

ON THE SUPPLEMENTARY FEEDBACK EFFECT SPECIFIC FOR ACCELERATOR-COUPLED SYSTEMS (ACS)

Pavel M. Bokov, Danas Ridikas

DSM/DAPNIA/SPhN, CEA Saclay, F-91191 Gif-sur-Yvette, France

Email: pavel.bokov@cea.fr

Igor S. Slessarev

29, rés. Tivoli, allée des Peupliers, F-13090 Aix-en-Provence, France

Abstract

In this work a new approach to the realisation of an accelerator-coupled hybrid system (ACS) is proposed. A significant improvement of the feedback effect due to the particularities of the neutron production in a spallation target is expected. In the present study, we explain the principles of system functioning as well as the advantages and disadvantages of the proposed concept. The quantitative analysis of the innovative ACS operation is based on a generalised point kinetics approach. In the framework of this simplified model, we show that the particular dependence of the spallation neutron yield allows for the creation of a supplementary negative feedback effect (Doppler-like). Implementation of this concept should compensate, to some extent, the eventual feedback degradation in the cores dedicated to the transmutation of nuclear waste.

Introduction

In general, nuclear systems devoted to minor actinide (MA) transmutation may suffer from significant degradation of safety characteristics. In particular, such important parameters as delayed neutron fraction can decrease by several times compared to conventional nuclear reactors. Another serious problem arising in such systems is the reduction of the Doppler effect – the fastest and most important temperature feedback effect in the reactor core. This degradation of safety properties makes the control of such systems rather delicate.

An innovative solution to handle the above problem was proposed recently and consists of the artificial enhancement of system neutronics, which involves an external neutron source added to the core permitting the system to operate in subcritical mode (so-called hybrid nuclear reactor). In an accelerator-driven system (ADS) [1] where a subcritical core serves only to amplify the incident beam energy, a large subcriticality margin ($k_{\text{eff}} \sim 0.95-0.97$) mitigates the negative consequences of the degradation of safety parameters. However, this significant subcriticality level requires a powerful and expensive particle accelerator. Another way to deal with the problem is to employ the concept of the accelerator-coupled system (ACS) [2]. With an ACS, an external neutron source, which is coupled directly to the core power and is artificially or naturally delayed, can compensate the decrease of delayed neutron fraction. In this case, less powerful (and thus less expensive) particle accelerators may be applied. On the other hand, the ACS inherits some properties of a critical nuclear system. In particular, the degradation of feedback effects (e.g. Doppler) makes power and temperature excursions possible in the case of unprotected reactivity insertion.

In the present work, we propose a new approach for the realisation of ACS where a significant improvement of the feedback effect is expected due to the modification of the accelerator-core coupling mode and due to the particularities of neutron production in a spallation target.

Generalities of hybrid systems

In principle, core subcriticality will improve safety when feedback effects, the delayed neutron fraction or other safety-related parameters are degraded due to the presence of long-lived actinides that are subjected to transmutation. There are at least two different ways a subcritical core can function in combination with an external neutron source. In brief, this source can be independent of neutron (energy) production in the core [as in accelerator-driven systems (ADS)]. Or, the source can depend on neutron (energy) production in the core and in this way become “coupled” or “co-ordinated” by core power level [as in accelerator-coupled system (ACS [2])]. Each combination opens some new opportunities related to safety improvement. Major features of ADS and ACS are summarised below.

In the case of ADS, an *independent* mechanism of supplementary neutron production is used to achieve the desired power level and the accelerator power is supplied via an independent energy grid.

In the case of ACS, a source of “artificially delayed neutrons” consumes a portion of in-core released energy. In this way the external neutron source becomes “coupled” with the core power level. As a result, the supplementary neutron creation will be delayed to time required for fission energy transfer from the core to a chosen neutron production mechanism (e.g. spallation, nuclear fusion, *bremsstrahlung*-photonuclear, etc.). In other words, this intermediate process temporarily “hides” neutrons (of some neutron generation) in order to recover them later. This allows for the artificial increasing of neutron lifetime and for the slow down of dangerous transients [3].

Compared to conventional critical reactors, this particular property of the ACS can improve the reactor dynamics significantly. Moreover, the ACS operates in critical mode and, therefore, in contrast to the ADS, takes advantage of favourable temperature feedback, which might exist in these systems [3].

In terms of safety, ADS is *inherently* more favourable (compared with similar critical reactor) in regards to reactivity accidents where core subcriticality mitigates consequences of reactivity insertion. On the other hand, a system functioning in a critical regime (including ACS) is *intrinsically* safer in the case of thermo-hydraulic type transients. Therefore, it would be attractive to combine the inherent advantages of both ADS and ACS in a single installation. In other words, one needs to realise a system where the following occurs during *unprotected transients*:

- a) The intensity of an external neutron source decreases with the decrease of core power.
- b) The intensity of an external neutron source remains stable or even decreases with the increase of core power.
- c) Conditions a) and b) must be *intrinsic*.

One possible solution to merge the above advantages is presented in the following section. It is based on the physical processes taking place in the neutron production target, which makes our approach inherent.

Accelerator-core coupling modes in ACS

Traditionally, it is assumed that in hybrid systems the current of a proton accelerator is the coupling parameter, which one can vary to change the neutron source intensity. In the case of ACS, at least two modes of coupling between the external neutron source and the core could be envisaged.

1. When it is supposed to modify the intensity of an external neutron source Q by varying the proton beam current I_p at a fixed nominal value of the proton energy, namely:

$$I_p = I_{p,0} P^{out} / P_0^{out} \quad (1)$$

Here P^{out} is the output power of the installation and subscript “0” denotes nominal values of the corresponding variables. Hereafter, this method of “accelerator-core” coupling is designated as “*I-mode*” coupling.

2. When *any change of an output power leads to a proportional change of proton energy* e_p at a fixed nominal value of the proton current, namely:

$$e_p = e_{p,0} P^{out} / P_0^{out} \quad (2)$$

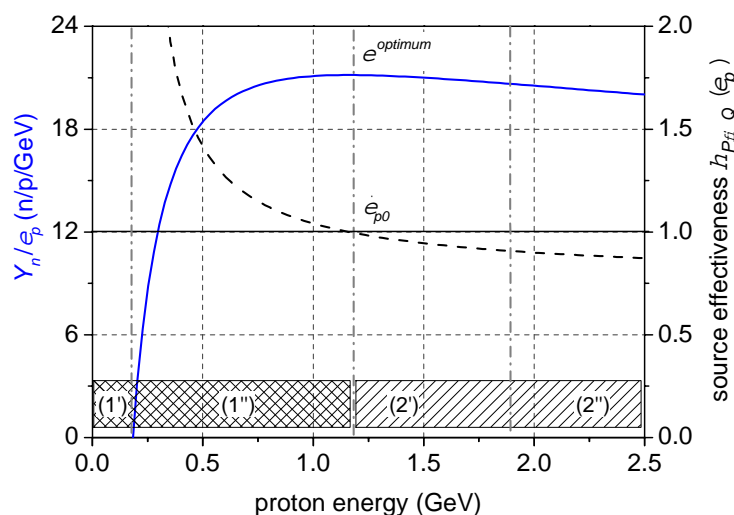
This coupling method is hereafter denoted as “*E-mode*” coupling.

In this work we propose *to utilise the proton energy as a coupling parameter (E-mode ACS)*. The difference between *E-mode* and *I-mode*, of which we would like to make use, is based on the *non-linear behaviour of neutron yield Y_n with respect to the proton energy e_p variation* (hereafter the “ Y_n -effect”).

As shown in a number of studies, when the energy of incident protons becomes higher than ~ 1 GeV, for example, the neutron yield normalised per incident proton energy becomes nearly constant and even slightly decreases with proton energy (see Refs. [4-6] and references contained therein). There are two major reasons for this decrease of neutron production efficiency with energy increase - 1) opening of new reaction channels and 2) escape of high-energy particles from the spallation target with finite geometry.

This neutron production dependence is illustrated qualitatively in Figure 1. The neutron yield, after protons passed the reaction threshold [zone (1')], grows rather rapidly with energy [zone (1'')]; above a certain value of e_p , this dependence has a moderated quasi-linear behaviour [zone (2)]. Thus, there is a value of proton energy $e_p^{optimum}$, which is optimal with respect to neutron economy (i.e. neutron yield per one incident proton and per consumed energy reaches its maximal value). Therefore, it is generally considered nonsensical to increase the energy of protons beyond $e_p^{optimum}$ since the production of neutrons in the spallation target becomes less efficient compared with the equivalent increase of the proton current (accelerator power being constant).

Figure 1. Dependence of the spallation neutron yield $Y_n(e_p) / e_p$ (solid line) and that of the source effectiveness $h_{p\#Q}(e_p)$ (dash line)



Quantitatively, the Y_n -effect as a function of proton energy can be described by an empirical formula proposed in Ref. [6] with the units of neutron yield per one incident proton interacting with a thick and heavy metal target:

$$Y_n(e_p) = -a + b e_p^a \quad (3)$$

where parameters a , $b \neq 0$ and $0 \leq a \leq 1$ can be fitted to the experimental data depending on the target geometry and material. This particular dependence of the neutron yield on target geometry and material should not be neglected. Furthermore, one should make use of these particular situations. Indeed, our preliminary estimates have shown that some optimisation on the geometry of the spallation target might further strengthen the Y_n -effect. More quantitative calculations in this context are needed.

Principle of the operation – DENNY concept

In this work, we propose to utilise this particularity of neutron production to form quasi-linear dependence (Y_n -effect) between energy production in the core and external neutron production in the spallation target, aiming to get auto-regulating behaviour of the ensemble “accelerator-subcritical core”. A proposed system (E -mode coupled ACS) would have the kinetics of a critical system with an artificial group of delayed neutrons as with a “standard” ACS. Also, its external neutron production would contain supplementary feedback, tending to stabilise installation power in its nominal state.

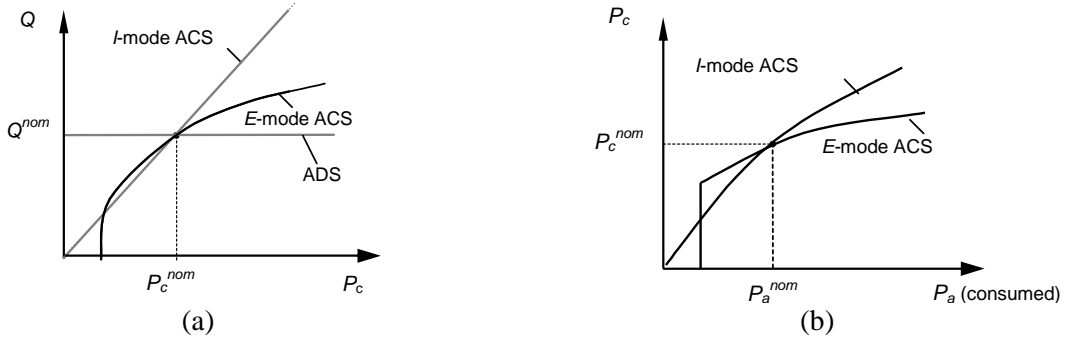
To elucidate this statement, we recall that ACS may be considered as a *critical* system with two types of neutrons contributing to the *global* neutron balance – “core neutrons” and “source neutrons”. Despite the fact that this separation of neutrons is relatively artificial, it reflects their origin and, thus, the corresponding neutron production feedback for each case. In the same context, the Y_n -effect can be compared to the Doppler feedback effect but for the external source neutrons. Similarly, as with the Doppler feedback effect, the Y_n -effect is intrinsic. It would be quite advantageous for system safety to have this supplementary feedback acting on the entire neutron balance if the “standard” core feedback is degraded and cannot play a self-stabilising role, which is indispensable for inherent system safety.

The advantage of the above realisation of a coupled hybrid system can be illustrated by the “neutron production versus core power” [Figure 2(a)] as well as by the “core power versus accelerator power” [Figure 2(b)] diagrams during unprotected accidents. We note the equivalence between Figure 2(a) (E -mode ACS) and Figure 1 for the neutron yield Y_n dependence, which is possible to make use of only in the case of E -coupling. According to the new concept (proposed E -mode ACS), the power (and temperature) excursion would be less important than in the “standard” I -mode ACS, which is clearly seen in Figure 2(b). For the present work, the system with an accelerator coupled to the core in E -mode is named DENNY (delayed enhanced neutronics with non-linear neutron yield). Below we propose the principle of DENNY functioning.

Let us consider the E -mode ACS with a pre-defined subcriticality level $r_0 = (1 - k_{\text{eff},0}) / k_{\text{eff},0}$ and a fraction $f < 1$ of the produced core power, which is used to drive an external neutron source. External neutrons are created in the spallation target by incident protons accelerated up to the energy e_p . It is preferable to choose the nominal proton energy $e_{p,0} > e_p^{\text{optimum}}$ in order to avoid an eventual instability of the DENNY power with respect to negative reactivity insertions (power decrease). Hence, the proton energy must be chosen as follows: $e_{p,0} = e_p^{\text{optimum}} + D e_m$ [zone (2'') in Figure 1]. Here the margin $D e_m$ [zone (2') in Figure 1] makes the system more stable with respect to negative reactivity insertions. This is valid if during system operation the proton energy remains beyond the optimal energy, i.e. the condition $e_p \neq e_p^{\text{optimum}}$ is fulfilled.

Figure 2. Diagrams of intrinsic dependences

(a) Neutron production Q dependence on core power P and (b) equilibrium core power P_c dependence on accelerator power P_a for different concepts of a hybrid system



The nominal values of proton current ($I_{p,0}$) and of fraction of accelerator feed power (f_0) are chosen in such a way to sustain the power level P_0 in a nominal state ($I_{p,0} = r_0 P_0$). The value of the proton current is fixed over all periods of the E -mode ACS functioning. On the contrary, the fraction f may be adjusted to compensate eventual reactivity swing (e.g. due to burn-up). In other words, for proton energy we write:

$$e_p = e_{p,0} \frac{fP}{f_0 P_0} \quad (4)$$

Above we explained schematically the principle of DENNY functioning where some details are omitted with a view to simplify the description. For example, we suppose that accelerator efficiency is identical for all proton energies, importance of source neutrons does not depend on proton energy, etc. A detailed description of a hybrid system based on the E -mode coupling is outside the scope of this paper. However, in order to provide some quantitative illustration of the main principles, a simplified model of system operation with E -coupling is presented below.

Results and discussion

Let us study the response of the E -mode ACS to an accidental reactivity insertion in order to qualitatively describe the influence of the Y_n -effect on its kinetics. A new equilibrium power level \bar{P} of the system after insertion of the reactivity Δr_{ext} can be found from the generalised reactivity-power balance equation [2,7,8], which follows from the stationary kinetic equation:

$$\Delta r_{ext} - r_0 + \Delta r_{feedback}(\bar{P}) + r_0 Q(\bar{P})/\bar{P} = 0 \quad (5)$$

where the term $Q(P) = P_0 Y_n(e_p(P))/Y_n(e_{p,0})$ describes the external source and the proton energy e_p was already defined in Eq. (4). In *this* context, the last term in Eq. (5) may be considered as “source (feedback) reactivity” [i.e. $r_{source} = r_0 Q(\bar{P})/\bar{P}$]. Equation (5) together with the feedback model and the neutron yield dependence describes the equilibrium states of the E -mode ACS after reactivity transients. In this case, a new power level \bar{P} after the reactivity transients will be determined not only by core feedback but also by the ability of the external source to produce sufficient neutrons to sustain this power.

Equation (5) is non-linear with respect to the variable \bar{P} and can be solved numerically. However, the linearisation of Eq. (5) allows us to characterise the Y_n -effect analytically with respect to an infinitesimal power fluctuation. Introducing the normalised power reactivity coefficients $A = P_0 \frac{d\chi_{feedback}(P_0)}{dP_0}$ and $B = P_0 \frac{d\chi_{source}(P_0)}{dP_0}$, we rewrite Eq. (5) in the linearised form:

$$d\chi_{ext} + d\bar{P} (A + B)/P_0 = 0 \quad (6)$$

Taking into account that $Q(P_0) = P_0$ (being the initial condition), and after some modifications, one obtains the following expression for the parameter B :

$$B = r_0 P_0 \left[\frac{d}{dP_0} \left(\frac{Q(P_0)}{P_0} \right) \right] = -r_0 \left(-h_{P_{fi} Q}(P_0) \right) \quad (7)$$

with the function $h_{P_{fi} Q}(P) = dQ/dP$ being a measure of the local source effectiveness, i.e. a source response due to an infinitesimal power change in a nominal state. With respect to the global neutron balance in the E -mode ACS, Eq. (7) demonstrates that parameter B may be considered as a coefficient, being a measured supplementary neutron production feedback and arising in the system due to the Y_n -effect. As it follows from Eq. (7), coefficient B is proportional to the nominal subcriticality level r_0 and depends on the $h_{P_{fi} Q}(P_0)$ functional behaviour.

Non-linear neutron production influences the equilibrium power level and its effectiveness [$h_{P_{fi} Q}(P_0)$] will depend on the choice of the nominal proton energy $e_{p,0}$. The Y_n -effect increases the asymptotical power if $e_{p,0} < e_p^{optimum}$ [zone (1) in Figure 1] and, on the contrary, it reduces power growth if $e_{p,0} \neq e_p^{optimum}$ [zone (2) in Figure 1]. In fact, we can see from Eq. (7) that if the condition $(dQ/dP) < 1$ is fulfilled, the external neutron source is not able to support the increasing power, which will limit the consequential power growth $d\bar{P} = \bar{P} - P_0$.

Let us suppose for simplicity that $f = f_0$. In this case the function $h_{P_{fi} Q}$ can be expressed as follows:

$$h_{P_{fi} Q}(e_p) = \left(\frac{e_p}{Y_n(e_p)} \right) \left(\frac{dY_n(e_p)}{de_p} \right) \quad (8)$$

As it follows from Eq. (3) and Eq. (8), at $\hat{e}_{p,0} = (a/(1-a)b)^{1/a}$ the function $h_{P_{fi} Q}(\hat{e}_{p,0}) = 1$. This energy point defines the limit between the “destabilising” area of the Y_n -effect (amplification of $d\bar{P}$, similar to positive feedback) at $e_{p,0} < \hat{e}_{p,0}$ and the “stabilising” domain of the Y_n -effect (suppression of $d\bar{P}$, similar to negative feedback) at $e_{p,0} \neq \hat{e}_{p,0}$ (Figure 1). It is important to note that in the present case, $\hat{e}_{p,0}$ is equal to the optimum energy $e_p^{optimum}$ with respect to neutron economy.

What is the real gain of the proposed DENNY concept? Below we perform a comparative analysis for the ACS case with I -mode coupling and E -mode coupling, which results in a linear $Q(P)$ dependence and a non-linear $Q(P)$ dependence, respectively [see Figure 2(a)]. The effectiveness of

the Y_n -effect for safety improvement can be described by the *transient suppression parameter* D . It is defined as the ratio of asymptotic power values of E -coupled and I -coupled systems after a certain reactivity insertion transient, namely:

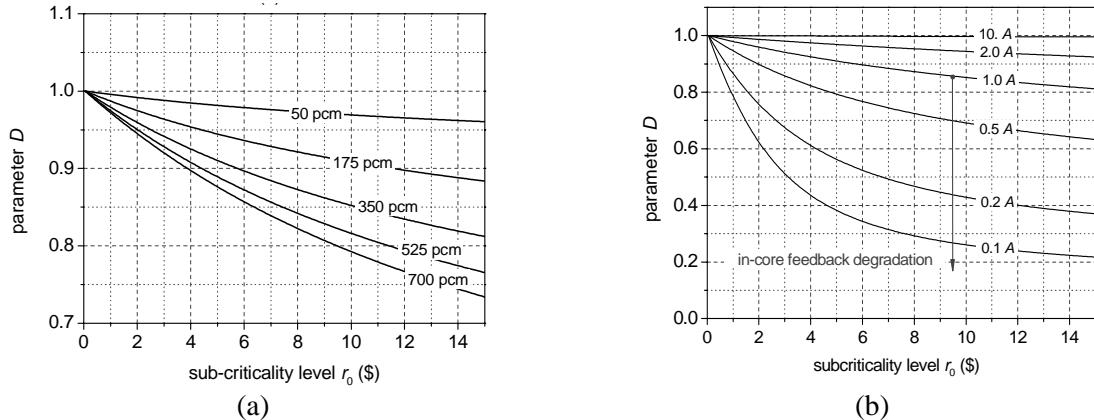
$$D = \frac{\overline{P}^{(E-mod e)}}{\overline{P}^{(I-mod e)}} \quad (9)$$

If $D < 1$, it signifies that the Y_n -effect stabilises the system. The D -values at different r_0 and $D r_{ext}$ for the linear model of in-core feedback are presented in Figure 3(a). For a quantitative comparison we defined the parameters in Eq. (3), which we took from Ref. [6], namely $a = 8.2$, $b = 29.3$ and $a = 0.75$. According to the discussion in the previous section, we chose nominal energy value $e_{p,0} = 1.6$ GeV greater than $\hat{e}_{p,0} = 1.16$ GeV for our comparative analysis, from which the following conclusions were drawn:

- The stabilising role of the Y_n -effect increases when both r_0 and $D r_{ext}$ increase. This effect can be quite significant (up to 27% at $r_0 = 15b$) even in the case of “good” in-core feedback ($A = -488$ pcm). Further growth of $D r_{ext}$ leads to the saturation of such a tendency.
- Augmentation of the nominal proton energy $e_{p,0}$ enhances the stabilising impact of the Y_n -effect due to the reduction of the source effectiveness $h_{pfi Q}(e_{p0})$.

Figure 3. Transient suppression parameter D as a function of subcriticality level r_0

(a) At different values of the inserted reactivity $D r_{ext}$ (feedback coefficient $A = -488$ pcm),
 (b) at different values of the parameter A (the inserted reactivity $D r_{ext} = 350$ pcm); $b = 350$ pcm



Parameter D depends also on the feedback coefficient A , defined earlier in this work. We recall that this parameter reflects both the in-core feedback effects and the thermo-hydraulics of the system. Figure 3(b) demonstrates that the impact of the Y_n -effect on power stabilisation increases when the absolute value of feedback coefficient A decreases. This dependence of the transient suppression parameter D on parameter A was predictable. Indeed, if $A \rightarrow 0$, i.e. in-core feedback effects are absent, the Y_n -effect becomes the only feedback effect, existing in the system.

Conclusions

In the present work, a new approach for the realisation of an accelerator-coupled hybrid system (ACS) was proposed and nominated as the DENNY system (delayed enhanced neutronics with

non-linear neutron yield). This concept is based on the particularity of neutron production forming a quasi-linear dependence between energy production (coupled to the proton energy) in the core and the external neutron yield Y_n in the spallation target (Y_n -effect). This particular dependence provides auto-regulating behaviour of the ensemble “accelerator-subcritical core”. The proposed system has the kinetics of a critical system with an artificial group of delayed neutrons as with the “standard” ACS. In addition, its external neutron production contains supplementary feedback, which is able to stabilise the installation power in its nominal state.

We showed that significant improvement of the feedback effect due to this particular coupling between an accelerator and a subcritical core (E -mode coupling) could be achieved. The proposed Y_n -effect can be compared to the Doppler feedback effect but for external source neutrons. Similar to the Doppler effect, the Y_n -effect is intrinsic. Lastly, our qualitative estimates showed that implementation of this concept could compensate eventual feedback degradation in cores dedicated to the transmutation of nuclear waste. Further and more quantitative analysis is urgently needed. Such further studies should include feasibility estimates to show whether the E -mode ACS could be realised in practice.

REFERENCES

- [1] Rubbia, C., *et al.*, *Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier*, CERN/AT/ 95-44, Geneva, Switzerland (1995).
- [2] Gandini, A., M. Salvatores, I. Slessarev, “Coupling of Reactor Power with Accelerator Current in ADS Systems”, *Annals of Nuclear Energy*, 27(13), p. 1 147 (2000).
- [3] Slessarev, I., P. Bokov, “Deterministic Safety Study of Advanced Molten Salt Nuclear Systems for Prospective Nuclear Power”, *Nucl. Eng. Design.*, 231(1), pp. 67-88 (2004).
- [4] Andriamonje, S., *et al.*, “Experimental Determination of the Energy Generated in Nuclear Cascades by a High Energy Beam”, *Phys. Lett.*, B 348, p. 697 (1995).
- [5] Letourneau, A., J. Galin, F. Goldenbaum, *et al.*, “Neutron Production in Bombardments of Thin and Thick W, Hg, Pb Targets by 0.4, 0.8, 1.2, 1.8 and 2.5 GeV Protons”, *Nuclear Instruments and Methods in Physics Research*, B 170, pp. 299-322 (2000).
- [6] Pankratov, D., *et al.*, “Secondary Neutron Yields from Thick Pb and W Targets Irradiated by Protons with Energy 0.8 and 1.6 GeV”, *Proceedings of the 2nd International Conference on Accelerator-driven Transmutation Technologies and Applications*, V2, Kalmar, Sweden (1996).
- [7] Wade, D., “LMR Core Design for Inherent Safety”, *Proceedings of the NEA/CRP Meeting*, Paris, France (1986).
- [8] Gandini, A., M. Salvatores, I. Slessarev, “Balance of Power in ADS Operation and Safety”, *Annals of Nuclear Energy*, 27, pp. 71-84 (1999).

TABLE OF CONTENTS

Foreword	3
Executive Summary.....	11
Welcome.....	15
<i>D-S. Yoon</i> Congratulatory Address	17
<i>I-S. Chang</i> Welcome Address	19
<i>G.H. Marcus</i> OECD Welcome	21
GENERAL SESSION: ACCELERATOR PROGRAMMES AND APPLICATIONS.....	23
<i>CHAIRS: B-H. CHOI, R. SHEFFIELD</i>	
<i>T. Mukaiyama</i> Background/Perspective.....	25
<i>M. Salvatores</i> Accelerator-driven Systems in Advanced Fuel Cycles	27
<i>S. Noguchi</i> Present Status of the J-PARC Accelerator Complex	37
<i>H. Takano</i> R&D of ADS in Japan.....	45
<i>R.W. Garnett, A.J. Jason</i> Los Alamos Perspective on High-intensity Accelerators.....	57
<i>J-M. Lagniel</i> French Accelerator Research for ADS Developments.....	69
<i>T-Y. Song, J-E. Cha, C-H. Cho, C-H. Cho, Y. Kim, B-O. Lee, B-S. Lee, W-S. Park, M-J. Shin</i> Hybrid Power Extraction Reactor (HYPER) Project	81

<i>V.P. Bhatnagar, S. Casalta, M. Hugon</i> Research and Development on Accelerator-driven Systems in the EURATOM 5 th and 6 th Framework Programmes.....	89
<i>S. Monti, L. Picardi, C. Rubbia, M. Salvatores, F. Troiani</i> Status of the TRADE Experiment.....	101
<i>P. D'hondt, B. Carlucci</i> The European Project PDS-XADS “Preliminary Design Studies of an Experimental Accelerator-driven System”.....	113
<i>F. Groeschel, A. Cadiou, C. Fazio, T. Kirchner, G. Laffont, K. Thomsen</i> Status of the MEGAPIE Project.....	125
<i>P. Pierini, L. Burgazzi</i> ADS Accelerator Reliability Activities in Europe	137
<i>W. Gudowski</i> ADS Neutronics	149
<i>P. Coddington</i> ADS Safety	151
<i>Y. Cho</i> Technological Aspects and Challenges for High-power Proton Accelerator-driven System Application.....	153
TECHNICAL SESSION I: ACCELERATOR RELIABILITY.....	163
<i>CHAIRS: A. MUELLER, P. PIERINI</i>	
<i>D. Vandeplasseche, Y. Jongen (for the PDS-XADS Working Package 3 Collaboration)</i> The PDS-XADS Reference Accelerator	165
<i>N. Ouchi, N. Akaoka, H. Asano, E. Chishiro, Y. Namekawa, H. Suzuki, T. Ueno, S. Noguchi, E. Kako, N. Ohuchi, K. Saito, T. Shishido, K. Tsuchiya, K. Ohkubo, M. Matsuoka, K. Sennyu, T. Murai, T. Ohtani, C. Tsukishima</i> Development of a Superconducting Proton Linac for ADS.....	175
<i>C. Miélot</i> Spoke Cavities: An Asset for the High Reliability of a Superconducting Accelerator; Studies and Test Results of a $\beta = 0.35$, Two-gap Prototype and its Power Coupler at IPN Orsay	185
<i>X.L. Guan, S.N. Fu, B.C. Cui, H.F. Ouyang, Z.H. Zhang, W.W. Xu, T.G. Xu</i> Chinese Status of HPPA Development	195

<i>J.L. Biarrotte, M. Novati, P. Pierini, H. Safa, D. Uriot</i> Beam Dynamics Studies for the Fault Tolerance Assessment of the PDS-XADS Linac	203
<i>P.A. Schmelzbach</i> High-energy Beat Transport Lines and Delivery System for Intense Proton Beams	215
<i>M. Tanigaki, K. Mishima, S. Shiroya, Y. Ishi, S. Fukumoto, S. Machida, Y. Mori, M. Inoue</i> Construction of a FFAG Complex for ADS Research in KURRI	217
<i>G. Ciavola, L. Celona, S. Gammino, L. Andò, M. Presti, A. Galatà, F. Chines, S. Passarello, XZh. Zhang, M. Winkler, R. Gobin, R. Ferdinand, J. Sherman</i> Improvement of Reliability of the TRASCO Intense Proton Source (TRIPS) at INFN-LNS	223
<i>R.W. Garnett, F.L. Krawczyk, G.H. Neuschaefer</i> An Improved Superconducting ADS Driver Linac Design.....	235
<i>A.P. Durkin, I.V. Shumakov, S.V. Vinogradov</i> Methods and Codes for Estimation of Tolerance in Reliable Radiation-free High-power Linac	245
<i>S. Henderson</i> Status of the Spallation Neutron Source Accelerator Complex	257
TECHNICAL SESSION II: TARGET, WINDOW AND COOLANT TECHNOLOGY.....	265
CHAIRS: X. CHENG, T-Y. SONG	
<i>Y. Kurata, K. Kikuchi, S. Saito, K. Kamata, T. Kitano, H. Oigawa</i> Research and Development on Lead-bismuth Technology for Accelerator-driven Transmutation System at JAERI	267
<i>P. Michelato, E. Bari, E. Cavaliere, L. Monaco, D. Sertore, A. Bonucci, R. Giannantonio, L. Cinotti, P. Turroni</i> Vacuum Gas Dynamics Investigation and Experimental Results on the TRASCO ADS Windowless Interface	279
<i>J-E. Cha, C-H. Cho, T-Y. Song</i> Corrosion Tests in the Static Condition and Installation of Corrosion Loop at KAERI for Lead-bismuth Eutectic	291
<i>P. Schuurmans, P. Kupschus, A. Verstrepen, J. Cools, H. Ait Abderrahim</i> The Vacuum Interface Compatibility Experiment (VICE) Supporting the MYRRHA Windowless Target Design	301

<i>C-H. Cho, Y. Kim, T-Y. Song</i> Introduction of a Dual Injection Tube for the Design of a 20 MW Lead-bismuth Target System.....	313
<i>H. Oigawa, K. Tsujimoto, K. Kikuchi, Y. Kurata, T. Sasa, M. Umeno, K. Nishihara, S. Saito, M. Mizumoto, H. Takano, K. Nakai, A. Iwata</i> Design Study Around Beam Window of ADS.....	325
<i>S. Fan, W. Luo, F. Yan, H. Zhang, Z. Zhao</i> Primary Isotopic Yields for MSDM Calculations of Spallation Reactions on ²⁸⁰ Pb with Proton Energy of 1 GeV.....	335
<i>N. Tak, H-J. Neitzel, X. Cheng</i> CFD Analysis on the Active Part of Window Target Unit for LBE-cooled XADS.....	343
<i>T. Sawada, M. Orito, H. Kobayashi, T. Sasa, V. Artisyuk</i> Optimisation of a Code to Improve Spallation Yield Predictions in an ADS Target System.....	355
TECHNICAL SESSION III: SUBCRITICAL SYSTEM DESIGN AND ADS SIMULATIONS.....	363
<i>CHAIRS: W. GUDOWSKI, H. OIGAWA</i>	
<i>T. Misawa, H. Unesaki, C.H. Pyeon, C. Ichihara, S. Shiroya</i> Research on the Accelerator-driven Subcritical Reactor at the Kyoto University Critical Assembly (KUCA) with an FFAG Proton Accelerator.....	365
<i>K. Nishihara, K. Tsujimoto, H. Oigawa</i> Improvement of Burn-up Swing for an Accelerator-driven System	373
<i>S. Monti, L. Picardi, C. Ronsivalle, C. Rubbia, F. Troiani</i> Status of the Conceptual Design of an Accelerator and Beam Transport Line for Trade.....	383
<i>A.M. Degtyarev, A.K. Kalugin, L.I. Ponomarev</i> Estimation of some Characteristics of the Cascade Subcritical Molten Salt Reactor (CSMSR).....	393
<i>F. Roelofs, E. Komen, K. Van Tichelen, P. Kupschus, H. Ait Abderrahim</i> CFD Analysis of the Heavy Liquid Metal Flow Field in the MYRRHA Pool.....	401
<i>A. D'Angelo, B. Arien, V. Sobolev, G. Van den Eynde, H. Ait Abderrahim, F. Gabrielli</i> Results of the Second Phase of Calculations Relevant to the WPPT Benchmark on Beam Interruptions	411

TECHNICAL SESSION IV: SAFETY AND CONTROL OF ADS 423

CHAIRS: J-M. LAGNIEL, P. CODDINGTON

*P. Coddington, K. Mikityuk, M. Schikorr, W. Maschek,
R. Sehgal, J. Champigny, L. Mansani, P. Meloni, H. Wider*
Safety Analysis of the EU PDS-XADS Designs..... 425

*X-N. Chen, T. Suzuki, A. Rineiski, C. Matzerath-Boccaccini,
E. Wiegner, W. Maschek*
Comparative Transient Analyses of Accelerator-driven Systems
with Mixed Oxide and Advanced Fertile-free Fuels 439

P. Coddington, K. Mikityuk, R. Chawla
Comparative Transient Analysis of Pb/Bi
and Gas-cooled XADS Concepts 453

B.R. Sehgal, W.M. Ma, A. Karbojian
Thermal-hydraulic Experiments on the TALL LBE Test Facility 465

K. Nishihara, H. Oigawa
Analysis of Lead-bismuth Eutectic Flowing into Beam Duct..... 477

P.M. Bokov, D. Ridikas, I.S. Slessarev
On the Supplementary Feedback Effect Specific
for Accelerator-coupled Systems (ACS)..... 485

W. Haeck, H. Ait Abderrahim, C. Wagemans
 K_{eff} and K_s Burn-up Swing Compensation in MYRRHA 495

TECHNICAL SESSION V: ADS EXPERIMENTS AND TEST FACILITIES 505

CHAIRS: P. D'HONDT, V. BHATNAGAR

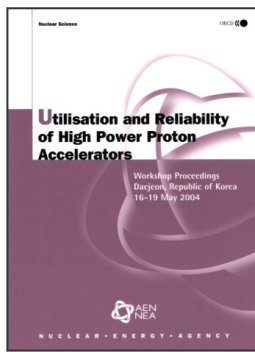
*H. Oigawa, T. Sasa, K. Kikuchi, K. Nishihara, Y. Kurata, M. Umeno,
K. Tsujimoto, S. Saito, M. Futakawa, M. Mizumoto, H. Takano*
Concept of Transmutation Experimental Facility 507

M. Hron, M. Mikisek, I. Peka, P. Hosnedl
Experimental Verification of Selected Transmutation Technology and Materials
for Basic Components of a Demonstration Transmuter with Liquid Fuel
Based on Molten Fluorides (Development of New Technologies for
Nuclear Incineration of PWR Spent Fuel in the Czech Republic) 519

Y. Kim, T-Y. Song
Application of the HYPER System to the DUPIC Fuel Cycle..... 529

M. Plaschy, S. Pelloni, P. Coddington, R. Chawla, G. Rimpault, F. Mellier
Numerical Comparisons Between Neutronic Characteristics of MUSE4
Configurations and XADS-type Models 539

<i>B-S. Lee, Y. Kim, J-H. Lee, T-Y. Song</i> Thermal Stability of the U-Zr Fuel and its Interfacial Reaction with Lead	549
SUMMARIES OF TECHNICAL SESSIONS	557
<i>CHAIRS: R. SHEFFIELD, B-H. CHOI</i>	
<i>Chairs: A.C. Mueller, P. Pierini</i> Summary of Technical Session I: Accelerator Reliability	559
<i>Chairs: X. Cheng, T-Y. Song</i> Summary of Technical Session II: Target, Window and Coolant Technology	565
<i>Chairs: W. Gudowski, H. Oigawa</i> Summary of Technical Session III: Subcritical System Design and ADS Simulations.....	571
<i>Chairs: J-M. Lagniel, P. Coddington</i> Summary of Technical Session IV: Safety and Control of ADS	575
<i>Chairs: P. D'hondt, V. Bhatagnar</i> Summary of Technical Session V: ADS Experiments and Test Facilities.....	577
SUMMARIES OF WORKING GROUP DISCUSSION SESSIONS	581
<i>CHAIRS: R. SHEFFIELD, B-H. CHOI</i>	
<i>Chair: P.K. Sigg</i> Summary of Working Group Discussion on Accelerators.....	583
<i>Chair: W. Gudowski</i> Summary of Working Group Discussion on Subcritical Systems and Interface Engineering	587
<i>Chair: P. Coddington</i> Summary of Working Group Discussion on Safety and Control of ADS.....	591
<i>Annex 1: List of workshop organisers</i>	<i>595</i>
<i>Annex 2: List of participants.....</i>	<i>597</i>



From:

Utilisation and Reliability of High Power Proton Accelerators

Workshop Proceedings, Daejeon, Republic of Korea, 16-19 May 2004

Access the complete publication at:

<https://doi.org/10.1787/9789264013810-en>

Please cite this chapter as:

Bokov, Pavel M. and Danas Ridikas (2006), "On the Supplementary Feedback Effect Specific for Accelerator-Coupled Systems ACS", in OECD/Nuclear Energy Agency, *Utilisation and Reliability of High Power Proton Accelerators: Workshop Proceedings, Daejeon, Republic of Korea, 16-19 May 2004*, OECD Publishing, Paris.

DOI: <https://doi.org/10.1787/9789264013810-49-en>

This work is published under the responsibility of the Secretary-General of the OECD. The opinions expressed and arguments employed herein do not necessarily reflect the official views of OECD member countries.

This document and any map included herein are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

You can copy, download or print OECD content for your own use, and you can include excerpts from OECD publications, databases and multimedia products in your own documents, presentations, blogs, websites and teaching materials, provided that suitable acknowledgment of OECD as source and copyright owner is given. All requests for public or commercial use and translation rights should be submitted to rights@oecd.org. Requests for permission to photocopy portions of this material for public or commercial use shall be addressed directly to the Copyright Clearance Center (CCC) at info@copyright.com or the Centre français d'exploitation du droit de copie (CFC) at contact@cfcopies.com.