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DEVELOPMENT OF ROBUST TECHNOLOGY FOR ASSEMBLING ANNULAR TARGETS CARRYING LEU FOILS FOR PRODUCTION OF MO-99

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ABSTRACT

This paper will present analysis, design work, and experimental investigation for development of an effective drawing process and device for assembling the inner and outer tubes of the ANL-designed LEU-foil target. The developed device and process are semi-automated and robust in order to meet minimum productivity of 2000 defects-free targets annually. All technical constraints of both process and device designs are identified. Mechanics of the developed process are analyzed using both analytical and finite element techniques in order to explore the design conditions that assure integrity of the assembled targets and safety during their irradiation. The new design is flexible and can be easily adjusted for assembling annular targets with different dimensions needed for accommodating LEU foils with different sizes.

1. Introduction

More than 30 different radiopharmaceuticals use Technetium-99m (Tc-99m) for imaging and performing functional studies of the brain, myocardium, thyroid, lungs, liver, gallbladder, kidneys, skeleton, blood, and tumors. Tc-99m, is the daughter (decay) product of molybdenum-99 (Mo-99). At the present time, most of the world's fission product Mo-99 (95% of all production) is produced using high enriched uranium (HEU); ≥20% enriched in U-235[1-8]. Worldwide concerns regarding transport of weapons-grade material are forcing the conversion of HEU targets to low-enriched uranium (LEU) ones [1, 2, 8]. This represents the main mission of the international programs: Global Threat Reduction–Conversion program [1-6]. Argonne National Laboratory has demonstrated that fission product Mo-99 can be produced using low enriched uranium (LEU); <20% enriched in U-235 [1, 2, 8]. Furthermore, LEU-foil target has been successfully irradiated, disassembled, and processed in Indonesia, Argentina, and Australia [5-7]. A commercial fue1 supplier (CERCA) in France has fabricated LEU-foil annular targets for ANSTO [4]**.** Argonne National Laboratory has fabricated a mock IRE target that will produce an equivalent amount of Mo-99 as their current HEU target. CNEA has irradiated and processed its LEU dispersion target commercially over the past few years. In all the trials attempted for investigating the feasibility converting of HEU targets to low-enriched uranium (LEU) targets, small scale prototypes for assembly and disassembling of the targets have been used. The development of these prototypes is based on trial and errors approach and can only meet very small fraction of the needed Mo-99. There are needs for robust technology and designs for high production that can fulfill economic constraints, quality, safety issues, and affordability for all countries around the World.

2. Current Assembly Technology

The assembly of the target starts with wrapping the LEU foil with nickel foil of 0.015 mm thick. The wrapped foil is then inserted between two concentric aluminum tubes (annular target) as shown in Figure 1. To prevent foil slip during insertion, a grove is made in the inner tube. A longitudinal line was scribed on the outer tube for the foil gap indication. In order to assure good contact between the foil in the concentric tubes, a draw press is used to draw the whole assembly of the annular target as shown in Figure 2. The ends of the target are sealed by TIG welding process. The detailed procedure was written in the Argonne procedure for target assembly [9]. The average dimensions of aluminum tubes for annular target are as follows: Outer tube has ID 28.27 mm and OD 30.00 mm. While, inner tube has ID 26.23 mm and OD 27.98 mm.

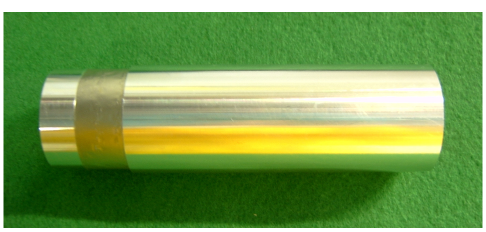


Figure 1 Annular Target before Drawing

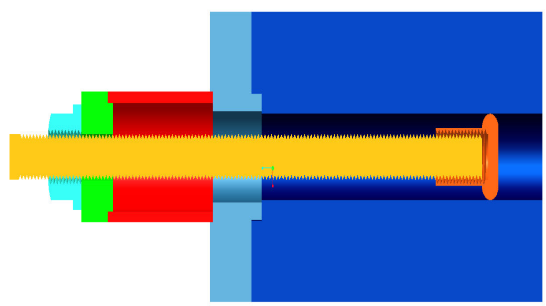


Figure 2 Drawing Press Developed at ANL

The present investigation started by conducting failure modes and effects analysis on the Argonne current design for the drawing process in order to identify all difficulties existed with it. This was followed by analyzing the mechanics of the Argonne drawing process using finite element method. The objective of this analysis is to explore the safe operating conditions that would result on sound consolidated target without any defects.

2.1 Finite Element Analysis of the Current Drawing Process

The drawing process is simulated using ABAQUS/Explicit. ABAQUS/ Explicit solves for a state of dynamic equilibrium at the start of current time increment *t*:

$$M^{NM}\,\ddot{u}^{N}\Big|_t = \left(P^{N} - I^{N}\right)\Big|_t$$

where M^{NM} is the mass matrix, $\ddot{u}^{N}$ is the acceleration vector, P^{N} is the external force or applied load vector, and I^{N} is the internal force vector (the 'internal force' created by stresses in the elements).

Geometric Modeling of the Parts

The inner and outer tubes and the Foil are modeled as deformable materials. It must be mentioned that the foil materials were limited to the LEU foil and the fission-recoil barrier was eliminated in order to simplify the analysis for this phase of the research. The punch and die are modeled as rigid materials. The assembled FEA model with different parts during the drawing process is shown in Figure 3. Figure 4 shows the section view of the process model. The foil is sandwiched between the recess provided in the inner tube and outer tube internal surface.

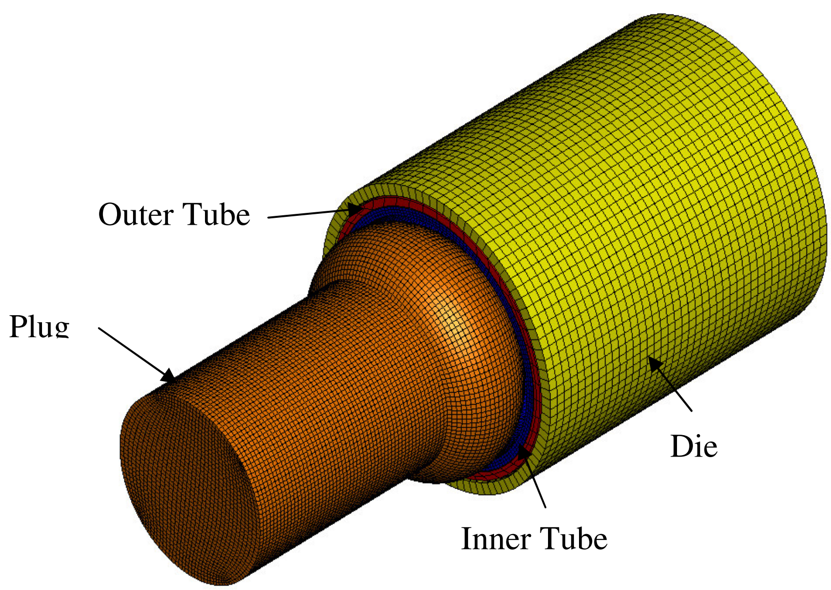


Figure 3 Isometric View of Initial Setup of Finite Element Model

Material Modeling

Material in this analysis is modeled as elasto-plastic material using the constitutive equation,

$$\sigma = K\,(\varepsilon)^{n}$$

Where σ is the flow stress of Al 3003, ε is the deformation strain, K is the strength coefficient = 110 MPa and n is the strain hardening coefficient= 0.2.

The inner and outer tubes are modeled as annealed Al-3003 material. Foil is modeled as Uranium foil, (Table 1).

Contact Conditions

Coulomb's Law is used to simulate Contact Interaction.
Co-efficient of Friction between all interacting parts is 0.3

Meshing Techniques

Tubes and Foils are modeled as deformable while the punch and die are modeled as rigid material. This is done to reduce the computation and still get accurate results due to the fact that punch and die undergo relatively small deformations compared to tubes and foils. Eight Node 3D Stress (C3D8R) elements are used to model the tubes and foil. Tubes and foil undergo high deformation during the swaging process and lead to distorted elements. In order to obtain results from a high quality of meshing, Adaptive Meshing technique has been used in this simulation. This is achieved through re-meshing of the model at pre-determined intervals without altering the topology.

Table 1. Material Properties

Al- 3003, Annealed [http://en.wikipedia.org/wiki/Aluminium]	Uranium [http://en.wikipedia.org/wiki/Uranium]
Young's Modulus: 68.9 GPa	Young's Modulus: 190 GPa
Poisson's Ratio : 0.33	Poisson's Ratio : 0.22
Yield Strength : 41.4 MPa	Yield Strength : 200 MPa
Ultimate Strength : 110 MPa	Ultimate Strength : 400 MPa

Analysis of the Numerical Model Results

Uniform deformation of the tubes can be seen in Figure 4. The punch moves along the axis of the tubes, pushing the inner tube towards the outer tube causing deformation of the inner tube wall and the foil, thereby closing the gap between them and creating direct contact.

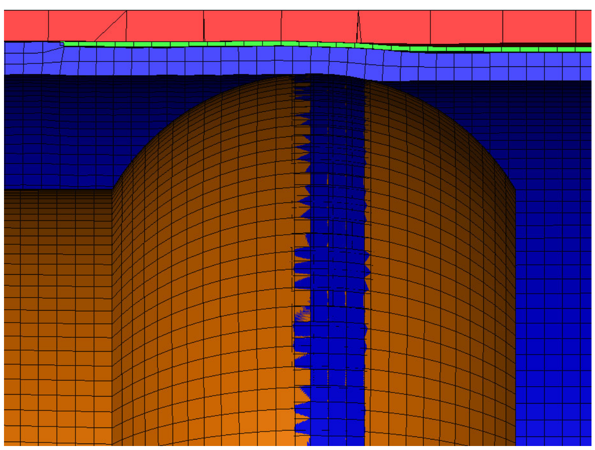


Figure 4 An Enlarged View of Process Model Showing Deformation of all Target Elements

The results of the finite element analysis indicated that the inner tube experienced effective stress of 57.1 MPa and effective strain of 0.27. Both values exceeded the yielding values of the aluminum and therefore the inner tube was subjected to plastic deformation. The outer tube on the other hand experienced less effective stress of 40 MPa and effective strain of 0.01 which mean that the wall of the outer tube was under elastic deformation. The foil material was subjected to effective stress and effective strain of 202MPa and 0.06 respectively which are very close from the elastic limit of the foil material and therefore almost no plastic deformation occurs in the foil. The developed stress distribution gives no indication of any potential rupture of any elements of the assembly. The analysis also indicated that if the drawing process takes place at high speed as in case of using motor driven press, there is potential of inner tube failure by buckling due to higher axial stress in the tube wall in addition to stresses caused by the inertia forces.

2.2 Experimental Investigation of the Effectiveness of Current Technology

The effective drawing parameters obtained numerically were used in investigating the process experimentally. An experimental hydraulic press (shown in Figure 5) was used with the existing drawing tools. A copper foil was used in the experiment to simulate the LEU foil. The assembled target was then sectioned in order to prepare samples for Scanning Electron Microscopy (SEM) investigation. The resulting SEM micrograph is displayed in Figure 6. It is evident from the figure that the drawing process was effective to establish perfect contact between the inner and the outer tubes and the copper foil with its nickel envelop.

Figure 5 Experimental Drawing Press

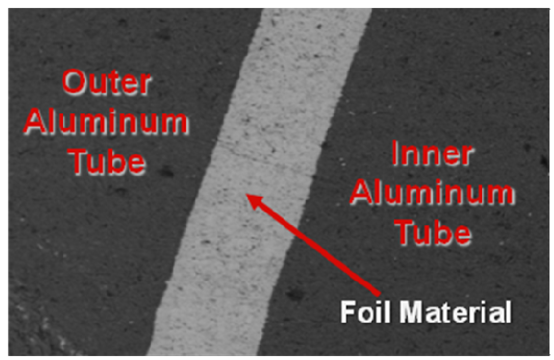


Figure 6 SEM Micrograph of Assembled Target

3. Development of Robust Annular Target Assembly

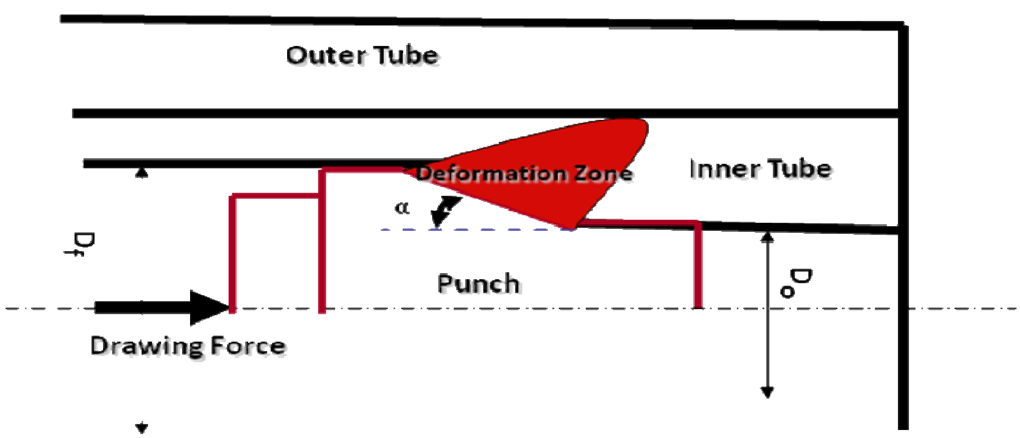


Figure 7 Schematic of the drawing process of Annular Target using Conical Punch

Figure 7 displays the arrangement of a drawing process using the proposed conical punch. The conical surface of the punch has a semi-plug angle α that allows for gradual plastic deformation of the inner tube equivalent to the one provided by the original spherical punch. In this plug design the maximum amount of deformation occurs over a larger area instead of a single line as in the case of the spherical punch of the current technology. This design would help in stability of deformation and preventing any relaxation or elastic recovery of the inner tube wall. The new arrangement involves also pushing the plug instead of pulling it through the inner tube as in the case of the original design. This was done based on the common technology of drawing tubes using floating plug and to improve stability and robustness of the process. The drawing process design followed the analysis proposed by Schey [10]. This design allows for plastic deformation zone to cover the entire inner tube thickness (Figure 7). Force is applied through the punch. Deformation of the wall of the inner tube is caused by compressive stresses along axial, radial and hoop directions. The drawing force needed for the given dimensions and materials is calculated to be 1592 *N* (352 *lb.f*). A finite element model for the new process is established using same approach described in sec. 2.1. In this model the designed new conical plugs (one of them is displayed in Figure 8), is used. Figure 9 displays a section through the FEM model for the entire process. It includes: the inner and outer tubes; the LEU foil the Ni envelop, and the interfaces that exist between all elements. At the present time the FEM model is still under refinement and further investigation for the purpose of exploring the optimum target, process, and tooling design.

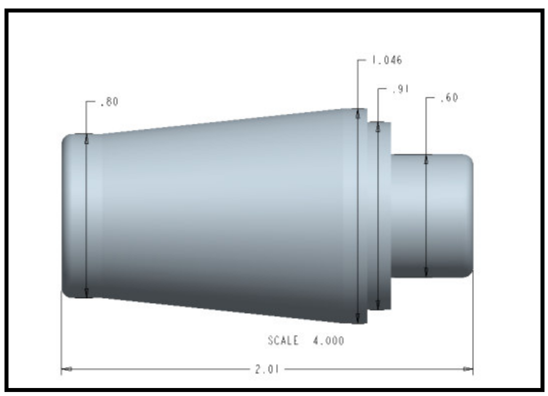


Figure 8 Typical Conical Plug Design

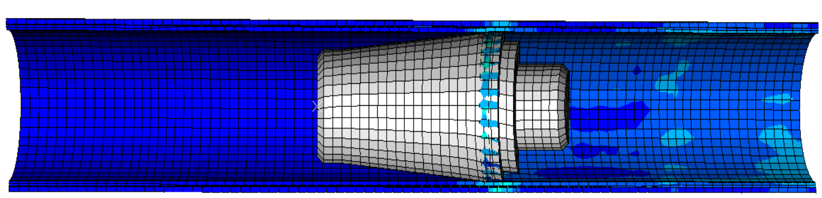


Figure 9 FEM Model for Target Drawing Using the New Plug Design

3.1 New Drawing Press Design for Assembly of Annular Targets

The new design shown in Figure 10 uses hydraulic actuator equipped with pressure monitoring device to give feedback on the success of the process. It is provided with features to allow for quick loading and unloading of the annular targets. The present development involved also redesign and optimization of the drawing plugs using conical ones instead of the spherical plugs of the original design. The new features of the drawing press enable the assembly process for providing minimum of 2000 sound targets annually to meet productivity requirements in any country. Figures 11 -14 show the succession of the assembly operations starting with loading of the loose target, drawing of the annular target, opening the press, removing the die cap, and finally removing of the assembled target.

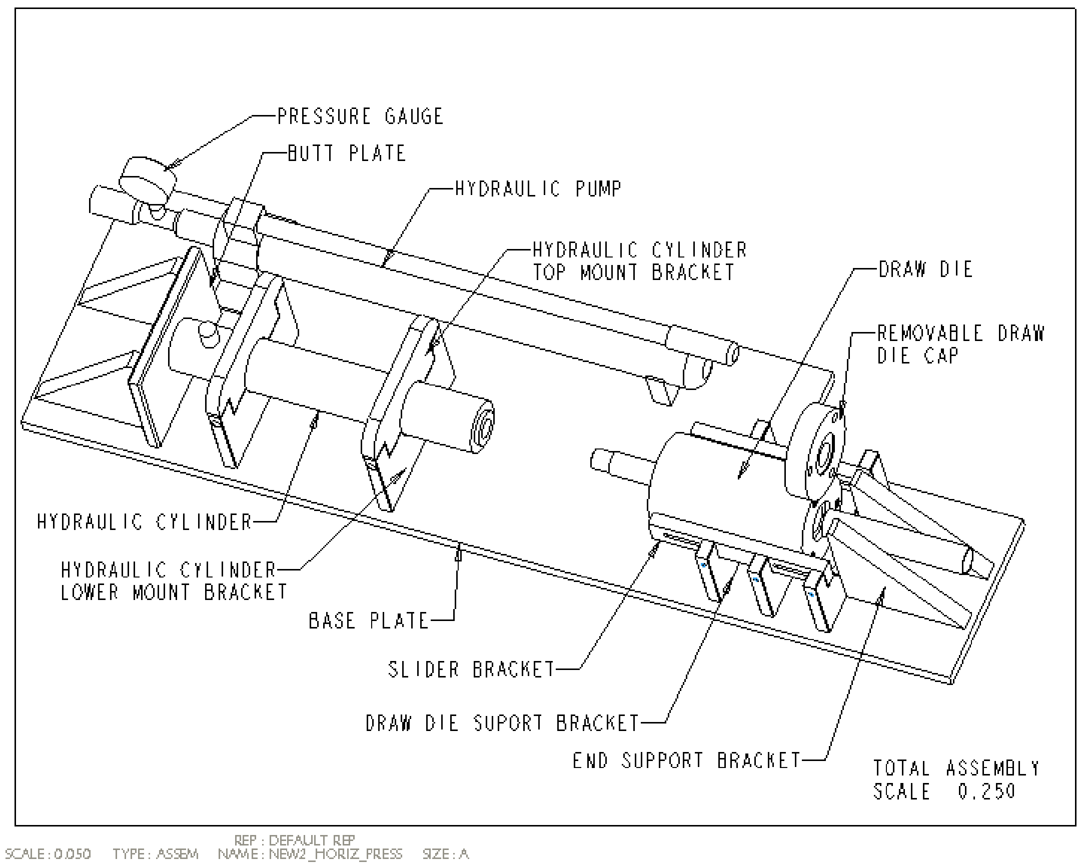


Figure 10 New Design of Drawing Press for Annular Target Assembly

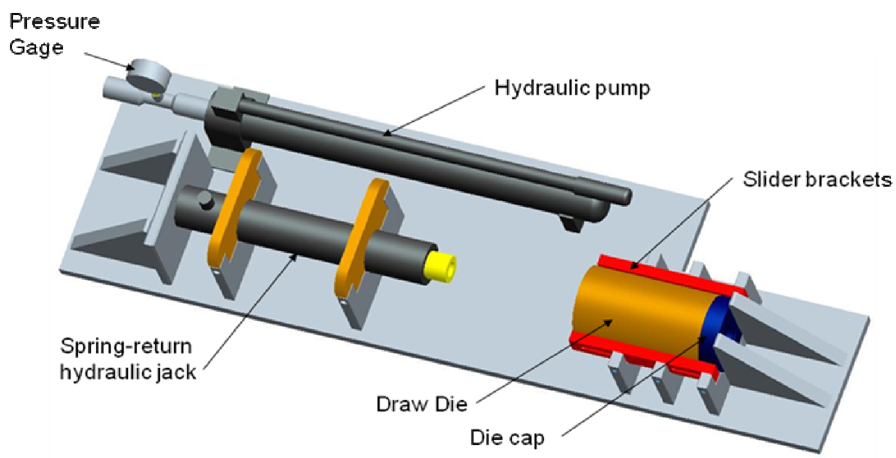


Figure 11 Drawing Press before Loading

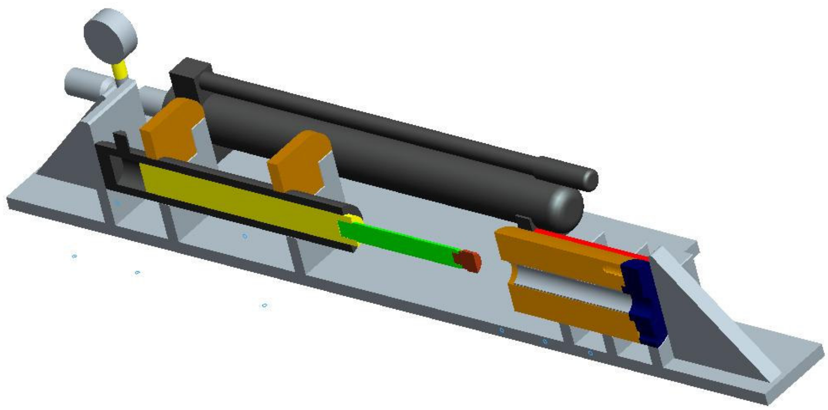
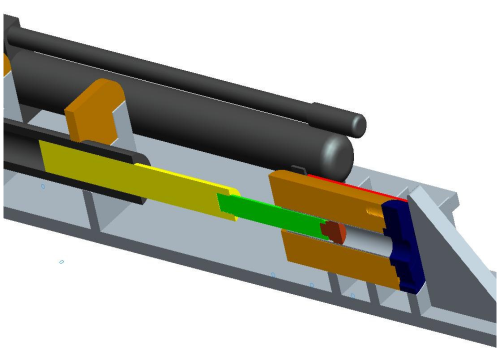


Figure 12 Drawing Press Loaded with Tooling and a Target



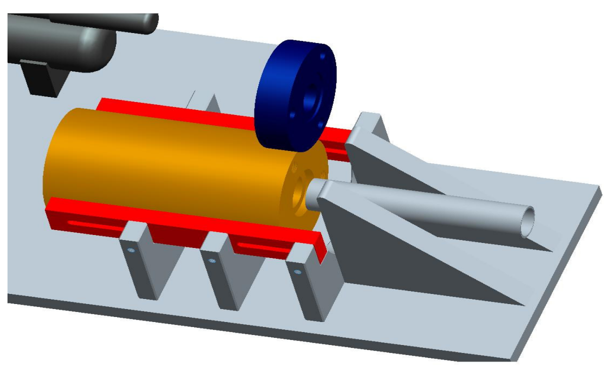


Figure 13 Drawing of the Target

Figure 14 Removing the Assembled Target

4. Conclusions and Recommendations

- The new Hydraulically Driven Drawing Press is designed to meet the objectives of sustaining required productivity at different countries in the world and meeting the needed quality and safety of annular targets carrying LEU foils for production of Mo-99.
- The new design is flexible and can be easily modified for drawing annular targets with different dimensions needed for accommodating larger LEU foils.
- The developed design should be refined, standardized, and tested for distribution worldwide for timely conversion of HEU targets to LEU ones in production of Mo-99, in order to ease world concerns regarding transport of weapons-grade material.
- It is also recommended to conduct finite element analysis on the foil materials and the entire annular target during assembly using the larger LEU foil to check integrity of the target during heavy deformation. Furthermore, this analysis will give realistic picture of the morphology of the contacts between different components of the target after assembly. This is essential for the prediction of thermal contact resistance during irradiation.

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6. References

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