RERTR 2009 — 31st INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

November 1-5, 2009
Kempinski Hotel Beijing Lufthansa Center
Beijing, China

A ROAD-MAP FOR HEU CLEAN-OUT: UPDATED BASELINE INVENTORY AND FUTURE OBJECTIVES OF HEU MINIMIZATION – THE NORWEGIAN PERSPECTIVE

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ABSTRACT

Norway has had a broad and consistent engagement for control, protection and minimization of fissile materials in general, and HEU in particular since 2005. This paper describes the Norwegian efforts and priorities based on an updated overview of HEU consumption and the number of HEU-fuelled facilities. As of 2009, projections for 2020 indicate naval propulsion will continue to be the main large-scale are of HEU use globally. In addition, a large number of HEU research facilities, in this paper 93 in total globally, mostly in Russia, will continue to be in operation in 2020. At that point, other significant uses of HEU, such as in targets and fast reactors will be decommissioned if no new facilities are established. In order to facilitate a real HEU clean-out in research reactors, this paper suggest to evaluate alternatives to reactor core conversion, such as refurbishment of already LEU fuelled reactors and to a larger extent to promote non-Tc99m medical procedures. Because of the indirect nature of their action these are well-suited for the IAEA, in particular if the Agency in stead of only supporting existing initiatives was put in the position to actively promote HEU minimisation activities on its own initiative.

1. INTRODUCTION.

In 1980, the International Fuel Cycle Evaluation (INFCE) study led representatives from 59 states to realize that the widespread use of HEU in various types of applications posed significant proliferation risks, and a push was instigated to minimize the civilian use of HEU and reduce the number of sites with HEU. Efforts to minimize the use of HEU in civilian nuclear applications have been re-invigorated and revitalized recently, in particular through the Global Threat Reduction Initiative (GTRI), however, also as part of the Global Initiative to Combat Nuclear Terrorism and the G-8 Global Partnership. In this paper, the objectives and activities of the Norwegian government to this aim are highlighted. On that basis, the progress in HEU minimization have been completed by assessing the decrease in HEU consumption (kg/ year, number of facilities, regions) 2000 – 2009, and the expected results 2010 – 2019 - area-for-area and facility-by-facility considerations – using the baseline measurement established in 1978 as part of the International Fuel Cycle Evaluation (INFCE) study in 1980 and updated in 2007 as part of an effort made under the International Panel for Fissile Materials (IPFM). [1] Finally we suggest measures to accelerate the minimization and complete elimination of the use of HEU globally.

2. THE NORWEGIAN PERSPECTIVE ON HEU MINIMISATION

Norway has for several years been part of a group of countries advocating the long-term vision of a ban against using HEU for civilian purposes. This policy has been based on that use of HEU represents a security threat. Even small quantities of HEU can be used in an improvised nuclear device by terrorists, and the mere possibility of this should be sufficient grounds to support steps towards minimization of HEU. While the last fresh amounts of HEU in Norway were blended down about a decade ago, Norway has since 1995 been engaged in security HEU-fuelled facilities in Northwest-Russia as part of our G-8 Global Partnership commitment, civilian marine and naval facilities in particular. This effort has taught us that consolidation and removal is more sustainable than any security measure, and the Norwegian government has engaged in HEU minimisation with that lesson in mind. The goal of minimizing commerce, stocks and use of HEU is not merely a non-proliferation concern. It cannot be linked only to disarmament. And it is not just about the peaceful uses of nuclear energy. It can have important links with all three aspects, and it is in this broader context that the Norwegian government sees the task before us. With this in mind, Norway took the initiative to introduce HEU minimization objectives to the NPT Revision Conference in 2005 with the following main operating paragraphs [2]:

> (a) Encourage all countries to consider, and if deemed necessary, implement additional measures to protect and control existing HEU stocks;
> (b) Express the view that minimizing the use of and commerce in HEU for civilian purposes is desirable, as is the goal of total elimination of HEU in the civilian nuclear sector as soon as technically feasible;
> (c) Encourage all countries to eliminate or commit to converting those civilian HEU-fuelled installations under their control, for which there is a continuing need, to LEU fuels as soon as technically feasible;
> (d) Discourage all countries from undertaking or supporting new civilian projects involving HEU fuel other than for the purpose of down-blending that fuel to LEU;
> (e) Encourage the IAEA to establish a comprehensive global inventory of HEU in civilian use and to report to the next NPT Review Conference on the progress made in fuel conversion and in the elimination of reactors and critical assemblies internationally.

This working paper was introduced to the Revision Conference, however, the proposals were not considered further as the conference ended without and final document. However, some countries seemed to think that efforts to reduce HEU in the civilian sector might undermine the rights to peaceful use of nuclear energy under the NPT, while others worried that a narrow focus on civilian HEU could detract attention from the large military stocks of fissile materials. A few even denied that the use of HEU posed any danger at all.

In June 2006, Norway, in cooperation with the IAEA, hosted an international symposium in Oslo to mobilise support for measures to restrict the use of HEU in the civilian sector in cooperation with the IAEA (www.nrpa.no/symposium). The symposium provided a venue for technical discussions on what practical steps could be taken to reduce the use of HEU, such as converting existing reactors from HEU to LEU. A main observation was that such conversion is indeed feasible. While technical experts welcomed efforts to minimize civilian use of HEU, the Oslo Symposium demonstrated that there still is significant political scepticism about the development of international norms against the use of HEU in the civilian sector. This sentiment has been reaffirmed as the subject has been briefly discussed in the decision-making organs of the IAEA after the Oslo symposium. The measures suggested at this point on the general level include enhanced transparency, guidelines, and a code of conduct. A renewed opportunity for discussing of all this suggestions will come at the Nuclear Security summit in April 2010. The long-term ambition must be clear: a *ban* against the use of HEU in the civilian sector, with the IAEA in the role as promoter and facilitator. The role of HEU in the overall context has been addressed by the Norwegian Foreign Minister at the beginning of the Norwegian effort in 2006 [3]:

> First, the countries involved should join forces to minimize and eventually eliminate the civilian use of HEU. Joint research should be conducted to address the remaining technical hurdles involved in converting from HEU to LEU operations. The commercial interests of the companies concerned should be protected. Financing should be made available where needed to assist countries with conversion operations. And the HEU fuel should be sent back to the countries of origin for downblending and reuse.
>
> Second, all countries should agree to stop producing fissile material for use in nuclear weapons. The elements are already in place for such an agreement, in the form of a Fissile Material Cut-off Treaty. It is high time to negotiate and conclude such a treaty.
>
> Third, to build confidence, countries with civilian and military HEU stockpiles should be encouraged to release clear inventories of those stockpiles, and to publish a schedule under which the remaining HEU will be verifiably downblended.

After 2006, the Norwegian government initiated an activity to realize a global inventory of HEU in operating reactors of which the results have been presented regularly for the international community. However, the main activities have been to support the IAEA in its efforts in order to support the building of a global norm for HEU minimization. In this effort, the initial priorities from 2005 have constituted the basis of the program by supporting measures for transparency and the participation of all countries, also the developing countries in this work. Among the specific measures have been IAEA technical meetings, participation in the coordinated research projects in this are in the Agency, both related to non-HEU based production of Mo-99 and the conversion of the miniature neutron research reactors.

3. HEU MINIMISATION PROGRESS MEASUREMENT UPDATE

Overall status pr. 2009. In 2007, over 300 HEU-fueled facilities were identified, annually in need more than 10 000 kg of HEU with various enrichment levels, out of which more than 3 500 kg is HEU for naval propulsion, more than 900 kg HEU in civilian research reactors, and more than 80 kg HEU for isotope production in civilian facilities, in addition to 6 000 kg HEU in various other types of reactors, such as breeder facilities, Russian Pu-production reactors and other military reactors. Most of the facilities in the last three categories, however, are due to be decommissioned in the coming years and no action is thus necessary at this point. Though only a fraction of the HEU consumption annually, the usage of HEU spent for isotope production in civilian facilities has been a matter of considerable controversy the last two years as the irradiation facilities have experience several unplanned outages resulting in shortages in Tc-99**.** No effort is currently being made to convert the Russian civilian icebreaker propulsion reactors, as is also the case with respect to the nuclear navies using HEU (UK, US, Russia). The US naval propulsion fleet alone has annual consumption levels in the range of 2 metric tonnes of HEU.

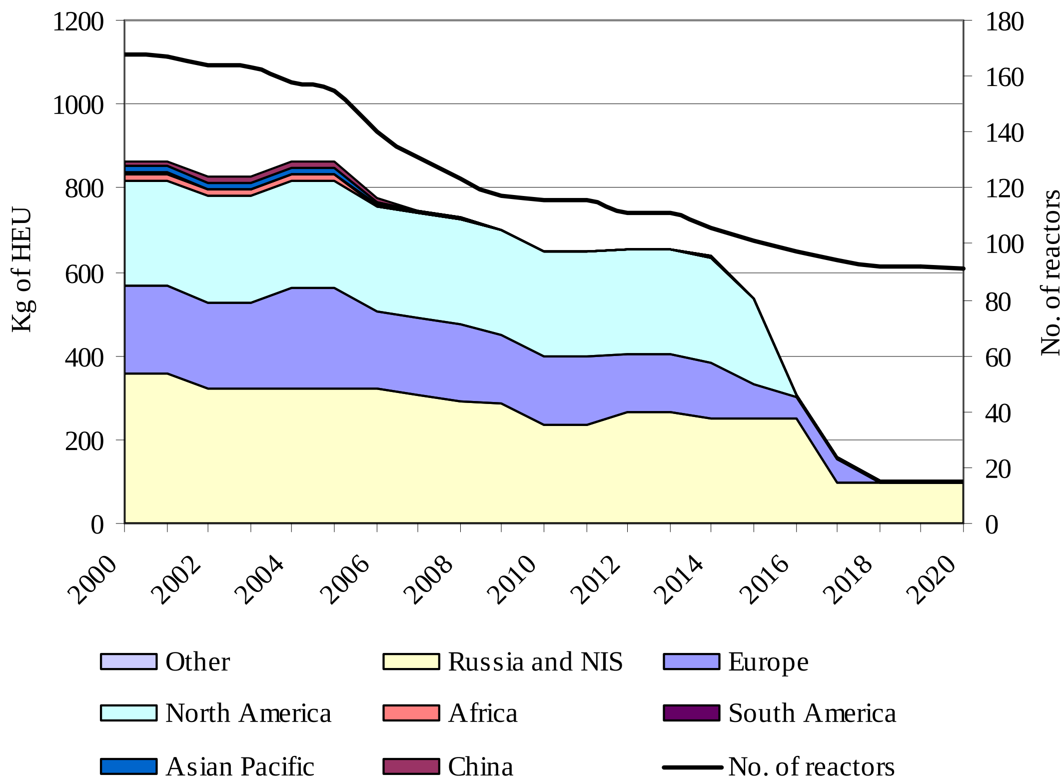

Fig. 1. Operational HEU-fueled research reactors and associated HEU consumption (kg) 2000 - 2020

Status and projection HEU-fuelled research reactors: In 2009, as seen in table 1, the total number of HEU-fueled research facilities (steady-state research reactors, pulsed reactors, critical assemblies), summarize to 117 facilities. The most significant addition is the Russian IRV-M2 pool type reactor, 4 MW, and the reactor began operation in 2008 using 90% HEU. One French military HEU fueled facility has been added: the fast neutron source CALIBAN. The number of Russian non-power facilities has been adjusted after additional information on the nature and existence of such reactors in Russia (pulsed reactors, critical assemblies) has been published recently. [4, 5, 6] With respect to completed converted reactors, included above is the Japanese KUR reactor, VVRM Kiev, the Indian APSARA facility, the Polish MARIA reactor and the Mexican TRIGA MARK III completed after many years of work. Shutdown facilities include the UK CONSORT, the Russian RBT-6 together with the critical assembly STRELA. For the US, the converted facilities include the OSTR, WSUR, UWNR and the NRAD facility. Out of scope for table 1, the Russian fast reactor BOR-60 was scheduled for shut-down in 2009, and the Russian production reactor ADE-2 was closed this year in June. In total 64 facilities has completed conversion, while 122 HEU-fuelled facilities have been converted since 1978.

Table 1. Operational HEU-fuelled research reactors 2009

		Russia & NIS	China	Europe	US	Other	**Total**
Critical assemblies		36	1	4	5	2	48
Pulsed reactors		16	0	3	3	0	22
Steady-state research reactors (MW)	< 0,25	2	3	4	1	11	21
	0,25 – 1	1	0	0	0	0	1
	1 – 2	0	0	0	0	0	0
	2 – 10	6	0	1	2	1	10
	10 – 250	6	0	6	4	0	16
Total		**67**	**4**	**17**	**15**	**14**	**117**

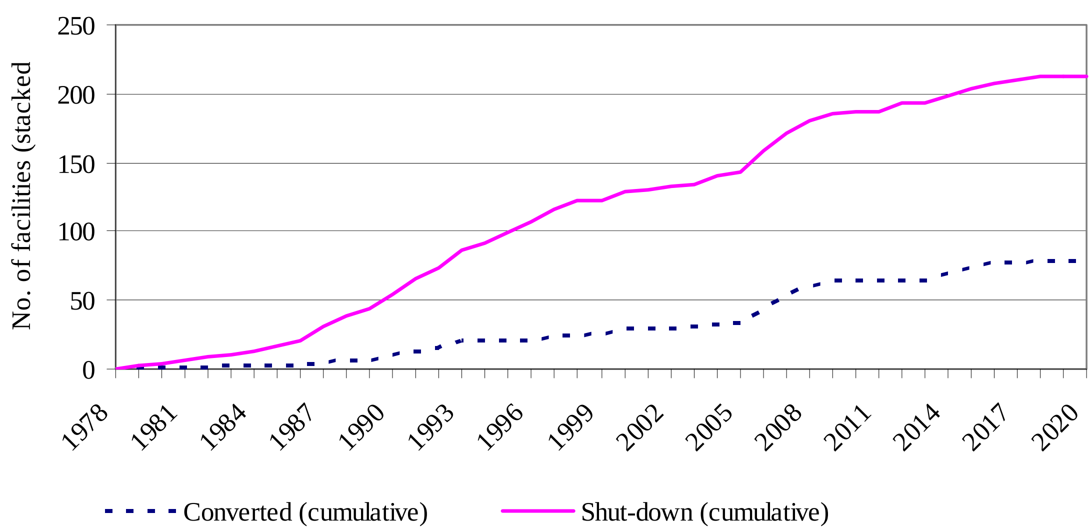

Fig 2: Converted and shut-down research reactors (stacked)

The most notably addition to the previous overview is the Russian PIK-reactor which now is believed to start operations in 2012, adding 70 kg. of HEU to the annual consumption for research reactors described in Fig 1 in the period 2012 - 2020, in earlier statistics not included due to the uncertainty for ever starting operations. The calculations for HEU consumption in the Russian PIK-reactor has been based on the standard properties for such reactors used as the default value in the calculation for this paper: 250 full power days, 40% burn-up, in addition then that the reactor is 100 MW using 90% enriched fuel. Regarding the overall number of facilities in Russia and NIS, 58 facilities, 56 out of those are in Russia. Regarding IRV-M2 the projected shut-down is 2040, IVV-2M the projected shut-down is 2025, while PIK, not yet in operation, shall be working until 2062. For Europe, the remaining HEU-fuelled reactors are 9 pulsed reactors and critical assemblies, 6 of which are French. While 8 US non-power facilities still remains in 2020, at least for now there are no plans to convert those, Canada may have 3 slowpoke facilities in addition to that the MNSR-facilities in Syria, Pakistan and Iran may remain in operation as today. The only large steady-state HEU-fuelled facility outside Russia in 2020 may be the Israeli IRR-1 reactor (5 MW).

Table 2. Operational HEU-fuelled research reactors 2020

		Russia & NIS	China	Europe	US	Other	**Total**
Critical assemblies		36	1	4	5	2	48
Pulsed reactors		16	0	3	3	0	22
Steady-state research reactors (MW)	< 0,25	2	2	2	1	11	18
	0,25 – 1	1	0	0	0	0	1
	1 – 2	0	0	0	0	0	0
	2 – 10	0	0	0	0	1	1
	10 – 250	3	0	0	0	0	3
Total		**58**	**2**	**9**	**9**	**14**	**93**

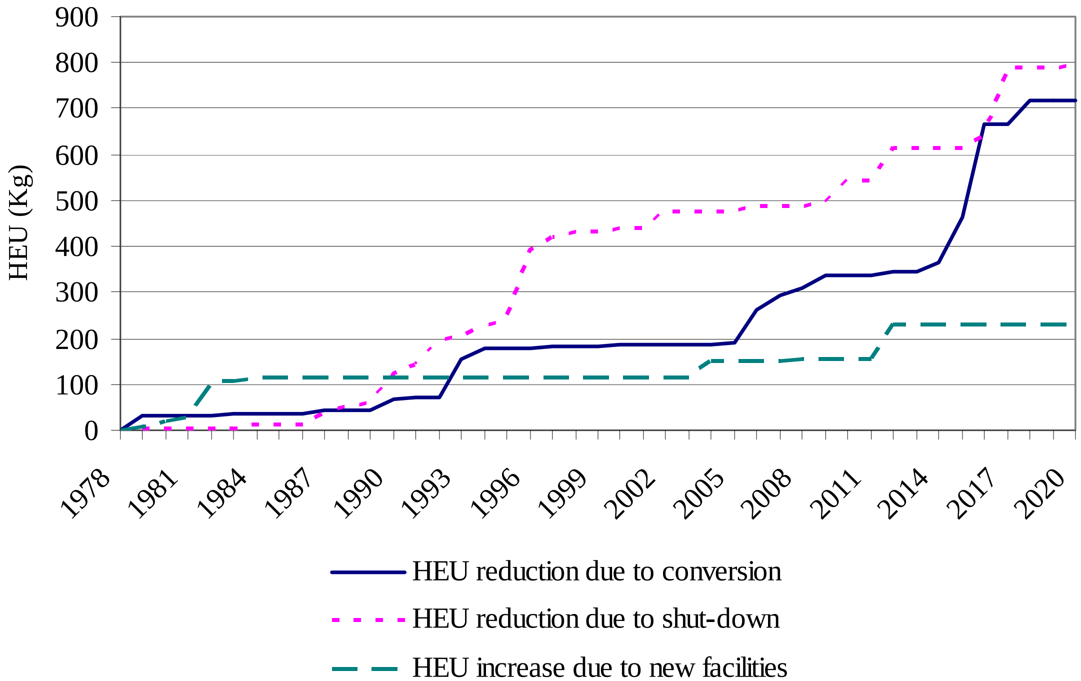

Fig. 3. Amounts (in kg.) of HEU with respect to HEU reduction (conversion or shut-down), and due to the increase of new facilities.

In total, taking the current plans for conversion and shut-down into account, 93 HEU-fuelled facilities remain in operation in 2020, out which 23 steady-state reactors. The corresponding HEU consumption as described in Fig. 1, divided into regions and having left axis measuring the consumption while to right axis shows the number of facilities, are reduced to 96 kg., primarily in the PIK reactor. In total, 79 facilities will then have been converted to LEU and 134 HEU-facilities shut-down from 1978 with the progress described in Fig. 2. With respect to the reduction in HEU consumption due to conversion and shut-down, and the increase due to new reactors, this has been described for the period 1978 – 2020 in Fig 3 (below). An important element, decisive for the overall results from the conversion effort, is the 4 – 6 period ahead as the large high-flux reactors shall be converted in that period.

4. ROADMAP FOR HEU CLEAN-OUT

There is technically no distinction between the various types of applications using HEU, thus, the overall objective should be a global HEU clean-out from all areas of use. The use in various types of breeder facilities, Russian Pu-production reactors and other military reactors in Russia shall be phased out in the coming years and no action is thus necessary at this point. However, marine propulsion, research facilities and isotope production constitute significant areas of use and should be addressed accordingly. The figures above suggest, despite the recent success of RERTR and GTRI that HEU minimization in research and various types of production facilities should be considered more closely as a significant number of HEU-fuelled facilities may remain in 2020.

Research facilities. Decommissioning and dismantling should play a significant role in the future HEU minimization effort as well, thus a combination of the means in the current RERTR/ GTRI-programs and other, possible new initiatives has to be applied. The recent OECD/NEA report on nuclear test facilities required for the future states that there is a need for facilities offering a high quality of research. [7] They also stressed the benefits of collaborative projects. This was seen as the best use of a finite resource, both of capital and human. There was also emphasized the importance of smaller facilities able to perform more routine tasks. Continued operation of such facilities can be justified for national strategic reasons, specifically in enabling a nation to maintain human resource with nuclear technology expertise. This point has received new relevance due to the increased global interest in nuclear power. Despite this new interest the underlying concerns for nuclear safety at research facilities are dominated by economic constraints. Under-utilization of research reactors is a major contributor to the economic constraints of many of the world's fleet of research reactors. Operators of those research reactors which are HEU fuelled often view conversion to LEU fuel as an opportunity to in addition improve the operational capabilities of their reactor. This is often necessary to enable the operator to meet its new mission. However, despite inclusions of currently popular activities such as medical isotope production and BNCT most research reactors will not be able to cover operational cost from sales of these services. The remaining deficit is often being met by direct state funding, or subsidies. This in turn biases the market for reactor services making it difficult to obtain a fair market price, undermining the sustainability of reactor operation and leaving the operator unable to meet challenging maintenance issues without governmental intervention, as has been the case for both HFR, in the Netherlands, and Canada's NRU.

The issue of decommissioning funding also needs to be considered, as recommended by the IAEA. It is often impossible for an owner organization to choose to decommission a reactor facility which no longer meets the organization's requirements. This is due to the large cost associated with decommissioning, a rough estimate being 10 times annual operating costs, or more if the reactor is underutilized. In order for this option to be seriously considered there must be not just an acceptance of the need to decommission by state institutions but also an open commitment to provide funds. Those organizations with reactors which by good fortune are fuelled by HEU have been provided with an alternative. By converting they have also been able to obtain funding to replace or improve experimental facilities and safety systems with the hope to improving the sustainability of their reactor's operation. This has left reactors which are originally LEU fuelled at a disadvantage. Economically speaking it may be of more benefit to upgrade an LEU fuelled reactor and decommission a HEU fuelled one than the other way round. The means of assessing reactors in a case by case manner with respect to HEU minimization has perhaps been suboptimal to other important goals, such as maintaining the world's fleet of nuclear research facilities. It would be of great benefit if these two goals could be brought together and not undertaken separately as is currently the case. This would mean involving also LEU fuelled reactors in the planning of conversion and supply them also with aid in upgrading experimental and safety systems with the aim of providing the best fleet-wide capabilities. Finally, due to a limitation in funding for operation a down sizing of the worlds nuclear test facilities should also be considered. This has been the past trend and despite the increased activity in the nuclear power industry is projected to also be the future trend.

Targets. The lack of profit in the irradiation part of Tc99m production has lead to new producers also trying to develop Tc99m generators. The profit margins are thought to be better for this part of the production chain. However this is a more technically demanding part of the process which requires considerable capital to initiate. This in part explains why the current crisis has lasted and why no new significant producers have appeared on the market leaving as the only solution to repair both Petten and NRU reactors, however, the new legislation introduced by the US administration supports new production in the US and a cut-off of HEU exports during the next decade. Thus, in fact, changes will take place at the supply side of this market. Regarding the demand side the recent National Academes report on the state of the medical isotope production industry estimate the growth for Mo-99 generators to be between 3% and 10% pr. year. [8] The use of nuclear medicine is already well established in developed countries, so this growth is expected to be highest in developing countries as nuclear medicine becomes established. While there are alternatives to the use of Tc99m, such as Positron Emission Tomography (PET), Computed Tomography (CT) or Magnetic Resonance imaging (MRI), which provide the same kind of medical diagnostic information, however, costly at this stage and not widely available. Which technique is used for any particular patient is dependent on a variety of factors where availability and previous practice play important roles. As the procurement of medical imaging equipment is a long term investment, this results in a certain amount of inertia in switching from one technology to another. It is therefore important that investments in medical imaging equipment be taken also considering the implications for HEU minimization. Medical personnel are undoubtedly aware of the current shortage in Tc99m generators but may be unaware of the long term goal of HEU minimization. Here, raising awareness within the medical community will be an important contributor to the total HEU minimization effort. Further promotion of alternative technologies could be a more economic way to reduce the usage of HEU though reducing the demand for Tc99m.

Marine propulsion. The initial baseline measurement for HEU consumption shows naval nuclear naval propulsion accounts for a significant fraction of all HEU use. Insufficient attention is being paid to the possible use of LEU to fuel future naval propulsion reactors. Russia has developed LEU fuel for barge-mounted power reactors it plans to build for export, however, at the moment, no final confirmation has been made that these facilities will use LEU. The first step could be an international conference under UN auspices on the elimination of HEU-fueled facilities, in order to address both military and civilian issues. Such discussions are impossible within the current assistance frameworks, and a dedicated measure to address this are is necessary if progress shall be made.

Waste. As the HEU burn-up levels vary between 1-70%, large amounts of spent fuel and target material with significant amounts of HEU have been generated. Some is dealt with through reprocessing -- especially in Russia. However, significant quantities are stored at multiple facilities worldwide. Even if there now is a transparent overview over operating HEU-facilities as suggested by Norway in 2005, a similar overview over HEU in waste remains to be established.

5. CONCLUSIONS

Considering the fact that HEU is of particular concern due to the technical feasibility of constructing a crude nuclear explosive device from HEU, making it a possible choice for a terrorist group, Norway has had a broad and consistent engagement for HEU minimization. Fewer facilities and installations are crucial for curbing HEU use – and associated risks. Concerted international efforts and decommissioning have resulted in significant reductions in the number of reactors fueled with HEU. But many obstacles remain to a complete phase out. Although the risk of nuclear terrorism is clear, the threat apparently is insufficient to create the much needed push for swift political action and a global HEU clean-out. As of 2009, projections for 2020 indicate naval propulsion will continue to be the main large-scale are of HEU use globally. In addition, a large number of HEU research facilities, in this paper 93 in total globally, mostly in Russia, will continue to be in operation in 2020. At that point, other significant uses of HEU, such as in targets and fast reactors will be decommissioned if no new facilities are established. In order to facilitate a real HEU clean-out in research reactors, this paper suggest to evaluate alternatives to reactor core conversion, such as refurbishment of already LEU fuelled reactors and to a larger extent to promote non-Tc99m medical procedures. Because of the indirect nature of their action these are well-suited for the IAEA; in particular if the Agency in stead of only supporting existing initiatives was put in the position to actively promote HEU minimisation activities on its own initiative.

6. ACKNOWLEDGEMENTS

This paper is based on previous work by the authors presented at the RERTR meetings in 2006, 2007 and 2008. The paper has been written with the support from the Norwegian Ministry of Foreign Affairs. The opinions expressed are, however, those of the authors and should not be considered as official statements from the Government of Norway. Dr. Pavel Podvig's effort to update the inventory of HEU-fuelled facilities in Russia – [4] – in addition to personal communication with the author constitutes the main source for update of the inventory data. Any mistakes, errors and inconsistencies are the sole responsibility of the authors.

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