High Density LEU Annular Target Qualification

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1.INTRODUCTION

- HD-LEU Annular Target is a unique product that is designed to replace HEU target from production of medical radioisotope and to reduce the HEU utilization from civil application in order to sustain the nonproliferation goal.
- Qualification of this product implies the development of entire qualification methodology based on:

  - definition of irradiation conditions;

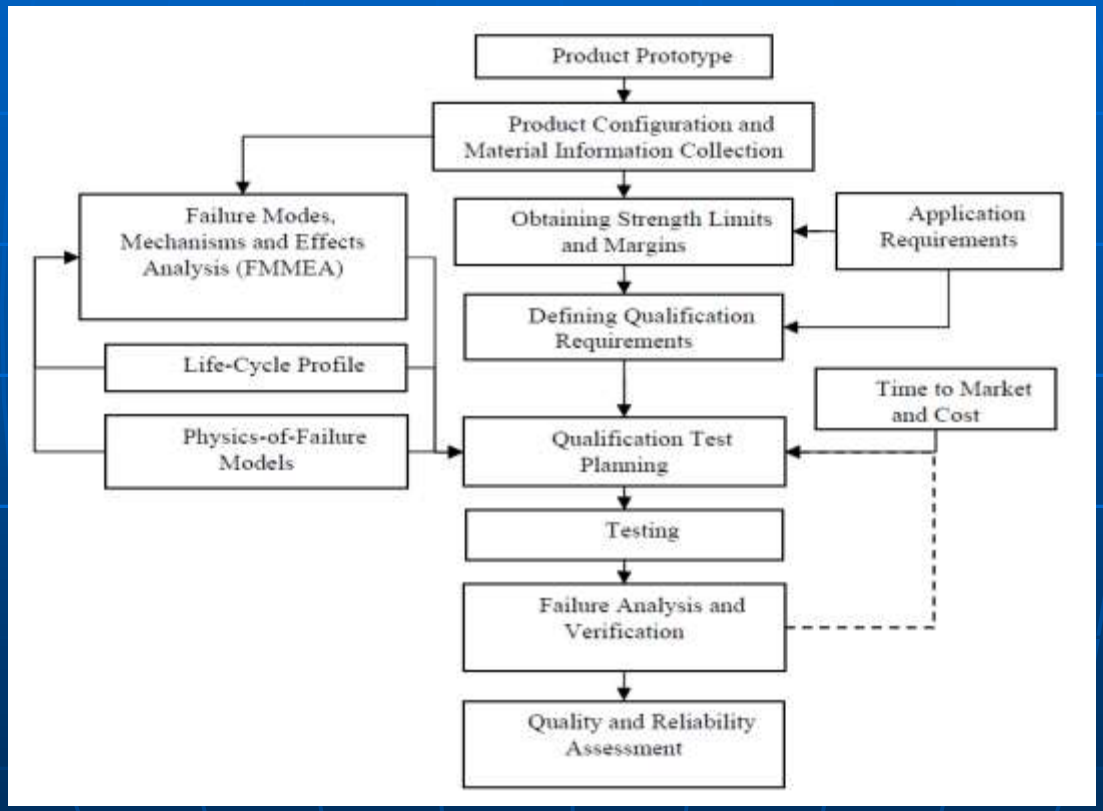
  - set up a nuclear safety analysis for testing licensing and as reference document for future utilization;

  - development of methods and procedures for post irradiation examination and data collection and processing;

  - design, manufacture and installation of dedicated tools, instruments and devices remote control for irradiation and post irradiation examination.

2. Qualification methodology for HD-LEU Annular Target

- The methodology of qualification of HD-LEU Annular Target was conceived to demonstrate that the design, manufacturing and utilization of targets for 99Mo-99mTc production for medical applications meet or exceed the specified requirements.



Flowchart of methodology of product qualification

2.1. Product configuration and materials

- Product was described and designed by "Argonne National Laboratory – LEU Modified Cintichem Process".
- There are three candidate LEU foil material obtained by three technologies A, B, C, and four candidate materials for fission recoil products barriers as nickel foil, aluminum foil, nickel electroplated, zinc electroplated ;
- The aluminum tubes circumferential welded and selected geometrical dimensions are internal diameter 27.99mm, external diameter 29.77mm, length 165mm. The product has many similarities with a tubular i.e. annular fuel element with aluminum cladding.
- The cladding ensure mechanical stability, heat transfer, corrosion resistance and the most important function is the first barrier for fission products generated during irradiation of internal contented metallic LEU foil.

2.2. Application requirements

- Application requirements means:
  - acceptable behavior during irradiation process;
  - acceptable behavior during handling;
  - acceptable behavior during LEU foil recovery;
- Acceptable behavior during irradiation process means that:
  - mechanical stability of product due to internal stress at foil cladding interface as a consequence of LEU foil growing under irradiation;
  - the cladding integrity should be maintain and ensured during in core irradiation to prevent target failure and releases of gaseous fission products from inside to the reactor pool;
  - the corrosion resistance of aluminum alloy tubes and welds should be controlled;
  - the resistance to wearing due to flow induced vibration should be evaluated;
  - low man power/man hours consumption at the hot cell during LEU foil recovery and aluminum cladding separation as solid waste before chemical dissolution of foils should kept at minimum;
  - the foil handling after recovery from cladding should prevent target foil damage.

2.3. Strength limits and margins, failure modes/mechanism

- Strength limits are those of aluminum alloy tubes following the manufacturer data and standards at operation temperature i.e. ~ 100degC, For this application the design provide 20% margins for clad strength before clad rupture due to aluminum alloy ductility;
- Failure mechanism is the peculiar one as was presented by complex analysis. The worst case is presented by excessive LEU foil growing where foil clad interaction mechanism could lead to target deformation and eventual to clad or weld failure which is an unacceptable condition for this product. Effect analysis concern the releases of short life gaseous fission products from cladding that is similar with an fuel element failure in the reactor core leading, at least of several days reactor unavailability.

2.4. Definition of qualification requirements/1

- All targets containing LEU foils from A, B, C technologies and types recoil barriers will be irradiated in similar conditions to avoid variability in behavior during harsh environment, this means:

  - thermal power of each target will be maximum 10kW;

  - LEU foil temperature 125degC;

  - Target cladding temperature 117degC;

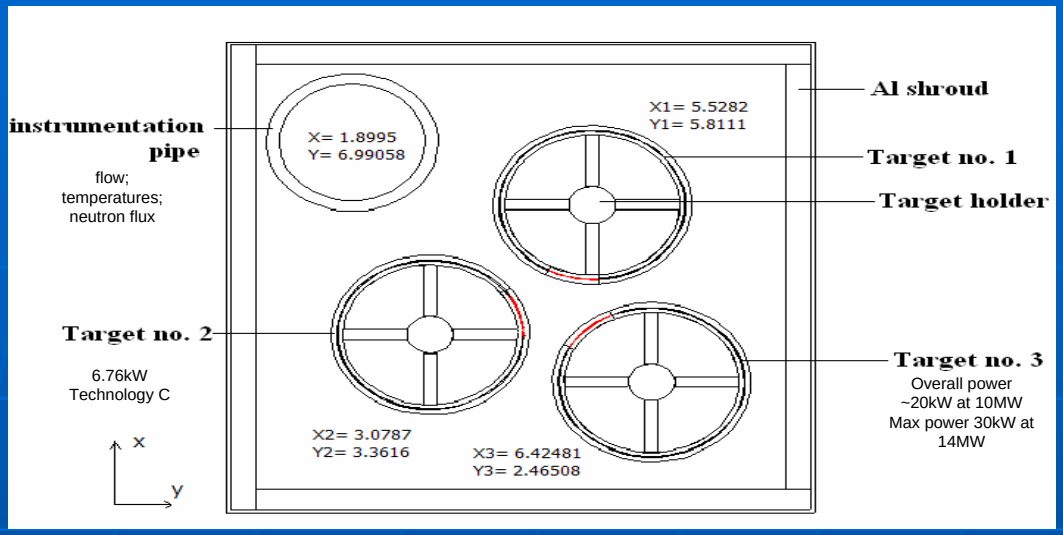
- Neutron flux distribution and thermal hydraulic analysis of LEU Foil Target, irradiation conditions for target, power and temperature for foil and cladding, water flow and temperature in core flow were performed during WO No.1 Task T1.1.1.;

  - first condition for qualification is cladding integrity in any forecasted circumstances;

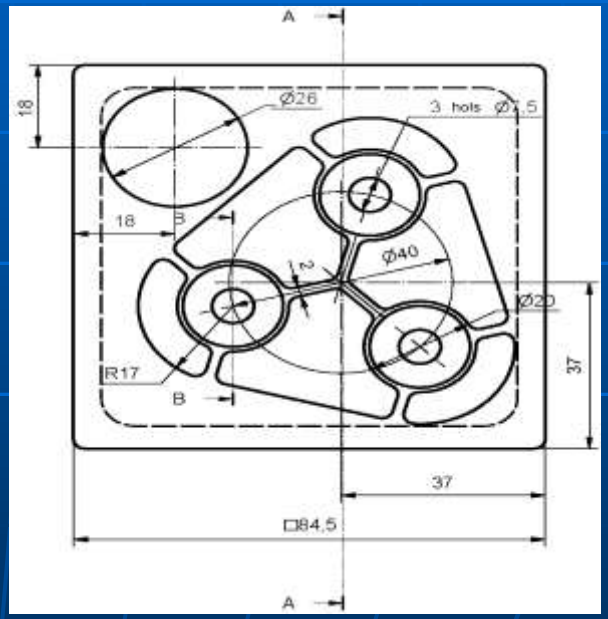
  - second condition for qualification is mechanical stability of cladding, dimensional modification for all dimensions will be less than 1% from nominal as manufactured geometry;

  - the third condition concern the foil recovery in the hot cell without efforts when the foil is not stick (bonded) to aluminum tubes (internal barrier efficiency);

2.4. Definition of qualification requirements/2



Model for irradiation condition computation



Design of irradiation device

2.5. Qualification tests planning/1

- Methodology of qualification by testing request that the product will be subject of a series of tests and examinations representative for normal conditions of utilization and in limiting conditions which can lead to failure.
- The test provide testing of three type of targets containing each one foil **A, B, C** type technology with four type barriers which means third targets for one level of power and time duration. For three levels of power will be necessary 36 targets. Simultaneous irradiation of three targets containing foils A, B and C means 12 irradiations campaigns followed by 36 targets post irradiation examination.

2.5. Qualification tests planning/2

- To perform this qualification test planning several categories of activities were engaged as:

  - neutron and thermal hydraulic design of irradiation;

  - set up on safety report for a special experiment license;

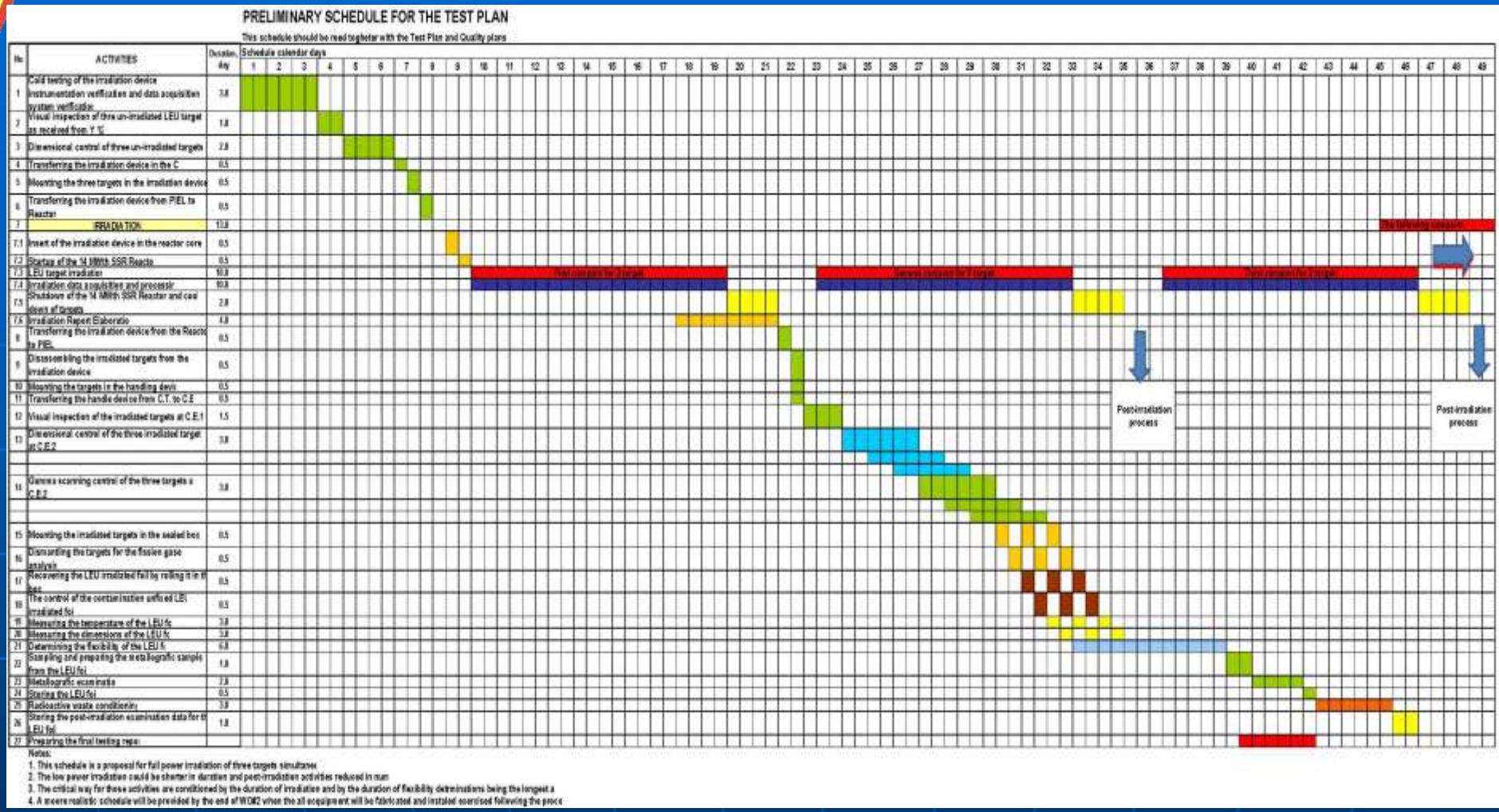
  - design and manufacturing of a instrumented reusable irradiation device which ensure similar conditions for irradiation of targets A, B and C (see Figure 4);

  - design build and installation of necessary devices, instruments, fixtures to meet special post irradiation (PIE) examination and measurements;

  - development of method and procedures qualified for PIE and data acquisition and processing;

  - design of a data base which will incorporate:

1. *all data concerning product configuration and materials originated from history of fabrication file which will accompany each target;*
2. *irradiation history of each target;*
3. *results of nondestructive examination of each target;*
4. *result of destructive examination of each target;*
5. *results of LEU foils examination at the end of irradiation.*



Qualification test plan

This is partial presentation of test plan for three sets of targets i.e. nine targets from the total of 36

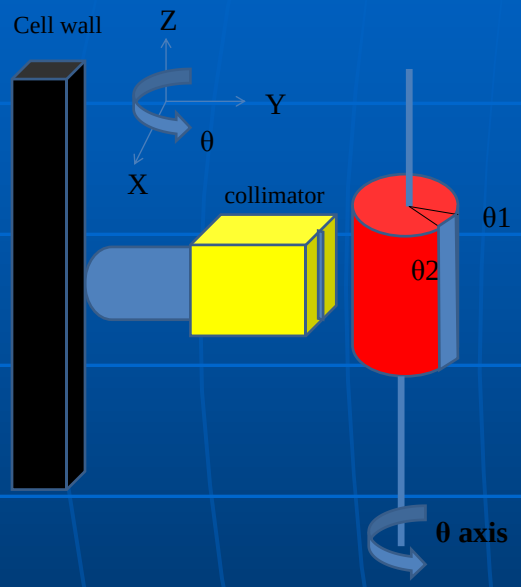
2.6. Qualification test/1

- The life cycle profiles (LCP) of HD LEU target is a simple one corresponding with an irradiation at a constant level of power where some unscheduled reactor shut down may occur but this are not part of typical LCP. Failure mode/mechanism and effects analysis (FMMEA) are determined by the life cycle loads in fact there are not typical cycle loads;
- The first critical failure mechanism is that which lead to cladding degradation by foil cladding interaction;
- The second failure mechanism which is not critical will enhance the geometry of target deformation in correlation with heat transfer and acceleration of clad degradation. The qualification test of HD LEU Target concern the over power irradiation test for a life cycle with 100% than the usual time of irradiation. This could be called "quantitative accelerate testing" when the researcher is interested to identify failure modes precursors and evolution without attempting to forecast product life under normal use condition when the life is relative shorter. The accelerate loads factor associated to accelerated testing are the values of specific power level produced by target and double life cycle duration.

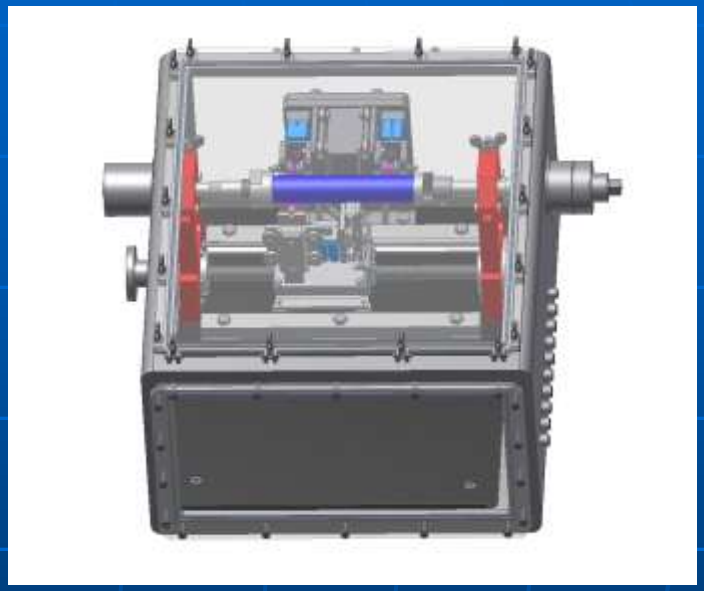
2.6. Qualification test/2

- The testing program provide for each irradiated target the following dedicated PIE.:
- visual examination/inspection pictures documented;
- metrology, profilometry determination, dimensional control, data acquisition concerning straightness, bending, ovality, elongation useful for mechanical analysis of target structural stability/behavior, precision of measurements is 0.01mm;
- gamma scanning of irradiated target to evaluate exposure and power distribution in order to infer internal stress and straight of foil constraint between claddings;
- remote operation of target disassembling device inside of a tight box installed in hot cell in order to determine the composition and amount of noble fission product releases using a quadrupols mass spectrometer;
- determination of barrier foils contamination;
- dimensional measurement of LEU foil through wall periscope and digital images analysis;
- metallographic of cross section of foil and SEM on fragments of foil in order to evaluate the swelling of foil manufactured followed A, B, C technologies;
- determination of flexibility of irradiated foils by comparison with those of un-irradiated.

EXAMPLES OF PIE DEVICES



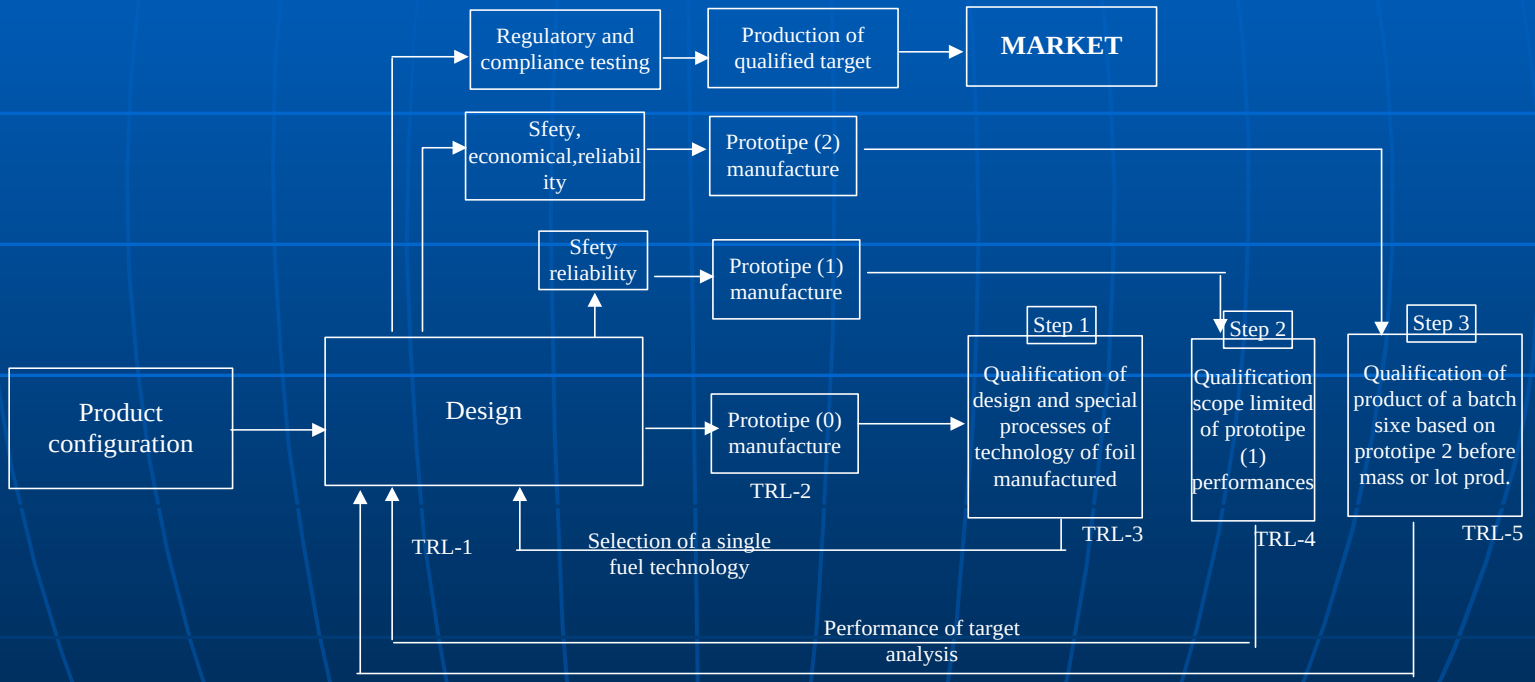
Irradiated target gamma scanning



Disassembling device

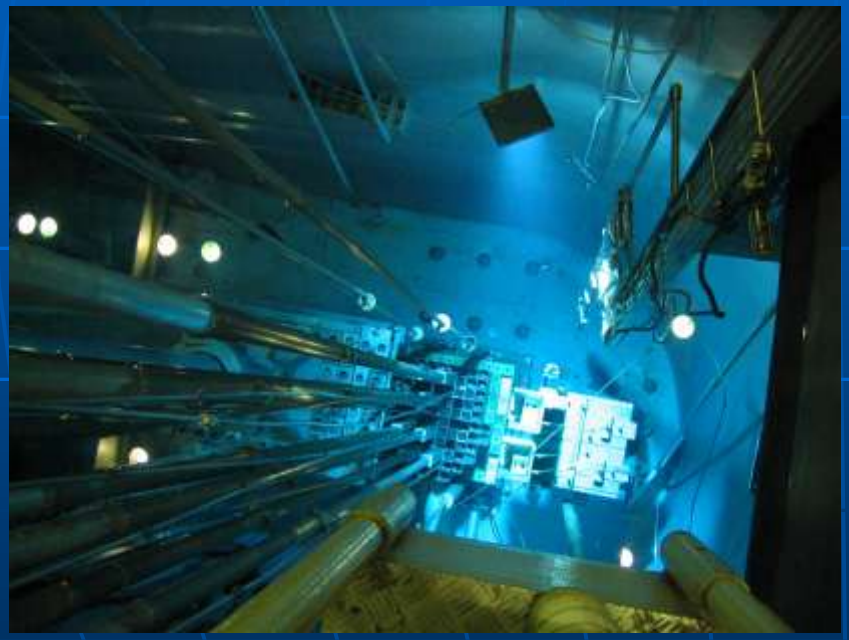
2.6. Qualification test/3

- The HD LEU Annular Target technology development is proposed to reach TRL5 for the higher volume production including technology demonstration;
- Relationship between technology Readiness Level and stages of qualification of product including successive feedback to design and manufacture is presented bellow;

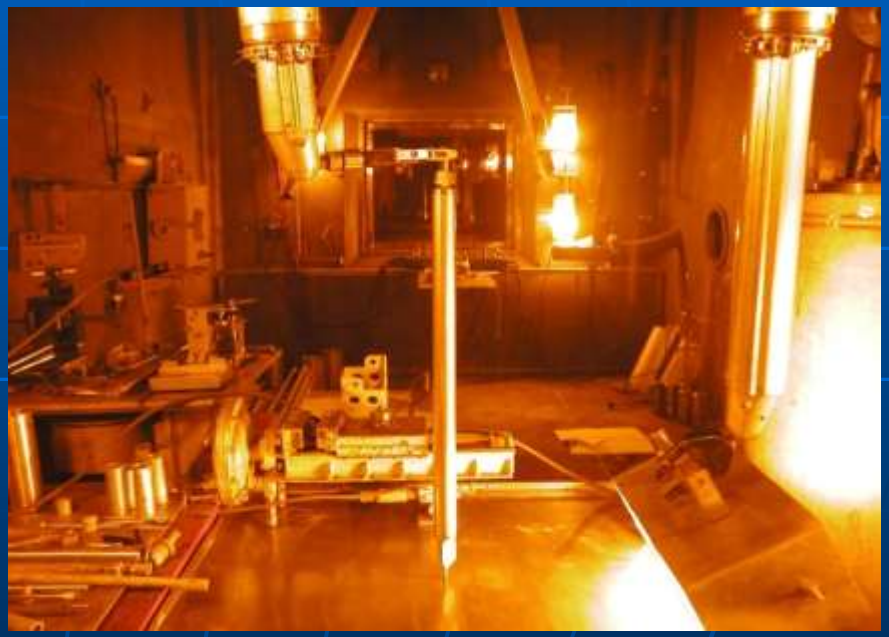


3. Dedicated research infrastructure for HD-LEU Annular Target Qualification

- The Institute for Nuclear Research Pitesti Romania was engaged in the process of HD-LEU Target qualification having the ability to design, build, commissioning of experimental and testing equipments dedicated to sustain the qualification process. The INR operate 14MW TRIGA research reactor, the post irradiation laboratory and radioactive waste facility which allow the implementation of qualification program.



14MW TRIGA Reactor



PIE inside view

4.Institute experience

- In the past decades the INR Pitesti was involved in the development of nuclear fuel for CAND600 power reactor. Irradiation of experimental samples of fuel and type test were performed in special irradiation devices installed in 14MW TRIGA reactor. The post irradiation examination of fuel was performed in hot cell laboratory in order to evaluate the fuel technology features developed by Institute.
- In the framework of the basic BOA agreement **1J-30301-0001A** a team of specialists from Argonne National Laboratory, Missouri University, Y12 National Security Complex Oak Ridge working together Institute specialists in a team work performed the evaluation of program concerning HD LEU Target qualification.

5. Integrated Institute management system

- The Institute has a log tradition in application of provision of Quality Assurance standard since 1978 being now accredited by Lloyd's Register Quality Management in conformity with ISO-OH SAS current standards. The processes developed by Institute are based on validated procedures and methods.

6.Conclusions

- HD-LEU Annular Target qualification include physical tests on the manufactured prototype and accelerated testes for successful product qualification, product configuration and material and technology including the lifetime are considered as inputs to identify critical potential failure mechanism.
- Duration of testing program and continuity of qualification process control the time to market of product and increases of cost of the product. Time to market and cost are to important factors for HD-LEU Annular Target being a new product as well a new technology with important tangible results.


Thank you for your attention!