manipulator, a control cabinet and two fuel assembly holding boxes. Each box is freely accessible from one side, and is open for visual inspection. The SFAs or control assemblies placed into the boxes can be individually rotated to allow inspection from all sides. The compact, portable control cabinet is used to control the overall system from the edge of the fuel pool. The inspection manipulator is fitted with one or two underwater video cameras which are mounted on a co-ordinate-controlled traveling table which in turn is mounted on a mast-guided carriage. This arrangement allows the cameras to traverse the entire length of the fuel assembly, including the top and bottom end pieces. The carriage can also be raised to the top edge of the fuel pool, where the cameras can be removed and replaced above the surface of the water.

The inspection manipulator can be used for a wide variety of applications by simply attaching the appropriate equipment modules. For example, the system permits optical measurement of bowing and dimensional changes. In addition to the timesaving semi-automatic measurement of the oxide layer thickness on peripheral fuel rods, the same measurements can be made on all interior fuel rods at any height using the INOXIS system.

The MULTI-INSPECTION system is available in several different versions, so it can be tailored to meet the requirements of individual power plants. The fundamental principle of operation, however remains the same. At the Grafenrheinfeld PWR plant in Germany, for example, the new fuel elevator has been appropriately modified. A different system design has been implemented at the Philippsburg 2 PWR plant in Germany, in which the dual inspection boxes are hung in backpack fashion on a fuel storage rack.

2.2. The AUTOMATIC CO-ORDINATE-CONTROLLED CARRIAGE

Siemens uses an AUTOMATIC CO-ORDINATE-CONTROLLED CARRIAGE (Fig. 3) to perform fuel reconstitution when testing of the integrity of cladding tubes is also required. This new device is a further development of the carriage already used for transferring fuel rods to new fuel cages. It is integrated into the existing reconstitution device, and makes fully automated testing of the integrity of the cladding tubes of all the fuel rods in a fuel assembly possible. The fuel rods are grabbed as before by the fuel rod exchange device and examined using the eddy-current method as they are withdrawn. Friction force is also measured during this process. Fuel rods which are within permissible tolerances are reinserted, and defective ones replaced.

Using the new co-ordinate-controlled carriage (Fig. 3), the fuel rod inspection for one fuel assembly takes only about ten hours, i.e., three service personnel shifts per fuel assembly less than needed with earlier inspection methods.

3. EARLY ENCAPSULATION

The encapsulation technology provides the possibility to encapsulate both PWR and BWR SFAs at the end of the wet storage period. The encapsulation process takes place in the SFA storage pools at reactor site. It is based on well approved service technologies in all individual process steps. Among other consideration there is the advantage that the final packing of the SF occurs in using reliably performing processes conducted by those engineers which are familiar with the design, fabrication and operation performance of the fuel (Fig. 4).

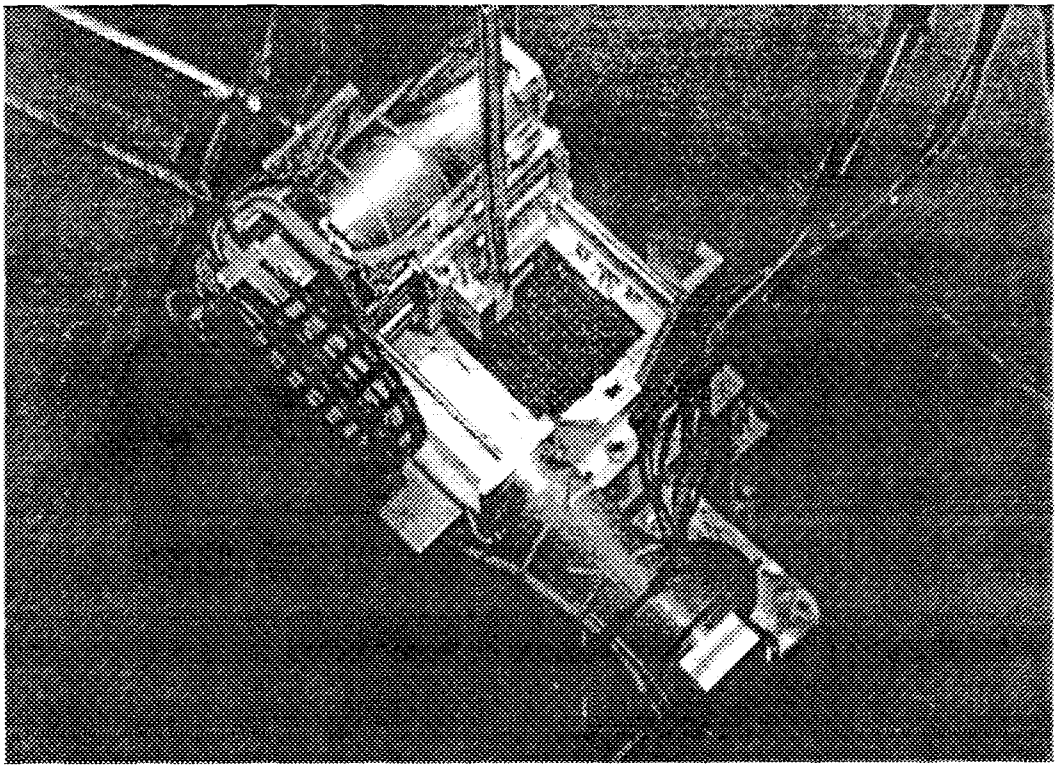
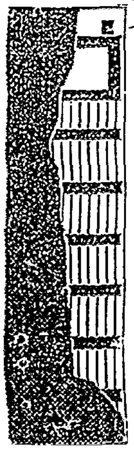


FIG. 3. The Siemens co-ordinate-controlled carriage (shown in operation on top of a SFA)

no longer extended ARS pool storage, extremely long interim storage AFR and complex interfacing between front end & back end of the fuel cycle even for FA with increased burn up



Each spent FA is loaded into a capsule. The capsule interior is dried and made inert, and the capsule is seal welded. The encapsulation is performed just prior to dual porpose cask loading as a sevice

- *the capsule assumes the barrier function instead of the cladding*
  → *the FA EOL condition plays no longer a major part if the cask loading is performed*
- *the capsule is designed to take all loads from handling processes and in storage*
  → *the capsule minimizes the number of interfaces between front end and back end and allows for seperate optimization*
- *the encapsulation provides an early conditioning of the spent FA for the repository*
  → *adequately designed SS capsules provides a better long term storage performance than a high burn up FA in its EOL condition*
- *individually encapsulated spent FA provides the smallest decay heat per package*
  → *this is the only chance to limit the the interim storage for U-MOX-FA even with higher burn up to < 100a for all kind of geological rock formations discussef for the final repository*

FIG. 4. Early encapsulation creates benefits throughout the entire backend of the nuclear fuel cycle

3.1. The equipment

The encapsulation process occurs remotely and will have the capacity of several SFAs per day. The early encapsulation makes use in all subsequent steps of the back end of the fuel cycle from the available and approved technologies like transportation and storage casks and final disposal techniques. Only the cages in the SFA-casks needs some slight modifications. Fig. 5 exhibits the back end of the fuel cycle when early encapsulation is selected for the final packaging of the SF already in the SF pool at reactor site.

The transportable encapsulation device (Fig. 6) consists of :

- the encapsulation station with 2 individual process modules for the encapsulation working in parallel;
- one joint service module which contains all necessary tooling and the welding device;
- 2 intermediate SFA storage positions for receiving the SFA from the storage racks and after completion of the encapsulation process for passing the encapsulated SFA for either further storage in the pool or for being immediately loaded into a waiting transport and storage cask;
- a first transportation cover to lower the empty capsule in a dry manner down into the encapsulation module;
- a second transportation cover with an integrated SFA drying device to transfer the SFA from the receiving position to the encapsulation module and to dry the SFA;
- a third transportation cover with an integrated He-leak-detector system to remove the encapsulated SFA from the encapsulation module, to provide necessary leak testing and to forward the encapsulated SFA to the second intermediate storage position.

3.2. The process

Fig. 7 describes the complete encapsulation process. For handling of heavy components the overhead crane in the containment provides the necessary support, the transportation of the SFA is carried out whether by the fuel manipulator crane or by the auxiliary hoist available at the fuel manipulator crane. The encapsulation process can be described by the following characteristic process steps:

1. On the floor aside of the SF storage pool the empty capsule is raised into a vertical position and filled with Argon (Fig. 8);
2. The Argon-filled capsule is transported with its cover lid in a dry manner down to the encapsulation module, connected to the locking device and lowered down to the encapsulation module (Fig. 9). The cover lid of the capsule is now removed into a waiting position;
3. Parallel to the process steps 1 through 3 a SFA is taken with the SFA handling machine from the storage racks and brought in the first intermediate storage position (Fig. 10);
4. The SFA is subsequently removed from the first intermediate storage position by the second transportation cover, docked on top of the encapsulation module which contains the empty capsule and is drained;
5. After drying the SFA to the specified value by heating it with electrical heaters and by subsequent vacuum the SFA is ready to be inserted into the encapsulation module;
6. The SFA is lowered down into the capsule. The cover lid of the capsule is taken back from its waiting position and positioned on top of the capsule now containing the SFA;
7. The capsule is now closed by an automated TIG-(tungsten inert gas) welding process. During the welding process a valve - contained in the cover lid of the capsule - is kept open and allows an pressure equalization between the capsule and the encapsulation module thus avoiding a material blow out in the very last moment when the weld tightens the capsule closure;

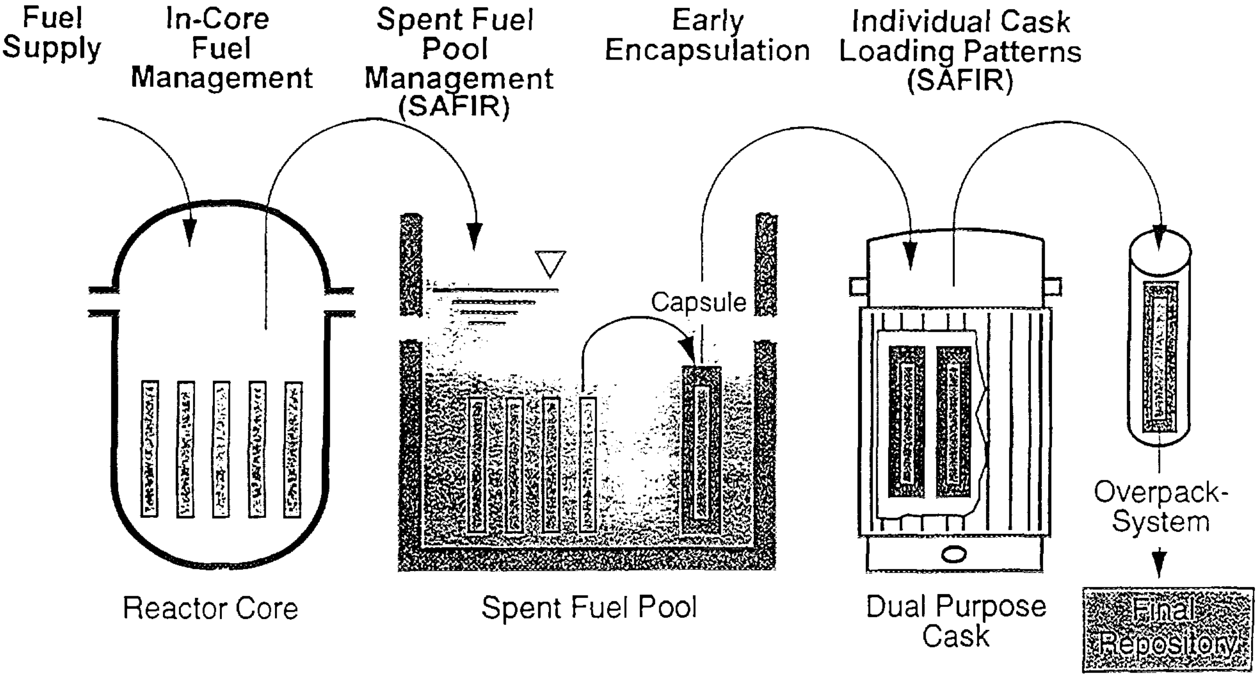


FIG. 5. Optimization of the entire process

The transportable encapsulation device consists of:

- the encapsulation station with 2 individual process modules for working in parralel **(1)**
- one joint service module which contains all automated tooling **(2)**
- 2 intermediate FA storage positions for receiving the FA from the storage rack and after completion of the encapsulation process for passing the encapsulated FA for storage or for loading to transport and storage casks **(3)**
- a first transfer cover to lower the empty capsulein a dry manner down to the encapsulation station **(4)**
- a second transfer cover with an integrated FA drying device **(5)**
- a third transfer cover with an integrated He-leak-test device **(6)**

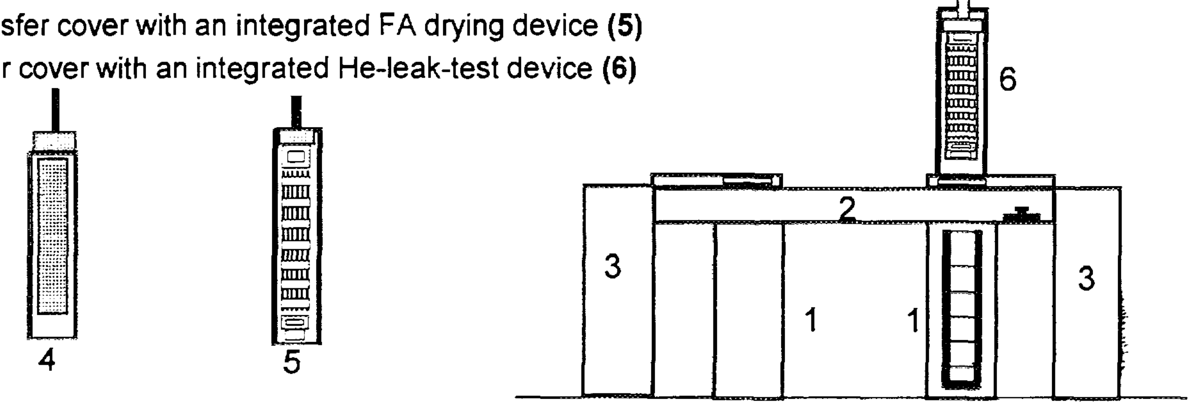
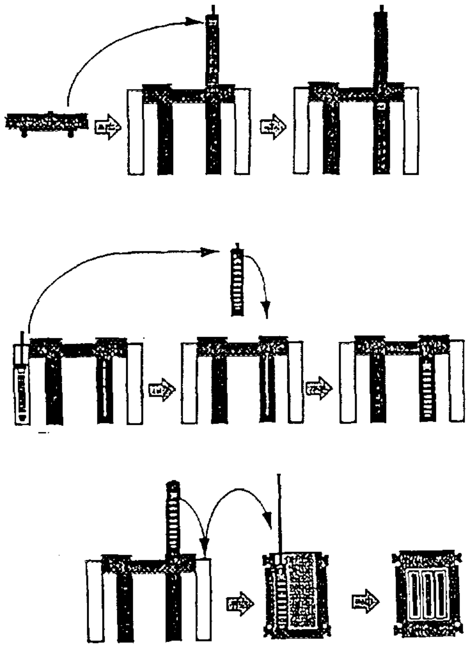


FIG. 6. Early encapsulation - the equipment

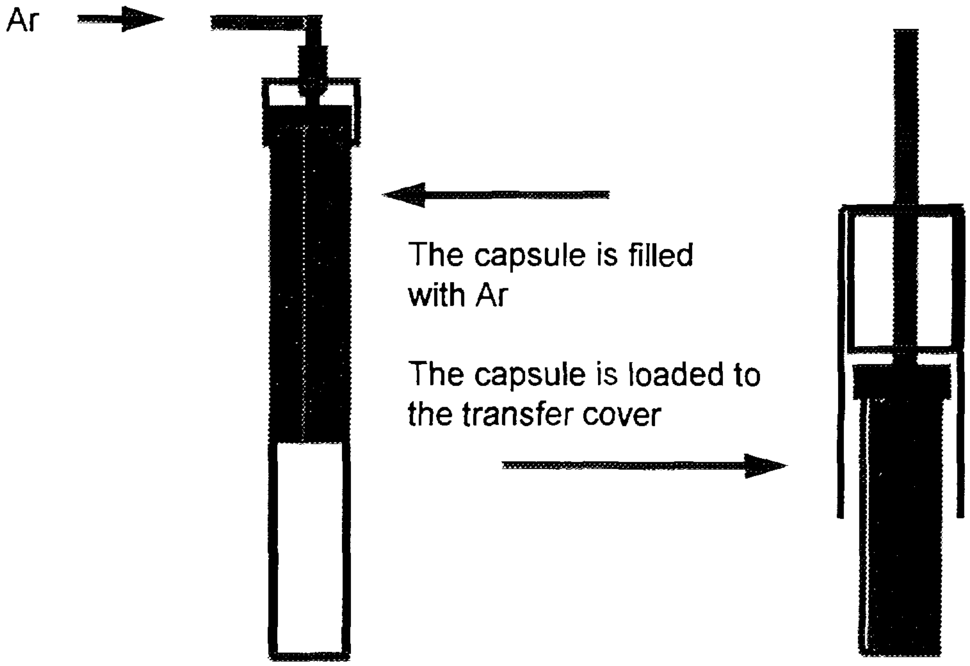


The capsule is inserted into the encapsulation device

The FA is removed from the storage racks and is inserted to the encapsulation device, dried, placed into the capsule and seal welded

The encapsulated FA is removed from the encapsulation device and loaded to the transport and storage cask

FIG. 7. Early encapsulation of a SFA occurs in a movable service equipment within the pool of a reactor



The capsule is filled with Ar

The capsule is loaded to the transfer cover

FIG. 8. Early encapsulation - the process

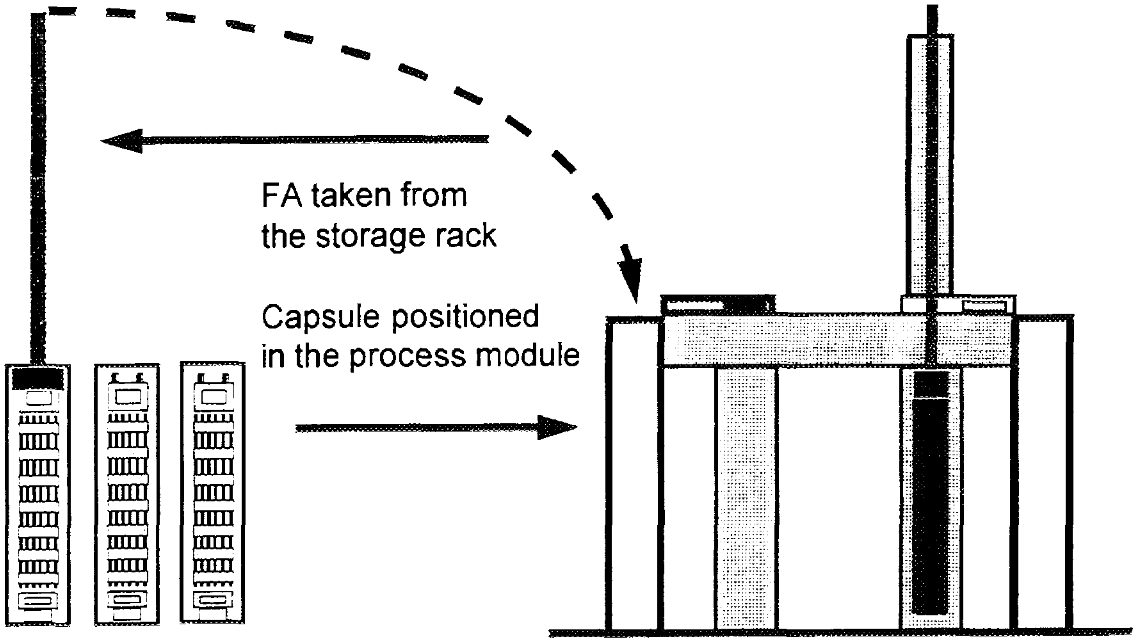


FIG. 9. Early encapsulation - the process (continued)

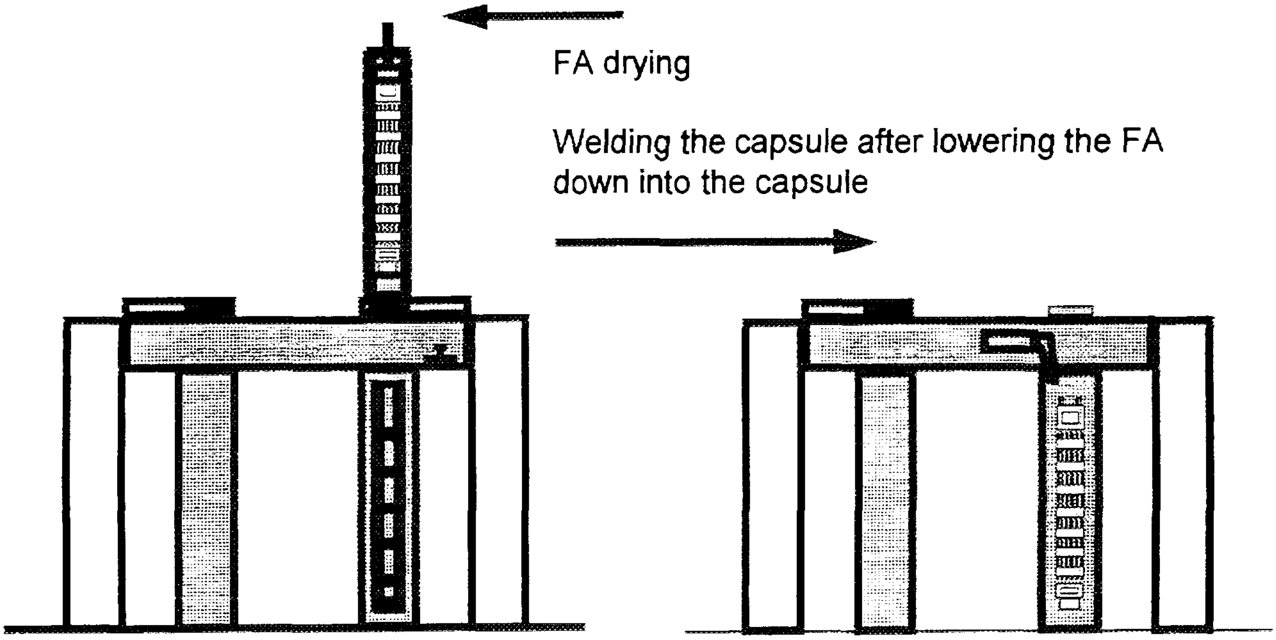


FIG. 10. Early encapsulation - the process (continued)

8. After completion of the main welding the still open valve in the capsule cover lid is connected to a gas supply system providing the right capsule internal gas pressure by feeding Argon and Helium. The Helium is later on needed to perform the He-leak test. Finally this gas valve is closed mechanically and welded (Fig. 11);
9. The encapsulated SFA is now tied up into the third transportation cover with the integrated He-leak testing system. Having passed the leak tight test successfully the transportation cover is disconnected from the encapsulation module and brought to the second intermediate storage position from where it might be transferred to the waiting storage position or to the storage and transportation cask.

The encapsulation process will performed remotely and automated. The „hands-off" operation mode in normal operation allows to minimize the doses applied the operating staff. The process can be operated in the forward direction to encapsulate the SFA and in the backward direction to decapsulate the SFA. Decapsulation is possible from each intermediate process step and from the final process step to ensure that the SFA can be removed from the encapsulation station independently what has happened.

Each electrically driven machinery is designed redundantly or can be remotely replaced by a new device. As a final measure each electrically driven motion can also be operated manually using long handling tools.

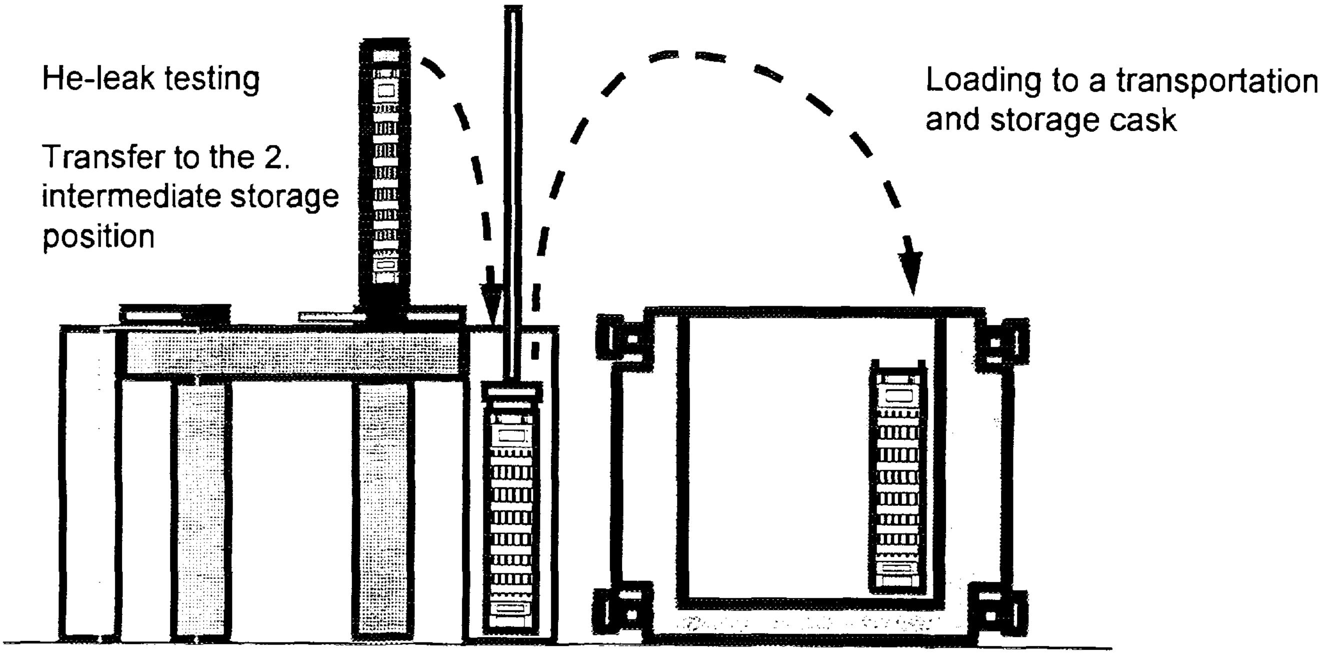


FIG. 11. Early encapsulation - the process (continued)

3.3. Selected considerations of technology

Exemplary for all other process steps the following steps will be discussed in greater detail to illustrate how the available know how is integrated in the SFA encapsulation process:

- From the two possible welding processes - laser welding and TIG welding - the TIG-welding was selected because of its larger scope of experience under remote service conditions. TIG-welding can be performed with and without material supply. Experience shows that the material supply during remote welding might be troublesome therefor it was decided to weld without any additional material supply during welding. Argon will be used as the welding atmosphere. Normally some hydrogen is added to Argon for better focusing the welding arc. Since we see safety related questions together with the hydrogen addition we will perform the welding in pure Argon. Gas cooled welding heads instead of water cooled were selected to avoid problems with water in case of malfunction. Since the operation temperature of such welders is somewhat higher we had to envisage an increased wear of the W-cathode;
- With respect towards long interim storage periods the SFA drying process during the encapsulation is of great interest. When water rinsing is completed there are still water films adhering to all surfaces of the SFA. On the fuel rod surfaces those water films will be easily evaporated by the support of the decay heat. The removal of residual water in the lower ends of the guide does not occur so nicely since the heat of evaporation must be taken only from the heat capacity of the SFA structure. Without any additional heat supply from external sources this water may freeze during vacuum drying. Therefor our concept foresees that in first step heat is supplied to the SFA structure from a heating system integrated into the drying device. Vacuum drying starts if the cold spot in the structure is heated to > 90°C. A second heating/drying cycle assures that relay all water is reliably removed. This drying procedure was developed experimentally first. In a second step this procedure was modeled theoretically. Finally the design of the drying equipment was performed by using this experimentally verified design code.

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