PNC TN8100 96－003

ロシア無機材料研究所との専門家会議

〔国際科学技術センター (International Science and Technology Center : ISTC)の政府支援プロジェクト「高レベル放射性金属廃棄物誘導スラグ溶融プロセスの開発」に関する1994年度分の研究報告会〕

1 9 9 6年3月

動力炉・核燃料開発事業団
東　海　事　業　所

PNC TN8100 96－003

１ ９ ９ ６ 年 ３ 月

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報告責任者　大内　仁[1)]　五十嵐　寛[1)]

編 集 者　河村　和廣[1)]　下田　良幸[2)]

篠崎　貢[3)]

要　旨

国際科学技術センター(ISTC)の政府支援プロジェクト「高レベル放射性金属廃棄物誘導溶融プロセスの開発」(Project N 143-94)に関する1994年度分の研究報告会が1996年3月20日から21日までの 2日間，東海事業所において開催された。本プロジェクトは国際的なロシア支援活動の一環として実施され，ISTC とロシア無機材料研究所(VNIINM)の間で1994年10月から1997年 9月までの 3年間の契約が締結されている。

VNIINM側から金属廃棄物の処理技術動向，本プロジェクトに使用する小型モックアップ装置ISWM-CC-1 についての報告があった。また，本プロジェクトの関連技術として，ロシア無機材料研究所におけるコールドクルーシブルを用いた高レベル廃液等の固化技術の紹介があった。

1）環境技術開発部　環境技術第一開発室

2）株式会社原燃環境（業務協力）

3）原子力技術株式会社

目　次

1. 議　　　　　事

1.1 議題

国際科学センター（ISTC）の政府支援プロジェクト「高レベル放射性金属廃棄物誘導スラグ溶融プロセスの開発」に関する1994年度分の研究報告

1.2 日程

1996年 2月20日

13:40～17:00　研究報告会

1996年 2月21日

10:00～12:00　研究報告会

13:30～14:20　再処理工場見学

14:30～16:45　研究報告会

1.3 出席者

ロシア無機材料研究所（VNIINM）

Project Manager, Senior Researcher

Pastushkov, V.G. 氏

Project Manager, Head of Laboratory

Kushnikov, V.V. 氏

Manager, Work Section on Project Engineer Technologist

Serebryakov, V.P. 氏

通訳　㈱ブレイン・インターナショナル

太田氏

動燃事業団(PNC)

国際部　国際協力室 :吉川室代

環境本部　処理・貯蔵研究Gr. : 久保田

技術開発推進部　研究開発調整室 :菖蒲

環境技術開発室　環境技術第一開発室 :大内室長、五十嵐室代、河村主査

小林主査、米谷、山下、捧、吉田、下田、篠崎

環境施設部　設計プロジェクトチーム :村山担当役

再処理技術開発部　プラント設計開発室 :天本担当役

核燃料技術開発部 :堀江担当役

1.4　配付資料

資料－1　Technico-Economic Aspects of Processes Used for Condition for Conditioning for Disposal of High-Activity Metal waste Arising from Spent Nuclear Fuel Reprocessing

資料－2　Mock-up Facility for Cold Crucible Induction Slag Melting of Chopped Fuel Claddings

資料－3　High Level Waste Solidification Technology by CCIM Method

資料－4　Proposal Project Concerning to the New Project with ISTC (as a Continuation of the Project N 143-94) under Financial Support of the Power Reactor and Nuclear Fuel Development Corporation

2. 会　議　内　容

2.1　ロシア無機材料研究所およびプロジェクトの概要

(VNIINM : Pastushkov)

VNIINMは５０年の歴史があり、約3000人の技術者がいる。U/Pu酸化物、金属燃料、被覆管材料等の原子力関連の材料の研究、使用済み核燃料の処理、超伝導材料、核融合材料の開発を行っている。

本プロジェクトはISTCの政府支援プロジェクトで、金属廃棄物の誘導スラグ溶融(ISWM)に関連するものである。研究期間は1994年10月から1997年 9月の３年間である。今回の報告では1994年度分の研究成果を報告する。本技術は原理的に高レベル廃液のガラス固化技術等への応用が可能であり、廃棄物処理技術として共通性の高いものである。尚、今後の開発にはPNC の意向を反映する予定である。

2.2　金属廃棄物処理技術動向

(VNIINM : Pastushkov)

配付資料－１に基づき金属廃棄物の処理方法の動向について説明があった。ハルの処理法としては現在６つのオプションがある。

1．セメント固化
2．硝酸洗浄後セメント固化
3．プレス後セメント固化
4．グラファイトとのコンポジット化
5．超高圧プレス
6．溶融

これらのプロセスの経済性を評価した。その結果コストが最も低いのは５．超高圧プレスと６．の溶融であった。

また、本試験に使用する模擬物質・フラックス（ペレット状に成型）のサンプルの説明があった。模擬物質は表面を酸化させたもの（皮膜厚さ30μm)と、酸化膜のないものと比較する予定であるフラックスの組成は、現在使用しているものから更に検討を進め

る予定である。フラックスと金属は連続的に供給している。

（◆模擬ハル、フラックス、酸化皮膜写真を入手／HTS 保管　写真2.2.1 ～2.2.5）

【質疑応答】

Q1　表２（配付試料－１）の金属廃棄物の放射能データはどのような条件のものか？

A1　軽水炉で28000 ～33000MWd/t燃焼させたものである。

Q2　ハル中にトリチウムは、どのような化学形態で取り込まれているのか？

A2　トリチウムに関する研究は行っていない。仏の研究データがある。オフガスから分子ふるいで分離し、トリチウム水として回収する。600t／y の処理で600Lのトリチウム水が回収される。

Q3　実ハルをコールドクルーシブルで溶融した経験はあるか？

A3　経験はない。研究所の施設で酸化膜を付けた模擬物質の溶融までの段階です。現在マヤックではハルは処理することなく、そのまま貯蔵されている。粉末状のものは発火の危険があるためアルミナと混合されて貯蔵されている。

Q4　金属廃棄物の放射能データはどこでとったのか？

A4　VNIINMには、実廃棄物を評価する設備がない。アイソトープ試験まではできる。ここに示してあるデータはフランスとロシアの共同研究報告結果であり、平均化したものである。マヤックで評価できるか検討中である。

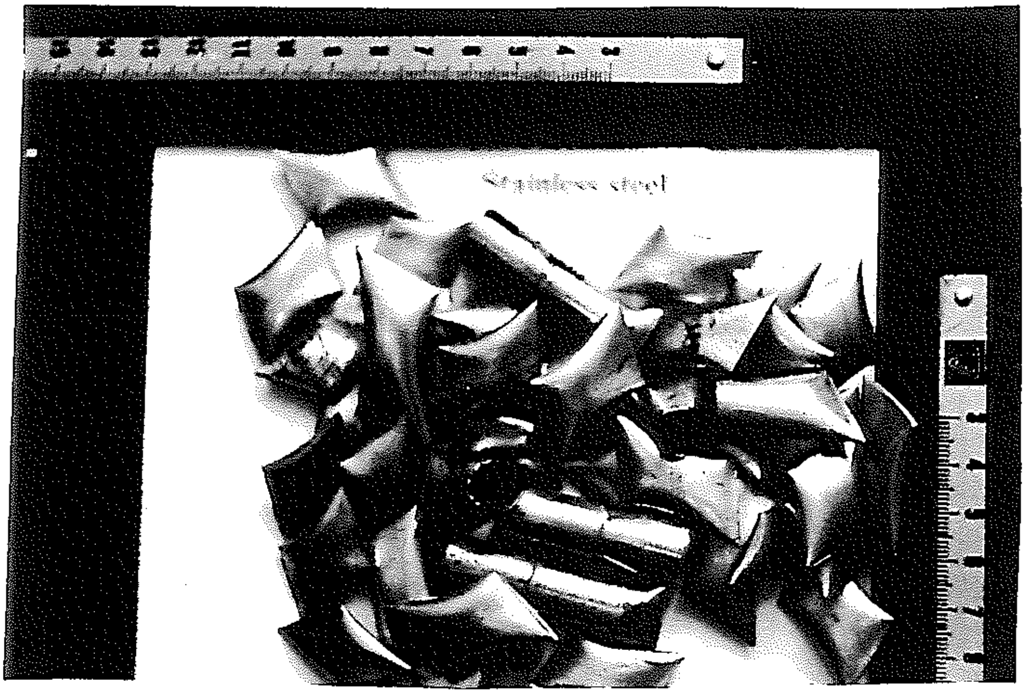


写真 2.2.3　模擬ハル（ステンレス鋼）

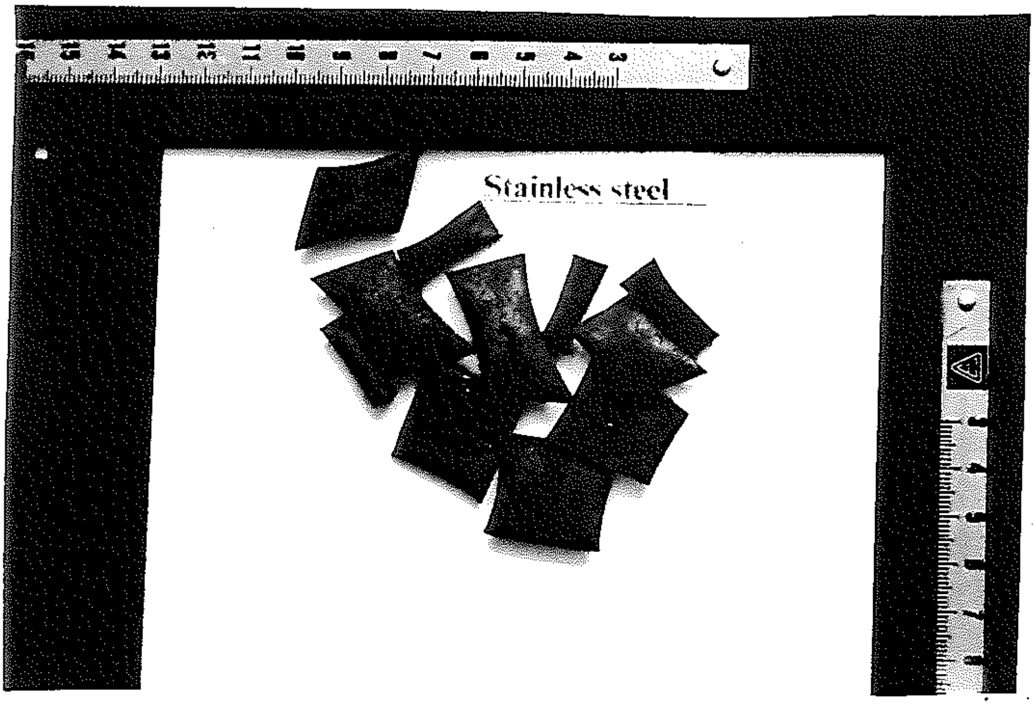


写真 2.2.4　模擬ハル（ステンレス鋼，表面酸化）

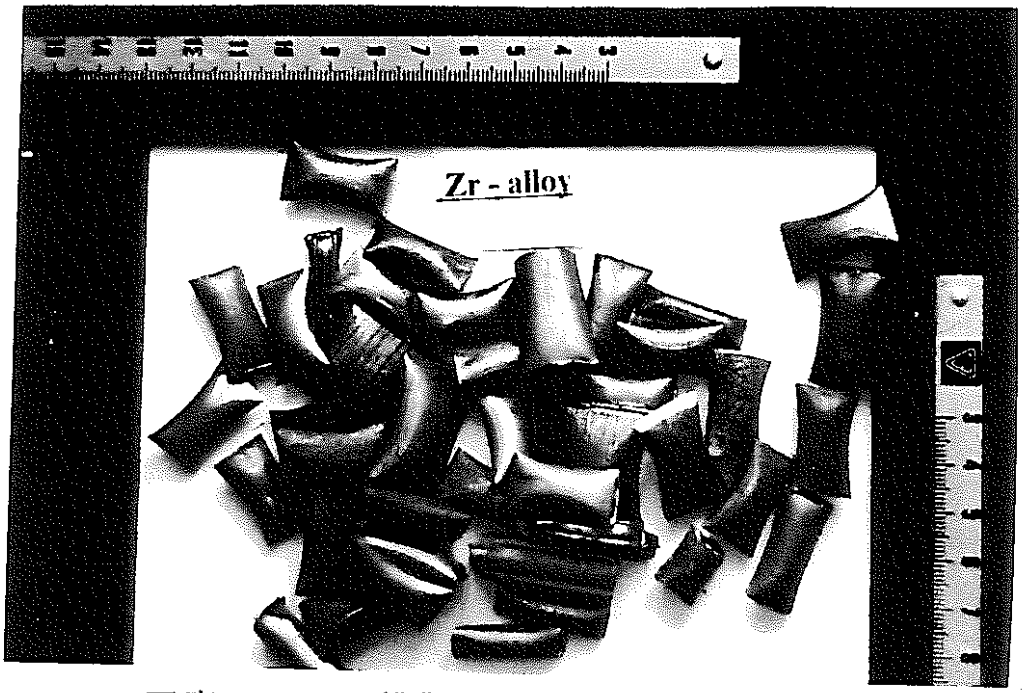


写真 2.2.1 模擬ハル（ジルカロイ）

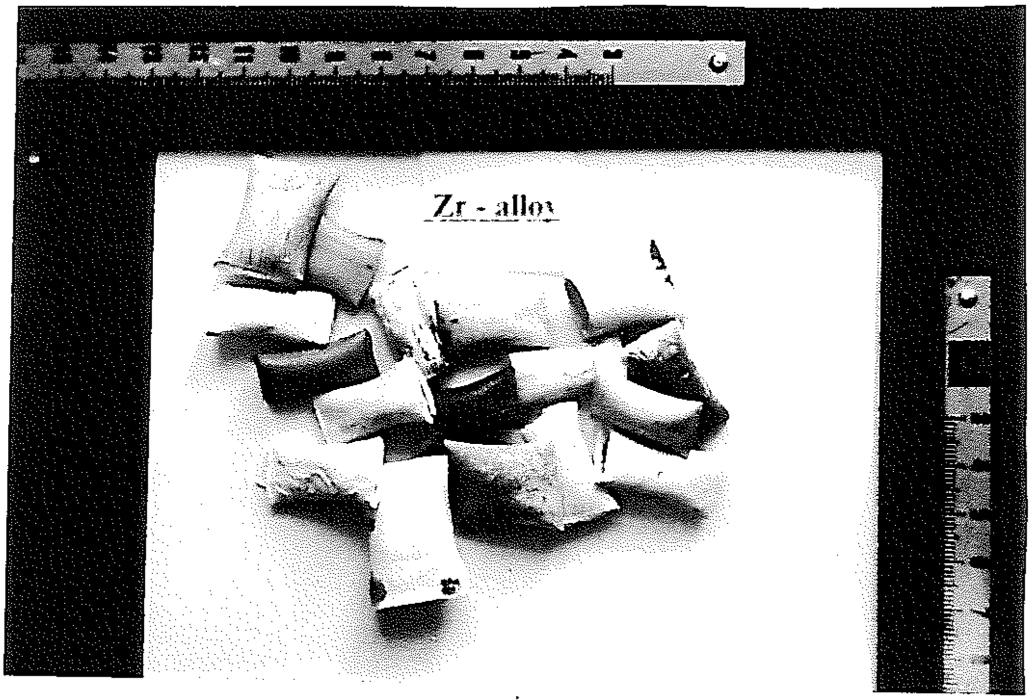


写真 2.2.2 模擬ハル（ジルカロイ，表面酸化）

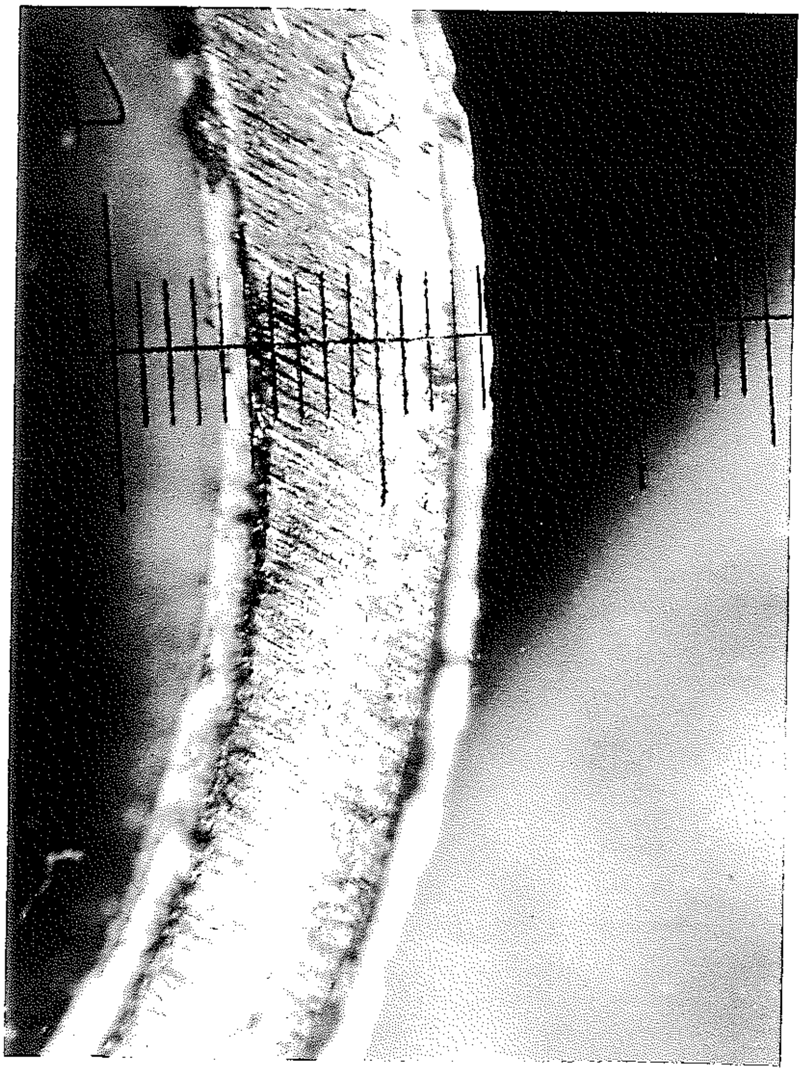


写真 2.2.5 模擬ハル断面（表面酸化）

2.3　モックアップ装置ISWM-CC-1

(VNIINM : Serebryakov)

配付資料-2に基づき本プロジェクトに使用するモックアップ装置ISWM-CC-1(図2.3.1)およびインダクションスラグ溶融プロセス(図2.3.2)について概略の説明があった。

クルーシブル直径	60mm	
インゴット長さ	100mm	(3kg 相当)
周波数	2400Hz	
出力	100kW	

今後ISWM-CC-1 を利用して、模擬物質の溶融・フラックスによる除染効果・スラグおよびインゴットの性状評価、二次廃棄物（スラグ）の処理技術に関する研究を進める予定である。 ISWM-CC-1は金属およびフラックスの供給装置、インゴットの抜き出し装置、オフガス装置、および冷却水系温度、真空度等の計装を備えている。ISWMはクルーシブルにスラグと金属を連続的に供給すると同時に下から引き抜くことによりインゴットを製造する。磁気体積力により溶融金属はドーム状に盛り上がり炉壁との接触が避けられる。溶融金属は磁気的に攪拌されこの現象はスラグ除染効果を向上させる。

【質疑応答】

Q1　クルーシブルの構造を詳細に説明して下さい。

A1　クルーシブルは18の銅製水冷セグメントで構成され、それぞれ電気的に絶縁されている。絶縁材は雲母を使用している。またインゴットの抜き出し力に対してクルーシブルを固定するため、セグメントをFRP で束ねている。

Q2　フラックスの供給速度は？

A2　金属の供給に対して、3－5％の割合で供給している。最初にフラックスの1/3 を一度に入れた後、残りは金属と一緒に連続的に供給している。

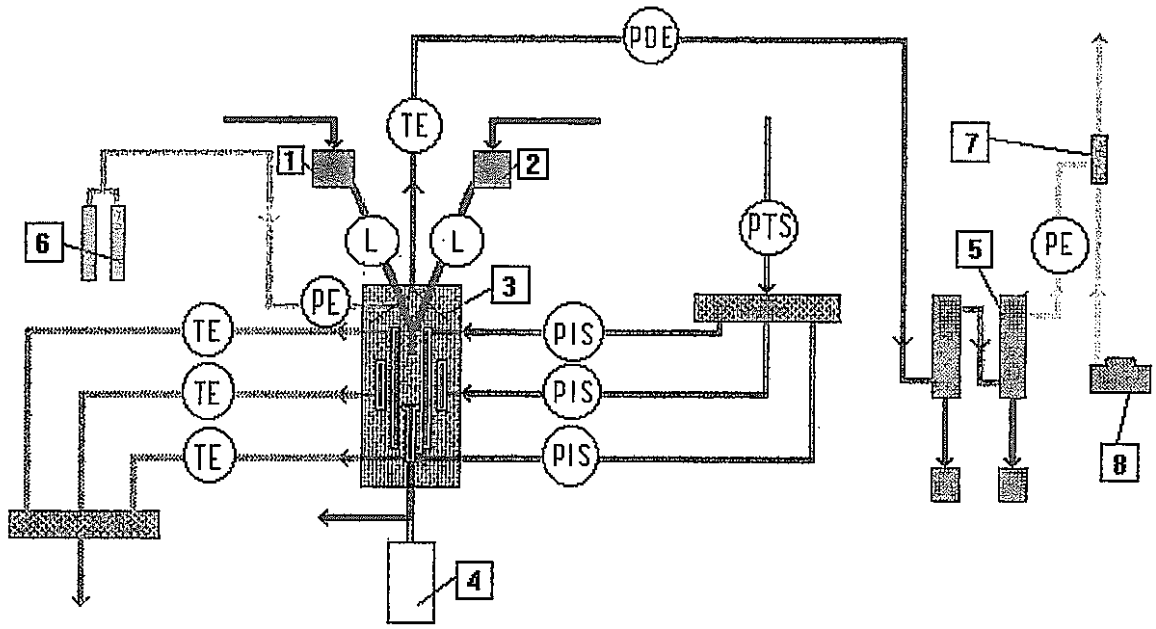
Q3　スラグのオフガスへの移行率を把握しているか。

A3　まだやっていない。2 段の金属ファイバ製フィルタでダストを回収できるようになっている（パルス的にフィルタ部を動かし、ダストを落とす仕組）。

Q4　ISWM-CC-1 とCC-2の違いは？

A4　CC-2のクルーシブル直径は220mm 、インゴット長さ650mm （200kg 相当）、周波数2400Hz、出力500kW ある。

Process Flow outline of "ISMW - CC - 1"



1. Vibrational Feeder. 2. Plate Feeder. 3. "Cold" Crucible. 4. Mechanism for Ingot Drawing. 5. Gas Clean - up. 6. Cylinder Containing an Inert Gas. 7. Ejector. 8. Compressor.

図 2.3.1

Sheme of melting with extension

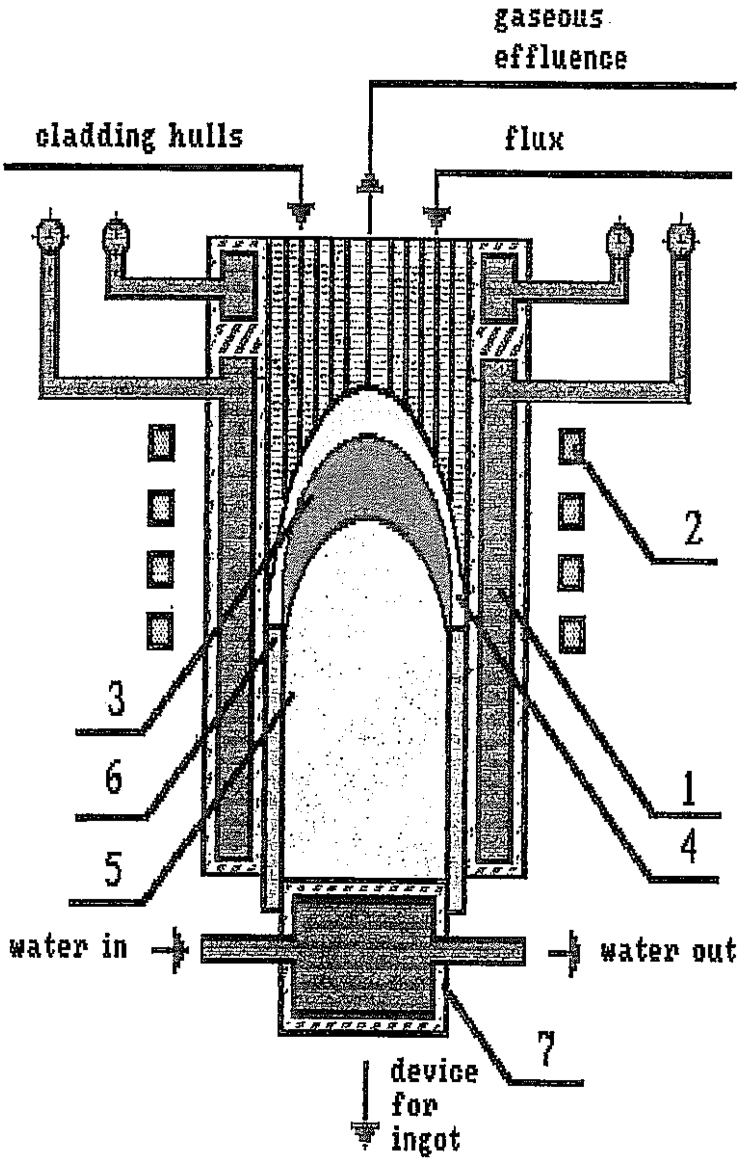


Fig. 2

1. Cooled body.
2. Inductor coil.
3. Melting sone.
4. Liquid slag.
5. ingot.
6. Solid slag.
7. Cooled hearth.

図 2.3.2

2.4　ロシア無機材料研究所におけるコールドクルーシブルによる高レベル廃液のガラス固化技術

(VNIINM : Kushnikov)

配付資料-3に基づきVNIINMのコールドクルーシブルによる高レベル廃液のガラス固化技術に関する報告があった。廃液としては、軽水炉、船用炉、軍事用炉からの燃料を処理した廃液、廃液から群分離した分離液を対象に、リン酸ガラス、ホウケイ酸ガラスによる固化法、固化体特性を研究してきた。

マヤックでは直接通電式の炉で製法が単純なリン酸ガラスで処理してきたが、Mo電極、炉材の腐食が激しいので、代替技術として高温処理が可能で制御性の良いコールドクルーシブル技術を開発してきた。プロセスとしては廃液の仮焼および溶融の２段階で行い、オーバーフロー式でガラスをクルーシブルから抜き出す方法である。今年中にマヤックに実廃液用装置を設置する予定である。

【質疑応答】

Q1　金属溶融のスラグの処理法は？

A1　そのまま固化よりもコールドクルーシブルでガラス固化した方が固化体特性上良い。

Q2　マヤックに設置する装置の運転予定は？

A2　今年度の第一四半期に据え付けを終了し、第二第三四半期に慣らし運転、第四四半期から模擬廃液運転を始める。実廃液運転は未定。（図2.4.1,　図2.4.2）

Q3　VNIINMで使用しているコールドクルーシブルの形状は？

A3　シリンダ状のものは、直径60、90、110mm 、マッチ箱状のものは、横400 ×幅200×高さ600mm （マヤックに設置する装置と同様、スプレイ仮焼装置付50L/hガラスで18kg/h処理可能）、シリンダ状の直径500mm の炉は0.44MHz で35kg/hで処理可能（マヤックの二期工事で設置計画がある　図2.4.3,　図2.4.4）

Q4　クルーシブルを大型化する場合の問題点はあるか？

A4　高レベル廃液の処理プラントは100L/hの処理速度で計算しており、大型化する予定はない。処理量を増やす場合はメルタの数を増やし並列で操業することで対処する。

Q5　マヤックに設置する２槽式のコールドクルーシブルの構造を説明してほしい。

A5　しきり部の構造およびガラスの抜き出し方法（オーバーフロー）について説明があった(図2.4.5)。直径500mm の炉の場合も２槽、オーバーフロー式

Q6　マヤックに設置する装置に付ける廃液前処理用のエバポレータについて説明してほしい。

A6　エバポレータの胴部に巻付けたチューブ内に廃液を通し、外部からスチームで加熱し、水分をチューブ内で蒸発させ、胴内に噴き出させる構造。クルーシブルには硝酸塩と若干の水分が供給される。

Q7　液体供給時の問題点は何か？

A7　処理能力低下である。上記エバポレータを付けた場合溶融能力は160kW の出力で18kg／h 、250kWで30kg／h 、スプレイ仮焼装置を付けた場合160kWで30kg/h

Q8　金属溶融用のデモンストレーション装置の設置計画はあるか？

A8　このプロジェクトが順調に進めば、マヤックに設置することになるだろう。

Q9　Ehp-500 の2 号炉の運転状況はどうか？

A9　1992年始めから運転を開始し、現在も寿命（3 年）を超えて運転中。10000m^3の廃液、ガラス放射能で2 億6000万Ciを処理した。今、２機の炉を製作中。新設分で３系列となる。

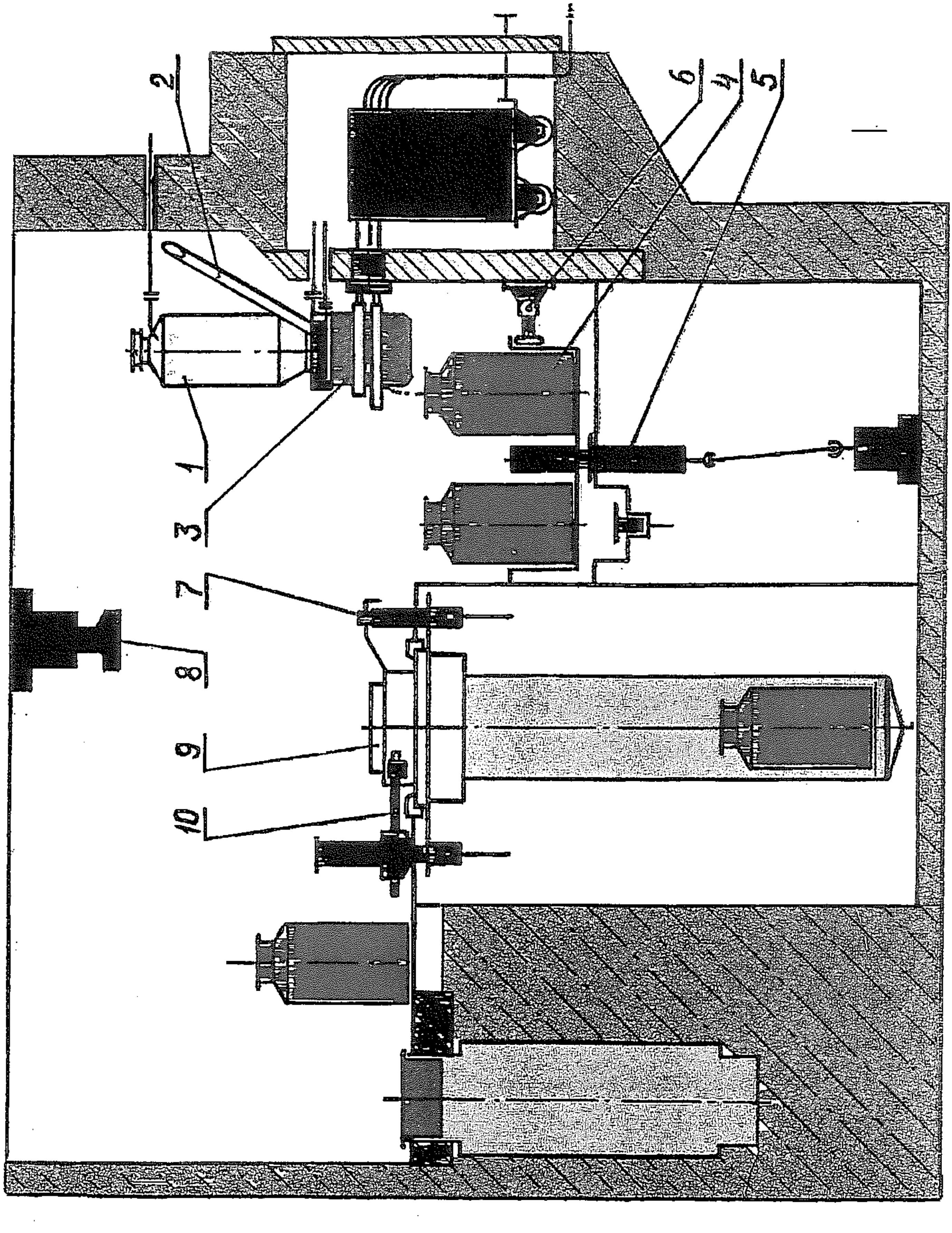


図 2.4.1

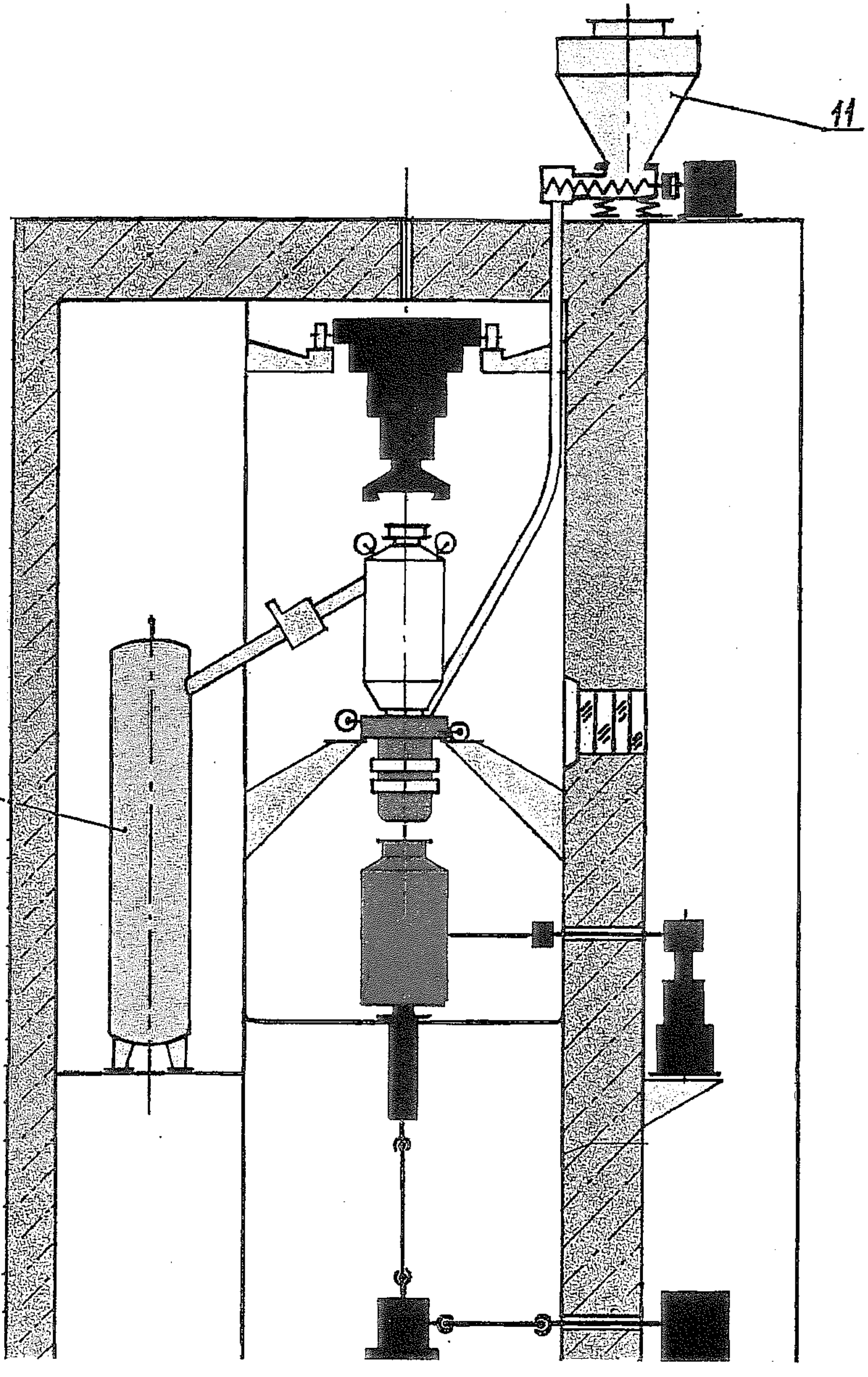
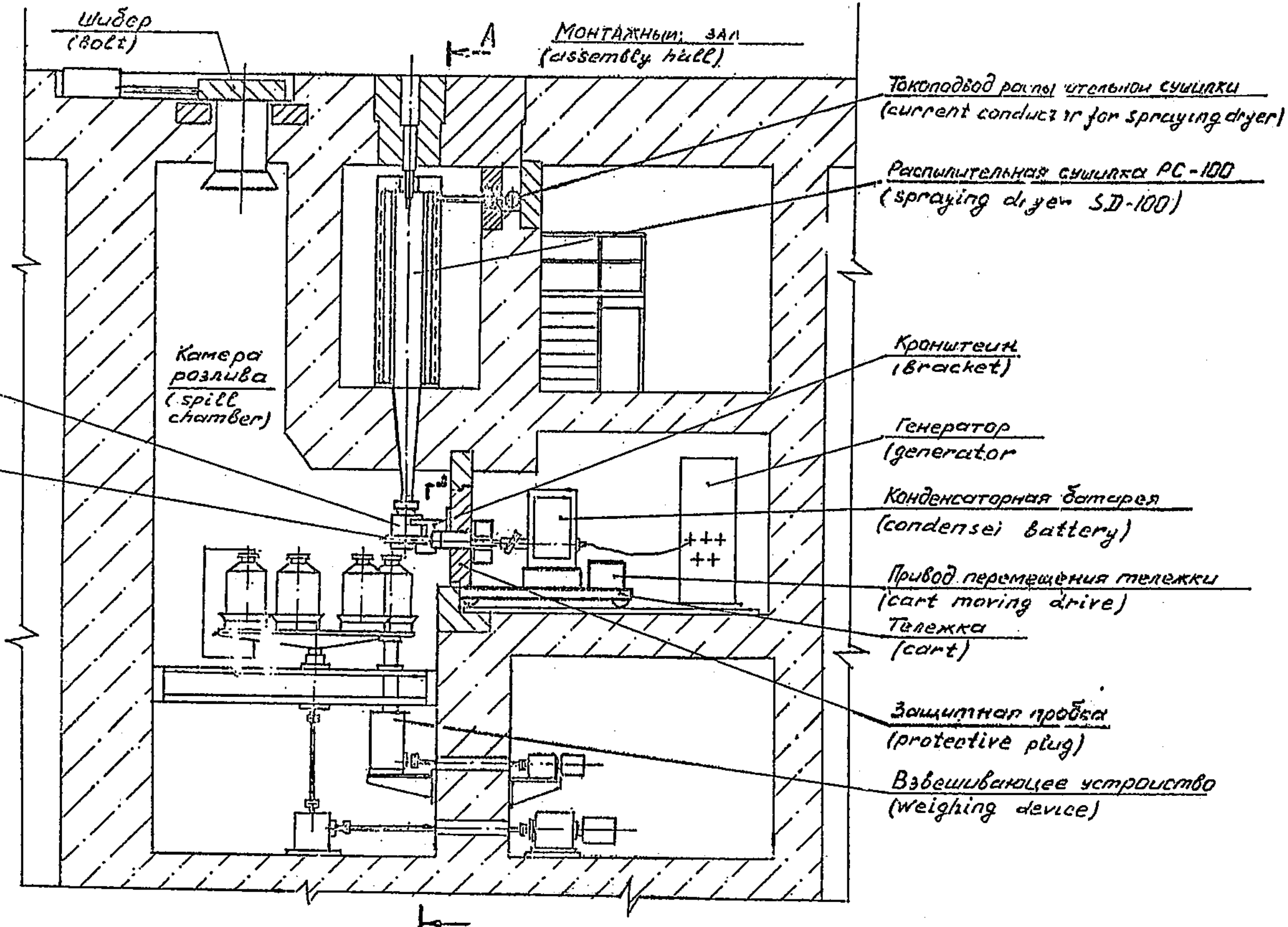


図 2.4.2



Двухстадийная установка РС-ИПХТ
(Double-stage SD-IMCC installation)

図 2.4.3

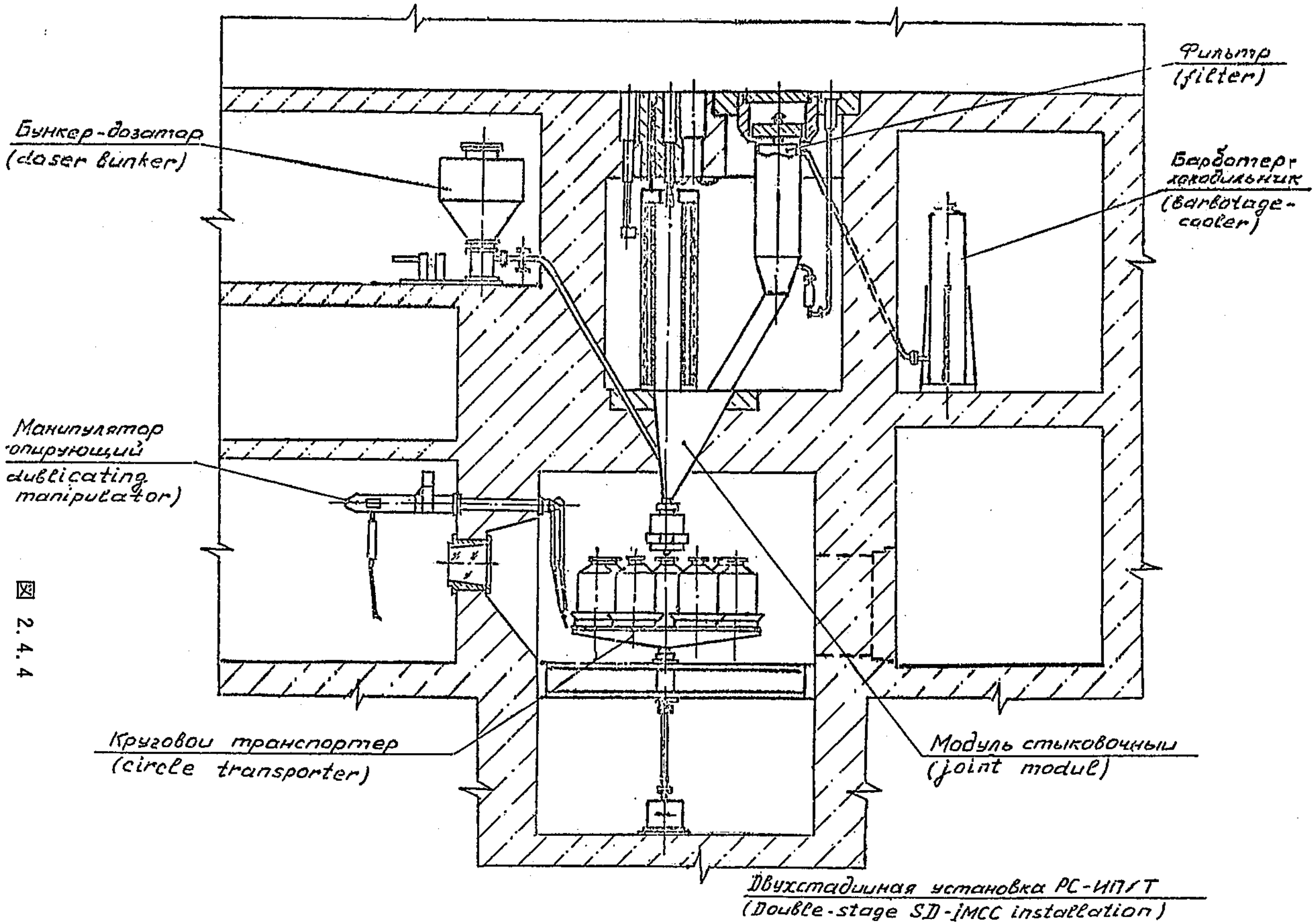

Фильтр
(filter)
Бункер-дозатор
(doser bunker)
Барботер-холодильник
(barbotage-cooler)
Манипулятор копирующий
(dublicating manipulator)
Круговой транспортер
(circle transporter)
Модуль стыковочный
(joint module)
Двухстадийная установка РС-ИП/Т
(Double-stage SD-IMCC installation)

図 2.4.4

индукционный плавитель с холодным тиглем (ипхт)

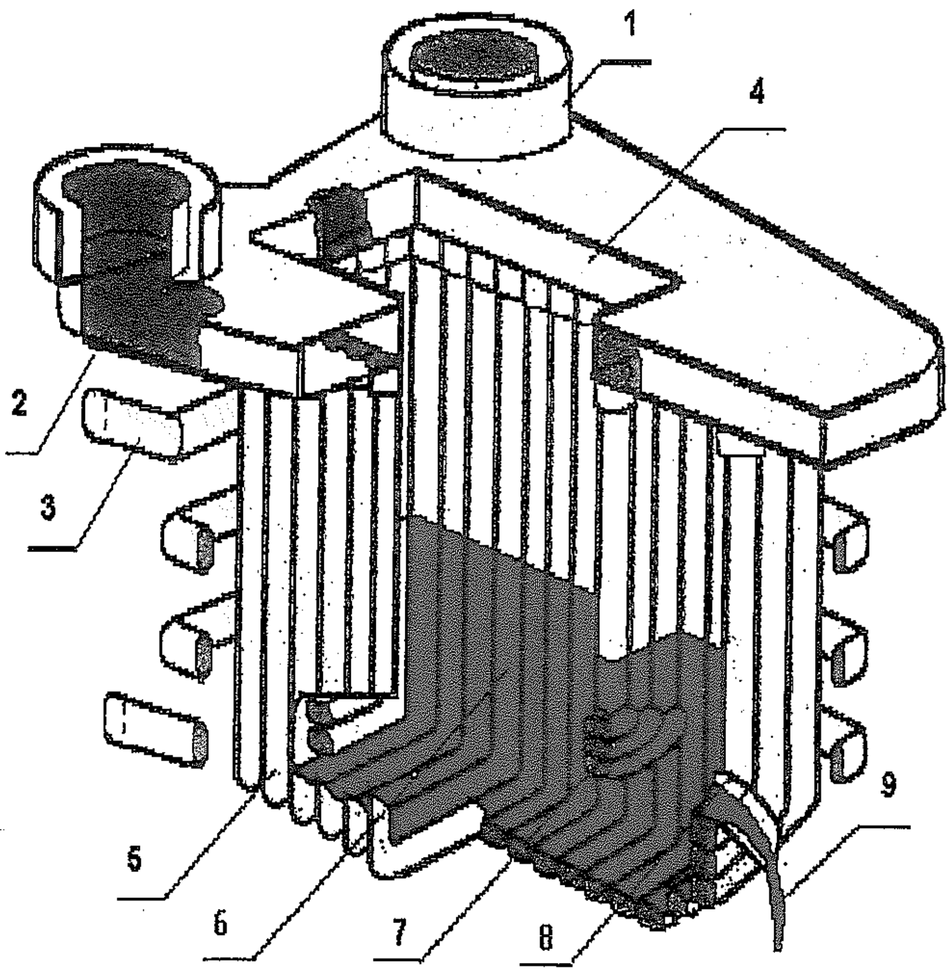


Рис.1

1. Плавкий разъем.
2. Вода для охлаждения трубчатых секций тигля.
3.Индуктор.
4.Загрузка поступающего на плавление материала.
5.Трубчатые секции тигля.
6.Расплав.
7.Перегородка.
8.Струя расплава.

図 2.4.5

2.5　その他質疑応答

【Kushnikov 氏によるプロジェクト提案】

添付試料－４に基づきISTC N 143-94 の継続プロジェクトを提案。また高レベル廃液の減容、高耐久性マトリクス開発に関するISTC376 について説明があった。

【対応】

ISTC N 143-94 の継続プロジェクトについては、別途技術上のコメントを送る。プロジェクトの採否、予算は政府が決めるため、PNC でできるのは技術上のコメントのみである。

ISTC376 については、既に国際部にISTCから資料が送られきており、政府としては３月のISTC理事会でテーマとして採用を表明する予定である（国際部）。

Q1　CCIMによる溶融においてハル中にプラスチック、ラバー、セルロースが混入した場合の実験経験はあるか？コメントは？

A1　５％以内であれば問題はない。有機物は燃焼する。塩素等はオフガスで回収される。酸化物となったものはスラグになる。Sn、Fe、Ni、Co、Mnなど金属はインゴットの中に入る。

Q2　クルーシブルの材料として、金属溶融用には銅、酸化物用にはSUS を使用しているが処理温度の低い、酸化物にSUS を使用するのはなぜか、耐熱性を考えれば逆ではないか？

A2　クルーシブルの材質として、電気抵抗、熱伝導率の面から銅の方が良い。SUSを使用しているのはNOx の発生による腐食を考慮したためである。腐食性ガスの発生が無い場合は酸化物においても銅製のクルーシブルを使う方が良い。

Q3　冷却水の漏れを検知する技術はあるか。

A3　検知していない。冷却水の温度は60℃以下で管理している。また、クルーシブルの電気エロージョンはおこらない。冷却水の電気抵抗、塩濃度も管理している。管理していれば、1000回の溶融運転は可能である。

Q4　何が寿命要因となるのか？

A4　溶融金属が誘導コイル部より上になり、炉壁につき屋根状に残ってしまう（◆インゴットに空洞ができている写真あり　写真2.5.1）。上から機械的に削り

とる必要がある。溶融後、炉壁が平滑になっているか目視で確認している。炉壁が薄くなったら冷却水温度で検知可能。

Q5 フラックスの組成について説明してほしい。

A5 カルシウム、マグネシウム、アルミニウム、バリウム等のフッ化物、酸化物の混合系を考えている。組成は熱力学的検討により決定される。これらの開発は今後さらに研究を進める予定である。（◆フラックス組成に関するロシア語報告書を入手）

Q6 DF500 以上は達成できるのか？

A6 フランス等の研究結果より達成できると考えている。ステンレスは除染し易いがジルコニウムはやっかいである。

Q7 周波数を2.4kHzに設定した理由は？

A7 金属スクラップの大きさと透磁厚みから周波数を決定した。（◆ ISWM-CC-1の設計計算資料を入手）

Q8 クルーシブル径を変更した場合、周波数は変える必要はないのか？

A8 金属は透磁厚みが非常に薄いのでクルーシブルの直径を変更しても周波数を変更する必要はない。

Q9 自由表面のコントロールが重要と考えられるが、数値解析の経験はあるか。

A9 このプロセスでは自由表面は重要ではない、溶融金属のレベルをコントロールすることが重要だ。それについては計算結果がある。（◆電気熱機器研究所の関連論文入手。５．に添付）

Q10 ラドン（企業体）との関係は？

A10 ラドンは科学研究所、医療機関から発生する放射性廃棄物を処理している。無機材研とは過去協力関係にあり、CCIMに関する基本的技術内容については我々と同等である。

Q11 群分離、分離物の固化に関する情報を教えてほしい。

A11 今年、マヤックで高レベル廃液の分離設備が運転開始する。Cs、Srを抽出分離する。クラノヤルスクの工場向けの設備は設計段階である。分離により(Cs 、Sr）、（TRU 、希土類）、（その他）と分けられ、ガラス、鉱物に固化される。

（◆これらの質問の他、会議前にロシア側へ送付した質問状への回答文章を入手）

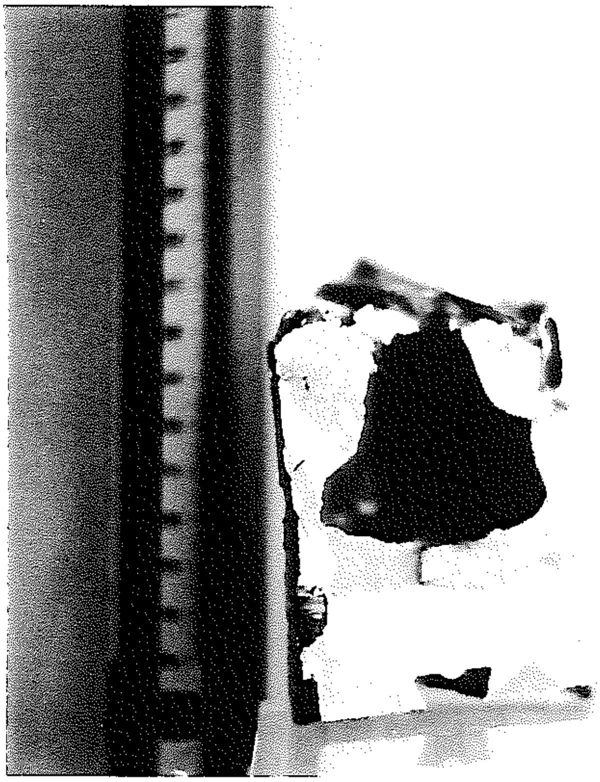


写真 2.5.1　インゴット断面（上部に空洞有り）

3. 配 付 資 料

3. 1 Technico-Economic Aspects of Processes Used for Conditionings for Disposal of High-Activity Metal Waste Arising from Spent Nuclear Fuel Reprocessing

TECHNICO-ECONOMIC ASPECTS OF PROCESSES USED FOR CONDITIONING FOR DISPOSAL OF HIGH-ACTIVITY METAL WASTE ARISING FROM SPENT NUCLEAR FUEL REPROCESSING

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1. Characterisation of Metal Waste

The regeneration of nuclear reactor spent fuel assemblies results in ≈300 kg metal waste per ton of spent fuel reprocessed. This waste is composed of chopped hulls of fuel claddings, wrappers and structural elements of fuel assemblies (FA) as well as cut off long length end pieces of FA_s (end and bottom caps).

The amounts and composition of metal waste arising from reprocessing the fuel of light water reactor (LWR type) FA_s are given in table 1.

(The FA_s of the Russian VVER type reactors have close characteristics in terms of the composition and amount of structural materials as well as their radiochemistry).

Table 1

Mass Balance (kg) of Metal Waste as Calculated per Ton of Heavy Metal

STRUCTURAL MATERIALS	HULLS AND STRUCTURAL PARTS (kg)	CAPS (kg)	FUEL ASSEMBLY (kg)
Stainless steel	13.9	27.7	41.66
Inconel	10.3	2.40	12.73
Zircaloy 4	261.4	—	261.36
Total	285.6	30.1	315.76

At the annual throughput of a radiochemical reprocessing plant of 600 t heavy metal, the amount of the accumulated metal waste to be disposed of will be 189.5 (171.4 t fuel claddings, 18.1 end caps of FA_s) ≈200 m^3 in volume. The resultant metal wastes are α-, β-, γ- irradiating materials the activity of which is induced by in-pile irradiation as well as available actinides and fission products diffusing into structural materials during the reactor operation and fuel reprocessing.

The high-activity metal wastes (HAMW) after FA holding for 3 years are radiochemically described in table 2.

Table 2

Radioactivity of Metal Waste

Radionuclides	Radioactivity of fuel claddings, TBq / t_{hm}	Radioactivity of end caps, TBq / t_{hm}
Fission products:		
^{3}H	10.36	
^{85}Kr	0.48	
$^{90}(Sr + Y)$	8.70	
$^{106}Ru + Rh$	8.70	
^{134}Cs	4.44	
$^{137}(Cs + mBa)$	13.51	
$^{144}(Ce + Pm)$	3.66	
^{147}Pm	3.00	
	$\Sigma = 59.0$	
Dissolution fines		
$^{106}(Ru + Rh)$	17.5	
Actinides:		
^{237}Np	2.2×10^{-5}	
^{238}Pu	4.9×10^{-2}	
^{239}Pu	5.7×10^{-3}	
^{240}Pu	8.2×10^{-3}	
^{241}Pu	1.96	
^{241}Am	1.9×10^{-2}	
^{244}Cm	1.9×10^{-2}	
	$\Sigma = 2.0$	
Activation products:		
^{54}Mn	2.6	0.15
^{55}Fe	65.6	26.3
^{57}Co	0.5	0.9×10^{-3}
^{60}Co	70.6	13.0
^{63}Ni	14.1	1.74
^{113}Sn	3.7×10^{-4}	—
^{119}Sn	14.8	—
^{123}Sb	20.1	—
	$\Sigma = 188.0$	$\Sigma = 41.0$
	Total: 266.5	Total: 41.0

After nuclear fuel dissolution and washing cut-off fuel claddings at their surfaces there remain 3-5% mass water and ≈ 0.35% mass U per 285.6 kg metal waste.

The metal waste conditioning results in heat releases basically due to β- and γ- emitters, i.e., products of fission and activation. The heat released by cut-off fuel claddings and end cups (FA_s as cooled for 3 years) is given in table 3.

Table 3

Heat Released by Metal Waste

Type of waste	Radionuclides	Heat release, W/t_{hm}
Cut-off claddings	Fission products	5.5
	Dissolution fines	2.3
	Actinides	$9x10^{-3}$
	Activation products	31.7
		$\Sigma = 39.6$
End caps	Activation products	5.4
		Total: 45.0

2. General Flow Sheets of Metal Waste Handling

In the closed fuel cycle adopted for the plants La Hague (France), Sellafield (UK), "Mayak" (Russia) cut-off fuel claddings and FA end caps are the main source of α-emitting solid waste. Handling this type of waste involves the following stages: acceptance → conditioning → packing → interim storage → shipping → disposal.

As a working hypothesis the HAMW reprocessing facility is assumed to be a self-sufficient unit. Fuel claddings and FA end caps arrive at the facility after rinsing with water as two individual streams in closed drums (canisters).

Each process of HAMW processing needs a facility meeting its individual requirements. For packaging two standard packages are under consideration, namely, "Cogema" modified cans and large cylindrical containers. The packages containing conditioned waste are monitored for the content of fissile material remaining in the metal and the residual contamination.

The interim storage of HAMW containing packages is accomplished at a reprocessing plant site. Following a one year interim storage the conditioned wastes are shipped in type B shielded casks (e.g., type B of the "Cogema" company has 2.5 m in the diameter and 7 m in height) to a disposal facility.

The HAMW containing casks are first accepted at the surface disposal site and then are disposed of in underground galleries. Since presently in no country in the world there are disposal sites for α-emitting wastes in geologic formations use is made of the concept developed for the Conrad Mine disposal facility for bitumenized or cemented wastes.

3. Routes of HAMW Management

On the basis of technological studies in different countries six general options of HAMW management were revealed and compared (see table 4) that can be grouped as follows:

a) cementation – direct incorporation of both types of HAMW into cement or cementation of pre-decontaminated cladding hulls (routes 1 and 2);

b) mechanical reduction of fuel hull volumes followed by HAMW incorporation either into cement or graphite or packaging HAMW into lead lined containers (routes 3, 4 and 5);

c) melting of cladding hulls and FA end caps (route 6).

3.1. The direct cementation route for cladding hulls and FA end caps was developed by CEA, France, and is in progress on a commercial scale at the UP-3 plant.

After rinsing with water metal wastes of both types arrive in baskets inside metal drums 1.75 m^3 in volume at a cementation facility. The drum is filled with cement grout, closed with an internal lid and is externally decontaminated. The decontamination of a drum results in ≈ 1.5 m^3 liquid low activity waste (≈ 346 m^3/year). The concrete is left to solidify, the external lid is closed and the drum is sent for the interim storage.

Each drum contains ≈ 820 kg waste. At the reprocessing plant throughput of 600 t h.m. per year the volume of conditioned waste corresponds to 231 drums or 400 m^3. The waste volume reduction factor is 0.47 (see table 5).

3.2. The routes of fuel cladding hull pre-decontamination and cementation of both types of HAMW were studied at CEN/SCK, Mole, Belgium. Fuel claddings are decontaminated with a solution of cool HNO_3 3 m/l with the aim of reducing the α-activity of waste.

Cladding hulls as placed in baskets are rinsed with HNO_3 and afterwards with water in a column. As decontaminated they are blended with FA end caps and subjected to cementation by the process described above.

Table 4

Results of HAMW Conditioning for Disposal

Operation	Cladding hulls	End caps	Cladding hulls	End caps	Cladding hulls	End caps	Cladding hulls	End caps	Cladding hulls	End caps	Cladding hulls	End caps
Treatment	↓	↓	Liquid decontamination ↓	↓	Drying ↓ rolling ↓	↓	Drying ↓ rolling ↓	↓	Drying ↓ compaction ↓	↓	Drying ↓ melting in "cold" crucible ↓	↓ melting in ceramic crucible ↓
Conditioning	Incorporation into cement		Incorporation into cement		Incorporation into cement		Incorporation into graphite		Packaging into lead lined container	Incorporation into cement	Packaging into container	
Route	1		2		3		4		5		6	

The spent HNO_3 effluents are evaporated and recycled resulting in 3 m^3/year low activity waste (β,γ = 7.8 GBq/year, α = 3.8 x 10^{-4} GBq/year) that are also subjected to cementation.

Table 5

Characterization of Waste Containing Packages

Type of Waste	Total mass of 1 drum, kg	Mass of waste, kg	Radioactivity		Heat release, W
			α, GBq	β,γ, GBq	
Claddings hulls and FA end caps	3500	820	260	800	117

The amount of waste as conditioned by this route is also 231 drums (≈ 400 m^3/year) and volume reduction factor is ≈ 0.47.

The characteristics of waste containing packages are the same as in Route 1 except for the radionuclide composition: the radioactivity α = 13 GBq, β,γ = 747 TBq, heat release of 111 W.

3.3. The route of cladding hulls rolling and waste cementation was developed by KFK (Kernforschungszentrum Karlsruhe), Germany.

Taking into account that cladding hulls have the largest volume in metal waste they are processed individually apart from FA end pieces. Cladding hulls are rolling mill flattened in an inert atmosphere thus reducing their volume by ≈ 40% and placed into an insert steel drum that is filled with a cement grout.

After the cement is solidified the drum is closed with a double lid and transported to an interim storage.

In view of their sizes and massive design the FA end caps are not subjected to flattening. They are conditioned individually by the same cementation route as used for cladding hulls.

The decontamination of the drum surfaces results in 10 m^3/year liquid waste of the total activity ≈ 0.5 MBq.

During rolling gaseous wastes are released in small amounts (0.1% ^3H and 1% Kr) of the total activity ≈ 10 TBq.

The annual quantity of cemented waste will be 460 drums (325 ones containing cladding hulls and 135 ones containing FA end caps). The total waste volume is ≈230 m^3.

The cladding hulls volume reduction factor is 1.05.

Table 6

Characterization of Waste Cladding Packages

Type of waste	Total mass of 1 drum, kg	Mass of waste, kg	Radioactivity		Heat release, W
			α, TBq	β,γ, TBq	
Cladding hulls	1310	528	3,8	489	73
End pieces	1060	134	—	183	24

3.4. The route of cladding hulls rolling and waste incorporation into graphite was developed by the Nukem company, Germany.

Cladding hulls and FA end pieces are processed individually. Both types of wastes are initially dried. Cladding hulls are then compacted in a rolling mill at the compaction factor of ≈ 2.5. A portion of as rolled claddings is blended with graphite and in a graphite sleeve placed into a steel insert container capable of sustaining the pressure. This unit is first pre-compacted at ≈ 3 MPa, then heated to 130°C and worked to 20 MPa followed by heating to 150°C and holding for 15 min.

After 20 min cooling down to 80°C the minipackage is removed from the tank where it was worked. Two packages of this type are placed into a 200 l drum to which a lid is welded.

FA end caps are processed similary except for the operation of pre-rolling.

The activity of arising liquid effluents is assessed to be ≈ 1 GBq and that of gaseous ones to be ≈ 10 TBq.

The annual number of packages containing compacted and graphite incorporated waste will be 865 drums (715 containing cladding hulls and 150 containing FA end caps). The total waste volume is 208 m^3. The waste volume reduction factor will be 0.9 ÷ 1.0.

Table 7

Characterization of Waste Containing Packages

Type of waste	Total mass of 1 drum, kg	Mass of waste, kg	Radioactivity		Heat release, W
			α, TBq	β,γ, TBq	
Cladding hulls	620	240	1.73	223	33
End caps	550	121	—	165	22

3.5. The route of cladding hull compaction followed by sealing with lead and cementation of FA end caps was developed by the CSN/SCK company, Belgium.

As dried cladding hulls are loaded in portions into a steel container and compacted using a hydraulic press at 250 MPa at the compaction factor of 5.0. The resultant disks are removed from the press and stacked in the quantity of 14 pieces (as a cylinder) into a Cogema modified canister internally lined with lead (12 mm thick). Then a lead shell and a steel lid are successively welded onto the canister to be shipped to an interim storage.

The FA end caps are processed individually by the direct cementation route followed by the decontamination of the drum external surface and shipping to an interim storage.

The operations of cladding hulls drying and package decontamination result in ≈10 m^3/year low level liquid effluents. The activity of off-gases (^3H and ^{85}Kr) will be ≈10 TBq and that of solid aerosols will be ≈15 MBq.

The annual quantity of packages containing conditioned waste will be 227 canisters with cladding hulls and 22 drums with cemented FA end caps.

The volumes of wastes in storage will be 55.4 m^3/year cladding hulls, 38.5 m^3/year end caps with the total volume of 94 m^3/year. The total volume reduction factor will be ≈ 2.

Table 8

Characterization of Waste Containing Packages

Type of waste	Total mass of drum, kg	Mass of waste, kg	Radioactivity		Heat release, W
			α, TBq	β,γ, TBq	
Cladding hulls	919	619	2.2	577	86
End caps	3500	820	—	1120	148

3.6. The process of melting cladding hulls and FA end caps was developed by CEA, France, and mastered in the Nuclear Centre at Marcoule.

For the reasons of the technology cladding hulls and FA end caps are processed individually, namely, the former are melted in an induction furnace with a "cold" crucible and the latter as well as FA structural components (e.g., grids) are melted in a "hot" ceramic crucible.

After the removal of spacer grids cladding hulls are dried, cleaned with an argon flow and loaded into a water cooled "cold" crucible. To decontaminate the metal and facilitate the drawing of a resultant ingot mineral salts (flux) are added to the molten metal.

Zirconium and steel claddings are melted at 1500°C in an inert atmosphere (argon) at the throughput of ≈ 40 kg/hour. A purified metal ingot 180 mm in the diameter and 1270 mm high is placed into a canister designed by "Cogema" (0.435 m dia, height of 1.35 m, volume of 0.2 m^3). A can of this type accomodates 3 ingots of the total mass of 540 kg or 250 kg slag.

FA end caps and grids are melted in an induction furnace with a refractory crucible from which the metal is poured into moulds to produce ingots ≈ 280 kg in mass. Two ingots of this type are placed into a Cogema can.

Liquid effluents arising from drying fuel claddings and off-gas processing are evaporated and the resultant concentrates are vitrified. The annual radioactivity of liquid effluents is as follows: $\beta,\gamma \approx$ 6200 TBq (mainly tritium), $\alpha \approx$ 11.1 TBq.

Off-gases (tritium and krypton) released in the process of melting are processed by the known technology; tritium is converted to tritiated water that is adsorbed on molecular sieves (the annual volume ≈600 l); some tritium (14 TBq) together with krypton (289 TBq) is released to the atmosphere.

The plant throughput of 600 t heavy metal per year results in 302 cans with fuel cladding ingots, 49 cans with ingots produced from FA end caps and grids and 16 cans with slag which makes 367 cans of the total volume of 73.4 m^3. In the melting process the waste volume reduction factor is 2.6.

Table 9

Characterization of Waste Containing Packages

Type of waste	Total weight of can, kg	Mass of waste, kg	Radioactivity		Heat release, W
			α	β,γ, TBq	
Hulls	621	541	37.7 GBq	278	41.5
Caps and grids	632	552	—	1539	203
Slag	330	250	2.95 TBq	619	63

4. Comparison between HAMW Reprocessing Routes

Fuel rod cladding hulls and FA end caps as a result of nuclear fuel regeneration are one of the main streams (~ 40% vol.) of α-emitting waste to be disposed of into geological formations. During the past ten years in different countries a lot of research was carried out with the aim of improving the HAMW management and, primarily, reducing the waste volume and improving the waste incorporating matrix. Therefore, it seems important to compare alternative routes of HAMW processing and conditioning basing on radiologic and economic criteria.

For comparison the above six routes of HAMW reprocessing were taken including the operations of shipping, interim storage of waste containing packages and their final disposal.

The characterization of HAMW packages and the calculated results are tabulated in table 10.

In the comparison between the HAMW reprocessing routes consideration was given to two streams of waste (fuel cladding hulls and FA end caps).

It follows from the data of table 10 that the volumes of the annual waste accumulation and the resultant HAMW volume reduction factor differ, respectively, by ≈300 m^3 and a factor of ≈ 5 for different routes. It is to be noted that the preliminary decontamination of cladding hulls reduces the α-emitter and fission product activity but does not affect the concentration of metal activation products, particularly, nuclides of long half-lives (^{63}Ni and ^{93}Zr). The now in action criteria for near surface and mine storage facilities do not tolerate the disposal of FA end caps and fuel rod claddings even after they are decontaminated.

Some routes(e.g., melting) provide for both the volume reduction of HAMW and improvement of the metal qualitative composition. The other routes (NN 4 and 5) may

Table 10

Comparative Characterization of HAMW Reprocessing Routes

N of route	Packages with conditioned waste		N of drums/year	Total waste volume, m^3	Waste volume reduction factor	Off-gases, MBq/year	Liquid effluents, MBq/year
	size (m)	volume (m^3)					
1	$\varnothing = 1.14$ $H = 1.71$	1.75	231	404	0.47	0	not determined
2	$\varnothing = 1.14$ $H = 1.71$	1.75	231	404	0.47	0	$\alpha = 3.8 \times 10^{-5}$ $\beta,\gamma = 3.8 \times 10^{-9}$
3	$\varnothing = 0.75$ $H = 1.15$	0.50	460	230	0.83	$^3H = 6200$ $Kr = 2900$	0.5
4	$\varnothing = 0.60$ $H = 0.85$	0.24	965	208	0.92	$^3H = 6200$ $Kr = 2900$	10^{-3}
5	$\varnothing = 0.43$ $H = 1.35$	1.75	299	94	2.0	$^3H = 6200$ $Kr = 2900$ $\beta,\gamma = 15.2$	not determined
6	$\varnothing = 0.43$ $H = 1.35$	0.20	367	73.4	2.6	$^3H = 14000$ $Kr = 20900$	$\alpha = 10^{-2}$ $\beta,\gamma = 6.3 \times 10^{-6}$

Table 11

Cost of Different Conditioning Routes for HAMW Arising from Reprocessing 600 t Fuel/Year

Operation	Cost, M ecu, 91	1	2	3	4	5	6
Processing and Conditioning	Capital expenditures	19.9	22.6	24.8	27.0	23.2	24.0
	Gross operating expenditures for 30 years	20.2	23.0	17.6	42.5	18.7	33.1
Shipping	Capital expenditures	3.5	3.5	1.8	1.8	0.9	0.9
	Gross operating expenditures for 30 years	102.3	102.3	51.8	58.5	23.9	18.6
Disposal	Capital expenditures	72.8	72.8	50.6	39.7	22.5	18.1
	Gross operating expenditures for 30 years	51.9	51.9	34.6	26.6	14.6	11.5
Total		270.6	276.1	181.2	196.1	103.8	106.2

involve the use of additional barriers (lead, graphite) that bring down the activity of a waste containing package.

In addition to the waste volume reduction the melting route also provides for other effects on HAMW reprocessing, specifically, evolution of all gases contained by a metal, an extra decontamination of a metal and a high corrosion resistance of massive ingots and vitrified waste.

Based on the general schemes of the HAMW management the CEC experts have evaluated the capital and operating costs of each intermediate stage of waste management (conditioning, packaging, interim storage, shipping, disposal). The results of the calculations (in the prices of 01.01.91) are listed in table 11.

It follows from the data of table 11 that the route of HAMW direct cementation is the most expensive one. The gradual reduction of the cost of waste conditioning for disposal is achieved through the use of more efficient processes of the waste volume reduction. The most cost-efficient routes of the 6 ones are waste compaction by pressing (route 5) and melting (route 6). By using those routes more than 60% can be saved compared to the other 4 HAMW management routes. It is to be noted that in all the routes under discussion the cost of the waste shipping and disposal operations is a decisive factor in the total cost of the HAMW management.

Proceeding from the comparison between the technico-economic parameters of the six routes of HAMW conditioning for disposal both France and Russia give the priority to the route of induction furnace melting of cladding hulls and FA end caps.

The activities under way at VNIINM in the framework of Project N 143 financed by ISTC deal with the investigations of this process.

3. 2 Mock-up Facility for Cold Crucible Induction Slag Melting of Chopped Fuel Claddings

MOCK-UP FACILITY FOR COLD CRUCIBLE INDUCTION SLAG MELTING OF CHOPPED FUEL CLADDINGS.

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The goal of project N 143-94 as agreed by VNIINM and ISTC is to design an equipment and master the technology of induction-slag melting high activity level metal waste (the ISMW-CC process) composed of Zr-alloys and stainless steel using simulation materials (chopped fuel cladding simulators) in mock-up and demonstration facilities.

The scope of the project activities covers:

- development, fabrication and tests of pilot equipment to be used for melting fuel claddings and fuel assembly (FA) end pieces;

- determination of the optimal conditions (process, electrotechnical etc) of melting Zr-alloy and stainless steel fuel claddings and FA end pieces in induction furnaces with "cold" crucibles to produce ingots of different sizes and lengths;

- assessment of the extent to which radionuclides are removed from the cladding metal by melting using different fluxes;

- studies of the structure and properties of metal waste melting products (ingot, slags);

- investigations of the technology used to reprocess the resultant secondary waste (gas phase, slags).

On the basis of the established technical requirements placed.on the design and arrangement of the equipment sited at the VNIINM rig the design documentation (DD) has been worked out for the mock-up "ISMW-CC-1" facility. The DD on the facility covers:

- assemblage drawing of the facility, specifications, drawings of the major units and mechanisms (melting unit, hydromechanical drive, charge metering feeders, gas-clean-up unit);

- circuits (general electrical of power supply to the facility, general electrical and electrical joints of the hydrodrive, general electrical and electrical joints of control and measuring instruments (CMI), a functional one for CMI, hydraulic scheme of cooling the melting unit components, pneumatic scheme of melting process control).

The work was carried out to fabricate, assemble and adjust the equipment of the mock-up facility.

The "ISMW-CC-1" facility is designed for R&D to support scientifically and technically the design of a demonstration "ISMW-CC-2" facility and in future the semi-commercial production for conditiong by induction cold crucible melting HLMW to be long-term stored and disposed of.

The mock-up "ISMW-CC-1" facility that is shown schematically in fig. 1 consists of:

- a unit for charging fuel cladding simulators (1) and a flux (2), including vibration and plate feeders, a gate device and a pipe-line system;

- an ingot drawing mechanism (4) comprising a hydromechanical drive and a thrust and lever system. The hydrodrive is composed of an electromotor, a V-belt drive, two force hydrocylinders, a filter and a tank for oil, a system of valves, throttles, cocks and pipe-lines;

- a system of water cooling "the cold crucible", inductor, "cold" tray, generator, capacitor battery and matching transformer;

- a system of a gas supply (6) and clean-up (5,7,8) comprising cylinders with compressed gases (argon, nitrogen), two successively sited recoverable metal cloth filters, a control block a compressor-booster of a gas flow rate and an ejection device for attaining the specified vacuum in the system;

- a system to control the melting process comprising several subsystems to stabilize the temperature, flow rate and electrical conditions of melting; to control the rate of the "cold" tray travel; to control gas supply and clean-up; to control the temperature and flow rate conditions of cooling.

Fig. 2 shows schematically the process taking place in the melting unit. Inside the water-cooled metal crucible (1) composed of vertical electrically insulated sections a molten bath (3) results. The crucible walls are transparent for the inductor electromagnetic field (2) the solenoid of which envelopes concentrically the crucible. The molten metal in the crucible is a conductor and absorbs the energy of the electromagnetic field converting it to heat that is used to compensate the heat losses and changes in the thermal condition of the charge. The molten metal is overheated by 50-150 °C, therefore the material arriving from feeders (1.2) is melted in the zone affected by the electromagnetic field (3) increasing the bath volume. Due to the heat transfer from the bottom via the "cold" tray the molten metal is crystallized to form an ingot (5). The ingot is removed from the crucible downwards with the hydrodrive. Under the conditions of local heating by the inductor the molten metal bath volume is limited and readily controlled. By changing the conditions of the charge supply and the ingot travel the rates of melting and crystallization may be fitted, thus, achieving the quasi-steadiness of the process with heat and material balances.

Over the surface of the molten metal-cold crucible wall contact a thin layer of solidified slag (6) results that prevents the molten metal from getting into gaps, protects the metal of the crucible against the permanent contact with the liquid metal phase as well as acts as a liner and thermal insulator of the bath preventing its intensive cooling.

The mock-up facility is designed to operate under the following conditions:

- molten metal output, kg/h	<5.
- cladding simulator dia, mm	6-10.
- cladding simulator length, mm	10-30
- cladding materials,	12X18H10T steel, Zr-Nb alloy.
- flux composition	CaF_2 + additives.
- flux amount, %	1-5% of the metal mass.
- crucible dia, mm	60.
- height of melting zone, mm	110.
- molten metal temperature, °C	< 2000.
- water flow rate, m^3/h	< 15.
- force on crucible tray, kgf	< 4000.
- off-gas temperature, °C	< 200.
- filter pressure drop, mm water column	< 200.

As a power supply source use is made of a machine generator of the type ВПЧ-100/2400 that provides 100 kW power and 2400Hz frequency. The electrical supply unit comprises a battery of the total capacity of 757.8 microfarad.

The following scientific and technical goals are to be carried out using the "ISMW-CC-1" facility:

- mastering the process and electrotechnical parameters of the process of induction melting multicomponent alloys in "cold" crucible;

- testing the units, mechanisms and systems of the mock-up facility upon melting fuel cladding simulators in "cold" crucible induction furnace;

- mastering the methods, means of control and management of different facility systems in the process of simulated waste melting;

- working out the initial data, technical proposals and technical assignment for designing a larger-scale demonstraton facility "ISMW-CC-2".

Sheme of melting with extension

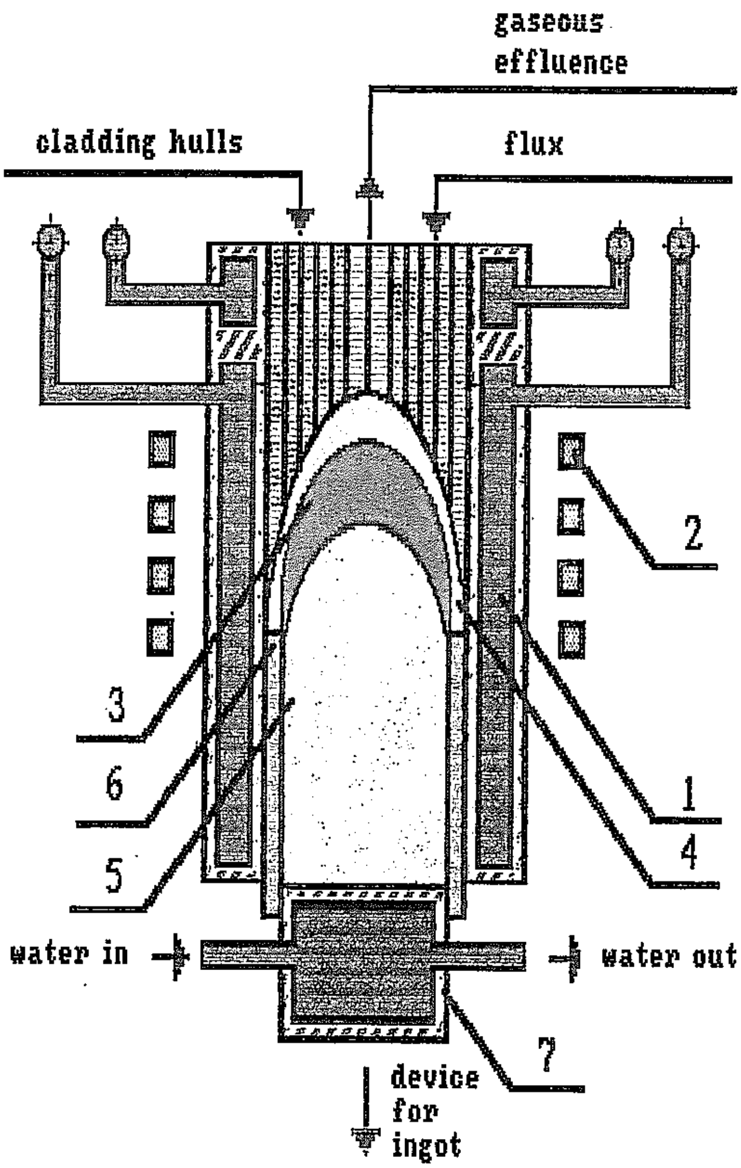

Fig. 2

1. Cooled body.
2. Inductor coil.
3. Melting sone.
4. Liquid slag.
5. Ingot.
6. Solid slag.
7. Cooled hearth.

3. 3 High Level Waste Solidification Technolgy by CCIM Method

HIGH LEVEL WASTE SOLIDIFICATION TECHNOLOGY by CCIM METHOD

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Today one of the most crucial and burning problems of the bodi end fuel cycle is the problem of decontamination of radioactive waste produced in the process of nuclear fuel reprocessing, their environmentally safe storage and disposal in solid fixed forms minimizing radionuclides delocalisation from them. Such forms are glass-like, glass-crystalline and crystalline materials of mineral-like type.

Solidified forms of waste shall comply with following requirements:

- high chemical stability and resistance in underground water;
- thermal and radiation resistance assuring mechanical strength, chemical stability and abcence of nuclides transfer to the environment during storage and disposal;
- thermophysical parametres of the material (thermal conductivity, heat capacity and temperature conductivity) shall facilitate heat removal during storage.

The tecnological process of waste solidification must provide for processing of various types of radioactive and toxic waste through remote and safe monitoring of the process, tranformation of all radionuclides into solid form and off-gas purification so that the permissible level of waste concentration is reached.

The method of high-level waste (HLW) solidification with production of glass-like matrixes of phosphate and borosilicate type in considered generally accepted. In Russia the method of HLW vitrification in the melter with direct electrical heating producing phosphate glass was developed and used on the industrial seale at the Productios Association (PA) "Mayak".

The technology of HLW incorporation in the phosphate glass attracted researchers and production engineers by seeming simplicity of fluxing initial HLW solutions by liquid glassformer (orthophosphoric acid) not affecting its homogeneity some time ago. This provides opportunity to feed solutions with optimized composition for thermal processing and to maintain low temperature while making glass. However, phosphate melts with significant concentrations of iron, chromium, nickel and sulfate-ions have high corrosion characteristics in respect of the design material of the melter.

Two-stage process using cold crucible induction melter (CCIM) is an alternative to one-stage process of HLW vitrification in direct electric heat melter. Phosphate glass will be the finalproduct of HLW vitrification process at the first stage of testing, though, as compared to borosilicate glass, all the more mineral-like materials; such phosphate glass has lower chemical stability and thermal resistance.

One of the main properties of oxide materials is rather high melting temperature, that causes a problem of choosing a method of such materials synthesis. Using of cold crucible induction melter demonstrated the better results.

Melting process in cold crucible induction melter is based on the property of electromagnic field to penetrate the material and attentuate in it releasing energy.

Induction heating and melting in CCIM are only after material heating by means of any heat sours up to the temperature at which HF-field starts attentuating in the material. The process of melting initiation is called initial heating. Preliminary or initial heating reduces specific electrical resistance of oxides, makes them opaque to electromagnetic field. In general the main purpose of the initial heating is inital change thermophysieal state of the materials when a current may be induced in the which current is sufficient for producing power capable not only compensate for hit losses from heating area but also to provide for melting of excess volume of blend.

To develop initial heating, blend or glass frt was placed in to the crucible, afterwards initial material was injected and covered with blend (glass frit).

As initial materials were used:

- graphite with size of particles 3-5 mm (burns up gradually within 1.5 - 2 hours);
- silicon carbide (being removed after the initiation of melting process);
- melted iron oxide (III) (in the form of piecws up to 25 mm);
- metallic titanium (in the form of cut preliminary compscted in the form of disk D=25 mm and 3-5 mm thick).

Tables 1 and 2 show the results of development of initial blend heating and repeated phosphate glass heating.

Table 1

Initial phosphate glass heating in CCIM

Initial material type	Cylinder crucible		Rectangular crucible	
	Quantity, g	Time, min.	Quantity, g	Time, min.
Silicon carbide	25 - 30	20 - 25	130 - 150	70 - 80
Melted iron oxide	30 - 40	8 - 10	——	——
Graphite	25 - 30	35 - 40	150 - 180	100 - 120
Metallic titanium	15 - 20	4 - 5	90 - 110	45 - 50

Table 2

Repeated phosphate glass heating in CCIM

Initial material type	Cylinder crucible		Rectangular crucible	
	Quantity, g	Time, min.	Quantity, g	Time, min.
Silicon carbide	25 - 30	18 - 22	130 - 150	50 - 60
Melted iron oxide	30 - 40	7 - 9	——	——
Graphite	25 - 35	30 - 33	150 - 180	90 - 100
Metallic titanium	15 - 20	4 - 5	90 - 110	35 - 45

The shown results are not absolute in respect of initial materifl and the time spent for initial and repefted start-up of the melter but are selected as applied to a particular type demention and a form of the crucible, as well as to glass (blend) composition.

Newertheless, it is obvious that the most acceptable for initial and repeated heating of the blend and phosphate glass is metallic titanium.

Water tiles solutions remaining after uranium and plutonium separation at reprocessing of spent nuclear fuel from power reactors and transport power plants are source of liquid HLW formation.

Moreover, in Russia considerable volumes of liquid and pulp-like HLW have been accumulated as a result military activities.

CCIM technology features allow to sinthesize various material greatly ranging in composition. This allows to use CCIM melting method for solidification of waste resulted from operation of various spent nuclear fuel processing technologies including fractionation, HLW as well as toxic waste containing heavy matals.

Composition of wastw simulator tested at CCIM technolofy development (g/dm^3):

Composition 1		Composition 2		Composition 3		Composition 4	
Na_2O	- 5,0	Al_2O_3	- 41,9	Al_2O_3	- 18,9	Al_2O_3	- 19,0
Cs_2O	- 5,3	Na_2O	- 3,1	Na_2O	- 54,0	Na_2O	- 67,4
K_2O	- 3,7	NiO	- 0,1	Cs_2O	- 0,5	NiO	- 6,3
NiO	- 0,2	Fe_2O_3	- 1,2	NiO	- 7,6	Fe_2O_3	- 7,0
CaO	- 0,3	Cr_2O_3	- 0,3	CaO	- 5,6	Cr_2O_3	- 3,0
Fe_2O_3	- 1,3	oxides REE	- 0,2	Fe_2O_3	- 14,3		
Cr_2O_3	- 0,3			Cr_2O_3	- 3,0		
MnO_2	- 0,5			MnO_2	- 3,2		
SrO	- 2,1			SrO	- 0,4		
BaO	- 2,2						
ZrO_2	- 6,8						
MoO_3	- 4,5						
RuO_2	- 4,0						
Rh_2O_3	- 1,7						
PdO	- 1,7						
oxides REE	- 16,7						

Composition 5		Composition 6		Composition 7	
Cs_2O	- 9,2	oxides Fe, Cr, Ni	- 64,3	oxides REE	- 30,3
SrO	- 4,5			ZrO_2	- 8,5
BaO	- 4,8				
PbO	- 1,1				

Moreover, to investigate iron, chromium, nickel and REE behavior in the process of phosphate glass melting in CCIM in case the concentrations considerably exeed their solubilities iron, chromium nickel and REE oxides were injected into the solution simulator of composition 1 so that injected oxides contects were 3 % and 10 % of masses above their contents in the original solution.

Since the major part of work is connected with the application of the CCIM technology for solidification of liquid HLW produced by the Production Association "Mayak" the process of HLW simulator incorporation if hposphate glass with the final product of the composition (%% mass.):

Na_2O and other one-valence oxides - 24,0 ± 2
Al_2O_3 and other multi-valence oxides - 21,0 ± 3
P_2O_5 - 55,0 ± 5

was developed in detail.

Table 3 shows chemical compositions of phosphate glasses synthesized by the CCIM method at solidification of solution simulator of composition 1.

Table 3

Chemical compositions of phosphate glasses synthesized by CCIM method

Material code	Na_2O	Al_2O_3	P_2O_5	Fe_2O_3	Cr_2O_3	NiO	FP_{ox} (including)		
								Cs_2O	SrO
GP-P_2	22,9	16,4	52,8	2,0	0,45	0,30	5,0	0,60	0,24
GP-P_3	22,8	14,3	52,5	4,0	0,90	0,60	5,0	0,60	0,24

To synthesize borosilicate glasses, blend was prepared by joint calcination of mixture of nitrates and datolite concentrate (as a source of boron anhydride) (table 4) or sodium tetraborate, silicon oxide and solution simulators (table 5).

Table 4

Chemical compositions of borosilicate glass in case of datolite concentrate use.

Composition	Matrix components, %% mass.					HLW components, %% mass.							
	Na_2O	Al_2O_3	Fe_2O_3	SiO_2	datolite conc-t	REE ox.	ZrO	Fe_2O_3	SrO	Cs_2O	BaO	PbO	FP ox.
1	20,1	16,4	0,7	14,0	41,8	-	-	-	1,5	3,3	1,7	0,4	0,1
2	16,2	13,2	0,6	11,2	33,8	-	-	25,0	-	-	-	-	-
3	16,2	13,2	0,6	11,2	33,8	18,9	6,1	-	-	-	-	-	-

Table 5

Chemical compositions of borosilicate glasses synthesized by CCIM method for solurion simulator of composition 1.

material code	Na_2O	Al_2O_3	B_2O_3	CaO	Fe_2O_3	SiO_2	$HLLW_{0x}$ (including)		
								Cs_2O	SrO
GP-B10	18,0	10,0	11,0	2,0	2,0	47,0	10,0	1,08	0,43
GP-B91	20,0	5,0	12,0	3,0	3,0	46,0	11,0	1,19	0,47

At injection of 3 and 10 % mass. of iron, chromium, nickel and REE oxides into the melt of three component glass Al_2O_3 - Na_2O - P_2O_5 even distribution of the indicated oxides along the block height was achieved. At the same time the glasses produced at 3 % mass. content of oxides are homogeneous and the materials containing 10 % mass. of oxides show formation of heterogeneous phase evenly distributed in the whole volume of the glass block. In the case of test with REE oxides this composition was not different from the homogeneous glass compositions and it may be argued that this phases are the arias of REE oversaturated solutions crystallization in the melt which occurs at the centres of crystallization which centres may be any microscopic particle at glass block cooling. At injection of 3 and 10 % mass. of iron, chromium, nickel and REE oxides into the multicomponent phosphate glass melt (the glass already containing fission products and equipment corrosion products totally no more then 5 % mass.) even distriburion of the indicated oxides in the volume of glass block was also achieved. Such oxide distribution in the melt above their chemical solubility in phosphate glasses synthesized in CCIM is caused by melt circulation due to effect produced by the currents been inducted and magnetic field which generates electrodynamic forces effect. Depending on the current frequemcy of HF-generator, the linear speed of melt circulation reaches 10-12 mm/sec. CCIM technology application allows to produce homogeneous melts of phosphate glasses with high percentage of corrosion-aggressive nuclides (iron, chromium, nickel) and some fission products that provides opportunity to process HLLW actually without any limitations on its composition in respect of these nuclides and considaribly increases percentage of incorpocation of some HLW components.

To study the behaviour of elements of platinum group at hposphate and borosilicate glasses synthesis by CCIM method, calcinates were prepared with injection of ruthenium, rhodium and palladium (table 6).

Table 6

Platinoid contents in phosphate and borosilicate glasses.

Element	Content in glass, g/kg	
	GP-P2*	GP-B91*
Ruthenium	9,7	10,4
Rhodium	2,9	3,9
Palladium	5,2	9,0

Note: Compositions of indicated glasses are shown in table 3 and 5.

Glass-like materials manufactured by CCIM method and, for comparison, in alundum crucibles in resistance melter. Melting modes and some glass characteristics are shown in table 7.

Table 7

Table modes and some characteristics of glass-like materials.

Material type	Production mode, ^{0}C, hours	Disperse particles concentration in glass	Notes
GP-P2 (direct heating)	1000, 4,0	3 10^3	Disperse particles (1-5 mcm) and their conglomerates (20-200 mcm)
GP-P2 (direct heating)	1200, 0,5	8 10^2	Heterogeneous phase consists of separate particles (1-2 mcm) and fractial structures (10-100 mcm across)
GP-P2 (induction heating)	1200, 0,5	4 10^2	Particles (1-3 mcm) and their conglomerates (10-540 mcm)

1	2	3	4
GP-B91 (direct heating)	1200, 4,0	4 10^3	RuO_2 needle-shaped crystalls 100 mcm long, disperse particles 1-3 mcm across and fractal structure up to 200 mcm.
GP-B91 (direct heating)	1400, 0,5	8 10^3	RuO_2 needle are lacking, particles 1-5 mcm across, fractal structures are twice as much as in the first case.
GP-B91 (induction heating)	1300, 0,5	1,2 10^4	RuO_2 crystalls and conglomerates with fractal structure are lacking. Disperse particles 0,5-1,0 mcm, system is practically monodisperse.

Composition of heterogeneous phases formed in the melt is mainly determined by glass melting temperature and in case of induction heating represents solid solutions RuO_2 - (Ru, Rh, Pd), Pd - Rh, as well as metallic ruthenium and rhodium oxide.

The perculiar feature of material melting in cold crucible is the necessity to maintain temperature significantly exceeding the material melting temperature. Thus, for example, it was established by way of testing that the process of phosphate glass melting in and from the cold crucible is stable at the temperature 1200 ^{0}C in melting and production areas.

Sush enforced increase in melt tank temperature raises a question of volatile fission products behavior at melting of different materials in the cold crucible, and first of all it concerns cesium.

Cesium carry-over to gazeous phase may be also decreased by covering melt surfice with a layer of blend material: calcinate or salt fusion cake. These barier, first, ensure significant temperature gradient between melt and gaseous phase due to their law heat conductivity and, secondly, are a kind of specific filter with good absorption properties.

The research demonstrated that cesium carry-over to vapour-gaseous phase at phosphate glass melting was equal to 0,6 %.

The basic properties of solidified HLW determining the conditions of intermediate storage and final disposal are chemical stability which is characterized by nuclides leaching at possible contact with underground water.

The conducted research demonstrated that the rate of caesium. strontium and cerium leaching from phosphate and borosilicate matrixes within the first 24 hours contact with distilled water amounted to $(1\text{-}3)*10^{-6}$ g/(sm^2*day), $(7\text{-}10)*10^{-6}$ g/(sm^2*day) and less than $1*10^{-7}$ g/(sm^2*day), respectively. After thirty days contact with water the rate of caesium and strontium leaching fell down to $(0{,}3\text{-}1)*10^{-6}$ g/(sm^2*day) and $(0{,}3\text{-}2{,}5)*10^{-6}$ g/(sm^2*day), respectively.

The best option for equipping two-stage solidification of HLW requires liquid HLW calcination in the spray calcinator (SC) at the first stage and melting of the calcinate formed with fluxing additives in CCIM at the second stage. In case of this option provided that original liquid HLW are properly calcinated (about 80-85 %) the power supplied to CCIM is used maximum possible for calcinate and flux melting and the highest specific efficiency of the melter in respect of made molten glass is achieved.

A spray calcinator for liquid HLW calcination is the simplest design that is capble to provide for high degree of calcination of solutions practically of any composition at 750-800 ^{0}C.

Demonstration plant for two stage process is installed at the vitrification workshop of the Production Association "Mayak" in the chamber for completing of canisters after decommissioning of the first industrial melter with direct electric heating. The chamber overall dimensions, even allowing for reconstruction, were not sufficient to install a plant of calcinator-melter type with the efficiency up to 100 dm^3/h for solution. So the forced technical decision was taken i.e. to substitute deep concentration of original solution in a direct-flow evaporator for the first stage of calcination. This caused a significant decrease in the CCIM efficiency in respect of molten glass production. However, at this stage of two-stage technology development on the industrial scale the task to achieve maximum CCIM productivity in respect of melt is not crucial.

Liquid HLW solidification comprises the following basic operation:

- selection of liquid HLW composition and its fluxing by orthophosphoric acid for achieving the given composition of phosphate glass;

- deep concentration of the original solution of HLW simulator in a direct-flow evaporator;
- vitrification of the produced salt fusion cake in CCIM;
- molten glass discharge into cans;
- furnishing containers in other container;
- off-gas scrubbing.

Fluxed HLW solution is being continuosly feeded (flow rate up to 100 dm^3/h) to the inlet of the direct-feed evaporator heated by vapour under pressure equal to 0.5 MPa and integrated with a separator. Deep concentration is monitored by original solution pressure at the inlet of direct-feed evaporator (DFE), heating vapour pressure, flow rate and content of salt in the original solution.

DFE is an upright apparatus with the working head in the form of spiral encased in a vapour jacket. Original solution and heating vapour are feeded in countercurrent. Stationary area for vapour phase and salt fusion cake separation is namely separator.

In the DFE the product goes through it is sequantially heated, evaporated, nitric acid being distilled off, nitrates contained in the product partially interact with orthophosphoric acid and then the product is dried. After vapour-gas phase and salt fusion cake are separated in the sepatation area the salt fusion cake is feeded by gravity to the CCIM with the flow rate 30-40 kg/h. Vapour-gas phase goes to a bubbler cooler which is the first stage of off-gas scrubbing.

In CCIM salt fusion cake is dehydrated, denitrified and melted at 1100-1200 $^{\circ}C$ with phosphate glass production at the production rate 15-18 kg/h.

CCIM is a rigid structure made of water-cooled tube sections assembled at common water collector. Crucible is encircled with a water-cooled inductor connected to HF-generator.

The melted product is discharged from the crucible in to containers with the capacity 200 dm^3 mounted in a carousel conveyor.

To monitor container filling-up, weighing facility is provided.

Standard operating mode of CCIM is characterized by continuous discharge of melt from crucible production area into containers. Melt stream is interrupted by a special mechanism only for the period of container substitution.

Molten glass discharge from the crucible is observed visually through sight glass of the chamber.

To put CCIM imto steady operation, mitial heating is required. Initial heating is performed due to interaction of HF-field with the conductive material placed into crucible. It may be performed both on blend and glass breahage (primary) and on molten glass longealed in the crucible (secondary).

After molten glass is cooled containers are sorted into other container which are sealed by welding and after test for leachs are placed in storage.

The first stage of vapour-gas phase scrubbing is bubbler-cooler where vapour is condensed, condensate is cooled and primary aerosol collection occurs.

Bubbler-cooler is a kind of column a lower part of which is permanently filled with condensate and in an upper part of which an additional cooler is installed. This cooler is designated for non-condensable gases cooling.

Vapour-gas mixture comes into cube part under the solution layer and bubles through the liquid in which coolers are installed. Vapour is condensed, heat is removed, aerosols are caught by the liquid and vapour and gases are absorbed.

In case of DFE-CCIM testing on solution simulators the second stage of off-gas scrubbing is adsorption column for nitric oxides catching after which scrubbed gas stream is discharged to atmosphere.

In case of real industrial liquid HLW vitrification at DFE-CCIM plant the system of off-gas scrubbing of direct electric heating melter will be operated which system is capable to provide for off-gas cleaning from radionuclides with a factor amounting to 10^8-10^9.

To provide for safe and reliable operation of the cooling system of CCIM and HF-generator demineralized water and condensate with specific resistance not less than 20,000 Om*sm from closed loop circulating cooling system.

The pilot plant for two-stage HLW solidification being created will be prototype of industrial plants for the second phase of vitrification department of PA "Mayak".

Technical parameters of basic equipment of two-stage vitrification plant DFE-CCIM

Two-stage vitrification pilot plant is installed in hot chamber and is designated for development of:

- HLW solidification technology on real industrial solution and solution simulators;
- mechanization means for remote of equipment;
- transport and technological plan for removal of containers filled up with solidified waste and equipment.

Camber owerall dimensions, mm:

length	8750
hight	4100
width	2000

In the chamber there is a recess on the side where DFE-CCIM is installed. The recess is elecignated for installation of conveyer with containers Its dimensions, mm:

length	2000
hight	1200
width	2000

HLW simulators solidification plant:

- volume efficiency per initial solution l/h	100
- temperature of glass poured into container, ^{0}C	1200

Direct-Flow Evaporator:

- volume efficiency per initial solution of HLW simulator, dm^3/h	100
- vapour consumption kg/h	120
- vapour temperature at coming into evaporator, ^{0}C	150
- operating vapour pressure at coming into evaporator, MPa	0,4-0,5
- overall dimensions, m:	
- diametr	0,55
- hight	1,2

Cold Crucible:

Crucible design-two-areas

- nominal tank capacity, dm^3	22,6
- melt surface area, dm^2	
making area	6,7
production area	1,8
- maximum operating temperature, ^0C	1500
- mass efficiency per glass. kg.h	до 18
- oscillating power of HF-generator, kW	160
- consumed power of HF-generator, kW	240
- operating frequency, MHz	1,76
- cooling water consumption per generator, m^3/h	
- cooling water consumption per inductor, m^3/h	2
- cooling water consumption per crucible, m^3/h	4
- cooling water temperature, ^0C	
at in-coming	25±5
at out-coming	45±5
- cooling water pressure, MPa	0,4

Bubbler-cooler

- volume consumption of vapour-gas mixture, m^3/h	210
- vapour-gas mixture temperature, ^0C	
at in-coming	300-600
at out-coming	55
- cooling water consumption, m^3/h	25
- cooling water temperature, ^0C	
at in-coming	25
at out-coming	30
- cooling water pressure, MPa	0,4

Carousel conveyer

- load rating, N	$1,2*10^3$
- quantity of sockets for containers, piece	2
- rotation angler per position, degree	180

Weighting unit

- mass of container with molten glass being weighed, kg	600
- weight betching electronic strain metric unit	
- measuring range, kg	0-800

Produced phosphate glass is being bached in containers with the following parameters:

- diameter, mm	575
- hight, mm	1000
- material	steel 3
- empty container mass, kg	95±10
- container volumem, dm^3	
total volume	220
working volume	200
- volume of molten glass being poured into container, dm^3	190±10
- mass of filled-up container,kg	610±40

3.4 Proposal Project Concerning to the New Project with ISTC (as a Continuation of the Project N 143-94) under Financial Support of the Power Reactor and Nuclear Fuel Development Corporation

Proposal project concerning to the new project with ISTC (as a continuation of the Project N 143-94) under financial support of the Power Reactor and Nuclear Fuel Development Corporation.

1. Name of Project: "Investigated tests of the process of induction-slag melting high activity level metal wastes (process "ISMW-CC").

2. Chief of project: Pastushkov Victor Georgievich
Senior researcher, VNIINM

3. Introduction and review.

On reprocessing spent nuclear fuel at radioachemical plants each ton of reprocessed fuel results in 330 kg of high activity metal waste (HAMW) comprising the fuel cladding hulls (Zr-alloy or stainless steel) and the cut end pieces of spent fuel assemblies (SFA).

It seems to be reasonable (in view of the technical and financial aspects) using of the induction-slag melting process in furnace with cold cruciable ("ISMW-CC-1") as the method of conditioning HAMW prior to expensive storage and final disposal.

Research and development of the process are currently being conducted at VNIINM using HAMW simulators to work out the process to the last details.

Said work are being carried out withing the frame work of the Project ISTC N 143-94.

In the course of the Project N 143-94 technical calendar plan the mock-up facility "ISMW-CC-1" has been designed, fabricated and adjusted on test bench at VNIINM in 1994-1995 years.

Facility is meant to be used for testing of thetechnology and equipment during the process of fuel clad simulators melting.

Based on the results of conducted tests of mock-up facility design development of the integrated demonstration facility "ISMW-CC-2" is planned in 1996-1997 years.

This integrated facility is meant to be used for melting of hulls and end pieces in an induction furnace with cold crucible with 220 mm dia and to drowing of produced ingot of up to 750 mm long, weighing about 250 kg each.

Proposed project seems to be logical continuation of the work according to Project N 143-94.

The main fgool of the present project is integrated tests of the process "ISMW-CC" on VNIINM test bench under conditions, which are similar in common to the hot cell operation conditions.

4. Anticipated Results.

In course of the technological parameters will be developed to their optimal values. Facility design, system of the remote process checking and onerating, system of the equipment installation and dismantling will be adjusted so that to be useful under hot-cell working conditions at the PO "Majak".

5. Scope of work.

The main scientific and technical goals of the project are:

- to assemble and tie of the facility "ISMW-CC" system of checking, measuring and automation on test bench at VNIINM;
- to improve the electrotechnical and tecnological parameters of the process "ISMW-CC" during industrial-scale ingot melting;
- to adjust the methods and means of collection and treatment of resultant slag;
- to adjust the methods and means of discharging of resultant ingot, its conveying into container;
- to adjust the methods and means for remote process operating and checking;
- to develope the project of hot-cell equipment arrangement for process "ISMW-CC", following the example of PO "Majak";
- to develope the recomendations concerning the technological requlation and equipment-technology flowsheet of "ISMW-CC".

6. Technical Approach and Methodology.

Bench tests of demonstration facility "ISMW-CC-2" at VNIINM under remotely-operational conditions for the following stage of the process:

- charging of HAMW simulators and flux into the cold crucible;
- melting and drowing of the resultant ingot;
- cooling;
- conveying and loading of the ingot into the container.

Making the experience-industrial lots of the salt flux and resultant slags.

Adjusting of the slag reprocessing technology that is to be used for its disposal.

Bassed on the results of the investigations and tests the recomendations concerning the technological regulation and equipment-technological flowsheet of the process "ISMW-CC" are to be developed.

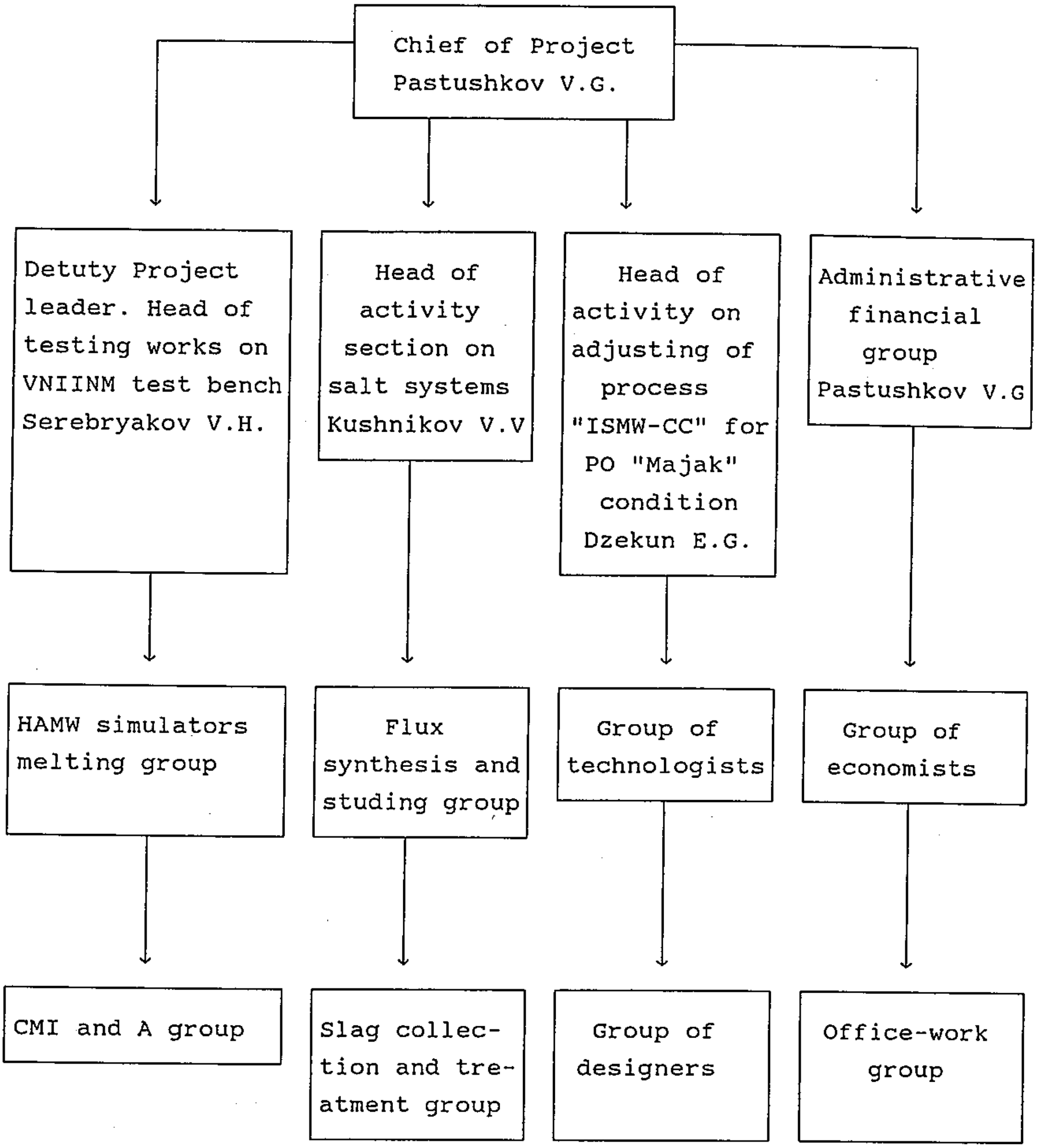
The project of the equipment arragement for using in hot-call (following the example of PO "Majak") is to be adjusted too.

7. Technical Calendar Plan.

Content of work at Project stage and deliverables	Designation of stages and number of quarter	Cost of works (thousand $ usa)
Adjusting of electrotechnical parameters of cold crucible melting process of large ingot from stainless steel (testing statement)	A-1 4-th quarter 1997	40.0
Adjusting of electrotechnical parameters of cold crucible melting process of large ingot from Zr-alloy (testing statement)	A-2 1-st quarter 1998	40.0

Adjusting of methods and means for charging of end pieces SFA simulators into cold crucible and remelting them together with lump charge (testing statement)	A-3 2-nd quarter 1998	40.0
Making of experience-industrial lost of flux and investigation their physical-chemical properties (certificate of tests)	A-4 3-d quarter 1998	33.0
Technological tests of melting process of stainless steel fuel clad simulators with salt-fluxs (certificate of tests)	B-5 4-st quarter 1998	35.0
Technological tests of melting process of stainless steel fuel clad and of end pieces SFA simulators with salt-fluxs (certificate of tests)	B-6 1-st quarter 1999	35.0
Technological tests of melting process of Zr-alloy fuel clad simulators and stainless steel end pieces SFA togethr with salt-flux (certificate of tests)	B-7 2-nd quarter 1999	38.0
Investigation of properties of resultant slags and ingots (report)	B-8 3-d quarter 1999	35.0
Development of technical assignment and rough draft of facility arrangement of "ISMW-CC" in hot-cell at PO "Majak" (tecnical assignment, rough draft)	C-9 4-th quarter 1999	40.0
Generalization of results of investigation and testing. Output of final report with recomenders concerning tecnological regulation and process flowsheet.	C-10 1-st quarter 2000	40.0
Total		370.0

8. Project organization-administration flowsheet.



9. Project site and Equipment.

The Project shell be carried out on the test bench at VNIINM (building "A", rooms 36, 37, 221, 221-a, building "I", room 111), using fabricated (within framework of the Project N 143-94) demonstration facility "ISMW-CC-2" and bought friquence transformer type TTF-500-2400. Moreover means for mechanization and remote process oneration will be used (they will have been fabricated in accordance with proposed project).

Newly designed equipment:

- device, assigned for detaching of the HAMW simulators ingots from the cold underbottom, transfering and orienting them to loading into the container;
- containers are designed to be loaded by of three ingot and transfered into the box for disposal;
- means of remote "ISMW-CC" process operation and control.

To performance the works according to the Project and process experimental results it is necessary supplementary equipment and office equipment are to be bought.

The approximate list of needed equipment as well as tentative cost are given in the table 1.1

Table 1.1

N/N	Equipment	Number	Cost, $ USA
1	Industrial television installa-tion (ITI-34)	1	8000-00
2	Means of liquid pressure measurement, type "Sapphire"	32	8000-00
3	Consumption liquid control value	32	7000-00
4	Personal computers, type "Pentium"	2	4600-00
5	Printer, type "HP-4V"	1	2500-00
6	Scanner , type "HP SCan-Jet IIIC"	1	1500-00
7	Xerox, type "Cannon FC-300"	1	700-00
		Total:	32300-00

10. Deliverables.

Project activities can be tentatively subdivided into three sections in accjrdance with which deliverables are to be generalized:

- mechanical and electrotechnical test of facility "ISMW-CC-2" on VNIINM test bench;
- technological studying of process "ISMW-CC-2" and properties of unitial and final products;
- development of technolodical regulation and equipment-tecnological flowsheet of "ISMW-CC-2" process;

development of the project of the equipment arragement in hot-cell at PO "Majak".

11. Financial Information.

Estimated expenditures related to Project and incurred by Executor, that are to be reimbersed by Center are summarized in nables 1.2 with annual schedule of anticipated financial investment during the whole period of Project realization.

Table 1.2

Executor expenditures budget

N/N	Items of expenditures budget	Year 1	Year 2	Year 3	Total
1	Specialists grants	72000	78000	40000	190000
2	Equipment	28000	25000	-	53000
3	Materials	34000	30000	-	64000
4	Bank fees	1500	1500	700	3700
5	Other direct exp.	4500	4500	2200	11300
6	Business trips:	13000	4000	11000	28000
	- inside UIS	3000	4000	1000	8000
	- foreign	10000	-	10000	20000
7	Advance fees (overhead expenses)	-	-	20000	20000
	Total:	153000	143000	73900	370000

4.　プロジェクト関連資料

4.1　Project Agreement

09/27/94-Project 143-94 MR-OF

PROJECT AGREEMENT

between

THE INTERNATIONAL SCIENCE AND TECHNOLOGY CENTER

and

THE ALL-RUSSIAN SCIENTIFIC RESEARCH INSTITUTE

OF INORGANIC MATERIALS

OPERATIVE COMMENCEMENT DATE: OCTOBER 1, 1994

The International Science and Technology Center (hereinafter referred to as "the Center") and the **All-Russian Scientific Research Institute of Inorganic Materials (ARSRIIM)** (hereinafter referred to as "the Institute"), represented for the purpose of the signature of this Project Agreement (hereinafter referred to as "the Agreement") by their authorized representatives (with the Center and the Institute hereinafter referred to collectively as "the Signatory Parties",

TAKING INTO ACCOUNT THE FOLLOWING CONSIDERATIONS:

The United States of America, Japan, the Russian Federation and, acting as one Party, the European Atomic Energy Community and the European Community (with these two organizations hereinafter referred to as "the European Community") signed the Agreement Establishing the International Science and Technology Center on November 27, 1992 (hereinafter referred to as "the ISTC Agreement") and the Protocol on Provisional Application of the Agreement Establishing the International Science and Technology Center on December 27, 1993 (hereinafter referred to as "the ISTC Protocol"),

Finland, Sweden and the Republic of Georgia have acceded, and additional States may accede, to the ISTC Agreement and to the ISTC Protocol to participate in the activities of the Center,

The Center is a legal entity and has been registered by the Ministry of Foreign Affairs of the Russian Federation as an international organization with its headquarters in Moscow,

The Institute is a legal entity within the Russian Federation, The Governing Board of the Center has approved the financing of a project through the Center in the domain covered by the Agreement,

Japan has agreed to provide financial support for such a project through its agency the Power Reactor and Nuclear Fuel Development Corporation (hereinafter referred to as "the Financing Party"),

As set forth in the ISTC Agreement, funds received by a legal entity in connection with the Center's projects shall be excluded in determining the profits of that organization for the purpose of tax liability and funds received by persons in connection with the Center's projects shall not be included in these persons' taxable incomes,

HAVE AGREED AS FOLLOWS:

Article 1 - Scope of the Agreement

1.1 The Institute shall carry out the work plan set forth in Annex I according to the conditions of the Agreement, subject to the provisions of the ISTC Agreement, the ISTC Protocol, and the Statute of the Center (hereinafter referred to as "the ISTC Statute") which govern in case of conflict. The activities carried out under the Agreement are entitled **"Research and Development of Induction Slag Melting Process of High Level Radioactive Metal Wastes"** (hereinafter referred to as **"the Project")**.

1.2 Subject to any special conditions in Article 11 or any amendments or exclusions by any other Articles, the detailed terms of the Agreement are specified in the Annexes which form an integral part of the Agreement. In the case of conflict between any provision in the Annexes and any other provision of the Agreement, the latter shall prevail.

Article 2 - Duration of the Project

The duration of the Project is estimated to be 36 months from October 1, 1994 (hereinafter referred to as "the Operative Commencement Date").

Article 3 - Sub-agreements with Other Participating Institutions

The scope of work of each institution which takes part in the Project, the organizational structure of the Project as well as financial requirements of such institution are defined and stipulated in ANNEX I. The Institute shall serve as the coordinating institution for all aspects of the Project, including the coordination of requests for payments associated with fulfilling the work plan. In this regard, within 30 days after the Operative Commencement Date, the Institute shall conclude a sub-agreement with the **Scientific Industrial Center "Inductor"** which covers all aspects of the involvement of these institutions in the Project and which clearly defines the scope of work and responsibilities of each institution. These sub-agreements will provide an essential part of the legal, institutional, and financial framework for carrying out the Project. All rights and obligations of the Center and of the Institute as well as other conditions set forth in the Agreement shall be included in the sub-agreements. The Institute and the institutions participating in such sub-agreements will hereinafter be referred to collectively as "the Recipient."

Article 4 - Financial Contribution of the Center

4.1 The total cost of the Project to the Center shall not exceed $430,000. This total includes (1) items to be reimbursed in cash to the Recipient in accordance with Article 4.2, (2) grants in cash to be made by the Center directly to the individual participants in the Project (hereinafter referred to as "Individual Participants") for financial support of the Individual Participants in accordance with Article 4.3, and (3) items to be provided in-kind by the Center to the Recipient in accordance with Article 4.4. After further consideration of the costs and availability of the items to be provided, the Recipient may, with the concurrence of the Center's representative, interchange items between Articles 4.2 and 4.4 with corresponding adjustments of the cost estimates for each Article.

4.2 The Center shall reimburse the Recipient for expenditures by the Recipient in accordance with Annexes I and II. The estimated cost of such expenditures is $179,400.

4.3 The Center shall make direct grants in dollars to Individual Participants in the Project in accordance with Annex I at an estimated cost of $217600. This amount can be increased at the request of the Institute and with the concurrence of the Center's representative and of the affected Individual Participants provided the costs of Article 4.2 and/or Article 4.4

are reduced accordingly.

4.4 The Center's in-kind contributions to the Recipient are estimated at $33,000. These in-kind contributions will be provided in accordance with the lists of items to be provided and the timetables set forth in Annex I in order to enable the Recipient to meet the work schedule for the Project. Failure by the Center to provide the in-kind contributions in a timely manner may give rise to a modification of the relevant provisions of the Agreement.

The Center's in-kind contributions, which are provided for exclusive use on the Project by the Recipient during the lifetime of the Project, include the following categories of items.

4.4.1 The Center shall provide in-kind international travel by the Recipient in accordance with Annex I (hereinafter referred to as "Center Provided Travel"). The cost of the Center's contribution will not exceed $28,700.

Center Provided Travel will be undertaken by participants in the Project only after advanced approval for each trip by the Center. The Institute shall send to the Center requests for travel not less than 30 days prior to the beginning of each trip unless a shorter time for advance request is approved by the Center for a specific trip. The Center will provide directly to the traveller the funds to cover such travel, provided that such travel is approved by the Center prior to the beginning of the travel.

The Center's responsibility does not include making arrangements for visits, passports, visas, or travel reservations but is limited to providing financial support, including funds to cover the costs of passport and visa fees as well as transportation and lodging, in accordance with the travel regulations of the Center.

The Institute is responsible to ensure that the financial support requested pursuant to this paragraph does not exceed the financial limit set forth above.

4.4.2 The Center shall provide in-kind the costs of certain bank transfer fees in accordance with Annex I (hereinafter referred to as Center Provided Bank Fees.) They will be limited to fees necessary to transfer funds of the Center into the bank account or accounts of the Recipient and fees associated with the payment of grants to Individual Participants in the Project. The payment for fees will be made directly by the Center to the appropriate banks.

Article 5 - Cash Payments by the Center

5.1 Pursuant to Article 4.2, the Center shall pay its financial contribution to the Recipient through special Bank Accounts to be established by the Recipient in Conversbank by installments as follows:

- An advance payment of $42,000, which is the estimated level of expenditures by the Recipient during the first six months of the Project, as soon as possible following the Operative Commencement Date;
- Quarterly payments within one month of the receipt by the Center of progress or annual reports and associated cost

statements in accordance with Article 6 and Annexes II and III. The amounts of the payments shall be estimates by the Center of the funds required to support the work plan set forth in Annex I during each of the succeeding quarters taking into account the cost statement from the previous period;

- A retention shall be made by the Center of $30,800. The retention shall be released to the Institute within one month following the approval by the Center of the last technical or financial document or other deliverable required by the Agreement.

5.2 Pursuant to Article 4.3, the Center shall make grant payments directly to Individual Participants in accordance with letters of agreement between the Center and the Individual Participants. The Center shall ensure that banking arrangements are established for these payments.

At the end of the third month following the Operative Commencement Date and every three months thereafter throughout the duration of the Project, the Institute represented by the Project Manager who is identified in Annex I will provide the Center with a list of grant payments that are due at that time to Individual Participants in accordance with the payment levels set forth in Annex I and the amount of time devoted to the Project by each Individual Participant as certified by the Project Manager. Such payments will then be promptly made as appropriate by the Center.

Since the Individual Participants will remain employees of the Recipient, the Center's act of direct grant payments to the Individual Participants will not transfer from the Recipient to the Center any liability for damages caused by the Individual Participants during execution of the Projects or any liability for damages to the Individual Participants during execution of the Project.

5.3 If there have been expenditures for the Project by the Recipient prior to the Operative Commencement Date pursuant to the Center's Letter of Commitment of June 24, 1994, the Center shall reimburse such expenditures as appropriate as soon as possible following the Operative Commencement Date. To this end, the Institute will promptly submit to the Center its claim for such payments together with supporting documentation. The Center will thereupon make such payments to the Recipient's bank account(s) and/or through direct grant payments to Individual Participants. Both types of payments will be included within the cost limits set forth in Article 4.

Article 6 - Cost Statements by the Recipient

6.1 Five copies in English and two in Russian of quarterly cost statements shall be submitted by the Institute to the Center. The first statement is to be submitted no later than four months after the Operative Commencement Date and will cover the first three months of project activity. Subsequent statements are to be submitted at three-month intervals following submission of the first statement. The statements will be appended to the relevant technical reports specified in Article 7. The statements will include the costs of grant payments directly to Individual Participants, but the requests for such grant payments in accordance with Article 5 should not be delayed pending preparation of the entire quarterly cost statements called for in this Article.

6.2 Five copies in English and two in Russian of a consolidated cost statement shall be submitted by the Institute within two months of the completion, cessation, or termination of the work financed by the Center. If such a statement is not submitted on time, the Center may request in writing its submission. If the Center does not receive the submission within thirty days after such a written request, the Center may consider the previously claimed costs to be final and determine to make no further reimbursement.

6.3 Cost statements shall comply with the formats prescribed in Annex III.

Article 7 - Reports and Other Project Outputs

7.1 The Institute shall submit five copies in English and two in Russian of the following reports in accordance with the format prescribed in Annex III:

- Quarterly progress reports covering each three-month period following the Operative Commencement Date to be submitted within one month after the end of each reporting period. If there have been prior expenditures as described in Article 5.3, the first report shall include any necessary modifications of the work plan. Progress reports are not required on those dates when annual reports are due.

- Annual reports. The first annual report will be submitted by November 1, 1995, and will cover the first twelve months of Project activity. The second annual report will be submitted by November 1, 1996. The Center will submit to the Institute its evaluation of the work performed and of the annual report within one month after receipt of it unless notification is given by the Center of the necessity for a longer review period. The Institute will inform the Center within one month following the receipt of the Center's evaluation of steps being taken to respond to the observations in the evaluation.
- A final report. A draft final report will be submitted within two months of the completion of the Project work plan, cessation or termination of the Agreement, or the agreed completion date of the Agreement, whichever will be the earliest. The Center will submit to the Institute its evaluation of the work performed and the draft final report within two months after receipt by the Center of the report. The definitive final report will then be submitted to the Center within one month following the receipt of the Center's evaluation and will take into account the Center's evaluation. If the Center does not submit an evaluation within two months, the draft final report shall be considered the definitive final report.
- Edited reports for publication as specified in Article 4.1 (c) of ANNEX II.

7.2 For the purposes of the Agreement, "deliverables" are defined as any significant outputs, including all reports, of the Project to be submitted in accordance with Annexes I, II, and III.

Article 8 - Ownership and Exploitation of Results

8.1 The results arising from the Agreement shall be the property of the Recipient in accordance with Part F of Annex II. The Recipient shall take appropriate action to exploit or commercialize the results and to make available the results to third parties in accordance with the framework specified in Part F of Annex II. Cooperation agreements with foreign institutions complementing, but not conflicting with, this framework may be entered into by the Recipient.

8.2 In accordance with Part F of Annex II, prior to completion of the Project, the Institute shall submit to the Center for its approval a Technology Implementation Plan.

8.3 Exploitation of results shall be limited to applications for peaceful purposes. In this regard, the Recipient shall ensure that any results which could result in concerns over proliferation of weapons technology and transfer of sensitive technologies will be protected in accordance with relevant laws of Russia and international agreements and conventions to which Russia is a Party.

Article 9 - Auditing and Monitoring

9.1 Access by the Center and the Financing Party to carry out on-site monitoring of all activities of the Project shall be granted by the Recipient, and information and assistance shall be given for the verification and evaluation of the Project activities as set out in Annex II.

9.2 Audits of costs may be carried out by the Center and the Financing Party as specified in Annex II.

Article 10 - Amendments, Variations, or Additions

The provisions of the Agreement and its Annexes may be amended or supplemented only by means of a written agreement signed by authorized representatives of the Signatory Parties.

Article 11 - Special Conditions

There are no special conditions relating to the Agreement.

Article 12 - Disputes

Disputes arising during performance of the Agreement including, in particular, (i) a claim by the Institute for any payments deemed due; (ii) an interpretation of a provision of the Agreement; or (iii) a request for relief or approval related to the Agreement, shall be subject to the following procedure.

The Institute shall submit any claim, demand, or request in writing to the Chief Procurement Officer of the Center. The written decision of the Center shall be delivered to the Institute within four weeks of the receipt of the submission.

Exceptionally, the Institute may appeal the Center's decision in writing through the Executive Director of the Center to the Governing Board of the Center within four weeks of the communication of the Center's decision.

The decision of the Governing Board shall be final and binding. Pending the final settlement of disputes, the Recipient shall, nevertheless, proceed diligently with the performance of the Agreement.

Article 13 - Liability

13.1 The Center shall not be liable for any material loss, damage, or injury of any nature arising from, or in connection with, the performance of the work under the Agreement solely by virtue of financing the Project, including liability from direct grant payments to Individual Participants as set forth in Article 5.2.

13.2 The Center shall not be liable to the Recipient or third parties for claims arising from

- the publication or transmission of any report in accordance with Articles 4 and 13 of Annex II,
- the application of the contents of any report by a third party, or
- the handling or use of products which result from the Project.

Article 14 - Termination of the Agreement

14.1 The Center may terminate the Agreement by a written notice to the Institute, with the termination to be effective after 30 days or a longer period as determined by the Center following receipt of the notice by the Institute. Notwithstanding any termination, the submission of reports and cost statements covering the period up to termination shall be required.

14.2 The Agreement may be terminated due to force majeure or to other factors beyond the control of the Recipient.

14.3 If the Agreement is terminated pursuant to paragraphs 14.1 or 14.2, costs shall be limited to the allowable costs incurred by the Recipient prior to the termination and such other costs as the Center considers to be fair and reasonable having regard to commitments which have been reasonably entered into and which cannot be cancelled or avoided.

The Recipient shall comply with the directions of the Center in the termination notice to reduce or mitigate these costs.

Notwithstanding any termination, the following provisions of the Agreement will continue to apply: Article 12 (Disputes), Paragraph 7 (Accounting Principles, Allowable Costs, and Transfer of Costs) and 8.2 (Equipment) of Annex II, and Part F of Annex II (Ownership, Exploitation, and Dissemination of Results).

14.4 Furthermore, if the Center terminates the Agreement because of actions by the Recipient which obviously violate the national laws of Russia or which obviously are contrary to the stated objectives of the Center or to other conditions specified under the ISTC Agreement or the ISTC Statute, the Recipient shall, upon demand by the Center, promptly return all payments and goods previously provided to the Recipient. Notwithstanding the provisions of Article 14.1, termination pursuant to this paragraph shall be effective immediately upon receipt of the written notification of the termination by the Institute. Notwithstanding any termination, Part F of Annex II will continue to apply.

Article 15 - Annexes

As specified in Article 1.2, the Annexes are an integral part of the Agreement. They are:

Annex I Work Plan

Annex II General Conditions

Annex III Formats for Progress and Cost Reports

Article 16 - Entry into Force of the Agreement

The Agreement shall enter into force on October 1, 1994.

Prepared in Moscow in the English and Russian languages. In the event of inconsistencies between the English and Russian texts, the English text shall take precedence.

For the Center

N. Yokoyama

(Name and Title)
NORIHIKO YOKOYAMA
CO-CHIEF PROCUREMENT OFFICER
(date)

For the Institute

Polyakov A.S.
Deputy Director
(Name and Title)
05.10.1994
Date

ANNEX I

PLAN OF WORK

on the Project N 143

1. Name of project: Research and Development of Induction Slag Melting Process of High Level Radioactive Metal Wastes

2. Chief of project: Pastushkov Victor Georgievich
Senior researcher, ARSRIIM,
Address: Rogov 5, 123060, Moscow.

3. Introduction and review

On reprocessing spent fuel assemblies (SFA) independent of the type of nuclear reactor each ton of reprocessed nuclear fuel results in 330 kg of high activity metal waste (HAMW) containing aside from fuel cladding hulls (Zr-alloys or stainless steel) different structural elements of SFA (spacer grids, wrappers and massive, but hollow end pieces of SFA (stainless steel).

Those metal wastes are α, β, γ - emitters the radioactivity of which is induced by in-pile irradiation and availability of U and fission products that diffuse from fuel into cladding during reactor operation and fuel reprocessing. Presently HAMW is not subject to reprocessing, it is stored in specially designed storage facilities (Zr-alloy waste is filled with alumina) which is rather expensive. Reprocessing and disposal of HAMW can be beneficial in several aspects:

- reduced space of storage facilities or repositories;
- conversion of a part of HAMW (stainless steel) to low- and intermediate activity waste and, hence, the storage and disposal become more simple and less expensive;
- improvement of environmental safety on HAMW storage and disposal.

In the diversity of the proposed methods of HAMW reprocessing, namely, two-stage compaction (USA, Germany, Japan), bituminization (Germany), oxidation of claddings followed by incorporation into silicate or alumosilicate compounds (USA, France) of the highest practical interest is the method of induction slag melting in a furnace with a cold crucible. This method has been studied in detail in France using Zr-alloy and stainless steel fuel claddings; the feasibility is shown of not only a factor of six reduction of the waste amount but also a 2-3 order decontamination of waste to remove long-lived radionuclides to produce monolithic ingots up to 200 mm dia and up to 1 m long suitable to be disposed of. The experience gained in France and preliminary studies carried out by ARSRIIM and ARSRIETE indicate the feasibility of induction-slag melting all types of HAMW in furnaces equipped with cold crucibles to produce ingots up to 500 mm dia and up to 2.5 m long.

The purpose of this project is to investigate and check the technology using simulated materials in pilot and demonstration facilities of induction-slag melting Zr-alloys and stainless steel that differ in composition, mass, geometry and extent of radionuclide contamination. It is expected that when commercially realized this process will result in a factor of 6 reduction of HAMW volume and, hence, in a reduction of space of expensive storage facilities and repositories as well as in improved environmental safety and economic efficiency of disposal of various HAMW. In accordance with the purposes and goals of ISTC the proposed project involves the resolution of issues relevant to ecologically safe management of active waste arising from nuclear fuel, weapons materials included, reprocessing.

The Governing Board of the Center has approved in June 24, 1994 the financing of a project through the Center in the framework of activity covered by the Agreement.

The Power Reactor and Nuclear Fuel Development Corporation, Japan, (hereinafter referred to as "the Financing Party") has agreed to provide financial support for such a project.

The work on the Project will be conducted in close organizational and technological cooperation with the PNC represented by Mr. S. Konomi, the General Manager. During realization of the research mutual exchange of information is planned by sending experts to each other.

The development of this project will promote the evolution of fundamental and applied R & D in Russia in the field of environmental protection as well as integration of Russian specialists to the international scientist community.

4. Anticipated Results

In the course of the project the technology shall be developed and using HAMW simulators pilot equipment shall be checked that is to be used for HAMW conditioning prior to disposal, decontamination and reliable fixation of remaining long-lived radionuclides (the half-life more than 10^4 years) in metal matricies the rate of leaching from which is less than 10^{-7} g cm^{-2} day^{-1}. Induction slag melting is expected to remove TUE and FP from metal waste at the decontamination factor of more than 500 and to produce ingots of specified mass and shape suitable for disposal.

5. Scope of Work

The main scientific and technical goals of the project are:

- to determine the optimal conditions (technological, electrotechnical, etc) of melting SFA Zr-alloy and stainless steel components in an induction furnace with cold crucible to produce ingots of different diameters and lengths;
- to assess the extent of TUE and FP removal from HAMW by induction slag melting with different fluxes;
- to investigate the technology of reprocessing resultant secondary wastes (slag, gas phase);
- to study the structure and properties of intermediate and final products of HAMW reprocessing;
- to design and fabricate a pilot equipment for melting different HAMW (subagreement with SPC "Inductor").

6. Technical Approach and Methodology

For fuel rod claddings, induction slag melting in a furnace with cold crucible produces an ingot drawn or incremented to specified mass and geometry with fixation of the main mass of TUE and FP in solid slag to be disposed of individually or added to flux used in LHLW vitrification.

For end pieces of SFA it is induction slag melting in furnace with cold crucible individually or together with spent fuel claddings. Based on the results of the variety of physical-chemical and metallographic analyses the amount and quality of radionuclide incorporation into metal and slag matrices as well as radionuclide distribution in ingot, slag, and gas phase are to be assessed, and the technological and electrotechnical parameters of processes of cold crucible melting simulated compositions, ingot formation and slag reprocessing are to be adjusted. Based on the results of testing individual units of pilot facilities (metering devices, crucibles, mechanism of ingot drawing, ets and oth.) and the design of facilities, their electrotechnical characteristics are to be adjusted and recommendations for designing remotely-operated equipment are to be developed.

7. Technical Calendar Plan

Events or activities (Content of work at Project stages and deliverables)	Time of Project work accomplishment (designation of stage and N of quarter)	Scope of work, man/month
1	2	3
Development of physical-chemical and electrotechnical aspects of induction-slag HAMW melting process (report)	A-1 1st quarter	50
Design development of mock-up facility "ISMW-CC-1" (design documentation)	A-2 2nd quarter	50

1	2	3
Fabrication of mock-up facility "ISMW-CC-1" (certificate of manufacture)	A-3 3d quarter	53
Installation and adjustment of "ISMW-CC-1" (certificate of commissioning)	A-4 4th quarter	34
Determination of electrotechnical characteristics of process of fuel clad simulator melting in cold crucible (certificate of testing)	B-5 5th quarter	54
Determination of process parameters of simulator fuel clad melting. Output of initial data and technical assignment for development of demonstration facility (report, technical assignment)	B-6 6th quarter	55
Development of demonstration facility "ISMW-CC-2" design (design documentation)	B-7 7th quarter	55
Fabrication of demonstration facility "ISMW-CC-2" (certificate of fabrication)	B-8 8th quarter	36
Investigation of slag properties and its reprocessing technology (report)	C-9 9th quarter	58

1	2	3
Assesment of the extent of HAMW decontamination from TUE and FP by reprocessing fuel clad simulators (report)	C-10 10^{th} quarter	58
Testing demonstration facility "ISMW-CC-2"(certificate of test)	C-11 11^{th} quarter	58
Generalization of the results of studies, output of final report (report)	C-12 12^{th} quarter	39

8. Participation of staff

8.1. "Weapons" scientists and engineers

NN	Name and surname	Date of birth	Previous activities	"Project" activities, days	University degree	Duration of Project work, days	Wage per day, $ USA
1	2	3	4	5	6	7	8
1	Pastushkov V.G.	1939	Reprocessing of HLW on fissionable material regeneration	Project leader	c.t.s.	530	20.0

1	2	3	4	5	6	7	8
2	Kushnikov V.V.	1939	Fissionable material reprocessing	Deputy Project leader	c.ch.s.	500	18,0
3	Serebryakov V.P.	1939	-"-	Head of activity section	-	500	16,0
4	Rakov N.A.	1934	-"-	Consultant	-	200	15,0
5	Drobyshev V.A.	1944	Melting and casting fissionable materials	HAMW melting	c.t.s.	460	15,0
6	Zolotarev A.B.	1943	-"-	-"-	-	460	13,0
7	Pychkov V.N.	1944	-"-	-"-	-	460	13,0
8	Dubikov A.A.	1958	-"-	-"-	-	360	12,0
9	Shestoperov I.N.	1958	-"-	-"-	-	460	13,0
10	Krylova N.V.	1927	Reprocessing of HLW on fissionable material regeneration	Study of slag properties	c.ch.s.	420	15,0
11	Musatov N.D.	1949	-"-	-"-	-	420	15,0
12	Matyunin Yu.I.	1957	-"-	-"-	-	360	12,0
13	Demin A.V.	1958	-"-	-"-	-	360	12,0
14	Mikheikin S.V.	1958	-"-	-"-	-	400	13,0

1	2	3	4	5	6	7	8
15	Smelova T.V.	1956	-"-	Investigation of slag reprocessing technology	-	420	15.0
16	Ignat'ev S.V.	1956	-"-	-"-	-	360	12.0
17	Molchanov A.V.	1940	-"-	Automation of process	c.t.s.	360	15,0
18	Demidovich N.N.	1939	-"-	Reprocessing gaseous effluents	-	360	15.0
19	Voronina Z.G.	1940	-"-	-"-	-	360	13.0
20	Kositsin V.F.	1937	Chemical analysis of fissionable materials	Analytical support	d.t.s.	360	15.0
21	Kuchumov V.A.	1940	-"-	-"-	c.ch.s.	360	15.0
22	Kudrayvtsev V.N.	1943	Mass-spectrometry of fissionable materials	-"-	-	360	15.0
23	Malugin Y.V.	1938	Automation of process	Automation of process	-	360	13,0
24	Sherbatuh V.I.	1938	-"-	-"-	c.t.s.	360	15,0
25	Konovalov L.N.	1938	Materiology of fissionable materials	Analytical support	d.ch.s.	360	15.0

8.2. Other Scientists and Engineers

NN	Name and surname	Date of birth	Previous activities	"Project" activities, days	University degree	Duration of Project work, days	Wage per day, $ USA
1	2	3	4	5	6	7	8
26	Eliseev N.P.	1951	Development of pilot equipment	Development of pilot equipment	-	250	13.0
27	Mikhailin G.V.	1951	-"-	-"-	-	250	12.0
28	Fortsman V.A.	1948	Patent and license investigation	Patent and license investigation	c.t.s.	200	13.0
29	Sinyagina E.D.	1942	-"-	-"-	-	300	12.0
30	Pirogova T.G.	1937	Accountancy	Accountancy	-	230	12.0
31	Sopova S.A.	1959	-"-	-"-	-	250	12.0
32	Shohina Z.D.	1949	-"-	-"-	-	250	12.0
33	Suslina A.K.	1945	Economics of R & D	Economics of R & D	-	300	10.0
34	Orlova S.A.	1939	-"-	-"-	-	250	10.0
35	Kozlyaeva V.B.	1928	Translation	Translation	-	400	12.0
36	Blau V.A.	1950	Head of group of international connections	Organization of international connections	-	200	10.0
37	Bolgov V.P.	1935	Engineering support	Engineering support	-	200	15.0

8.3. Auxilliary Personnel

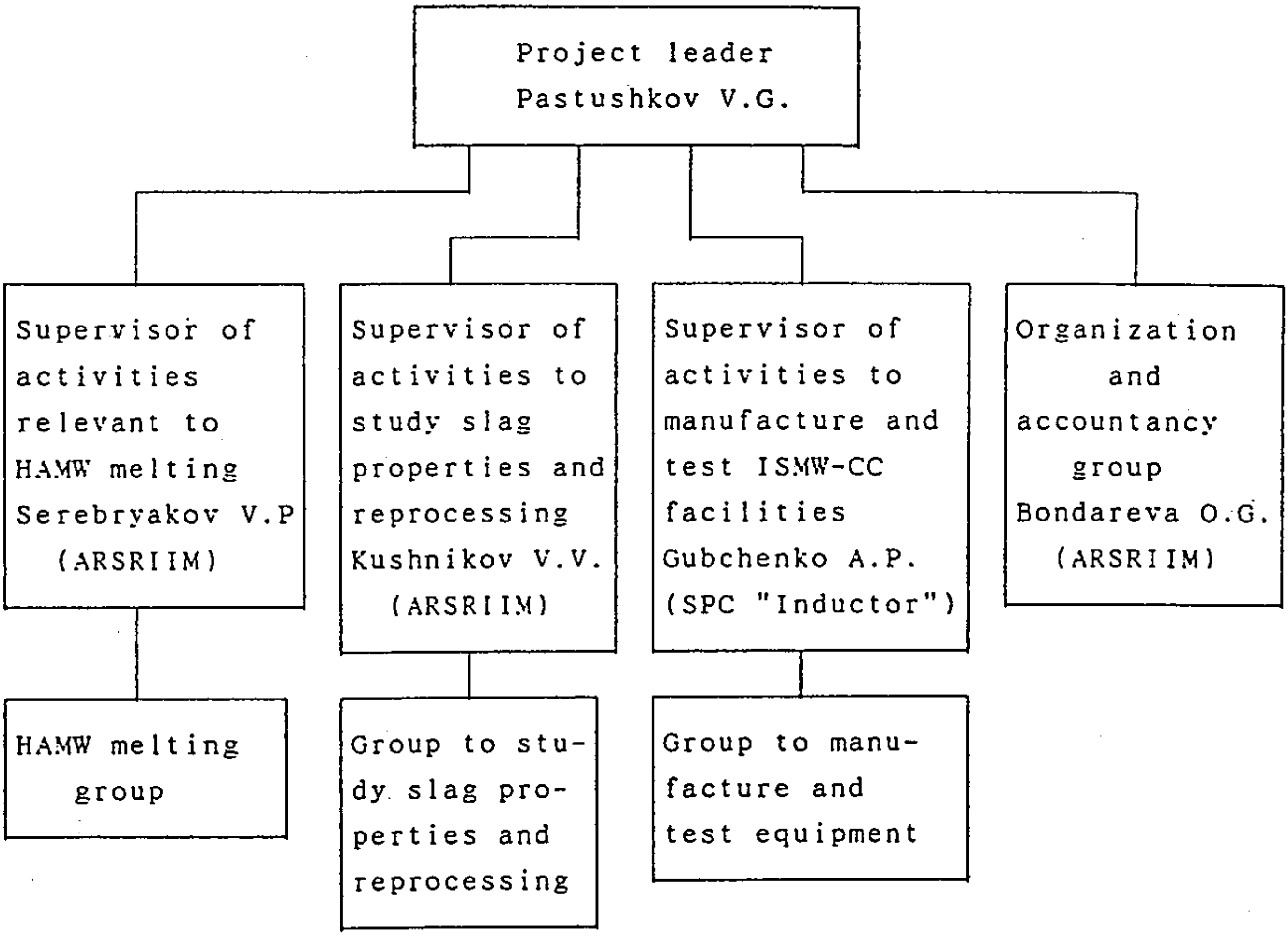
NN	Name and surname	Date of birth	Previous activities	"Project" activities, days	University degree	Duration of Project work, days	Wage per day, $ USA
1	2	3	4	5	6	7	8
38	Shevchuk A.V.	1944	Fabrication of pilot equipment	Fabrication of pilot equipment	-	300	13.0
39	Andreev A.A.	1944	-"-	-"-	-	300	10.0
40	Sumenkov V.A.	1958	-"-	-"-	-	300	10.0
41	Domanin V.G.	1954	-"-	-"-	-	300	10.0
42	Bondareva O.G.	1946	Clerical work	Clerical work	-	400	10.0
43	Savina ?.G.	1938	-"-	-"-	-	300	10.0

8.4. Auxilliary Personnel (SPC "Inductor")

NN	Name and surname	Date of birth	Previous activities	"Project" activities, days	University degree	Duration of Project work, days	Wage per day, $ USA
1	2	3	4	5	6	7	8
44	Gubchenko A.P.	1939	Development of electrotechnical equipment	Development of electrotechnical equipment	c.t.s.	300	15.0
45	Glebov I.I.	1934	-"-	-"-	-	250.	12.0

1	2	3	4	5	6	7	8
46	Ladozhsky V.G.	1932	-"-	-"-	-	200	11.0
47	Alekseev A.V.	1940	-"-	-"-	-	200	11.0
48	Aleshin A.S.	1944	-"-	-"-	-	200	11.0
49	Akhmedov M.M.	1939	-"-	-"-	-	250	10.0

Scheme of Project Management



9. Project Site and Equipment

The Project is to be carried out using test benches at ARSRI-IM (building "A", rooms 37 and 221) and SPC "Inductor" using its to be fabricated mock-up and demonstration facilities "ISMW-CC-1" and "ISMW-CC-2". To install and test "ISMW-CC" facilities "cosmetic" repair of room 37 (area of 55 m^2), building " A " at ARSRIIM and 250 kW and 10 kHz thyristor freguency generator (TFC-250-10 type) are needed.

Newly designed equipment:

- mock-up facility "ISMW-CC-1" is designed to investigate the process of induction slag melting simulated fuel clads in a cold crucible 60 mm dia to produce an ingot up to 200 mm long (using high frequency 2.4 kHz 100 kW generator).
- "ISMW-CC-2" demonstration facility is designed to master the process of induction slag melting simulated fuel clads and end-pieces of FA in a cold crucible 200 mm dia to produce an ingot up to 1 m long (using thyristor 250 kW and 10 kHz frequency generator).

To process experimental results and reported documents computers as well as accounting and business machinery are to be obtained.

The approximate list of needed equipment as well as tentative costs are given in the following table:

N	Equipment	Number	Cost, $ USA
1	Mock-up facility "ISMW-CC-1"	1	2.400
2	Thyristor frequency generator TFC-250-10	1	20.000
3	Demonstration facility "ISMW-CC-2"	1	50.000
4	Personal computers, type 486 DX	2	4.600
	type Note Book	1	2.000
5	Laser Printer (HP-4)	1	2.000
6	Ink-jet printer (HP Desk Jet)	1	2.500
7	Scanner (Scan Jet)	1	1.500
8	Xerox (A 4)	1	800
	(Type Cannon FC-330 or Mita CC-10)		
9	Digitizer	1	700
10	Telephones Panasonic with responder	2	300

10. Deliverables

Project activities can be tentatively subdivided into four sections in accordance with which deliverables are to be generalized:

- design, manufacture and tests of mock-up facility "ISMW-CC-1";
- design, manufacture and tests of demonstration facility "ISMW-CC-2";
- studying and mastering the technology of induction slag melting simulated HAMW;
- studying properties and investigating the technology of metallic ingot and resultant slag conditioning before disposal.

11. Financial Information

Estimated expenditures related to Project and incurred by Executor that are to be reimbursed by Center are summarized in tables 1-2 with annual and quarterly schedules of anticipated financial investment during the whole period of Project realization.

TABLE 1

Estimated Aggregate Expenditures by Recipient

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
1. GRANT PAY'T	37200	68200	72400	77000	217600
Category I	27000	45130	47900	50950	143980
Category II	4300	11640	12350	13130	37120
Category III	2100	6230	6620	7050	19900
Category IV	3800	5200	5530	5870	16600
2. EQUIPMENT	36800(*	36800(*	50000(*	0	86800(*
Modifications	0	0	0	0	0
Capital Eguip.	22400(*	22400(*	50000(*	0	72400(*
Non-Cap Eguip.	14400(*	14400(*	0	0	14400(*
Maint. & Repr.	0	0	0	0	0
Leased Eguip.	0	0	0	0	0
Usage Fees	0	0	0	0	0
Subtotal (1)*	36800	36800	50000	0	86800
Subtotal (2)**	0	0	0	0	0

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
3 .MATERIALS	1400'	4200'	7000'	2500'	13700'
Raw Materials	700	2100	4000	1300	7400
Lab. Supplies	400	1500	2300	500	4600
Safety devices	100	200	300	0	900
Other	200	400	400	400	1200
Subtotal (1)*	1400	4200	7000	2500	13700
Subtotal (2)**	0	0	0	0	0
4. BANK FEES	700	1400	1400	1500	4300
5. OTHER DIRECT	5300	10600	11900	[illegible]	35500
Computer Sup.	800	1800	2000	2200	6000
Account. Sup.	800	1300	1400	1500	4200
Reports/Publish	600	1300	1400	1600	4300
Communications	700	1300	1400	1500	4200
Security	800	1500	1500	1500	4500
Admin. Supplies	800	1600	1800	[illegible]	5400
Others.	800	1800	2400	[illegible]	6900
6.TRAVEL & PER DIEM	2500	12400	13800	[illegible]	41300
Internal ***	2500	3900	4400	4300	12600
Outside CIS	0	8500	9400	[illegible]	28700
7. OVERHEAD	0	0	0	30800	30800
Total	83900	133600	156500	[illegible]	430000

Remarks:

* Subtotal of Equipment or Materials purchased by Recipient

** Subtotal of Center Provided Equip. or Materials

*** Including local and inside-CIS Travels.

TABLE 1-2

Estimated Expenditures by VNIINM

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
1. GRANT PAY'T	33400	63200	66870	71130	201100
Category I	27000	45130	47900	50950	143980
Category II	4300	11540	12350	13130	37120
Category III	2100	6230	6620	7050	19900
Category IV	0	0	0	0	0
2. EQUIPMENT	34400*	34400*	0	0	34400*
Modifications	0	0	0	0	0
Capital Eqip.	20000*	20000*	50000*	0	72400*
Non-Cap Equip.	14400*	14400*	0	0	14400*
Maint. & Repr.	0	0	0	0	0
Leased Equip.	0	0	0	0	0
Usage Fees	0	0	0	0	0
Subtotal (1)*	34400	34400	0	0	34400
Subtotal (2)**	0	0	0	0	0
3 .MATERIALS	700*	1400*	2000*	2500*	5900*
Raw Materials	300	600	1000	1700	3300
Lab. Supplies	200	500	600	600	1700
Safety devices	100	100	200	0	300
Other	100	200	200	400	600
Subtotal (1)* .	700	1400	2000	2500	5900
Subtotal (2)**	0	0	0	0	0
4. BANK FEES	600	1300	1300	1400	4000
5. OTHER DIRECT	4400	8700	10000	10600	29300
Computer Sup.	800	1000	1500	1500	4000
Account. Sup.	700	1300	1300	1300	3900
Reports/Publish	500	1000	1200	1300	3500
Communications	500	1100	1200	1300	3600
Security	500	1000	1100	1200	3300
Admin. Supplies	600	1600	1700	1800	5100
Others.	800	1700	2000	2200	5900

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
6.TRAVEL & PER DIEM	2500	9900	11000	11800	32700
Internal ***	2500	3400	3500	3800	10700
Outside CIS	0	6500	7500	8000	22000
Overhead charges	0	0	0	25600	25600
Total	7600	118700	91170	123030	332900

Remarks:

* Subtotal of Equipment or Materials purchased by Recipient

** Subtotal of Center Provided Equip. or Materials

*** Including local and inside-CIS Travels.

TABLE 1-3

Estimated Expenditures by SPC "Inductor"

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
1. GRANT PAY'T	3300	5200	5530	5870	16600
Category I	0	0	0	0	0
Category II	0	0	0	0	0
Category III	0	0	0	0	0
Category IV	3300	5200	5530	5870	16600
2. EQUIPMENT	2400	2400	50000	0	52400
Modifications	0	0	0	0	0
Capital Eqip.	2400	2400	50000	0	52400
Non-Cap Equip.	0	0	0	0	0
Maint. & Repr.	0	0	0	0	0
Leased Equip.	0	0	0	0	0
Usage Fees	0	0	0	0	0
Subtotal (1)*	0	0	0	0	0
Subtotal (2)**	0	0	0	0	0

Category	1st & 2nd Quarter	Year-1	Year-2	Year-3	Total
3 .MATERIALS	600*	1400*	6000*	400*	7800*
Raw Materials	500	1000	5000	0	6000
Lab. Supplies	100	200	500	200	900
Safety devices	0	0	0	0	0
Other	0	200	500	200	900
Subtotal (1)*	600	1400	6000	400	7800
Subtotal (2)**	0	0	0	0	0
4. BANK FEES	50	100	100	100	300
5. OTHER DIRECT	900	1900	1900	2400	6200
Computer Sup.	0	0	0	0	0
Account. Sup.	50	100	100	100	300
Reports/Publish	100	200	300	400	900
Communications	200	500	600	700	1800
Security	100	300	300	400	1000
Admin. Supplies	100	300	300	400	1000
Others.	200	500	300	400	1200
6.TRAVEL & PER DIEM	200	2500	2800	3300	8600
Internal ***	200	500	800	800	2100
Outside CIS	0	2000	2000	2500	6500
Overhead charges	0	0	0	5200	5200
Total	7950	13500	66330	17270	97100

Remarks:

* Subtotal of Equipment or Materials purchased by Recipient

** Subtotal of Center Provided Equip. or Materials

*** Including local and inside-CIS Travels.

Equipment requirements

Equipment To Be Provided In-Kind by Center is not provided.

Equipment To Be Purchased By Recipient.

TABLE 2

Type of Equipment	Anticipated Use	Estimated Cost	Required Delivery Time
1.Mock-up facility "ISMW-CC-1"	Improvement of technology of melting HAMW	2400	Quarter-3
2.Thyristor frequency generator TFC-250-10	Improvement of the experimental equipment	20000	Quarter-2
3 Demonstration facility "ISMW-CC-2"	Tests of the experimental equipment	50000	Quarter-8

Type of Equipment	Anticipated Use	Estimated Cost	Required Delivery Time
4 Personal computers,	Processing of		
type 486 DX	results of	4600	Quarter-1
type Note Book	researches	2000	Quarter-1
5 Laser Printer (HP-4)	Clerical work	2000	Quarter-1
6 Ink-jet printer (HP Desk Jet)	-"-	2500	Quarter-1
7 Scanner (Scan Jet)	-"-	1500	Quarter-1
8 Xerox (A 4) Type Cannon FC-330)	-"-	800	Quarter-1
9 Digitizer	Processing of results of researches	700	Quarter-1
10 Telephones Panasonic with responder	Communications	300	Quarter-1

ANNEX II GENERAL CONDITIONS

Contents:

Annex II General Conditions

Part A - Implementation of the Work

Article 1 - General Provisions

1.1 The Recipient shall make best efforts to achieve the objectives of the Project and shall comply with all Russian laws applicable to the Project.

1.2 The Recipient shall, in particular, comply with all applicable laws and regulations related to safety.

1.3 The Institute shall notify the Center's Project representative without delay of:
(a) any event or circumstance which may materially affect the Project, and
(b) any proposal for significant changes of key personnel during the Project.

Article 2 - Subcontracting

2.1 Subcontracting shall require the advance written approval of the Center. However, approval shall not normally be given for subcontracting in any State that is not a Party to the ISTC Agreement unless the Center determines in writing that such subcontracting is essential for the Project.

2.2 The Recipient shall impose on a subcontractor the same obligations as apply to itself with respect to any rights of the Center or the Financing Party concerning the Project.

2.3 The provisions of Article 2.1 of this Annex shall not apply to Sub-agreements pursuant to Article 3 of the Agreement or to orders for materials, equipment, and services which are incidental to or intended to facilitate the execution of the Agreement and placed in the normal course of business in accordance with the internal procedures and rules of the Recipient.

Article 3 - Monitoring of the Work

3.1 The Center, or its representatives, shall:

(a) Have access to portions of facilities where the Project is being carried out and to all equipment, documentation, information, data systems, materials, supplies, personnel, and services which concern the Project for monitoring the progress of the Project as described in Annex I.

(b) Be provided with technical and cost information concerning the management and progress of the Project requested at any time.

(c) Give the Institute not less than 20 days advance notice of any intended on-site monitoring of the Project.

3.2 The Financing Party, or its representatives, shall be entitled to the same rights as the Center under Article 3.1 should they choose to exercise them through the Center.

3.3 The Recipient has the right to protect those portions of facilities that are not related to the Project.

3.4 After completion or termination of the Project, the Recipient may utilize the facility or portion of the facility previously used for the Project for other work. However, all documentation and records including those associated with equipment, data systems, materials, supplies, and services utilized on the Project must be maintained and available for review by the Center, the Financing Party, or their representatives, for up to two years following the Project's completion or termination.

3.5 The Institute shall, if requested by the Center, participate and assist in meetings to review or evaluate the Project during the lifetime of the Project.

Article 4 - Reports

4.1 The Institute shall submit the following reports, in a suitable quality to enable direct reproduction, to the Center for approval:

(a) Periodic technical and cost reports, in English and Russian, as required in Articles 6 and 7 of the Agreement prepared according to the specifications in Annex III;

(b) A final report, in English and Russian, covering all the work, the objectives, the results, and the conclusions, including a suitable summary of all these aspects; and

(c) Reports, as mutually agreed, prepared in a suitable form for publication and satisfactory to the Center.

4.2 The Institute shall submit any additional reports or any other deliverables specified in the Agreement.

4.3 The Recipient should clearly identify any reports or portions of reports that contain business confidential information as defined in Part F, Article 14(8) of this Annex. The Recipient also may include a suitable disclaimer in any report against possible claims by third parties.

Article 5 - Completion or Expiration of the Agreement

5.1 The Agreement shall be deemed to be completed on the approval by the Center of the last deliverable required or last payment by the Center, whichever shall be the later.

5.2 Subject and without prejudice to the provisions in Part D of this Annex, the Institute shall be deemed to have discharged its obligations in respect of the performance of the work after the approval of all the reports and any other deliverables required by the Agreement.

Part B - Payments

Article 6 - Payments by the Center to the Recipient

Payments of allowable costs other than the Center's in-kind contributions, the Center's grant payments to Individual Participants, and overhead payments shall be made in accordance with the following principles.

6.1 Cost statements shall be expressed in US dollars unless otherwise specified in the Agreement. All payments by the Center shall be made in that currency unless otherwise agreed.

6.2 The financial contribution by the Center shall be paid in installments as specified in Article 5 of the Agreement.

6.3 If the Center considers that the work has not effectively been commenced within three months of the payment of the first advance, the Center may require the reimbursement of the advance together with any interest earned on the advance.

6.4 If on completion, cessation, or termination of the work, the payments made by the Center exceed the actual allowable costs, the Recipient shall promptly reimburse the difference to the Center. Interest may be added to this amount at the prevailing market rate as determined by the Center one month after the reimbursement date specified by the Center.

6.5 Subject to Article 12 of this Annex, periodic payments made against cost statements shall be considered as advances until acceptance of the appropriate deliverables, in accordance with Annex I, or, if no deliverables are specified, until acceptance of the final report.

Part C - Allowable Costs

Article 7 - Accounting Principles, Allowable Costs, and Transfer of Costs

7.1 Costs shall include actual costs incurred for the Project after the Operative Commencement Date which are necessary for the performance of the Project, with the exception that costs incurred prior to the Operative Commencement Date in accordance with the Center's Letter of Commitment of June 24, 1994, may also be included. Allowable costs may only include the cost categories defined in Articles 8 to 10 of this Annex.

7.2 The original estimates of expenditures set forth in Annex I may be adjusted by the Institute between categories without the prior approval of the Center, except for reductions in personnel costs and increases in travel costs, and provided that the transfers do not fundamentally affect the scope or content of the Project.

7.3 The Recipient shall ensure that no unnecessary cost or unnecessarily high or extravagant cost is charged to the Agreement.

Article 8 - Direct Costs

8.1 <u>Personnel</u>

8.1.1 Personnel costs shall be separated into four categories as described in Annex I and reflected in the reporting form in Annex III. Even though some or all of these costs may be reimbursed by the Center through direct grant payments to the Individual Participants, the Recipient is responsible for certifying the times devoted to the Project by the Individual Participants and for maintaining necessary documentation to support such certification.

8.1.2 Personnel costs shall be charged to reflect the actual eight-hour days, or one-half days when appropriate, worked by personnel assigned by the Recipient to the Project in accordance with Annex I. Work periods of less than four hours may not be charged.

8.1.3 Personnel costs for a specific period of time may not be charged to this Project if reimbursement is being received from other sources for the same period of time.

8.1.4 The Project Manager may increase or decrease the time commitments of personnel by up to 10 percent during one year of any individual without approval of the Center but may not change the daily rate without approval by the Center. The Project Manager may request more significant changes in the personnel commitments, including changes in the names of the personnel, at the beginning of each quarter with a brief explanation of the reasons for the changes. In unusual situations, the Project Manager may request changes during the quarter. The Center will respond promptly to such requests. Changes in scientific personnel must provide for the new participants to have technical credentials and weapons experience comparable to those of the personnel they replace.

8.1.5 The Center will not reimburse personnel costs associated with holidays, annual vacations, overtime, or sick leave. Such additional costs, if any, are the responsibility of the Recipient.

8.1.6 The Project Manager shall ensure that the scheduling of annual leave by the Individual Participants does not interfere with accomplishment of the Work Plan in Annex I.

8.1.7 The Recipient is responsible for any medical expenses or compensation claims for injuries or other losses for personnel working on the Project which are directly or indirectly related to the Project.

8.1.8 Individual weekly records of time devoted to the Project must be signed by all personnel assigned to the Project, and all records must be certified at least monthly by the Project Manager or by another appropriate senior employee of the Recipient.

8.2 Equipment

8.2.1 Equipment shall be categorized according to the location of its use -- in a facility, in a laboratory, or in an office; and equipment costs shall be further categorized as indicated in the reporting form in Annex III.

8.2.2 The cost of equipment used in the Project which is purchased, fabricated, or leased after the Operative Commencement Date may be charged as a direct cost. The total leasing cost of any piece of equipment shall not exceed the cost which would have been allowable for its purchase.

8.2.3 Unless specified otherwise in Article 11 of the Agreement, title of purchased equipment with an acquisition cost per unit of less than $2,500 (non-capital equipment) shall vest in the Recipient upon delivery to the Recipient, whether purchased by the Recipient or provided in-kind by the Center. The title to equipment costing more than $2,500 (capital equipment) shall be vested in the Center throughout the duration of the Project unless the Center vests the title in the Recipient. Upon completion, cessation, or termination of the Project, the title to such equipment shall be vested in the Recipient unless the Center informs the Institute on or before that date of its intent to retain title to the equipment. The Center shall reimburse the Recipient for any costs associated with the storage or movement of the equipment should the Center decide to retain title to the equipment after completion of the Project.

8.3 Materials

The costs of required materials shall be allowable costs. They shall be categorized as raw materials, laboratory supplies, safety devices and protective gear, and other as indicated on the reporting form in Annex III.

8.4 Other Direct Costs

8.4.1 Other direct costs shall be categorized as indicated in the reporting form in Annex III.

8.4.2 Costs incurred by the Recipient in using its internal resources for performance of the Agreement such as costs associated with (a) testing facilities, (b) computer services, (c) special test equipment, (d) dedicated security services, and (e) dedicated accounting services, but excluding items covered by Article 9 of Annex II, may be charged as direct costs through valid cost allocation formulas approved by the Center to the extent such costs contribute to the Project, provided such facilities and services are open to access for monitoring and auditing in accordance with Article 9 of the Agreement.

8.5 Travel and Per Diem for the Recipient

Travel and per diem within the CIS shall be charged in accordance with the internal rules of the Recipient which are subject to approval by the Center. International travel shall be provided by the Center in accordance with Article 4 of the Agreement.

8.6 Sub-Agreements and Subcontracts

8.6.1 Subject to Article 2 of this Annex, costs of subcontracts shall be allowable costs and shall be included as discrete entries in the appropriate categories on the reporting form of Annex III. If the subcontractor is a scientific institution being engaged in a sub-agreement pursuant to Article 3 of the Agreement, costs are allowable only to the extent that they would be allowable if incurred directly under the Agreement. In selecting a subcontractor other than a scientific institution pursuant to Article 3 of the Agreement, the Recipient shall compare prices and quality of several subcontractors and choose the most cost-effective offer. For any subcontract costing more than the equivalent of $25,000, the Recipient shall organize a bidding process. For any subcontract costing between $10,000 and $25,000 (equivalent) written quotations shall be obtained from three sources to the extent possible.

8.6.2 Should the Institute enter into a sub-agreement with a scientific institution pursuant to Article 3 of the Agreement, the reporting form in Annex III shall include the costs incurred pursuant to the sub-agreement which shall be supported by detailed information.

Article 9 - Overhead

A fixed payment may be charged with respect to overhead which covers items such as general administration, institutional management, depreciation of buildings and general equipment, maintenance of building and grounds, telephones, heating, lighting, electricity for the buildings, and general staff training.

The payment shall not exceed 10% of the direct Project costs, excluding equipment, travel, and subsistence.

Since the overhead will be retained by the Center until acceptance of the final report, the Institute need not include this item on the reporting form in Annex III.

Article 10 - Costs Not Allowed

Allowable costs shall not include, among others:

- any profit;
- any contributions to pension, medical, or other social funds;
- any provisions for possible future losses or liabilities;
- any taxes, including profit tax, value added tax, personal income tax, and local taxes, as well as any other tariffs, dues,

custom duties, import duties, fees, or other imposed taxes or similar charges;
- any costs allocable to other projects;

The Center will determine the use of any interest earned from funds provided by the Center or return on investment of such funds. Such interest or return on investment must be reported to the Center.

Part D - Justification of Costs and Auditing

Article 11 - Books of Account and Documentation

The Recipient shall maintain in accordance with the accounting practices set forth in the Agreement proper books of account and appropriate documentation, such as invoices and time sheets to support and justify the costs reported. These shall be made available for audits by the Center and the Financing Party during the period of the Project and for a period of up to two years following the Project's completion or termination.

Article 12 - Auditing

12.1 Cost statements are subject to verification even after the Center has reimbursed costs. The Center and the Financing Party have the right pursuant to the ISTC Agreement and ISTC Statute to carry out on-site auditing of all activities of the Project. The Institute will be given not less than 20 days notice of any intended audit. For the purposes of the audit, the Recipient shall make accessible all portions of facilities, equipment, documentation, information, data systems, materials, supplies, personnel, and services related to the Project.

12.2 The Recipient has the right to protect those portions of facilities that are not related to the Project.

12.3 The Recipient shall maintain all documentation and records including those associated with equipment, data systems, materials, supplies, and services utilized on the Project and shall make such documents, records, and to the extent possible personnel available for audit for a period of up to two years following the Project's completion or termination.

12.4 The Center and the Financing Party shall have the right to select Courts of Auditors or other organizations or individuals to carry out audits of the Project; and they shall be entitled to the same rights, should they choose to exercise them, as the Center and the Financing Party in respect of access to, and verification of, any document under the Agreement for the purpose of any audit.

Part E - Confidentiality and Promotion of Information

Article 13 - Promotion of Technology and Information on Results

Confidentiality

13.1 All reports or portions of reports specified by the Institute as confidential, other than those specified in Article 4.1(c) shall remain confidential.

13.2 Subject to any obligations under this Agreement and in accordance with applicable laws and regulations, the Signatory Parties undertake to keep confidential any matter communicated to them as confidential in relation to the execution of this Agreement, unless information so disclosed is or becomes legitimately available to the receiving party through other sources without any covenant as regards its confidentiality.

Information and Technology Promotion

13.3 The Center and Recipient shall take appropriate steps to publicize new developments so that third parties may become aware of opportunities to license technology developed with Center support. The final report publishable under Article 4.1(c) of this Annex shall include adequate information on the results arising from the Project concerned, their availability and other aspects of relevance for potential users or interested parties.

13.4 The Center shall be entitled to publish general information on the Agreement in respect of the Recipient, its title and objective, its estimated allowable costs, its duration, the Center's financial contribution, and the names of managers and laboratories where the research is being carried out.

13.5 Any communication or publication concerning the Project shall acknowledge the Recipient, and the cooperative support of the Center and of the Financing Party.

13.6 Each Party to the ISTC Agreement and the Center shall be entitled to a non-exclusive, irrevocable, royalty-free license with the right to sub-license in all countries, to translate, to reproduce and to publicly distribute scientific and technical journal articles, reports and books directly arising from the Project.[1] All publicly distributed copies of a copyrighted work arising from cooperation under the Agreement shall indicate the names of the authors of the work, unless an author explicitly declines to be named.

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[1] When the objective of a project is only to produce an article, report, or book that is expected to be valuable in itself, the Financing Party (or its designee) and the Recipient (or its designee) may agree to protect, allocate, and manage any intellectual property under mutually agreed terms.

Part F - Ownership, Exploitation, and Dissemination of Results

Article 14 - Definitions

For the purpose of Part F of this Annex:

1) "Intellectual Property" shall have the meaning defined in Article 2 of the Convention Establishing the World Intellectual Property Organization, done at Stockholm on July 14, 1967.

2) "Foreground Results" means Foreground Information and Foreground Patents.

3) "Foreground Information" means information, including all kinds of results, generated in the execution of this Agreement.

4) "Foreground Patents" means patent applications, patents, copyrights, plant variety rights, and other similar statutory rights for inventions or improvements made or conceived by the Recipient or any person employed or engaged by the Recipient in the execution of this Agreement.

5) "Background Results" means Background Information and Background Patents.

6) "Background Information" means information, excluding Foreground Information, owned or controlled by the Recipient in the same or related fields as the research under this Agreement and generated outside the Project.

7) "Background Patents" means patent applications, patents, copyrights, plant variety rights and other equivalent statutory rights excluding Foreground Patents, owned or controlled by the Recipient in the same or related fields to the research executed under this Agreement and originated outside the Project.

8) "Business Confidential Information" means information containing know-how, trade secrets, or technical, commercial or financial information, which either:
--[i] Has been held in confidence by its owner,
--[ii] Is not generally known or available from other sources,
--[iii] Has not been made available by its owner to other parties without an obligation concerning its confidentiality, or
--[iv] Is not available to the receiving party without obligations concerning confidentiality.

9) In the application of the provisions concerning the granting of licenses, access and user rights for Information and Patents within or beyond projects:
   - "fair and reasonable conditions" means conditions which have regards to the mutual interests of the Center and

the Parties to the ISTC Agreement and do not abusively restrict exploitation, commercialization or competition;
- "transfer conditions" means conditions which have a value lower than the favorable conditions, normally the cost related to making the licenses and access or user rights available;
- "royalty-free" means at no cost and against no conditions other than those specified in Part E of this Annex.

Article 15 - Ownership

15.1 All rights worldwide to intellectual property arising from the Project, including patent protection for industrial property, shall be held by the Recipient (or its designee).

15.2 When two or more institutions are involved in the execution of this Agreement, they shall agree on the arrangements for the allocation of ownership, as between themselves, of Foregrounds Results.

15.3 The Recipient (or its designee) owning Foreground Results shall provide adequate protection for Foreground Information and Patents at its own expense, except as provided in Article 16.2 of this Annex.

15.4 If the Recipient (or its designee) owning Foreground Results decides not to provide adequate protection for Information or Patents described in Article 15.3 in the territory of a Party to the ISTC Agreement other than the territory of the Party or Parties where the Recipient is located, each such Party (or its designee) and the Financing Party (or its designee) have the option to provide such protection in that territory at its own expense.

15.5 Each Party to the ISTC Agreement is expected to use its best endeavors to ensure that rights acquired are exercised in such a way as to encourage:

(a) The dissemination and use of non-confidential information created, provided, or exchanged in the course of the Project;

(b) The adoption and implementation of international technical standards; and

(c) Fair competition in areas affected by the Agreement.

Article 16 - Access Rights for Commercial Purposes

16.1 The Recipient (or its designee) shall develop, exploit, or commercialize Foreground Results in conformity with the principles and timescale established in a Technology Implementation Plan agreed with the Center at, or before, the end of the Project. The Financing Party will, if requested, provide assistance to the Recipient in managing the intellectual property.

16.2 The Recipient (or its designee) shall grant the Financing

Annex III Formats for Progress and Cost Reports

Format for Technical Reports

Quarterly reports shall specify the progress, any actual or proposed deviations and modifications to the Work Plan in Annex I, and the results obtained. The reports shall contain sufficient information to enable assessment of the progress and cooperation within the Project. The details of the Annual Report shall be agreed upon at an appropriate time by the Recipient and the Center's Project representative. A suggested format for quarterly reports is as follows:

I. Summary of Technical Progress (By task in the Work Plan)
II. Milestones Completed
III. Summary of Personnel Commitments
IV. Major Equipment Acquired
V. Description of Significant Travel
VI. Current Technical Status (on schedule, behind schedule, ahead of schedule)
VI. Delays, Problems, Suggestions

The quarterly report should be between three and five pages (single space).

Party (or its designee) an exclusive, irrevocable, royalty-free license, with the right to sub-license, for commercial purposes in that Party's territory. In such cases, the Financing Party and the Recipient shall agree on appropriate compensation for persons named as inventors. Costs of protection in that territory shall be borne by the licensee. When the benefits from the exploitation of intellectual property arising from the Project are expected to exceed significantly the Financing Party's expected contribution to the Project, the Recipient (or its designee) and the Financing Party (or its designee) may agree to protect, allocate, and manage intellectual property under mutually agreed provisions that are consistent with their laws and regulations and the principles of the ISTC Agreement.

16.3 Upon the request of the Financing Party (or its designee), the Recipient (or its designee) shall enter negotiations for licenses in additional territories on fair and reasonable terms.

16.4 Upon the request of a non-Financing Party (or its designee), a non-exclusive license for commercial purposes, with the right to sub-license, shall be granted in that non-Financing Party's territory, on fair and reasonable terms to be mutually agreed, taking into account that non-Financing Party's contribution to the establishment and operation of the Center; the Financing Party (or its designee) shall be entitled to a license on the same terms in that non-Financing Party's territory.

16.5 The Recipient shall grant on reasonable conditions access rights for Background Results owned by the Recipient necessary for the exploitation of intellectual property arising from the Project, provided that the Recipient entity is free to disclose such Background Results, that no major business interests of the Recipient oppose the granting of access rights, and that in making this opposition such interests are not abusively restricting the exploitation of such rights.

16.6 Persons named as inventors shall receive not less than 15% of any royalties earned by the Recipient.

Article 17 - Access Rights for Non-commercial Purposes

<u>Foreground Results</u>

17.1 The Recipient owning Foreground Results shall grant an non-exclusive, irrevocable license to Foreground Results on transfer conditions for non-commercial purposes, with the right to sub-license, to the Center and to each Party to the ISTC Agreement (or its designee) for the territory of each Party in which the intellectual property is protected. Upon request the Parties will exchange information on licenses and sub-licenses granted under this paragraph.

<u>Background Results</u>

17.2 The Recipient shall grant a license, with right to sub-license, to Background Results necessary for the use of Foreground Results described in Article 17.1 for non-commercial purposes.

Article 18 - Notification of Limitations, Restrictions and Obligations

18.1 The Recipient shall use reasonable care and diligence in determining whether Information or Patents are, or may become, subject to the limitation, obligations, or restrictions of this Article.

18.2 The Institute shall notify the Center prior to the signature of, and promptly during this Agreement of:

(a) Any contractual limitation that may limit access rights for Background Results;

(b) Any obligation to grant rights for Foreground Results to a third party, which may affect the exploitation or commercialization of the Foreground Results;

(c) Any restriction arising from government or similar regulations which may materially and adversely affect rights necessary for the performance of the work or the exploitation or commercialization of the results of the work.

Article 19 - Duration and Implementation of Part F

19.1 The rights and obligations of the Recipient resulting from this part of this Annex shall apply;

[i] For the duration of the Foreground Patent, in respect of Articles 16.1-3 and 17.1-2;

[ii] For a period of 10 years after the expiration, or termination, of this Agreement in respect of the remaining obligations.

19.2 The cessation of the rights and obligations under this Article shall not affect the continuance of any access rights where they were duly requested prior to such cessation.

TABLE 4

Aggregate Quarterly Financial Reports by Recipient

Reporting Period:

Cost Category	Cost for Quarter	Accumulated Cost	Total Budget
1.GRANT PAY'T			
Category I			
Category II			
Category III			
Category IV			
2.EQUIPMENT			
Modifications			
Capital Equip.			
Non-Cap Equip.			
Maint.&Repair			
Leased Equip.			
Usage Fees			
Subtotal (1)*			
Subtotal (2)**			
3.MATERIALS			
Raw Materials			
Lab.Supplies			
Safety Devices			
Other			
Subtotal (1)*			
Subtotal (2)**			
4.BANK FEES			
5.OTHER DIRECT			
Computer Sup.			
Account. Sup.			
Reports/Publish			
Communications			
Security			
Admin.Supplies			
Others			
6.TRAVEL&PERDIEM			
Internal ***			
Outside CIS			
Total	________	________	________

Remarks:

*Subtotal of Equipment or Materials purchased by Recipient

**Subtotal of Center Provided Equipment or Materials

***Including Local and Inside-CIS Travels

(AUG/05/94)

TABLE 4-2

Quarterly Financial Reports by Each Institution

Name of Institution:
Reporting Period:

Cost Category	Cost for Quarter	Accumulated Cost	Total Budget
1.GRANT PAY'T			
Category I			
Category II			
Category III			
Category IV			
2.EQUIPMENT			
Modifications			
Capital Equip.			
Non-Cap Equip.			
Maint.&Repair			
Leased Equip.			
Usage Fees			
Subtotal (1)*			
Subtotal (2)**			
3.MATERIALS			
Raw Materials			
Lab.Supplies			
Safety Devices			
Other			
Subtotal (1)*			
Subtotal (2)**			
4.BANK FEES			
5.OTHER DIRECT			
Computer Sup.			
Account. Sup.			
Reports/Publish			
Communications			
Security			
Admin.Supplies			
Others			
6.TRAVEL&PERDIEM			
Internal ***			
Outside CIS			
Total			

Remarks:
*Subtotal of Equipment or Materials purchased by Recipient
**Subtotal of Center Provided Equipment or Materials
***Including Local and Inside-CIS Travels
(AUG/05/94)

Table 5

Requests for Grant Payments to Individual Participants

1) Name of Institution (Name of Handling Bank)

Name & Pass.No.	Proj.Respon.	Workdays	DayRate	AmountDue

Category I (Weapons Specialists)
1.
2.
3.
.
Category II (Other Specialists)
1.
2.
3.
.
Category III (Support Personnel)
1.
2.
3.
.
Category IV (Non-10/50 Personnel)
1.
2.
3.
.
Sub-total of Institution ____________

2) Name of Institution (Name of Handling Bank)
Category I
.
Category II
.
.
Sub-total of Institution ____________
.
.
Total
Category I
Category II
Category III
Category IV ____________

Grand-total ____________

____
Signature of Project Manager
Date

(AUG/05/94)

4. 2 Technical Report

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TECHNICAL REPORT
on
Activities Performed at Stage 1 of Project N 143-94.

1. In compliance with the technical calendar plan of the project (Stage A-1) in the last quarter of 1994 technical-scientific and patented information was generalized and analysis as relevant to the technology and equipment used to reprocess radioactive metal wastes aimed at their long-term storage or disposal. ["Analysis of Developments in the Field of Technology and Equipment for Reprocessing Radioactive Metal Wastes, Physico-Chemical and Electrotechnical Fundamentals of High-Activity Level Metal Waste Induction Slag Melting" by Pastushkov V. G., Kushnikov V. V., Serebryakov V. P. and oth. Report of ARSRIIM, N 8314, 1994 (43 pp., 4 figs, 18 tables, 57 references)]. Special emphasis is placed on the problem relevant to conditioning for disposal of high activity metal waste (HAMW) as fuel rod cladding hulls, end fittings and spent fuel assembly (SFA) wrappers made of Zr-alloys or stainless steel. HAMW characteristics are described in detail, namely, composition and amount of structural materials in SFAs of different reactors; distribution of radionuclides in chopped fuel rod claddings as reactor operated and after fuel dissolution; technological properties of cladding hulls (density, bulk density, moisture content, particle size distribution, impurities etc.).

Consideration is given to three groups of processes of irradiated fuel rod cladding reprocessing, namely, mechanical (pressing), thermo-mechanical (hot pressing, melting) and chemical ones (oxidation and conversion of Zr to other chemical forms). It is noted that the choice of a specific method of HAMW reprocessing is to a significant extent determined by the national concept of RAW management, availability of stable geologic formations for RAW disposal, feasibility or need in the further recycle of a metal, requirements placed by the national safety standards.

It is also noted that the problem of conditioning HAMW to be long-term stored or disposed of becomes more urgent in countries developing nuclear power with the closed fuel cycle which is explained by increased amounts of wastes of this kind, their intricate storage due to the pyrophoric fine fraction of Zr-alloys and high activity level of wastes due to a wide range of long-lived fission products available and tritium evolution.

Presently there is no generally adopted concept of management of wastes having different activity levels. In most countries the re-use of a decontaminated metal is theoretically accepted, however, since there are no legislatively established national standards, the unlimited recycle of decontaminated metals (specifically, stainless steel) is made difficult nowadays. Despite the general tendency for the re-use of metals it is presently restricted to fabrication of containers or other equipment to be used in nuclear engineering.

Essentially all studies of HAMW reprocessing are at the stage of R&D; the exception is the process of pressing followed by cementation (Germany, France) and melting (France, Russia). From our point of view, the mostly mastered process of fuel cladding pressing followed by cementation in steel drums is little suited as a model for the establishment of a commercial technology due to the low life-time of a cement matrix ≈ 100 years, significant rates of radionuclide leaching from those matrices and low cladding content of the final product. For the same reason the practicability of employing other matrix materials (graphite+sulfur, glass, ceramics, Al or Pb alloys) is questionable.

Most promising are methods of HAMW melting that allows a factor of 5-6 reduction of waste volumes and a factor of 150 reduction of waste effective surface, decontamination of metals using fluxes (at K_{dec} 10^3) but also conversion of fuel rod claddings to the most stable metal form suitable if needed for a re-use. It is also shown that the process of induction-slag melting of HAMW in an induction furnace having a "cold" crucible avoids the arising of secondary waste as ceramic or graphite crucibles as is the case in the "hot" crucible melting of metals.

The melting experience gained in France using inactive waste on a commercial scale and active waste on a laboratory scale corroborates the promising character of induction-slag melting in induction furnaces with a "cold" crucible (IMCC) for both Zr-alloy cladding and stainless steel rod cladding and FA end fitting reprocessing. Besides, in Russia experience has been gained in design and operation of commercial facilities IMCC for melting different refractory metals and alloys as well as laboratory facilities for melting high activity level mixed salts.

The report deals in detail with the specific features of behaviour of molten metals and salt fluxes upon induction melting as hulls in a metallic sectional cooled ("cold") crucible, activity distribution in products of fuel clad melting (ingot, slag and gas phase), instrumentation of process (with ingot drawing or extending), behaviour of FGP, quality of a resultant ingot and radionuclide leaching rate.

The major directions for investigations and developments are established in compliance with the project:

- to optimize flux compositions for Zr-alloy and stainless steel melting aimed at improvement of decontamination efficiency and leaching resistance of resultant slag;
- to study the properties of ingots aimed at attaining the highest quality of them in terms of their following disposal;
- to develop and test devices for charging and metering fuel rod cladding hulls and long-length end-fittings of FAs into a "cold" crucible as well as devices for drawing out and ejecting resultant alloy ingots from a "cold" crucible;
- to develop methods and devices for collecting and conditioning resultant slags to be disposed of.

2. The volume of the work as planned for the 1st stage is completely carried out. Besides, the work has been started relevant to other stages of the plan, namely, technical requirements have been established for a pilot mock-up facility "ISMW-CC-1", recommendations have been worked out on synthesis of systems of

control and regulation of the process of HAMW melting and the general flow outline of a gas clean-up system in this facility. Developments are in progress relevant to methods of analysis of microand macro components of products. Volumes of consumption and account of materials and equipment to be acquired in the framework of the project have been determined. Direct expenditures and qverheads relevant to the project have been calculated.

3. 37 specialists (of 49 given in the list) participated in the activities of stage 1 of the plan.

4-5. In connection with the fact that before December 31, 1994 there was no funding of the Project equipment or materials were not acquired, other expenditures by the estimate were not made. For the same reason no business trips of specialists within CIS took place.

6-7. The work on the Project is in progress according to the technical plan. Delays or unexpected problems were not encountered.

Head of Project 143-94 ________ V. G. Pastushkov

" 16 " January 1995

State Science Center
A.A. Bochvar All-Russia Scientific Research
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TECHNICAL REPORT
on
Work Performed for Stage A-2 of Project N 143-94

1. In compliance with the technical calendar plan of project N 143-94 at Stage A-2 "Design of Mock-up Facility ISMW-CC-1" in the first quarter of 1995 the design documentation (project number KB-460.00.000) has been worked out for a mock-up facility "ISMW-CC-1" to be used for mastering the technology and equipment of the process of induction-slag melting fuel simulator chopped claddings in furnaces with a "cold" crucible.

In compliance with ГОСТ 2.102.-83 (ГОСТ - State Standard) the design documentation comprises:

a) general drawing of facility, specification, drawings of major units and mechanisms, namely, melting unit, hydraulic-mechanical drive, hopper-feeder of charge lumps, metal cloth filter, ejector and separator of dust;

b) general electric circuit of facility power supply, general electric circuit of hydraulic drive, general electric circuit of gauges, electrical connections of hydraulic drive, electrical connections of gauges, functional diagram of gauges;

c) instruction manual.

2. The scope of the work planned for Stage A-2 of the technical calendar plan was carried out completely. Aside from this, other activities were performed for the other stages of the plan:

a) Initial data were generated to choose and synthesis salt fluxes promising for purification of molten metals from oxides and radionuclides as well as to select options of reprocessing slags arising from induction-slag melting fuel rod claddings in furnaces with "cold" crucible;

b) Investigations were started of the mechanism and kinetics of interaction between molten metal and oxides both solid and molten ones;

c) Recommendations were worked out an analytical methods of determining major and impurity elements in ingots of multicomponent alloys and salt powder system;

d) A preliminary search was conducted of patented and scientific technical information on methods of molten metal purification from oxide inclusions;

e) Calculations were performed of electrical, thermal and technical parameters of "cold" crucible (60 mm dia) and inductor (120 mm dia) for the option of metal charge melting using a machine generator of 100 kW and working frequency of 2400 Hz;

f) Investigations were started of the technology of manufacturing simulations fuel rod cladding lumps and individual units of a mock-up facility (hydraulic drive, melting unit, aerosor filter).

3. Forty nine specialists (of 51 listed) participated in the work of the Stage A-2 of the technical plan.

4. In the 1st quarter of 1995 the major part of office equipment (not the main one) was purchased, namely, personal computers, xerox, scanner, printers and telephone sets. Negotiations are under way relevant to purchasing thyristor frequency converter of ТПЧ-630-2.4 type and a number of devices to control and regulate the process of fuel rod cladding melting.

5. In the period from 20 to 24 February 1995 the specialists Pastushkov V.G. and Mikheikin S.V. were send on a mission to Sneghinsk town of the Chelyabinsk region to participate in the International Seminar (under the aegis of ISTC) dedicated to the ecology issues relevant to nuclear power; then Mikheikin S.V. visited PU "Mayak" (Ozersk town) to specify the storage conditions and scope of HLMW arising from reprocessing spent nuclear fuel.

6. The project relevant work is under way in compliance with the technical calendar plan.

7. Since in 1995 in Russia the prices of materials, equipment and devices have grown and there is a need in purchasing, updating and repairing some ganges it is suggested (see the Notification sent to ISTC on March, 14, 1995) to review the estimate of project related expenses to be incurred by VNIINM reduce the sums in the item "other direct" and increase the expenses in the items "equipment" and "materials".

Project manager V.G. Pastushkov

ГОСУДАРСТВЕННЫЙ НАУЧНЫЙ ЦЕНТР РОССИЙСКОЙ ФЕДЕРАЦИИ

ВНИИНМ
имени А.А.Бочвара

ВСЕРОССИЙСКИЙ
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
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________ № ________

На № ________ от ________

[ ]

3 rd Quarter

TECHNICAL REPORT

ON

WORK PERFORMED FOR STAGE A-3 OF PROJECT N 143-94

1. In compliance with the technical calendar plan of project N 143-94 for stage A-3 in the second quarter of 1995 the mock-up facility " ISMW-CC-1" was fabricated. The goal is to master the process and equipment used for induction-slag melting chopped claddings of nuclear reactor fuel simulators in furnaces with a " cold " crucible (certificate of facility fabrication, VNIINMN 57/124 of 26.06.95).

The mock-up facility "ISMW-CC-1" was fabricated using the earlier worked-up project Ind KB - 460.000.000 and comprises the following major units and systems:

power supply system inserporating frequency converter of the type "ВПЧ - 100 - 2400", capacitor battery and matching high frequency transformer of "ТВД-3" type;

- melting units on line with inductor and " cold " crucible with tray;
- hydromechanical drive to transfer "cold"tray containing an ingot;
- unit for charging lumps of fuel claddings and flux; it incorporates a feeding bin, plate and vibration feeders;
- gas clean-up systems;
- gauge and automation systems.

Aside from the major units of the facility also fabricated were a device for gas clean-up system evacuation, a device for classification of solid phase contained by off-gases, gas phase samplers, cabinets for gauge and automation devices.

Primary and secondary gauge and automation devices are installed, work was started to install electrical, hydraulic and pneumatic circuits of power supply and arrange melting process control.

2. The scope of the activities planned for stage A-3 of the technical calendar plan was carried out completely. In addition, the work was started related to other stages of the plan:

- thermodynamic probability was assesed of interaction between components of oxide film at fuel cladding surface and molten metals and salts;
- procedure was worked out and tested for fuel simulator fabrication from stainless steel and zirconium having oxide films of specified thickness;

  search for and generalization were continued related to patented as well as science and engineering information pertaining to the technology of flux synthesis and composition of fluxes used to remove oxide inclusions from molten metals;

- in progress is mastering the methods of analysis of the main and impurity elements contained by alloy ingots and salt powder systems (fluxes and slags).

3. 52 specialists (of 55 listed) took part in the work at stage A-3 of the calendar plan.

4. I n the 2nd quarter of 1995 different devices for the gauges and automation circuit, matching high frequency transformer, computer programmes to translate technical information from foreign languages as well as different raw and laboratory materials were bought.

5. During 22 to 26 May, 1995, specialists Pastushkov V.G., Drobyshev V.A. and Chistov Yu.I. were on a business trip in Ust'-Kamenogorsk city (Kazakhstan) at Ul'ba metallurgical plant where they familiarized themselves with the experience gained in the operation of Be induction melting facility in a furnace with a "cold" crucible 200 mm in diameter and specifically with the arrangement of a system of gass clean-up to remove toxic dust and sublimates.

In the period 27-29 June,1995, specialists Kushnikov V.V. and Demidovich N.N. were on a business trip at VNIPIET (St.-Peterburg) to resolve the problems relevant to gas clean-up in IMCC processes.

6. The work on Project N143-94 is under way in compliance with the technical calendar plan.

7. No delays or unresolvable problems in project work performance were encountered.

Manager of Project N143-94 V. Pastushkov

ГОСУДАРСТВЕННЫЙ НАУЧНЫЙ ЦЕНТР РОССИЙСКОЙ ФЕДЕРАЦИИ

ВНИИНМ имени А.А.Бочвара

ВСЕРОССИЙСКИЙ
НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
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На ____________ № ____________

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TECHNICAL REPORT

ON

WORK PERFORMED FOR STAGE A-4 OF PROJECT N 143-94

1. In compliance with the technical calendar plan of Project N 143-94 for stage A-4 in the third quarter of 1995 the following work was carried out: the units were installed and the systems and mechanisms were adjusted of the mock-up facility "ISMW-CC-1" designed to master under laboratory conditions the technology and equipment used for the induction-slag melting of chopped claddings of nuclear reactor fuel simulators in a furnace with "cold crucible" (see certificate N 58/124 of 25.09.95 of commissioning "ISMW-CC-1", VNIINM).

The mock-up facility "ISMW-CC-1" as fabricated in accordance with the project Ind KB-460.00.000 is composed of the following units, mechanisms and systems:

- Power supply system incorporating machine frequency converter of the type ВПЧ-100-2400 that matches high frequency transformer of the type ТВД-3, current transformer of the type ТК-42, capacitor battery and current supply bars.

- Melting units composed of melting crucible inductor and "cold" tray. "cold" crucible is manufactured from 18 electrically insulated sections of a specifically shaped copper tube. The sections are assembled to form a vertical packet and have top and bottom fibre-glass laminate flanges. At there is a fixed inductor fabricated from 6 copper tube loops also electrically insulated. The "cold" tray is a copper cylinder in the top end of which there is a projection in the form of "a dovetial" to fix the top cold portion of an ingot when it goes down. At the bottom the tray is connected to thrust from a hydromechanical drive.

Each pair of cold crucible sections, inductor and tray have sleeves for inlet and outlet of cooling water.

- Unit for charging lumps of fuel rod claddings and flux. It incorporates a vibration feeder, a plate feeder, a system of drain pipl-lines and a gate device.

- Gas Clean-up System incorporating two succesively installed recoverable metal cloth filters, a control units, a gas flow rate hooster and an ejection device to create the specified evacuation of the system.

- Ingot Pulling Mechanism incorporating a hydromechanical drive and a system of thrusts and levers. The hydrodrives has an electric motor a V-helt drive, two force hydrocylinders, a pump, a filter and tank for oil, a system of cocks, valves, throttles and pipelines.

- System of Water Cooling melting unit components, a generator and a capacitor battery.

- Gange and Automation System incorporating several subsystems:

a subsystem to stabilize temperature, flow rate and electric power of melting;

a subsystem to control the rate of an ingot travel;

a subsystem to control gas supply and clean-up;

a subsystem to control cooling temperature and flow rate.

Primary and secondary devices and mechanisms of the gange and automation systems are installed in 5 cabinets and on a frame and connected to match with electrical, hydroulic and pneumatic circuits.

The above systems and units after adjustments have parameters close to the technical characteristics of the facility described in the Annex.

The mock-up facility "ISMW-CC-1" is prepared for mechanical and electrotechnical testing.

2. The scape of work as planned for stage A-4 of the technical calendar plan has been fukky accomplished.

Aside from this, during the 3-d quarter of 1995 the work was under way relevant to other stages of the plan:

- two pilot batches of fuel simulator claddings were fabricated from stainless steel and Zr-alloys;

- two pilot batches of briquetted fluxes have been prepared on CaF_2 - CaO base with SiO_2 and sodium metaphosphate additives;

- methods were mastered to analyze macro- and microcomponents of metal and salt systems;

- palent-licensing studies have been started to determine the patent purity and technical level of the technology of induction-slag melting of fuel rod claddings that is now under development;

at SPC "Inductor" the pilot facility with the cold crucible has been reconstructed for testing the option of fuel cladding melting with incrementing an ingot.

3. 52. specialists (of 55 listed) participated in the work at stage A-4 of the technical calendar plan.

4. To perform the project work the following items were bought in the 3-d quarter of 1995: secondary devices (supply units, amplifiers, connectors) to install the gange and automation

system, a high temperature furnace of type 3.1650 HT to investigate flux and slag properties, Zr-alloy, semi-products (ingot, bars, tubes) to master the technology of YAMW melting.

5. During the reported period no specialists were sent on business trips in connection with Project N 143-94.

6. The work on project is performed in compliance with the technical calendar plan.

7. In view of the underutilization of the funds allocated for businnes-trips in the 1-st fiscal year after the coordination with the ISTC in August 1995 the funds were redistributed to other items of estimated expenditures relevant to the project no delays or undersolvable problems in the project work performance were encountered.

Manager of Project N 143-94

V.G. Pastushkov

27.09.95

ANNEX to
Technical Report on Stage A-4

TECHNICAL CHARACTERISTICS of Mock-up Facility "ISMW-CC-1"

1. Purpose - melting and decontamination of chopped fuel rod isotope tagged simulator claddings			
2. Melting capacity,	кg/h	-	< 5
3. Cladding diameter,	mm	-	6-10
4. Cladding length,	mm	-	10-40
5. Cladding material		-	steel 12X18H10T alloy ЭИ-110
6. Flux composition		-	CaF_2 + additives
7. Flux amount	%	-	1-5 of metal mass
8. Crucible type		-	"cold"
9. Crucible diameter,	mm	-	60
10. Height of melting zone,	mm	-	110
11. Number of sections in crucible,	pieces	-	18
12. Material of crucible sections		-	copper M1
13. Temperature of molten mass,	C^0	-	< 2000
14. Cooling of crucible sections, inductor, tray, ganerator, capacitors		-	water
15. Temperature of inlet water,	C^0	-	15-20
16. Temperature of outlet water,	C^0	-	< 60
17. Water flow rate,	m^3/h	-	< 15
18. Type of pulling mechanism drive		-	hydraulic
19. Hydrosystem pressure,	MPa	-	< 18
20. Force on crucible tray,	kgf	-	< 4000
21. Type of feeder		-	plate
22. Type of generator		-	electromechanical
23. Power of generator,	кW	-	100
24. Frequency	Hz	-	2400
25. Total capacity of battery	mcF	-	757,8
26. Gas atmosphere above molten mass		-	technical nitrogen argon
27. Type of filter		-	metal cloth
28. Temperature of off-gases,	C^0	-	< 200
29. Gas flow rate (through leans),	m^3/h	-	< 30
30. Degree of gas clean-up,	%	-	< 99
31. Gas pressure drop in filter,	mm. w. c.	-	< 200
32. Method of filter recovery		-	electric pulse, dynamic
33. Type of gas houster		-	ejector
34. Evacuation,	mm. w. c.	-	< 500
35. Filter capacity (gas)	m^3/h	-	< 35

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Mr. A. Gerard
Deputy Executive Director
ISTC

12.10.1995
ISTC Project N 143-94

Annual Technical Report
on Work Performed for Project 143-94
"Research and Development of Induction Slag Melting Process of High-Level Radioactive Metal Wastes"
First Fiscal Year.

1. The leading Institute, participant of the contract, is A.A. Bochvar ARSRIIM (VNIINM), Moscow.

2. Co-participant of the Project is Science and Production Centre "Inductor", Moscow.

3. Project manager is Pastushkov V.G., senior researcher, ARSRIIM (VNIINM).

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fax: (095) 925-28-96 (Box A-39).

4. The time of the contract is 3 years (from 01.10.94 to 30.09.97).

5. The goal of the project is to study the technology of induction-slag melting Zr-alloys and stainless steel wastes (the ISMW-CC process) and its check-up using simulation materials (chopped cladding simulators) in pilot and demonstration facilities.

In conformity to the project the scope of the work comprises:

- determination of the optimized conditions (technological, electrotechnical etc.) for melting SFA components made of Zr-alloys and stainless steel in induction furnaces with "cold" crucible and making ingots of different diameters and lengths;

- assesment of the extent to which fuel claddings are cleaned from radionuclides by melting using different fluxes;

- investigation of the structure and properties of products resulting from metal waste melting (ingots, slags);

- investigation of the technology of reprocessing resultant secondary wastes (slags, gas phase);

- design, fabrication and test of a pilot equipment for fuel cladding melting.

The technical approach:

- choice and studies of the optimized composition and amount of fluxes;

- induction-slag melting chopped fuel claddings and end-pieces of SFA_S (individually and jointly) with pulling an ingot from the "cold" crucible and immobilizing radionuclides in a solid slag separable from a metal ingot;

- adjustments of technological and electrotechnical parameters of the melting process based on the results of physico-chemical and metallographic analyses of melting products;

-mastering the metal waste melting equipment based on the results of testing the mock-up (ISMW-CC-1) and demonstration (ISMW-CC-2) facilities.

In the course of the project the technology shall be developed and using HAMW simulators pilot equipment shall be checked that is to be used for HAMW conditioning prior to disposal, decontamination and reliable immobilization of remaining long-lived radionuclides (the half-life more than 10^4 years) in metal matricies the rate of leaching from which is less than 10^{-7} g cm^{-2} day^{-1}. Induction slag melting is expected to remove TUE and FP from metal waste at the decontamination factor of more than 500 and to propduce an ingot of a specified mass and shape suitable for disposal.

6-7. In accordance with the technical calendar plan of the project during the period October 1994 - September 1995 the work at stages A-1, A-2, A-3 and A-4 was carried out.During this period the physico-chemical bases of the HAMW induction-slag melting process and design documentation on the mock-up-facility "ISMW-CC-1" were developed; the facility was fabricated, installed and adjusted. The main research directions were formulated in the framework of project N 143-94, specifically:

- optimization of flux compositions used in melting Zr-alloys and stainless steel to improve the decontamination properties of a flux and the hydrolytic stability of resultant slags;
- studies of resultant ingot properties to achieve the highest quality in terms of the subsequent disposal;
- design and tests of devices and mechanisms for loading and metering small-lump and long-size wastes into a crucible for melting as well as devices and mechanisms for pulling ingots from a crucible;
- development of methods and devices for collecting and reprocessing resultant slags.

Based on the formulated technical requirements for the design and lay-out of the facility its design documentation (Project N KB-460.00.000) (see figs. 1, 2 and 3 Annex) has been developed using a rig of the mock-up-facility "ISMW-CC-1" at VNIINM. This facility is employed to master the technology and test equipment of the "ISMW-CC" process using chopped fuel cladding simulators.

The design documentation comprises:

- an assembly drawing of a facility, specifications, drawings of the main units and mechanisms (the melting unit, the hydromechanical drive, metering feeders for charge lumps, a metal cloth filter, an ejector, and a dust separator);
- circuits (an electrical general one of a facility power supply, an electrical general one and those of electrical connections of gauges and automated devices, functional gauges and automated devices, hydraulic and pneumatic ones to control the melting process);
- an explanatory note.

On the basis of the design documentation the mechanisms and system of the mock-up-facility "ISMW-CC-1" have been fabricated and installed at the VNIINM rig (VNIINM, certificate N 57/124 of 26.09.95).

The mock-up facility is composed of:

- a unit for charging fuel rod cladding simulators and a flux; it consists of vibration and plate feeders, a gate device and system of drain pipe-lines;

- a melting unit incorporating a "cold" crucible, an inductor and a "cold" tray. The crucible and the inductor are fabricated from an electrically insulated copper pipe having a specified shape;

- ingot pulling mechanism incorporating a hydromechanical drive and a system of thrusts and levers. The hydrodrive has an electric motor, a V-belt drive, two force hydrocylinders, a filter, a tank for oil, a system of cocks, valves, throttles and pipe-lines;

- a system of water cooling the "cold" crucible, inductor, "cold" tray, generator, capacity battery and matching transformer;

- a system of a gas supply and clean-up incorporating compressed gas (argon or nitrogen) cylinders, two successively installed recoverable metal cloth filters, a control unit, a compressor-gas flow-rate booster and an ejection device to create the specified evacuation of the system;

- a system to check-up and control the melting process incorporating several subsystems: a subsystem to stabilize the temperature, flow rate and electric power of melting; a subsystem to check-up and control the rate of a "cold" tray travel up and down; a subsystem to control gas supply and clean-up, a subsystem to control the cooling temperature and flow rate.

The mock-up facility "ISMW-CC-1" was installed in conformity to the developed instrumentation - process flow sheet, electrical, assembly, hydraulic and pneumatic schemas.

After the above mentioned units, mechanisms and systems were installed the start up-adjustments of the whole facility were performed and the facility was approved for operation with the aim of its mechanical and electrical testing (VNIINM, certificate, N 58/124 of 25.09.95). (The mock-up facility has characteristics listed in the table (see the Annex).

The scope of work planned for the first year of the project is completely fulfilled.

Aside from the work planned for stages A-1 - A-4 of the calendar plan the work for other stages of the plan was carried out. Specifically, the following was accomplished:

- recomendations on creation and operation of a system to check-up and control the "ISMW-CC" process;

- a general schema of a system for supplying gases to the zone of waste melting and off-gas clean-up to remove dust and aerosols;

- techniques of analysis of micro- and macrocomponents of initial fluxes and products of melting (ingots and slags);

- a technique for preparation of simulators from chopped Zr-alloy and stainless steel fuel claddings;

- patent and licensing studies are in progress to determine the technical level and the patent purity of the "ISMW-CC" process that is under development.

8. The work on the Project is in progress according to the schedule (the calendar plan). In future the following is to be done in accordance with the calendar plan:

- during the 2-nd year the electrotechnical and technological characteristics of the process of fuel cladding simulators melting are to be investigated, the design documentation is to be developed and a demonstration facility is to be fabricated;

- during the 3-d year it is planned to investigate the properties and technology of resultant slag reprocessing and the degree of cleaning the fuel cladding metal from radionuclides as well as to test the demonstration facility.

9. In February 20 to 23.02.95, VNIINM specialists Mr. Pastushkov V.G. and Mr. Mikheikin S.V. participated in the International Symposium (Sponsored by ISTC) that was held at VNIITPh (Snezhinsk city) and was devoted to the ecology problems in nuclear industry. Presentations were made dealing with the activities at VNIINM on Project N 143 and the ways of resolving problems relevant to solid active waste reprocessing.

In September 27, 1995, representatives from Japan as a funding party (Science and Technology Agency , PNC and JAERI) audited at the site the activities performed at VNIINM in relation to Project N 143-94 in the 1-st fiscal year. The numerous questions put by the Japanese auditors received the well-reasoned and comprehensive answers of the VNIINM specialists.

In the discussion of the results of the audit made by the Japanese experts the latter expressed their satifaction with the progress of the activities, the organization and reports on the project and declared their intention to inform their authorities of the advisability of further funding the project.

10. No delays or unresolvable problems relevant to the activities on the project were encountered.

In connection with a dramatic increase of prices for materials and equipment in 1995 in Russia and the underutilization of funds allocated on the Project in the 1-st fiscal year for other direct expenses and business-trips after the coordination with the ISTC in the 3-d quarter of 1995 the funds were redistributed to the "equipment" and "materials". A similar redistribution of funds would be advisable for 2-nd fiscal year.

11. The review report (VNIINM, N 8314, 1994) describes in detail the metal waste (the composition and quantity of structural materials in spent FA_s of different reactors, the radiochemical characteristics of chopped fuel claddings, their technological properties after fuel reprocessing). Consideration is given to the specific processes suggested for conditioning fuel claddings to be long-term stored and disposed. A detailed description is given of the technological and electrotechnical features of the process of induction slag metal waste melting in furnaces with a "cold" crucible.

Initial data have been acquired to choose salt systems promising for use as fluxes in process of induction slag high activity metal waste melting (VNIINM, N 8437, 1995).

Consideration was given to the state of impurities in metal during melting and the properties of fluoride and oxi-fluoride salt system.

The technology was described that is used to synthetize mixtures of salts for fluxes as well as the requirements were formulated for slags to be disposed of.

An assesment has been made of the thermodynamic probability of interaction between components of an oxide film on fuel claddings and metals (Zr, Fe, Cr, Ni, Al, Si) and fluorides (NaF, MgF_2, CaF_2, BaF_2, AlF_3) (VNIINM, N 8436, 1995).

Comparison was made between calculated values of the temperature dependence of the isobaric-isothermal potential and equilibrium constants in reactions between oxides of fuel components, fission products, structural metals and fluorides and metals. Al, Mg and Ca fluorides and Al and Si as deoxidants are shown to be promising.

VNIINM Deputy director A.S. Polyakov

Manager of Project N 143-94 V.G. Pastushkov

Annex

P. 1. The management of the staff attracted to work for the Project was carried out in accordance to the schema given in Fig.4 of the Annex. Altogether 69 specialists (61 belong to VNIINM and 8 belong to SPC " Inductor ") were engaged in the work on Project N 143 - 94 during the year. For different reasons 11 VNIINM specialists not embarking upon the work were replaced by other specialists having the same qualification. In connection with the completion of the Project work in the 3-d quarter of 1995 4 VNIINM specialists left the personnel team.

P. 2. In conformity to the approximate nomenclature of non - basic equipment given in the Plan of the Work 2 personal computer of 486DX2 type, a laser printer of HP-4Plus type, a jet printer of HP Desk-Jet 1200C type, a scanner of Scan Jet IIcx type, a copier of Canon FC-330 type, 2 telephone sets of Panasonic have been acquired. After the coordination with the project monitor Mr. Sh. Kato a matrix printer of Epson LQ-1170 type was acqured in place of the planned computer of note-book type and degitizer.

To accomplish the installation and adjustment of the system checking and controlling the "ISMW-CC" process and the electronic power supply system of the facility secondary devices (supply units, amplifiers, couples), a matching high-frequency transformer, polyethylene pipelines (hoses), copper tubes and a current carrying element.

For studying the properties of fluxes and slags a high temperature furnace of 3.1650 HT type was acquired that allows the synthesis of salt system in air at temperature up to 1600 ^{0}C.

Different salts, oxides and other raw and laboratory materials were acquired that are needed to prepare fluxes and investigate slags.

Tubes, bars and semi-products of Zr-alloys and stainless steel were acquired to prepare chopped fuel cladding simulators.

Process flow sheet of cladding melting

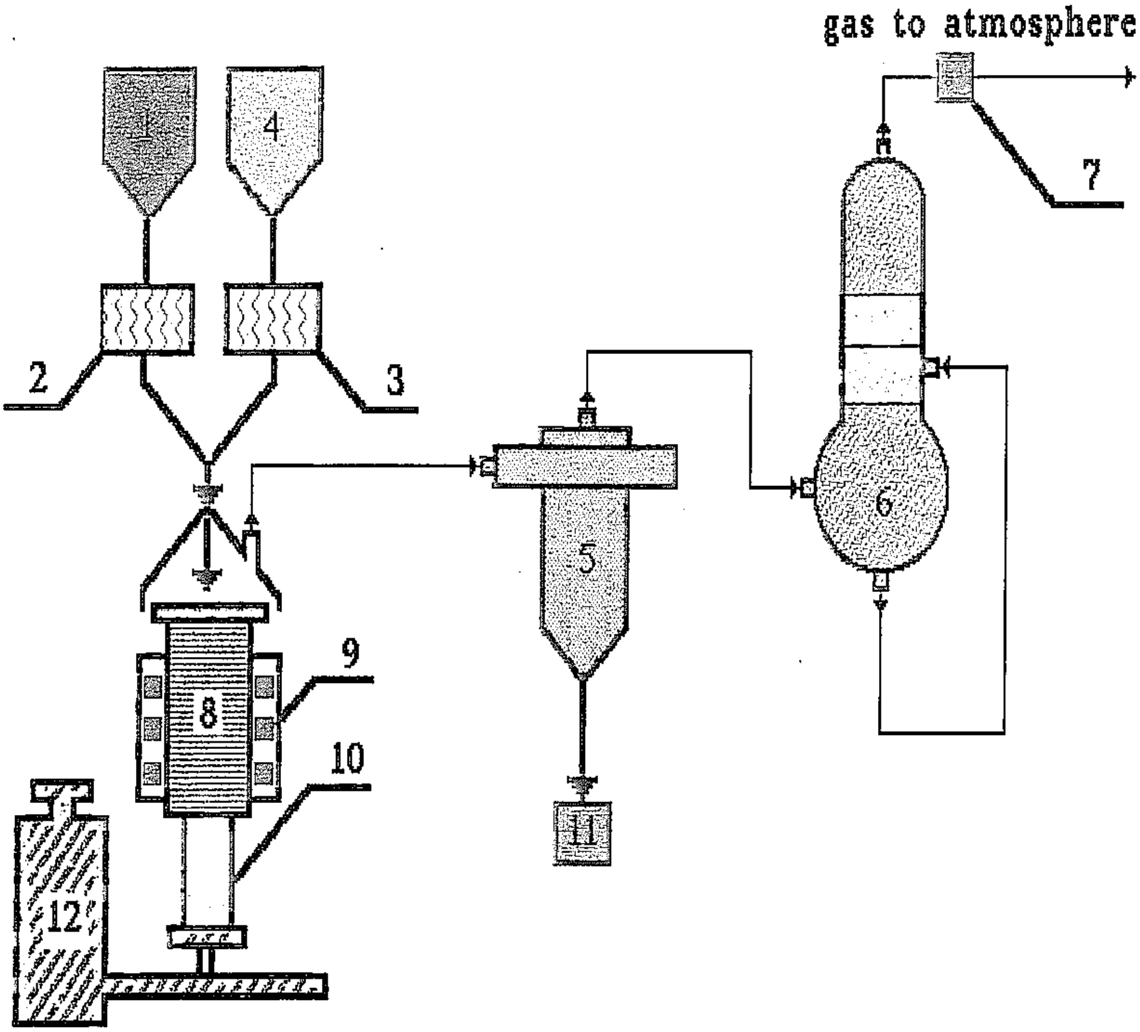


Fig. 1

1. Hopper for cladding.	**2. Cladding meter.**
3. Flux meter.	**4. Hopper for flux.**
5. Dust separator.	**6. Scrubbing column.**
7. Filter.	**8. Cold crucible.**
9. Inductor.	**10. Ingot.**
11. Container for dust.	**12. Device for ingot extension.**

Sheme of melting with extension

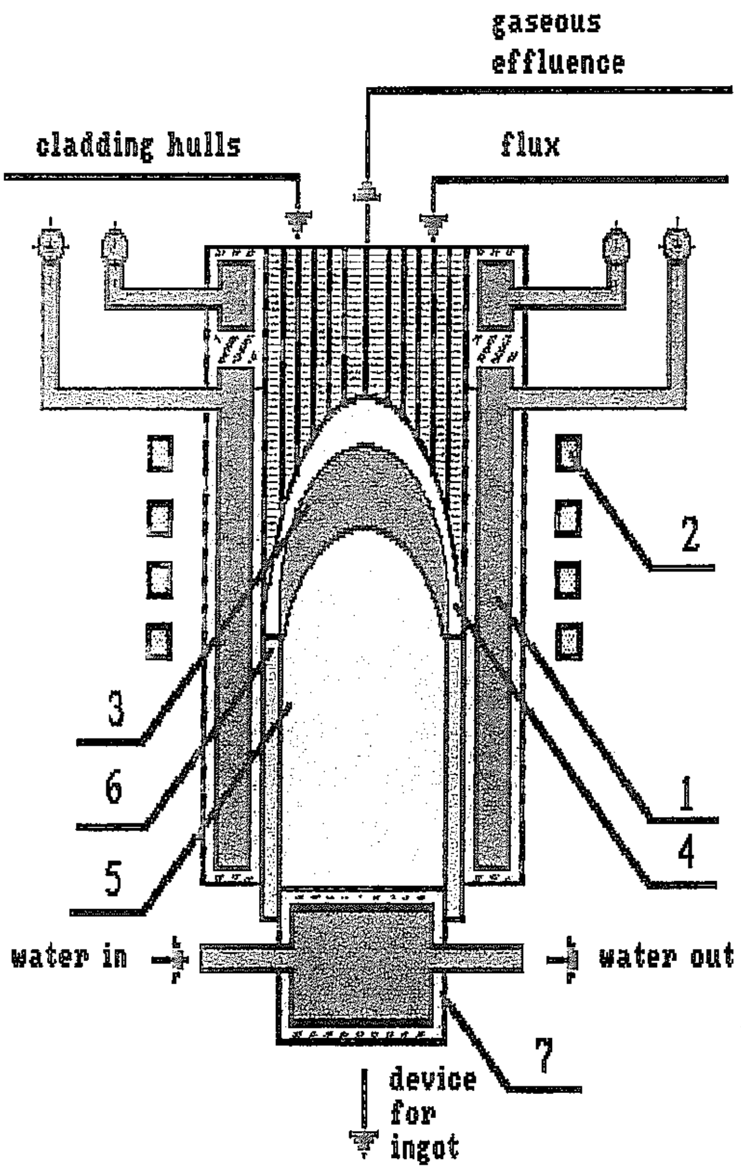


Fig. 2

1. Cooled body.
2. Inductor coil.
3. Melting sone.
4. Liquid slag.
5. Ingot.
6. Solid slag.
7. Cooled hearth.

Scheme of Mock-up Facility "ISMW - CC-1"

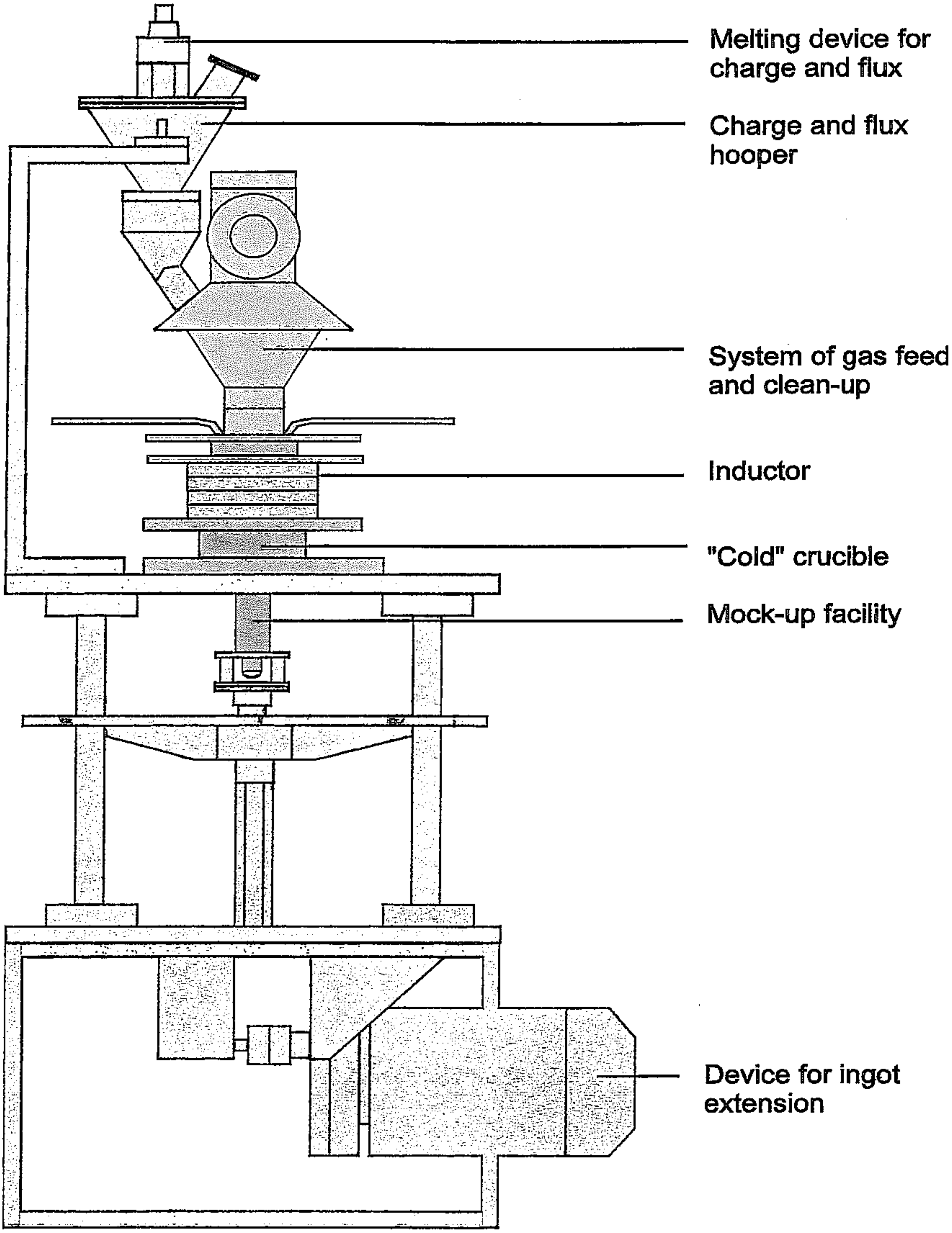


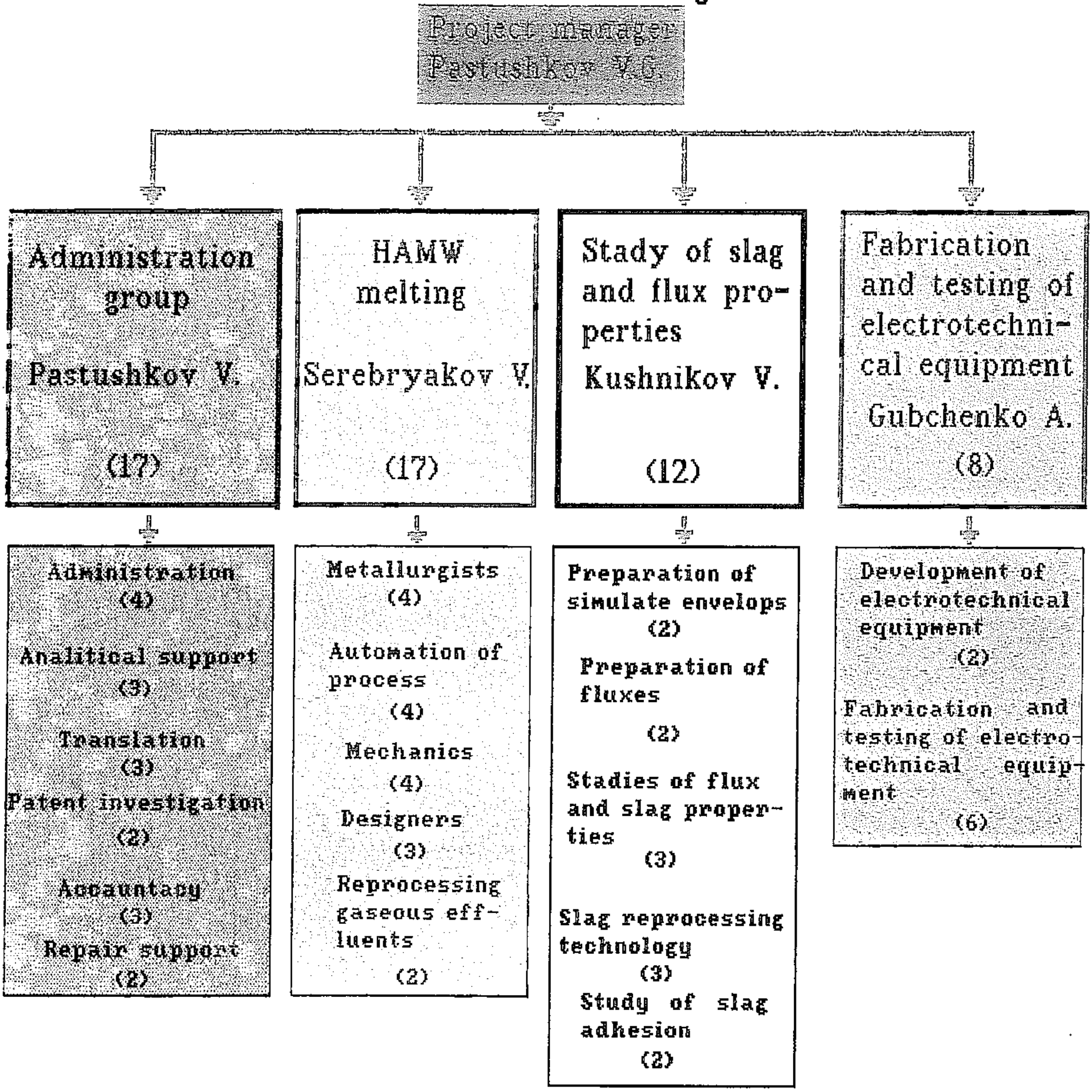
Fig. 3

TECHNICAL CHARACTERISTICS
of Mock-up Facility "ISMW-CC-1"

1. Purpose - melting and decontamination of chopped fuel rod isotope tagged simulator claddings

2. Melting capacity,	кg/h	-	< 5
3. Cladding diameter,	mm	-	6-10
4. Cladding length,	mm	-	10-40
5. Cladding material		-	steel 12X18H10T alloy Zr - Nb
6. Flux composition		-	CaF_2 + additives
7. Flux amount	%	-	1-5 of metal mass
8. Crucible type		-	"cold"
9. Crucible diameter,	mm	-	60
10.Height of melting zone,	mm	-	110
11.Number of sections in crucible,	pieces	-	18
12.Material of crucible sections		-	copper M1
13.Temperature of molten mass,	^0C	-	< 2000
14.Cooling of crucible sections, inductor, tray, generator, capacitors		-	water
15.Temperature of inlet water,	^0C	-	15-20
16.Temperature of outlet water,	^0C	-	< 60
17.Water flow rate,	m^3/h	-	< 15
18.Type of pulling mechanism drive		-	hydraulic
19.Hydrosystem pressure,	MP	-	< 18
20.Force on crucible tray,	kgf	-	< 4000
21.Type of feeder		-	plate
22.Type of generator		-	electromechanical
23.Power of generator,	кW	-	100
24.Frequency	Hz	-	2400
25.Total capacity of battery	mcF	-	757,8
26.Gas atmosphere above molten mass		-	technical nitrogen argon
27.Type of filter		-	metal cloth
28.Temperature of off-gases,	^0C	-	< 200
29.Gas flow rate (through leans),	m^3/h	-	< 30
30.Degree of gas clean-up,	%	-	< 99
31.Gas pressure drop in filter,	mm. w. c.	-	< 200
32.Method of filter recovery		-	electric pulse, dynamic
33.Type of gas holster		-	ejector
34.Evacuation,	mm. w. c.	-	< 500
35.Filter capacity (gas)	m^3/h	-	< 35

Scheme of Project Management



5. その他関連資料

Proceedings of The Sixth International Iron and Steel Congress, 1990, Nagoya, ISIJ

INDUCTION VACUUM MELTING IN A COLD CRUCIBLE

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VNIIETO, USSR

Synopsis:

Induction method of melting precludes contamination of the molten metal with a crucible material and provides additional refining of the melt.
Vacuum induction melting of metals in cold crucible is applied for: smelting complex alloys with big content of components greatly differing by their physical properties, refining melting, production of high-pure shaped castings, heat reduction of metals out of their compounds, retreatment of wastes from rare and precious metals as well as their alloys.
At present produced in the USSR are vacuum induction furnaces with cold crucibles with diameters from 0.04 m up to 1.0 m and volume from 1 up to 1500 l for various aims, viz.: production of ingots, preparation of alloys, shape casting (of which: with bottom tapping of the molten metal), reduction and refining of metals.

Induction melting in a metallic sectioned cooled crucible (cold crucible) is carried on for producing materials of high purity mainly on the basis of refractory and chemically active metals. Such a method of melting precludes a possibility of contaminating the molten metal with the crucible materials and it creates conditions for its additional refining.

Induction furnaces with a cold crucible (IFCCs) are melting initial charge materials and treat technologically the molten metal in conditions precluding any interaction of the charge with the crucible material and the ambient atmosphere.

During melting, the temperature at the crucible walls in the zone of contacting with the molten metal is maintained sufficiently low, which results that any interaction of the melt with the crucible material is absolutely excluded.

Due to combining at the IFCCs of a relatively cool metallic crucible surface in the zone of contacting with the molten metal, volumetric induction heating and a possibility of electromagnetic agitation and removal of the melt from the crucible walls, these furnaces are featuring the following positive properties: contamination of the molten metal precluded; possible simultaneous melting-down of the whole charge loaded into a crucible and holding the molten metal at a pre-given temperature for a necessary time-limit; availability of intensive electromagnatic agitation of the liquid metal without additional special devices, that allows to obtain the melt bath uniform in chemical composition and temperature; possibility to melt any type of charge materials, e.g.: lumps, powder, scale, sponge, shavings, etc. without preliminary preparation of electrodes thereout of; possible control of the crystallization front shape and ingot solidifying structure; availability of the melt developed free surface on account of electromagnetic removal of the molten metal from the crucible walls (Fig.2), that allows to intensity the processes of refining; possible electromagnetic weighting of relatively light additives, which allows to produce sophisticated alloys with extended numbers of components (up to 50% by mass) greatly differing from each other in melting points, densities and elasticities of vapours; possibilities of operating with any controlled atmosphere at any pressure values, etc.

By present, the experiments have confirmed a possibility of melting efficiently at the IFCCs of various metals and alloys /2/, viz.: titanium, tantalum, zirconium, niobium, copper, uranium, nickel, chromium, ittrium, lanthanum, cerium, molibdenum, silicon, tungsten, vanadium, etc. Produced have been various alloys, viz.: aluminium with zirconium (content of aluminium - 50 to 51% by mass), chromium with lanthanum, vanadium with helium, superalloys, etc.

It shall be most expedient to apply an IFCC for the following processes: smelting of sophisticated alloys with a wide range of components greatly differing by their physical properties; refining melting of chemically active and refractory metals; production of high-quality super-pure shaped castings; thermic reduction of metals out of their compounds, e.g.: oxides, fluorides, chlorides, etc.; retreatment of wastes from chemically active and refractory metals as well as various alloys; directed crystallization of a metal at the continuous production of ingots; manufacturing of metallic powders, etc.

By their production aims, the IFCCs might be subdivided into two types: for producing a metallic ingot at a cold crucible (Fig.1) and for producing castings (Fig.2). Table 1 gives the main technical data on some IFCCs for production of metals and alloys.

Table 1

Basic Technical Data on Some IFCCs

Parameters	Types of Electric Furnaces			
	ISV	IKVH	ITVH	INVH
Cold crucible capacity, l	230	670	20	20
Cold crucible diameter, m	0.2; 0.5	0.65	0.25	0.25
Permissible temperature of the melt in a crucible, °C	2600	2600	2500	2500
Vacuum in melting chamber, Pa	0.133	0.133	0.133	0.133
Frequency converter power, kW	1500	2000	1000	1000
Work-coil current frequency, Hz	2400	2400	2400	2400
Work-coil voltage, V	800	800	800	800
Quantity and power values of plasma generators, pcs/kW	-	-	2/250	1/250
Dimensions, m	11x6	10.6x8.3	10x5	10x9.5
Height	13.5	10	8	6.5
Mass, t	70	85	50	70

The ISV electric furnaces are designed for refining the melting of various metals. They are completed with replaceable crucibles of 0.2 and 0.5-m diameters. A height of an ingot smelted is up to 2 m.

The IKVH furnaces are designed for thermic reduction of metals. A unit consists of four melting chambers unified by a common vacuum system and one set of electrical equipment. Each melting chamber contains a powerful sectioned water-cooled crucible of 0.65 diameter and 2.0-m height with a work-coil. It is also equipped with travel mechanisms and unloading devices with an individual capacitor battery.

Processes of charging, melting, cooling the reaction products and unloading are carried on in each chamber in sequence (with the shifting in time relative to the other chambers).

The ITVH and INYH furnaces are designed for the production of high-purity shaped castings. The molten metal is tapped from a cold crucible through a copper cooled spout while the crucible is turned. The electric furnaces have two independent sources of heating, viz.: an induction one and an electron-plasma one, that can operate both simultaneously and separately. The molten metal could be tapped from the crucible either into a mould placed on a centrifugal table, or in a mould located at the pre-heating furnace, or in a metal mould.

The IFCCs feature a number of essential peculiarities, which make it different from conventional induction crucible furnaces. The main one of those peculiarities is the availability of a charging direct contact, including that of liquid metal with the crucible metallic surface cooled intensively. This causes big heat losses and makes an operator work at high induction values (for the given frequency) so as to secure a satisfactory efficiency of the unit. As a result, by means of a magnetic field, a considerable portion of the melt (meniscus) is removed from the crucible walls and that is combined with a relatively high rate of melting. Thus, the process of melting is carried on at the electromagnetic crucible

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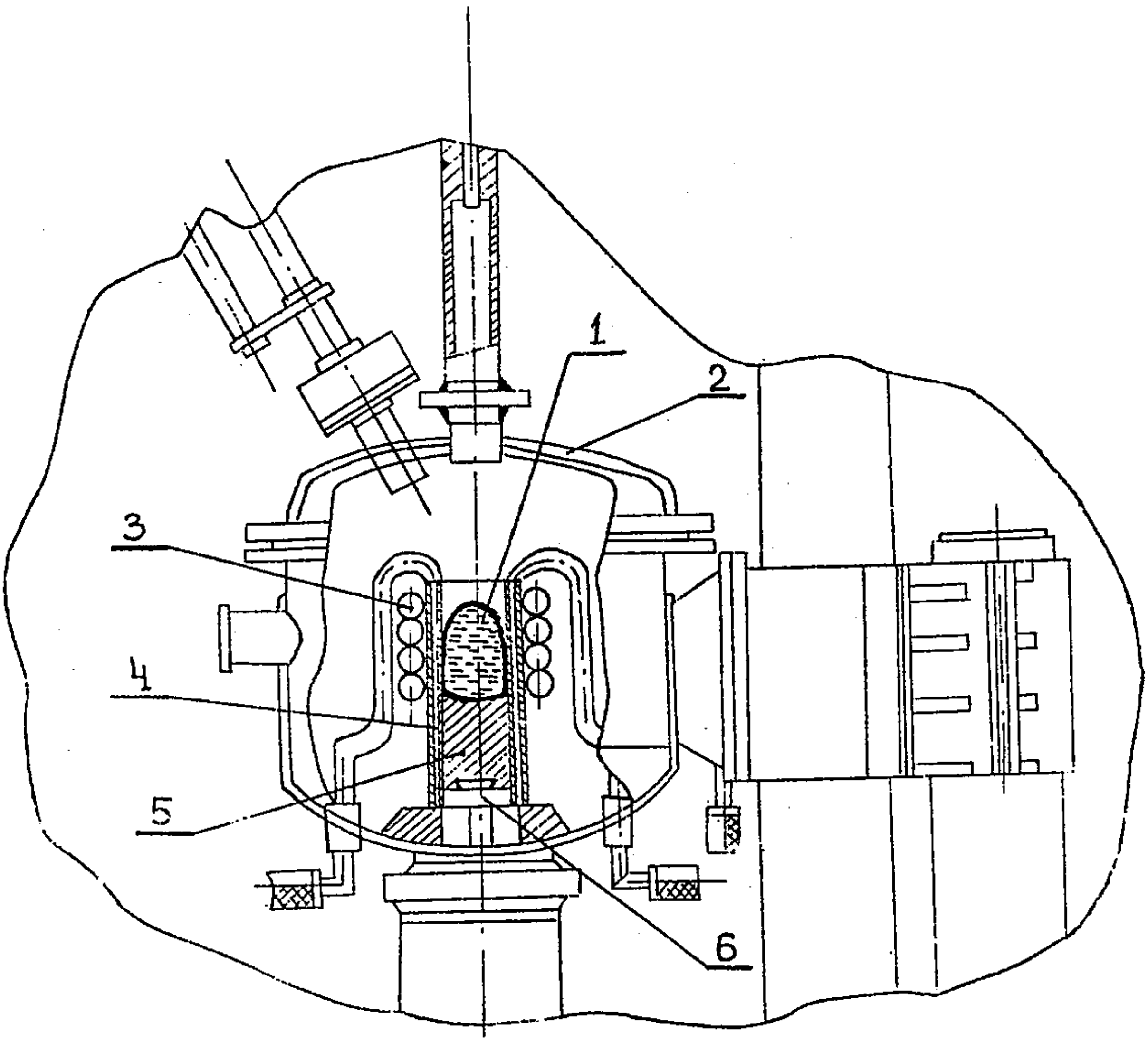

Fig.1
Generator view of an induction furnace with cold crucible:
1 - Molten metal; 2 - Vacuum chamber; 3 - Work-coil;
4 - Cold crucible; 5 - Ingot; 6 - Hearth.

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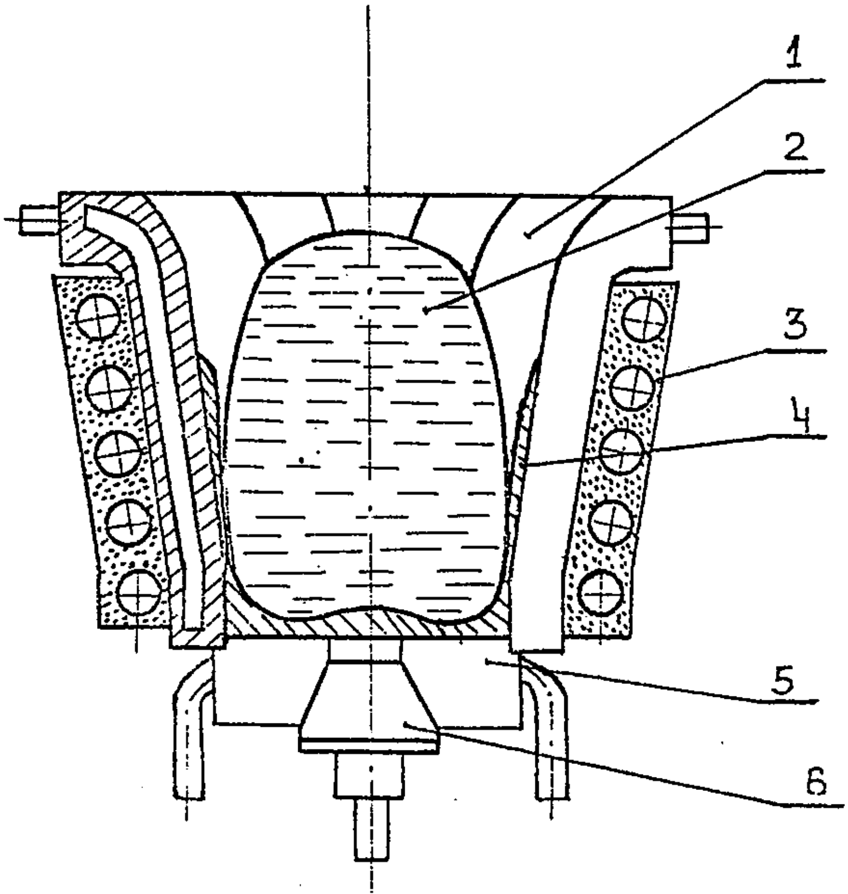

Fig.2

A sketch of the IFCC with bottom tapping of the molten metal:

1 - Cold crucinle; 2 - Molten metal; 3 - Work-coil;
4 - Skull; 5 - Hearth; 6 - Plug.

on a support /3/. Hydrodynamic non-stability of the meniscus causes non-stationary distortions of its surface, mainly in the shape of vertical folds. Dimensions of those folds cross-sections are usually of the same order with a depth of current penetrating into the molten metal. Therefore, their availability tells on the absorpzion of the field energy by the meniscus.

Availability in the zone of a powerful alternating electromagnetic field of the current conducting crucible elements has caused a necessity to survey voltages appearing thereinbetween and take certain steps for preventing damages to the crucible with electrical break-downs arising. The essence of the phenomenon is such that appearing at the powerful electromagnetic field at a cold crucible are considerable electromotive guidance forces. The crucible is flown along by high currents, a path of which could cross over the interface of the crucible with the molten metal. The melt surface adjoining to the crucible is non-stable, the contact zones available are disappearing periodically and new ones are arising.

Therefore in some conditions, discharges might appear in the shape of sparkings or arcs burning at the crucible furnace, which under certain circumstances might present a danger for the furnace normal operation. This problem is most essential while melting in vacuum. The discharges might also appear inbetween the crucible sections.

Substantial importance is attached only to those discharges, that might damage a construction of the furnace, viz.: formation of craters, burn-through, etc. One should note that damages of constructive elements even at a direct discharge thereonto are not inevitable due to the fact that the discharge effects depend on both its intensity and the intensity of heat to be removed at the discharge zone.

A necessary prerequisite of the operating IFCCs shall be high values of the energy density to be transfered to the molten metal. This problem required in particular to select on a substantiated basis a design and a number of sections in the crucible with due account to the field frequency and electrical contact resistance at the cold crucible/molten metal interface.

To survey the processes and select design decisions, developed have been methodics of digital modeling of electromagnetic and hydrodynamic fields at the IFCCs /4/.

The energy in-coming to the IFCC work-coil is consumed for electrical losses at the work-coil cold crucible sections and hearth as well as for the liberation of heat in the charge. In its turn this heat is consumed for heating up the charge and for thermal loss from charging to the walls of a cold crucible, to a hearth and into the furnace work space.

Table 2 gives data on some materials (metals) of the IFCC energy balance components in conditions of holding the molten metal /2/:

Table 2

Energy Balance of IFCC in Conditions of Holding the Molten Metal, %

Ser. Nos	Parameters	Super-Alloy	Chromium	Titanium
1.	Power given to converters	100	100	100
2.	Losses at the current lead	18.8	15.7	26.6
3.	Losses at capacitors	7.5	6.7	7.2
4.	Power coming to the work-coil	73.7	77.6	66.2
5.	Electrical losses at work-coil	16.7	19.2	24.3
6.	Electrical and thermal loss at the cold crucible	40.2	48.9	38.5
7.	Electrical and thermal loss at the hearth	6.8	9.5	3.4
8.	Electrical efficiency of IFCC	0.31	0.24	0.34

Table 3 gives experimental data on melting some metals at the IFCC /2/. Overall efficiency of the furnace per one cycle is determined by a relevant value of electrical efficiency, which does not depend actually on the process rates, and by a value of thermal efficiency, which depends directly on the process duration.

In a number of cases, applied for the IFCCs is an additional source of heating, the energy of which is not consumed for passing through a cold crucible. With a view to the above, utilized thereat is a plasma generator, which (beside heightening the effeciency) is providing also further extension of electric furnace technological possibilities (Fig.3)/1/.

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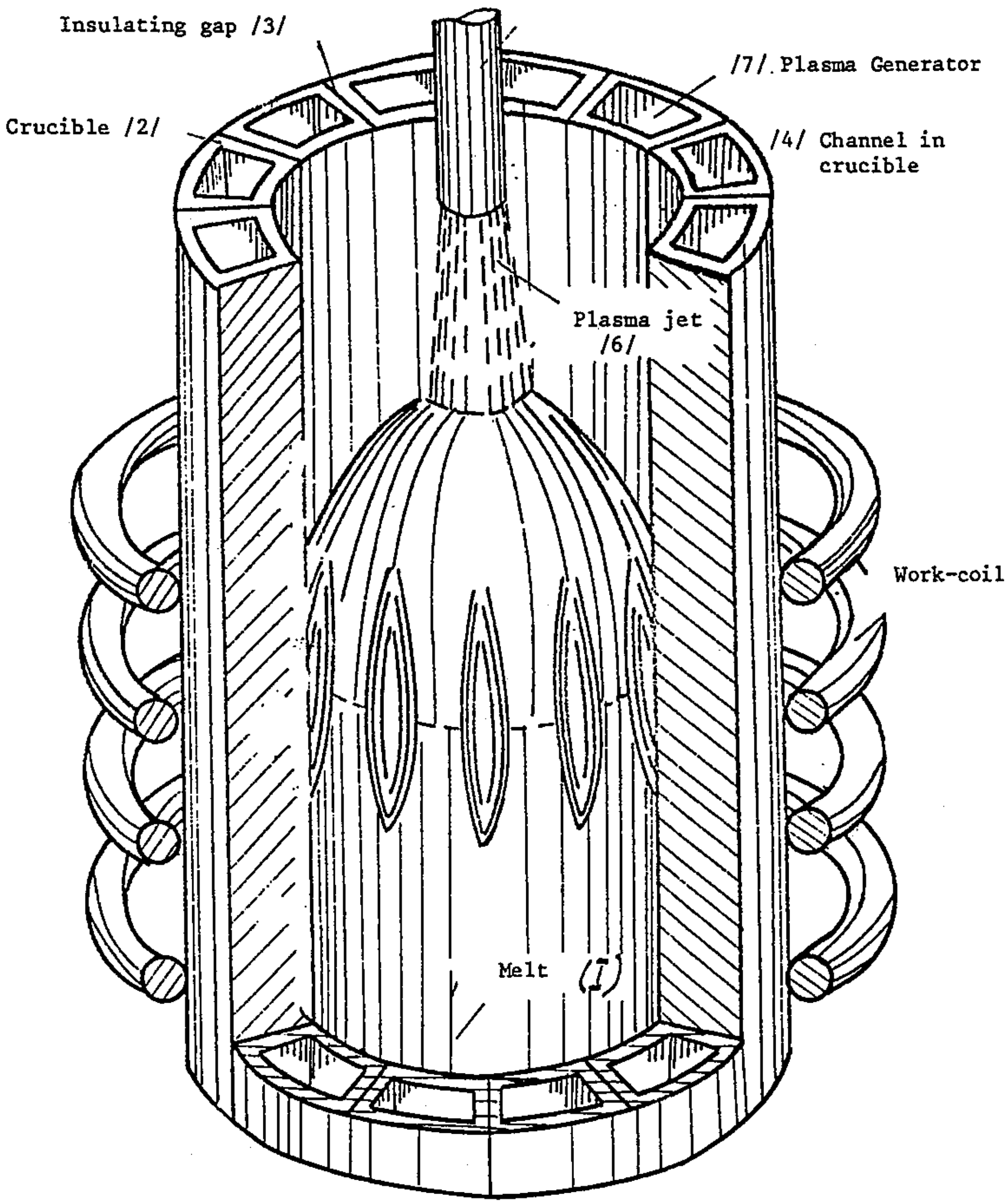

Fig.3

Diagram of the IFCC with a vacuum plasma generator

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Table 3

Specific Consumption of Electric Power and Overall Efficiency of the IFCC While Melting Some Metals in Periodic Duty

Parameters	Super--Alloy	Cr	Ti	Gd	Y	La	Ni
Specific consumption of electric power for melting-down, kWh/kg	2.1	3.2	2.3	1.1	2.2	1.2	5.0
Averaged efficiency of the IFCC for a period of melting	0.16	0.12	0.18	0.08	0.07	0.05	0.07

Produced at present in the USSR are the IFCCs with a cold crucible having diameters-from 0.06 m up to 1.0 m and heights - up to 2.5 m of various designs: for producing ingots, preparation of alloys, shape casting and refning of metals, as well as reduction thereof.

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ELECTROMAGNETIC (EM) AND HYDRODYNAMIC FIELDS MODELLING IN THE INDUCTION FURNACE WITH COLD CRUCIBLE

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Synopsis: Physical processes in induction furnaces with cold crucible (IFCC) are investigated. Paper offers system of 2D mathematical models and corresponding programs on PC for (i) EM an HD fields calculation, taking into account influence of sectioned conducting crucible on currents redistribution, particularly at small penetration depth of field in crucible and melt; (ii) temperature field calculation in horizontal cross - section of crucible; (iii) melt free surface form detection. Following numerical methods are used: finite difference method (FDM) for HD and EM fields, boundary element method (BEM) for temperature and EM fields in a case of high frequencies.

Key words: IFCC, EM field, temperature field, hydrodinamics, free surface, finite difference, boundary element.

1. Introduction.

Induction furnaces with cold crucible (IFCC) are perspective electrothermal equipment for melting metals and alloys (mainly chemical aggresive or with high melting temperature) without melt pollution from crucible walls [1-5]. Certain differences of IFCC from IF with ceramics crucible are following.

(i) Conducting (frequently copper), vertically sectioned with electroisolation gaps crucible under forced cooling (Fig.1).

(ii) Electromagnetic (EM) repulsing of remarkable part of melt side surface from crucible, decreasing heat losses.

Presence of sectioned conducting crucible provides penetration of inductors EM field into melt even at such field frequencies, at which unsectioned furnace works as ideal field screen.

On the other hand conducting sectioned crucible essentially disturbs characteristic axial symmetry of vortical currents in IFCC, however system

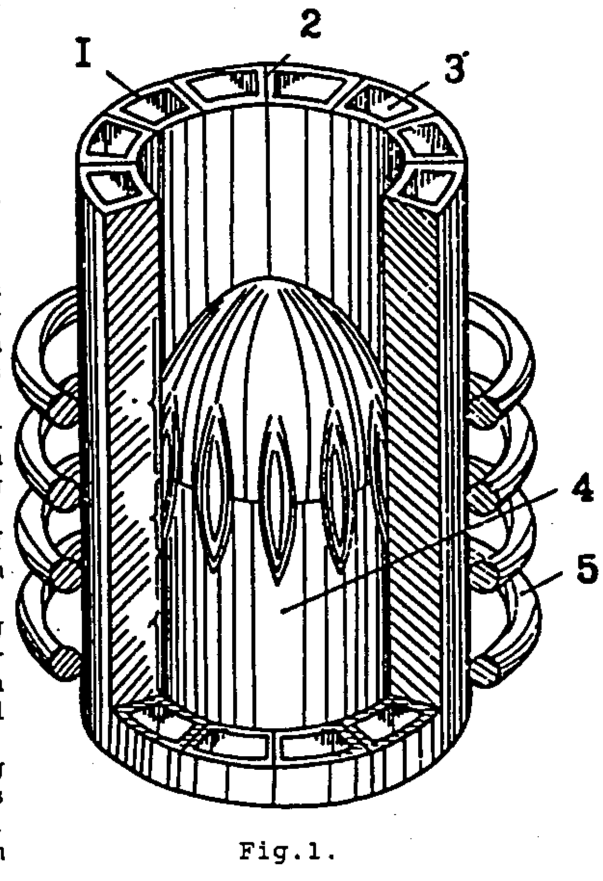

Fig.1.

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"inductor - crucible - melt" still keeps the bend symmetry. So, for the investigations of EM and hydrodynamical (HD) fields, IFCC appears a 3D object. However, necessity of great number field calculations essentially increases expense of investigations using 3D mathematical models. For the exploration of MHD-processes in IFCC chain of 2D mathematical models in horizontal (z=const) and vertical (α=const) cross sections, based on physically and experimentally grounded assumptions, is offered. Usage of 2D models facilitates detection and analysis of general factors affecting characteristics of IFCC.

Still last years untouched region of investigations are problems, deal with temperature field calculation in crucible section to provide defense of its erosion and melt free surface shape detection, essentially influencing EM and energetic characteristics of IFCC.

This paper offers system of 2D mathematical models and corresponding programs on PC allowing

- EM and HD fields calculation in vertical cross section of IFCC, taking into account influence of sectioned conducting crucible on currents redistribution, particularly at small penetration depth of field in crucible and/or melt;
- temperature field calculation in horizontal cross-section of crucible;
- melt free surface form detection in IFCC.

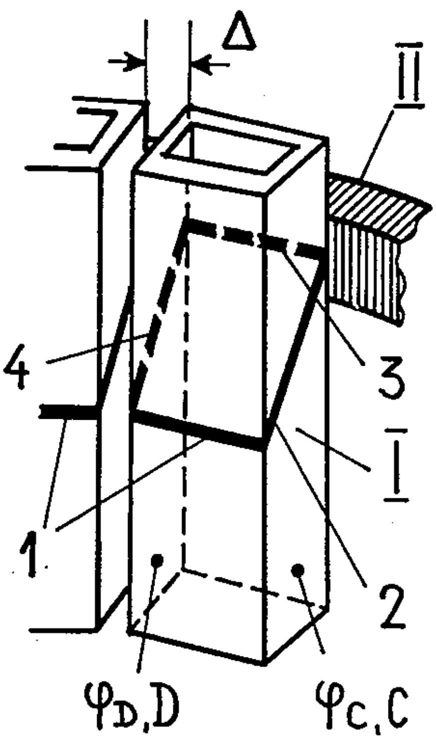

Fig.2.

2. EM field calculation in IFCC.

EM field in IFCC is 3D owing division of crucible into isolated sections. This produces current not only in azimuthal direction as in axysymmetric induction devices, but also current in (r,z) planes, mainly in side walls of crucible sections (Fig.2). Let us consider ways of development of 2D models describing 3D effects in furnace as

(i) redistribution of currents in side walls of crucible;

(ii) passing of currents through unaxysymmetric contacts "crucible - melt".

Equation system for EM field

$$rot\ \bar{B} = \mu_0\ \bar{j};\quad rot\ \bar{E} = -\ \partial\bar{B}/\partial t;$$
$$div\ \bar{B} = 0;\quad div\ \bar{j} = 0;\quad \bar{j} = \sigma\ \bar{E} \qquad (1)$$

leads to equation for vector potential of EM field $\bar{A}'$ ($\bar{B} = rot\ \bar{A}'$)

$$\Delta\ \bar{A}' = \mu_0\ \sigma\ \bar{E},\qquad \bar{E} = -\ \partial\bar{A}/\partial t - grad\ \varphi' + \bar{j}^{EX}\ /\ \sigma \qquad (2)$$

In practical case of sinusoidal inductor's current $\bar{A}' = \bar{A}\ e^{i\omega t}$, $\varphi' = \varphi e^{i\omega t}$,

$$\Delta\ \bar{A} = \mu_0\ \sigma\ (i\ \omega\ \bar{A} + grad\ \varphi) + \bar{j}^{EX}\ /\ \sigma, \qquad (3)$$

or in dimensionless form

$$\Delta\ \bar{A} = \omega^*\ (i\ \bar{A} + grad\ \varphi) + \bar{j}^{EX}, \qquad (4)$$

where $\omega^* = \mu_0\ \sigma_C\ \omega\ r_0^2 = \omega_C$ in crucible sections, $\omega^* = \mu_0 \cdot \sigma_M\ \omega\ r_0^2 = \omega_M$ in melt, external current $\bar{j}^{EX} = \bar{e}_\alpha$ in inductor, $\bar{A} \Rightarrow \bar{A}\ /\ A_0$, $A_0 = \mu_0\ r_0^2 j^{EX}$, $\varphi \Rightarrow \varphi\ /\varphi_0$, $\varphi_0 = r_0\ A_0\ \omega_0$, r_0 - radius of melt (Fig.2).

For 2D models development, following assumptions are considered

(i) Azimuthal orientation of currents in melt, inductor, front and back walls of crucible (pieces 1 and 3 of current path Fig.2);

(ii) Biparted erasure of magnetic fields of closely passing currents of opposite directions in crucible side walls (pieces 2 and 4 of current path Fig.2), i.e. due the bend symmetry of crucible these currents are equal, opposite and pass close enough each other.

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(iii) Magnetic field of azimuthal currents is still axysymmetric, i.e. gap between crucible sections is much less than width of section in azimuthal direction and can be neglected in EM field calculation.

Under such assumptions magnetic field is generated by only azimuthal currents $\bar{j} = j\ \bar{e}_\alpha$ and only $\bar{A} = A\ \bar{e}_\alpha$ can be considered. On this basis a chain of models is developed for EM field calculation in (r,z) plane.

2.1. Model of ideal crucible side walls conductivity.

Current density in front and back walls (regions Ω_2 and Ω_3, Fig.3)

$$j\ \bar{e}_\alpha = -\ \omega_C\ (i\ A\ \bar{e}_\alpha + \partial\varphi/\partial\alpha\ \bar{e}_\alpha\ /\ r), \quad (5)$$

but in melt due to axial symmetry

$$j\ \bar{e}_\alpha = -\ \omega_M\ i\ A\ \bar{e}_\alpha . \quad (6)$$

Distribution of A and φ in crucible inner and outer walls must satisfy law of currents conservation

$$\int_{\Omega_2} (i\ A + \frac{1}{r}\frac{\partial\varphi}{\partial\alpha})\ dr\ dz + \int_{\Omega_3} (i\ A + \frac{1}{r}\frac{\partial\varphi}{\partial\alpha})\ dr\ dz = 0. \quad (7)$$

In this model an additional assumption is accepted: let $\partial\varphi/\partial\alpha = const$, i.e. conductivity of crucible side walls is infinite, any redistribution of currents along height of crucible, satisfying (7), is allowed in side walls. The (7) leads to equation for $\partial\varphi/\partial\alpha$

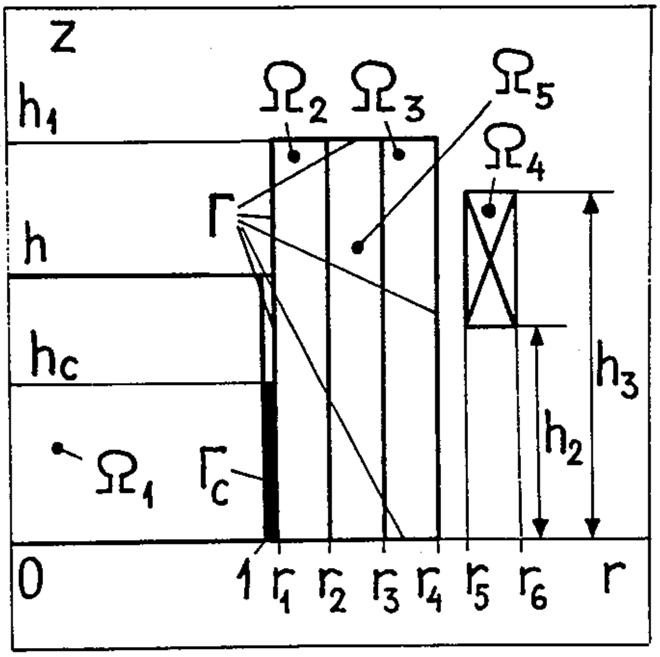

Fig.3.

$$\partial\varphi/\partial\alpha = -i\ \left[\int_{\Omega_2} A\ drdz + \int_{\Omega_3} A\ drdz\right] \Big/ \left[\int_{\Omega_2} drdz\ /\ r + \int_{\Omega_3} drdz\ /\ r\right] \quad (8)$$

and resulting system of EM-field equations (8+9)

$$\frac{1}{r}\frac{\partial}{\partial r}(r\ \frac{\partial A}{\partial r}) + \frac{\partial^2 A}{\partial z^2} - \frac{A}{r^2} = j,$$

$$j = \begin{cases} -\omega_M\ i\ A & \text{in } \Omega_1 \\ -\omega_C\ (i\ A+1/r\ \partial\varphi/\alpha) & \text{in } \Omega_2,\ \Omega_3 \\ 1 & \text{in } \Omega_4 \\ 0 & \text{in outer space} \end{cases} \quad (9)$$

For solution of (8,9) with boundary conditions of A=0 on infinity an iterative algorithm is developed with finite - difference approximation of (9) and $\partial\varphi/\partial\alpha$ calculation after each iteration.

Ideas of chapter 2.1 are close with [6].

An example of current density and corresponding current phase distribution along Z-axis is shown on Fig.4.a (current) and Fig. 4.b (phase) in melt (1) inner (2) and outer (3) crucible walls. In these figures ω_M= 10, ω_C= 100, inductor positioned in front of melt.

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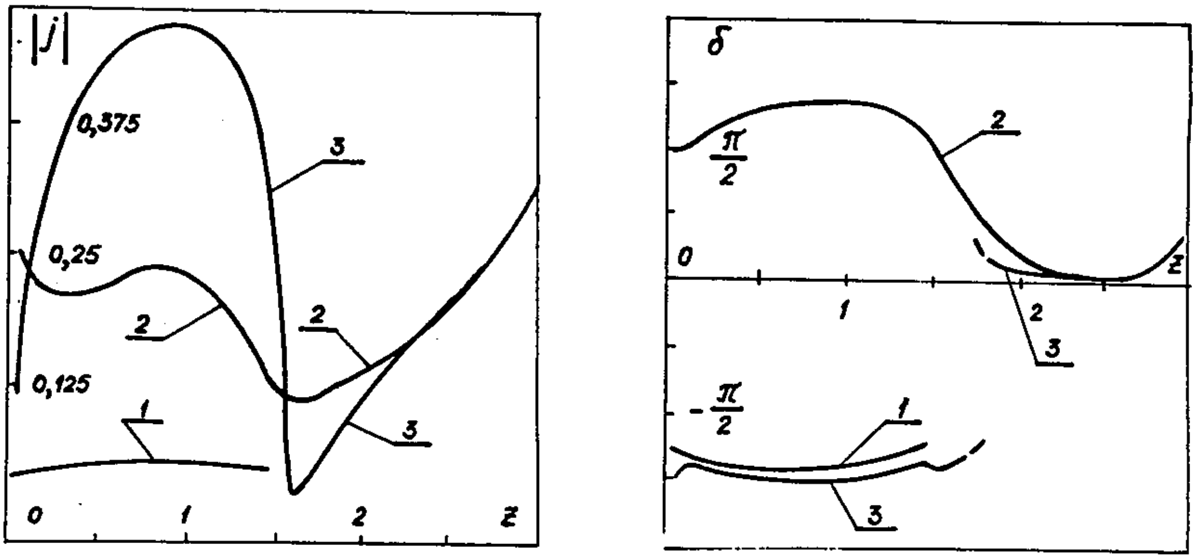

Fig.4a. Fig.4b.

2.2. Model of real side walls conductivity.

Let us take into account a dependence of $\partial\varphi/\partial\alpha$ on r and z. Then, instead of assumption $\partial\varphi/\partial\alpha$ = *const* in chapter 2.1., we must involve following ones
(i) Current flows along surfaces side walls of crucible (see Fig.2) which can be described by surface conductivity $\sigma_c = \sigma_c\,\delta_c$, δ_c - field penetration depth, if $\delta_c > \delta_s$ (δ_s - thickness of section side wall), then $\delta_c = \delta_s$.
(ii) field of surface currents is determined by distribution of scalar potential φ on the side walls.
Then from conservation of current we have dimensional equations for potential distribution on side walls C and D (Fig.2)

$$\sigma_s\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi_D}{\partial r}\right)+\frac{\partial^2\varphi_D}{\partial z^2}\right]=\sigma_\alpha\left[\frac{\varphi_D-\varphi_C}{r\,(2\pi/m-\Delta)}+i\,\omega\,A\right]$$
$$\sigma_s\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi_C}{\partial r}\right)+\frac{\partial^2\varphi_C}{\partial z^2}\right]=\sigma_\alpha\left[\frac{\varphi_C-\varphi_D}{r\,(2\pi/m-\Delta)}-i\,\omega\,A\right]. \quad (10)$$

where m- number of crucible sections, Δ - angular thickness of gap between crucible sections, σ_α - azimuthal conductivity of crucible ($\sigma_\alpha=\sigma_c$, if $r_1<r<r_2$, $r_3<r<r_4$; $\sigma_\alpha = 0$, if $r_2<r<r_2$ - see Fig.3).

Subtracting and transformation to dimensionless form of (10) gives us equation for $\varphi_\alpha = \partial\varphi/\partial\alpha$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi_\alpha}{\partial r}\right)+\frac{\partial^2\varphi_\alpha}{\partial z^2}=K\left(\frac{\varphi_\alpha}{r}+i\,A\right), \quad (11)$$

where

$$K=\begin{cases}2\,r_0\,(2\,\pi\,/\,m-\Delta)\,/\,\delta_c, & \text{in } \Omega_1,\ \Omega_2,\\ 0, & \text{in } \Omega_5\end{cases} \quad (12)$$

with boundary conditions of electroisolation $\partial\varphi_\alpha/\partial n|_\Gamma = 0$ on Γ (Fig.3).

Full equation system for EM field now is (9)+(11-12) with corresponding boundary conditions for φ_α and A.

Consider a brief analysis of (11-12). If $K \Rightarrow 0$, then $\Delta\varphi_\alpha \Rightarrow 0$, that

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leads to $\varphi_\alpha(r,z)$ = *const* in our case of boundary conditions and solution of EM problem become identical to solution of problem with ideal side wall conductivity. If $K \to \infty$, then $\varphi_\alpha \to - i\,r\,A$, i.e. solution correspond a case of furnace without cold crucible.

Equations (11-12) are solved in finite - difference manner, too, in conjugation with analogous of (9). Example of results are presented on Fig.5 for K=150 (other parameters like in Fig.4.).

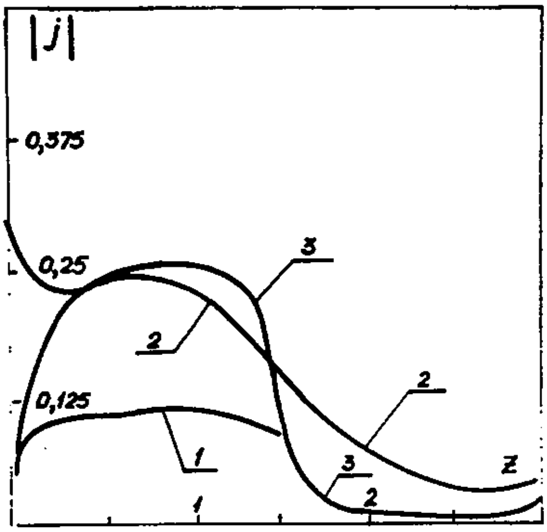

Fig.5a.

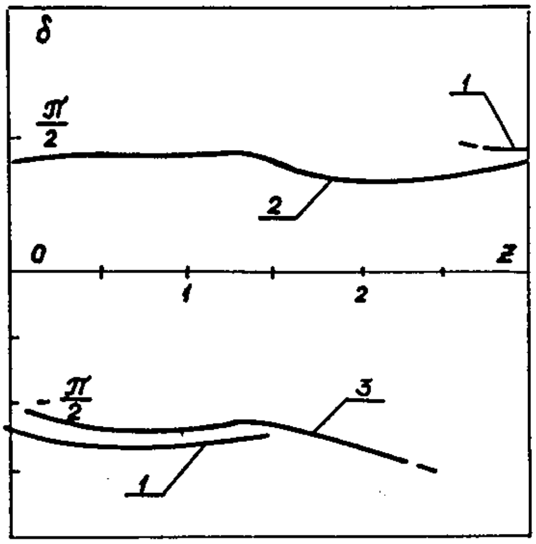

Fig.5b.

Given model have advantages over previous one in possibility of taking into account real number of crucible sections, thicknesses of side walls and gaps between them, it allows more exact calculation of current redistribution passing through side walls.

3. The calculation of free surface shape (FSS).

For industrially important work regimes the melt in IFCC can be with complicated free surface shape. FSS is strongly influenced by EM field bounded by the shape itself. We consider the FSS in the following way (see Fig. 6) taking into account

(i) The hydrostatic pressure $p_h = \rho\,g\,h$.

(ii) The surface tension forces $p_\sigma = \sigma(1/R + 1/r)$, where R and r are bend radiuss of surface.

(iii) The EM forces. In the practical cases of high frequencies repulsive EM forces are concentrated in thin skin layer. Therefore the Boundary Element method for EM field calculation is used. This calculation gives the linear current i distribution on surface. The EM pressure $p_{EM} = \mu_0\, i^2/2$.

For the equilibrium of free surface

$$p_h = p_\sigma + p_{EM},$$

in dimensionless form

$$h = C_\sigma\,(1/r_1 + 1/r_2) + C_{EM}\,i^2,$$

Where parameters

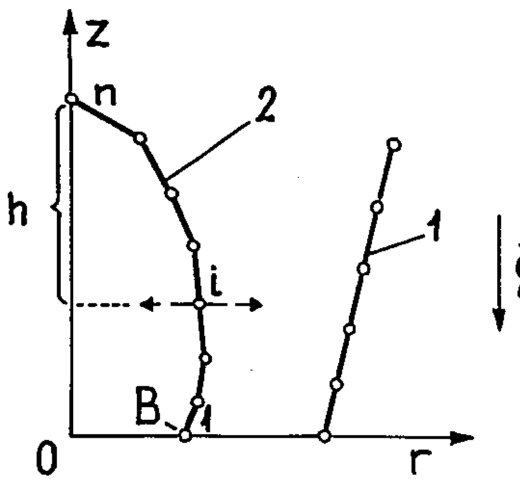

Fig.6

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$$C_\sigma = \sigma / \rho g h_0^2, \qquad C_{EM} = \mu_0 i_0^2 / 2\rho g h_0$$

and reference quantities are h_0 - height of melt, $i_0^{\cdot}$ - linear current density in inductor.

The following algorithm of FSS calculation is used:

(i) The start FSS is chosen,

(ii) The EM field and corresponding EM pressure, p_h and p_σ are calculated for each boundary element,

(iii) The boundary "r" coordinates are corrected in "r" direction by step

$$\zeta = \alpha [h - C_\sigma (1/r_1 + 1/r_2) - C_{EM} i^2],$$

where α - iteration parameter.

The following boundary conditions are used:

(i) If the surface tension forces are negligible, only one boundary condition is necessary, i.e. a height H of melt. Then the localization of point B is get by calculation process.

(ii) If the surface tension forces are taken into account, then two boundary conditions are used, i.e. height of melt H and a radial coordinate of point B.

In calculations the presence of cylindrical vessel is taken into account too, i.e. the radial coordinates of fice surface can't get greater as an inner vessel radius.

On fig.7. the example of calculation is presented, i.e. the calculated free surface shape and magnetic field lines in the case when melt is fully pulled back from vessel. Corresponding parameters values are C_σ=0, CE =0,4.

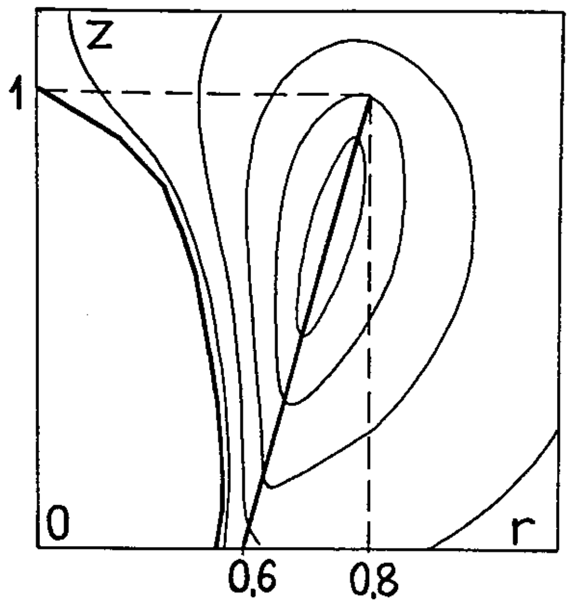

Fig.7.

For ultra-high frequencies $\hat{\omega} >> 1000$ boundary element method for EM field calculation in the system inductor-melt is found to be the best. These calculations is based on vector-potential calculation. All boundaries of regions are divided into boundary elements. It is assumed, that each element has its current, that causes a magnetic field around it. For inductor these currents are given, for melt - calculated to satisfy condition A=0 on the melt surface. These conditions form an algebraic equation system for unknown current values and are solved numerically. The calculated current values allow to calculate EM pressure and Joule heat.

An example of calculated EM field is presented on fig. 7.

4. Temperature field calculations.

Analysis of heat transfer through IFCC sections are complicated due to 3D character of temperature field. However a 2D mathematical model in horizontal cross section of IFCC section is offered, because of dominant role of horizontal temperature gradients in the contact between melt and section region (see Fig.8). The section 2 get thermal flux from melt 1

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through contact 3. The boundaries 4,5 are considered as thermal isolation (because of bend symmetry). The boundary 6 has a weak cooling condition. In the channel 7 flowing water determines the cooling regime of the whole section, inductor 8 cause the vortex currents in the section too. Because of Joule heat localization in the thin skin-layer, for the temperature field we can use the equation

$$\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 = 0.$$

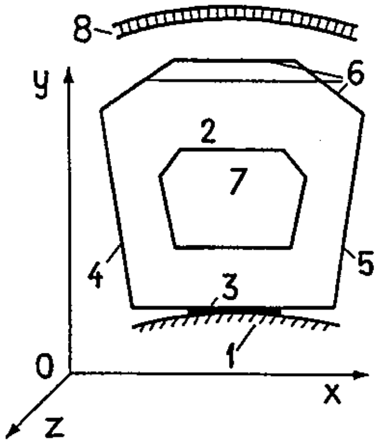

Fig.8.

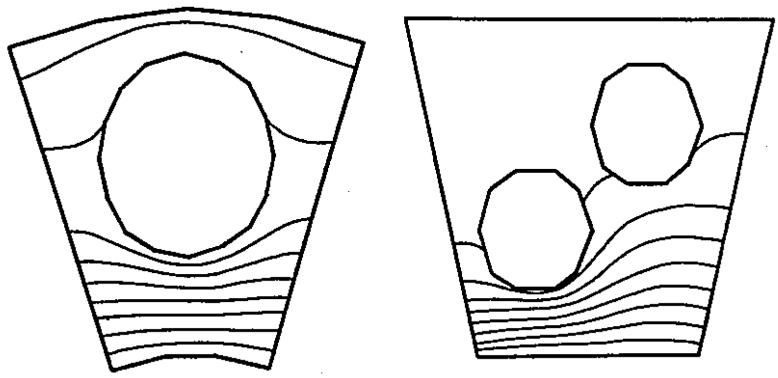

Fig.9.

This form of equation allows to use the boundary element method for temperature calculation, i.e. divide the boundary of horizontal cross-section of IFCC section into boundary elements. For these elements complex boundary conditions are found i.e. for boundary 3 the thermal flux from melt or melt temperature are given; for channel boundary the conditions of heat exchange between water and wall are used; for outer wall the heat exchange conditions between section and air are used. All these conditions are modified in order to take Joule heat into account. On fig.9 two examples of calculated temperature field (temperature isolines) in FCC sections, that have a complicated geometry, are presented. For these examples the upper boundary is a contact with melt.

5. Melt hydrodynamics.

For averaged turbulent MHD meridian flow description the Reynolds equation in Boussinesq approximation

$$\partial\bar{v}/\partial t+(\bar{v}\nabla)\bar{v}=-\nabla p+\Delta\bar{v}/Re_{EFF}+Al\bar{f}_{EM}+\bar{e}_z/Fr$$

and mass conservation law

$$\mathrm{div}\ \bar{v}=0$$

are used, where

$Re_{EFF} = v_0\ r_0\ /\ \nu$ − modified Reynolds number,

$Al = B_0\ /\ \mu_0\ \rho\ v_0^0$ − Alfven number,

$Fr = v_0\ /\ g\ r_0^2$ − Frud number.

For numerical calculation the problem with axial symmetry is considered and methods, based on variables stream function and vorticity [2,3] or natural variables [7] and SOLA-VOF scheme [8] are used.

It is assumed that $\nu_T \neq f(r)$, but $\nu_T \sim I$, where I − linear current density in inductor.

For heat and mass transfer processes investigation the simplified assumption $\nu_T \neq f(r)$ is changed to two-parameters k − ε model. That allows to calculate effective viscosity and gives the linear (corresponding to experiment), relation between maximal velocity and linear current density I (v ~ I). The equations for turbulent energy k and dissipation rate ε and equations for temperature and admixture concentration also are solved by FDM and stationarisation method.

On fig.10 the time dependent concentration field is shown (at the start moment admixture is localized in the free surface center). At the time moment t=1 hydrodynamical fields (v, ν_T) has achieved their stationary stations and subsequent homogenization follows at time independent hydrodynamical conditions. Because of k - ε model ν_T has a maximum in vortex center, the admixture diffusion perpendicular stream lines is favored, i.e. in the regions, where convective transport is small. It is possible to divide homogenization process into the periods:

(i) Convective admixture transport in the upper vortex.

(ii) Turbulent diffusion into vortex center.

(iii) Diffusion through both vortex boundary with characteristic time interval greater than revolve time for vortex.

In the case of great free surface (the one vortex flow) the homogenization time is determined by first two points.

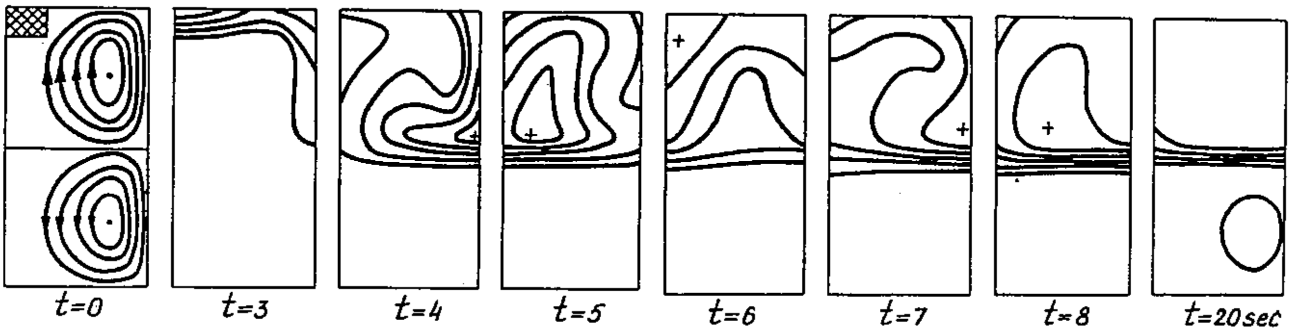

Fig.10.

7. Conclusions.

The offered system of mathematical models and corresponding calculation methods create the possibilities for investigation of aspects, important for industry

(i) EM forces influence on the melt and free surface forming process, thermal and energy characteristics of equipment;

(ii) temperature gradients in sections melt;

(iii) hydrodynamics and correlated with them mass transfer process.

The system of programs is developed in Latvia University (Riga) and is used for engineering calculations in company "Electroheat" (Elektroterm Moscow, USSR).

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INDUCTION MELTING OF METALS IN COLD CRUCIBLE

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Synopsis: The melting process in the induction furnace with a cold crucible (IFCC) is accompanied with a number of physical phenomena and effects controlling of which provides a possibility to realize different technological operations. The laboratory and commercial induction furnaces equipped cold crucibles of 0,2-1000l in capacity have been produced. IFCCs with additional arc, plasma or electroslag heating are highly promising. They are characterized by the 10-20% increase in the efficiency and widened technological possibilities.

Key words: IFCC, cold crucible, induction furnace, vacuum plasma, arc, electroslag.

1. Introduction

The production of high-quality materials depends essentially on satisfying requirements to electroheat equipment. The IFCC complies in high degree with such requirements. That is why IFCCs are used at present for fabrication of super clean refractory and chemicallyreactive metals and alloys, also pure oxides and other non-metal compounds. The most typical utilization field of IFCCs is production and recycling of materials for atomic industry and avia-cosmic technique. The further improvement o f energetic parameters of IFCCs will make economically reasonable their wide use in such branches of industry as ferrous and non-ferrous metallurgy, automobile-building and others.

2. Physical phenomena and effects in IFCC

The IFCC is a rather complicated electro-technological installation incorporating interacted electromagnetic, hydrodynamic, heat and mass-exchange processes.

It is well known that the influence of melt motion on the initiating magnetic field in an induction furnace may be usually neglected. It makes possible to consider the electromagnetic problem in the IFCC as separate one.

The electromagnetic convection in an induction furnace is by some orders more intensive than the thermogravitation convection. Therefore the hydrodynamic problem may be talked independently of the heat problem.

Solving the hydrodynamic problem it is necessary to take into account that the melt motion in the IFCC is turbulent. As to the heat problem it is important that Joule heat released in the IFCC is some orders higher than that caused by the viscous dissociation of the kinetic energy of the melt flow.

Taking into account the above the mathematical models and programs for calculation of physical fields in the IFCC have been developed [1]. Some results of such calculations are given in Fig.1.

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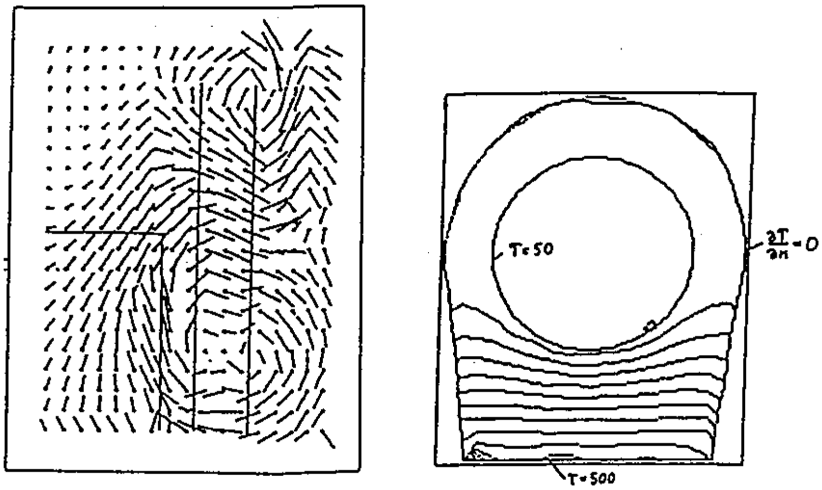

Fig.1 Vector diagram of the IFCC magnetic field (a). Cross-section temperaturefield of cold crucible segment (b).

As the result of the controlling the physical phenomena and effects in the IFCC very high technological results may be achieved.

Table 1. The main physical phenomena and effects of metal melting in IFCC

N	Physical phenomena	Outcome effects	Technological processes on the basis of outcome effects
1.	Electromagnetic interaction	Controlling free surface form and height of the melt	Refining remeltings, melting of multialloyed alloys, electromagnetic dosing of metal
		Electromagnetic repulsion of the melt from the crucible wall	Melting of refractory metals, metallotherm.reduction, melting of alloys, refining remeltings
		Electromagnetic convection of the melt	Melting of alloys, refining remeltings, foundry alloy remelting for providing composition homogeneity
		Magnetomechanical effects	Electromagnetic dosing of melt and its solidification in electromagnetic field
		Electromagnetic weight increase of some alloy components	Melting of alloys with high percentage of components (up to 50%) differed 2 - 20 times in melting temperature, density and vapor pressure

International Symposium on Electromagnetic Processing of Materials, 1994, Nagoya, ISIJ

	Melt stabilization in electric and magnetic fields	Production of powders by evaperating of melt from liquid metal column
2. Electrokinetic phenomena	Electromagnetic separation of non-metallic inclusions	Refining remeltings
3. Electromagnetic screening	Control of energy distribution in charge and melt motion	Melting of refractory and chemically reactive metals. Solidification of melt in electromagnetic field.
4. Heat action of electric currents and fields	Forming preset distribution of heat sources, thermogravitation convection of melt	Melting of metals and alloys, metallothermic reduction of metals, refining remeltings, directied solidification of melt, shrinkage cavity topping, separation of metallothermic reduction products
5. Mutual inductance	Change of electric contour inductance	Control and stabilization of melt level in cold crucible during metal and other technological processes
6. Electrical discharges	Local heating of charge	Metallothermic reduction
7. Ionization thermoelectronic emission	Generation of electronplasma discharge	Refining remeltings protection of melt surface against gas saturation
8. Phase transition from one aggregate state to another	Releasing (or absorption) of energy, separation of admixtures, evaporating cooling	Zone refining in the course of remelting, controlled solidification of melt, single-crystal production
9. Motion of charges particles in electric and magnetic fields	Increase in material temperature, dissociation of melt admixtures	Refining remeltings, casting process
10. Heat radiation of charge	Increase (or decrease) in change temperature	Metallithermic reduction, solidification processes
11. Surface tension	Prevention of melt penetration between cold crucible section	Melting of metals and alloys, refining remeltings etc.
12. Interaction under gravitation force	Control of height and shape of melt free surface, changing of	Melting of refractory metals and multialloyed alloys with different physical properties

International Symposium on Electromagnetic Processing of Materials, 1994, Nagoya, ISIJ

	melt gravity center	of components, metallothermic reduction
13. Chemical interaction of metal and slag bath	Transition of admixtures from melt to slag bath	Refining remeltings, metallothermic reduction
14. Overcooling of metal melt	Formation of solidification centers	Production of metal ingots with preset structure. Casting of gas turbine engine blades.
15. Interaction of electromagnetic field and electron -plasma discharge	Stabilization of electron-plasma discharge parameters	Production of metals and alloys in vacuum induction-plasma furnace with cold crucible

Electromagnetic containment of the metal melt on the base-plate (Fig.2) is of great importance for optimal realization of some technological processes in the IFCC.

2. Practical utilization of IFCCs

In accordance with technological intentions IFCCs may be divided into two groups: melting installations for producing ingots and casting ones for performing different casting processes.

Casting IFCCs are equipped with bottom or upper tapping devices. The capacity of cold crucibles depending upon the IFCC size are 0,2-1000 L [2]. The diagram of the IFCC equipped with a 800 L crucible is shown in Fig.3.

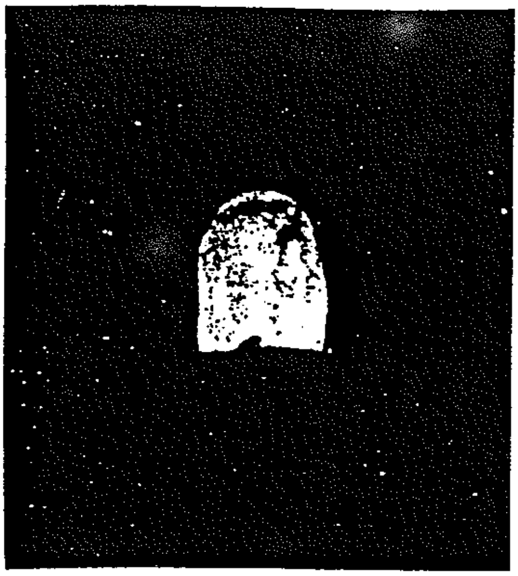

Fig.2 Process of metal melting in the electromagnetic crucible with a base plate

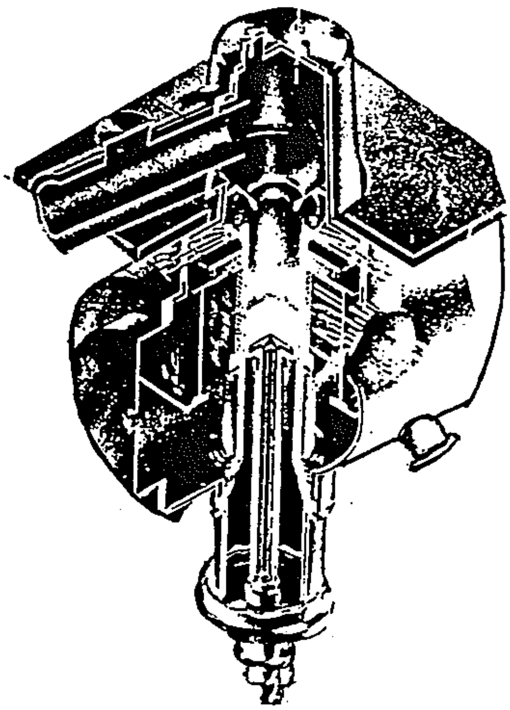

Fig.3 Diagram of the IFCC for metallothermie reduction of metals

International Symposium on Electromagnetic Processing of Materials, 1994, Nagoya, ISIJ

A special attention ought to be given to IFCCs with additional heat sources. Some laboratory and commercial installations of such type have been designed, produced and put into operation in Russia.

The additional heat sources in them are vacuum arc, vacuum plasma or electroslag types. Owing to the additional heating IFCC technological possibilities are widened and their overall efficiency is increased by 10-20%.

One of them combined induction-arc furnaces equipped with a cold crucible is used for melting of refractory steel and chrome. The melting in the furnace is performed using a consumable electrode. The arc is energized when a gap between the electrode tip and melt surface is about 0,015 m. The stable arc behaviour is observed in the course of increasing its length up to 0,04 m. The further increase of arc length initiate the arc rotation over melt surface and after achieving 0,06 m length the arc fails. It is noticed that the electrode heating in the electromagnetic field of the inductor takes place which has a positive effect on arc stability.

The use of additional electroslag heating in the IFCC provides more deep refining of liquid metal from non-metallic inclusions and creates the favourable conditions for bettering the crystal structure of the solidified ingot. The optimal regime in the induction-electroslag furnace corresponds the case when the inductor embraces both metal and slag baths and also the part of the electrode.

The vacuum induction-plasma furnace with cold crucible intended mainly for metal refining has been used for production of gas-turbine engine blades. The blades fabricated in such a furnace have higher strength characteristics as compared with those produced by the directed solidification method or having equiaxial grain structure.

The investigation of the low pressure electron-plasma discharge and the inductor electromagnetic field interaction has ascertained that this process may be studied with the model describing the behaivour of the ideal gas consisting of electrons and ions. The gas particles motion may be considered in this case as a sum of three constituents: the cyclotronic rotation around magnetic field intensity lines, the drifting of cyclotron center across the direction of the magnetic field and the free motion alongside the magnetic field intensity lines. In the gas discharge of low pressure the electric current is provided by the directed motion of charges particles of both sings. However, the share of the ion current is negligible as compared with the electron current due to relatively high mass of ions. For instance, in the argon plasma the mass of an ion is 80000 times higher than that of an electron. Therefore, because of the low velocities acquired by the ions in the electromagnetic field the resulting electric current of the discharge may be considered as the electron flow.

It was defined experimentally that a low pressure discharge is stable while having the following parameters: current 500-2000 A, argon consumption 10-200 l/h, pressure 1-50000 Pa, length of discharge column 0,03-0,35 m.

The electromagnetic field of the inductor stabilizes the discharge and prevents its conversion into the diffusion mode.

3. New IFCC developments

The latest researches in the field of IFCC have testified that electric losses in the cold crucible may be diminished practically to zero. The cooling system may be simplifed while safety and reliability of the equipment are improved. The above results are achieved with the use of a cooling system based on the heat tube principal and substitution of a vacuum chamber by a vacuum-tight jacket.

International Symposium on Electromagnetic Processing of Materials, 1994, Nagoya, ISIJ

4. Conclusions

The induction melting furnace with the cold crucible is a very promising high-tech equipment for super clean material production meeting strigent demands of different branches of industry. The latest developments covering improvement of energetic parameters, increase of the cooling system, efficiency and decrease of the furnace weight and dimensions create a good basis for more wide utilization ofIFCCs in the nearest future.

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VACUUM-INDUCTION AND INDUCTION PLASMA FURNACES WITH COLD CRUCIBLE

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Introduction

The effect of defects limiting the quality, performance, service life, etc. of metal products and components are well known. One of these defect is non-metallic inclusions usually oxides of different chemistry and morphology if introduced can not be removed during further processing of solidified material. A superclean initial material is the aim. The melting of a high performance alloy is carried out in vacuum induction furnace with a ceramic lining. Ceramic contamination of the melt during melting in VIM-furnace due to erosion and reaction between the melt and the ceramic lining can not be avoided completely. The most promising solution to avoid ceramic contamination is to melt in an induction heated, segmented and cooled metallic crucible.

The idea to melt in a water cooled segmented metallic crucible with induction heat is not new. The concept was patented to Siemens and Halske in Germany.[1] In the next 40 year period, the demand for superclean metal stimulated further research in the United States, France, West-Germany and the Soviet Union to improve the technical potential and commercial feasibility of the process.[2]

After intensive research on this process, the Electro Research Institute VNIIETO in the Soviet Union succeeded in up scaling the crucible dimension for commercial applications. The production of commercial cold crucible induction furnaces in the USSR began in 1980.

Design of Induction Cold Crucible for Production Melting

Laboratory research was conducted studying the physical processes in cold crucible melting. Two dimensional mathematical models were used to calculate the electromagnetic fields (EM) as well as hydrodynamically fields (HD) using finite element methods for calculating HD and EM fields and boundary element methods for calculating temperature and EM fields in the cases using high frequency. Computer analysis results in EM field calculations which are used to calculate the induction coil, energy losses in the crucible segment and crucible bottom as well as the energy balance of the melt. The calculations of the HD-field described precisely the extent of thermal losses in the melt.

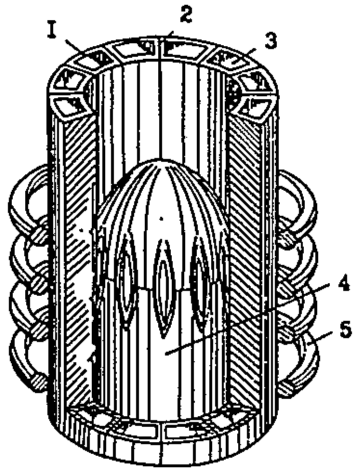


Figure 1 Schematic of cold crucible induction melting: (1) crucible segment, (2) electrical insulation, (3) channel for cooling medium, (4) melt, (5) induction coil

At present, the Soviet Union produces induction cold crucibles with diameters from 60 mm to 1000 mm and with height of up to 2500 mm for different application such as:

- melting and solidification of metal and alloys
- melting, refining and casting of metals and alloys
- metallothermic reduction of reactive and refractory metals from their components

Figures 2-4 show different types of cold crucibles. Another interesting aspect of the cold crucible induction furnace is the integration of an ingot withdrawal system as shown in Figure 5. In this case, ingots longer than the crucible can be produced. Figure 6 shows a cold crucible for this case. For casting of ingots, remelt electrodes, and precision cast parts, the cold crucible can be tilted as in classical VIM-furnaces. VNIIETO has developed a novel method for bottom tapping. Figure 7 shows schematically the bottom tapping system. The crucible and the crucible bottom must be specifically designed for this purpose. A crucible with bottom tapping arrangement is shown in Figure 8. With proper process control the amount of the remaining skull can be reduced to a great extent as shown in Figure 9. In Figure 10, the bottom tapping systems permits atomized melts of different metals and alloys. For this purpose, LEYBOLD DURFERRIT, has developed a melt guide system attached to the bottom of the crucible to control the melt stream geometry which is essential for atomization.

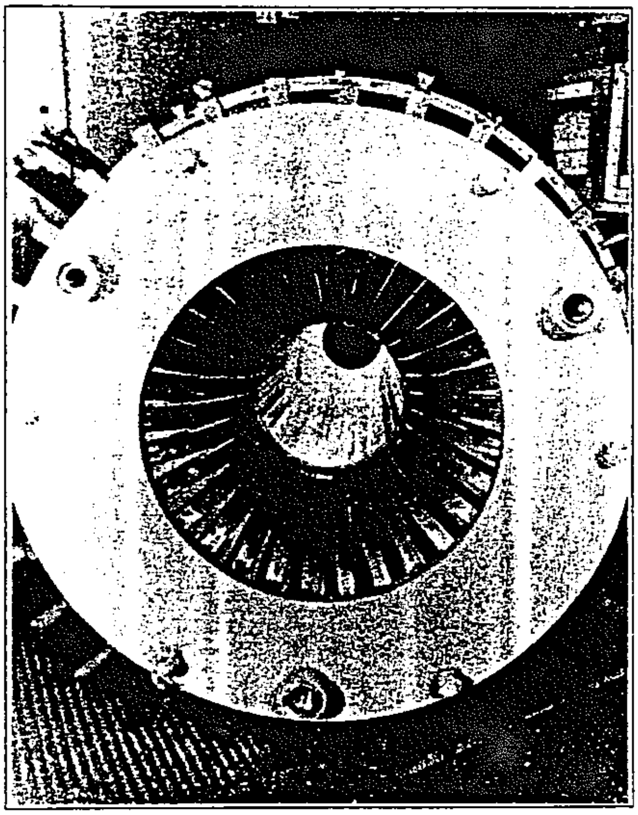


Figure 2 Top view of a Cold Crucible

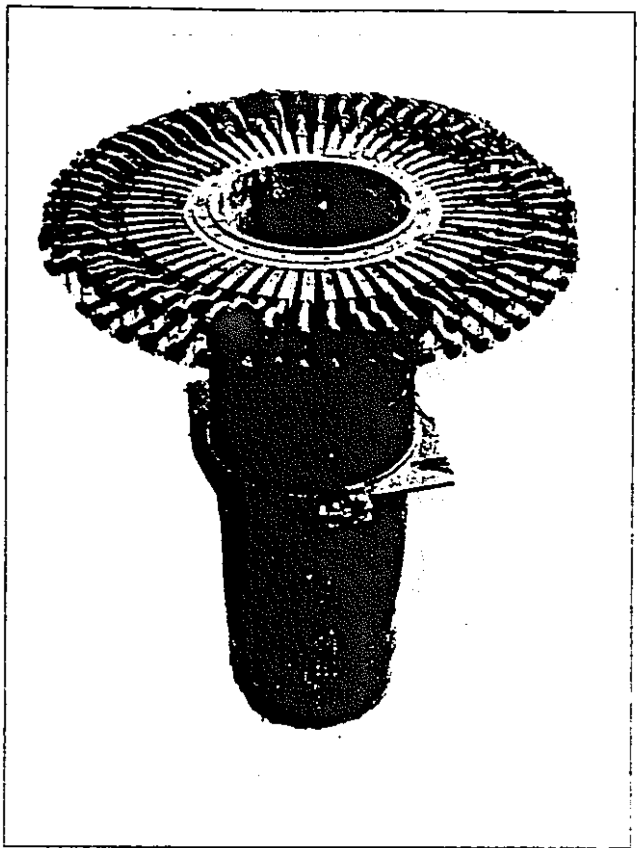


Figure 4 Cold crucible with a volume of 800 l for metallothermic reduction processes

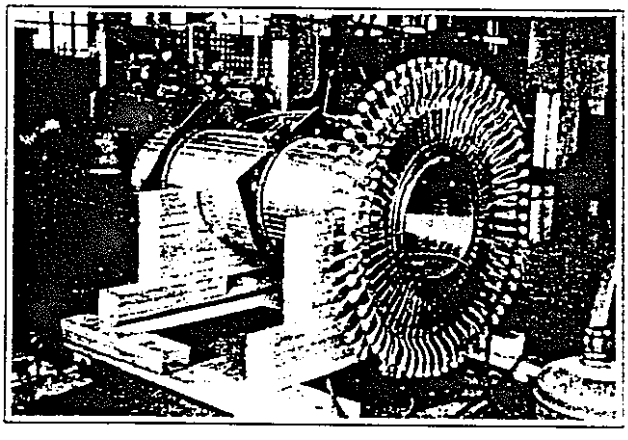


Figure 3 Cold crucible with a volume of 1000 l during manufacturing

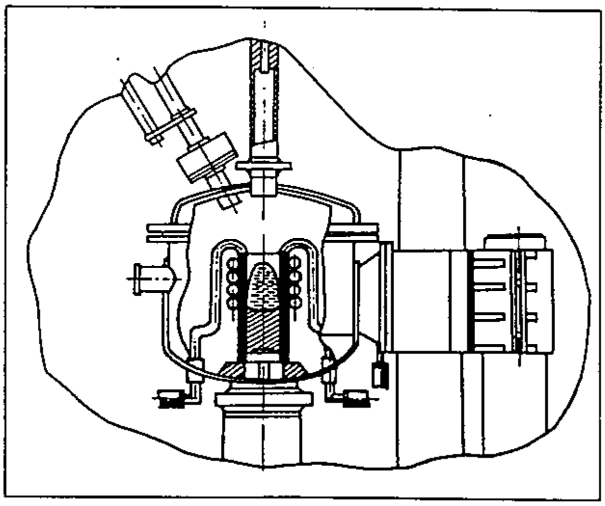


Figure 5 Schematic of a cold crucible induction furnace with ingot withdrawal

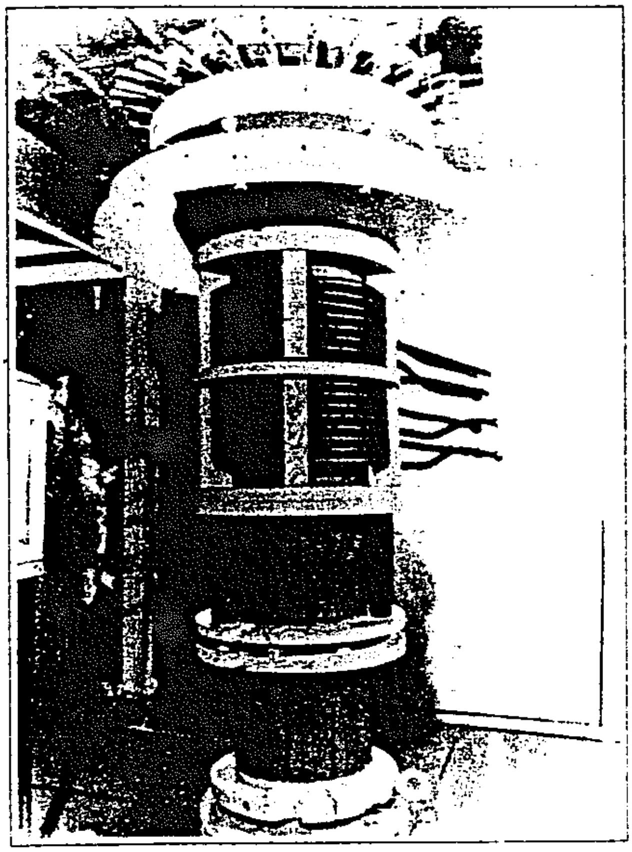


Figure 6 Cold crucible with ingot withdrawal system

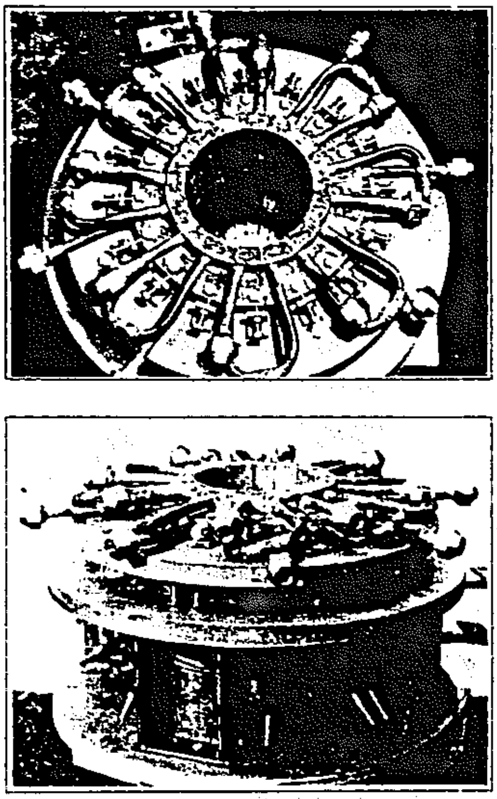


Figure 8 Cold crucible with bottom tapping of the melt

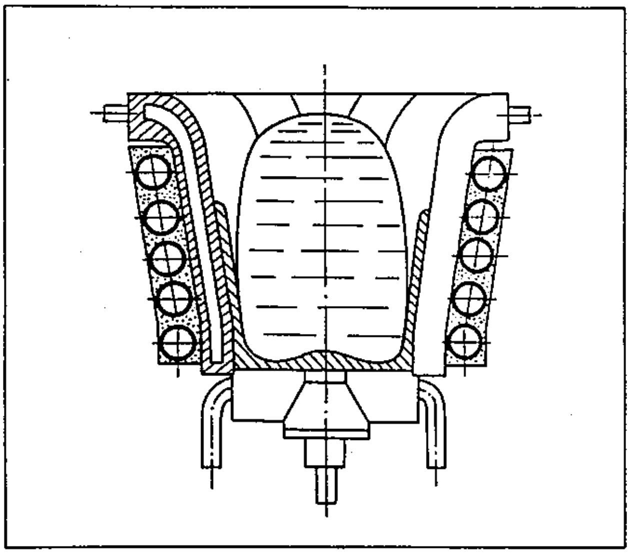


Figure 7 Schematic of a cold crucible with bottom tapping of the melt

Figure 9 Appearance of the remaining skull in the cold crucible after bottom tapping. Skull thickness 1 mm to 5 mm

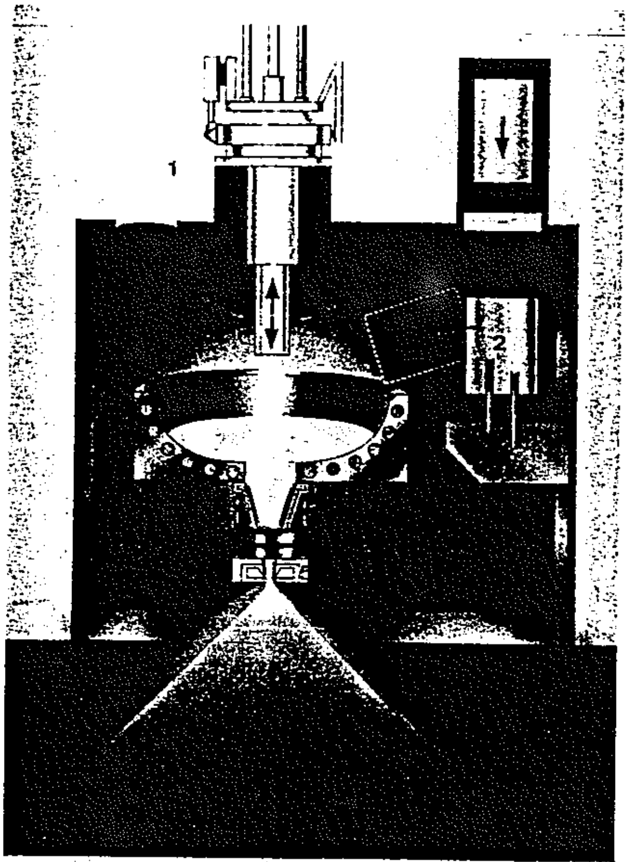
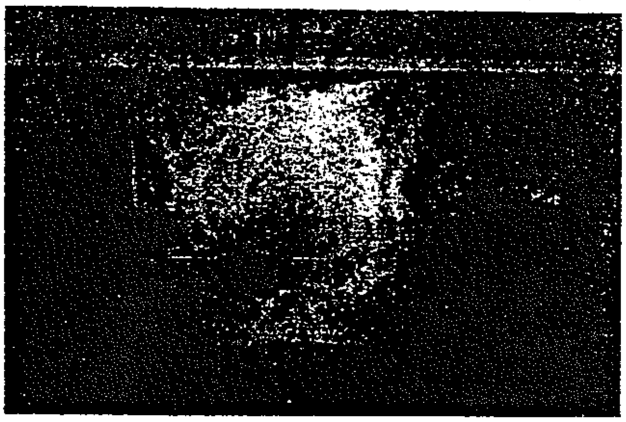


Figure 10 Plasma melting - Inert Gas Atomization: (1) Plasma torch, (2) charger, (3) melting crucible, (4) ceramic-free guiding system, (5) gas nozzle, (6) atomization tower



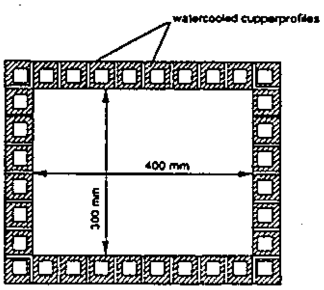


Figure 11 Cold crucible for square ingots

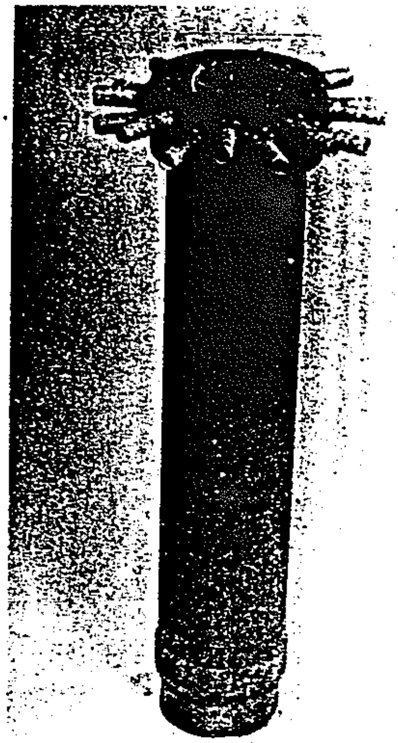


Figure 12 Cold crucible with a vacuum tight sealing made from non-conductive insulating composite material

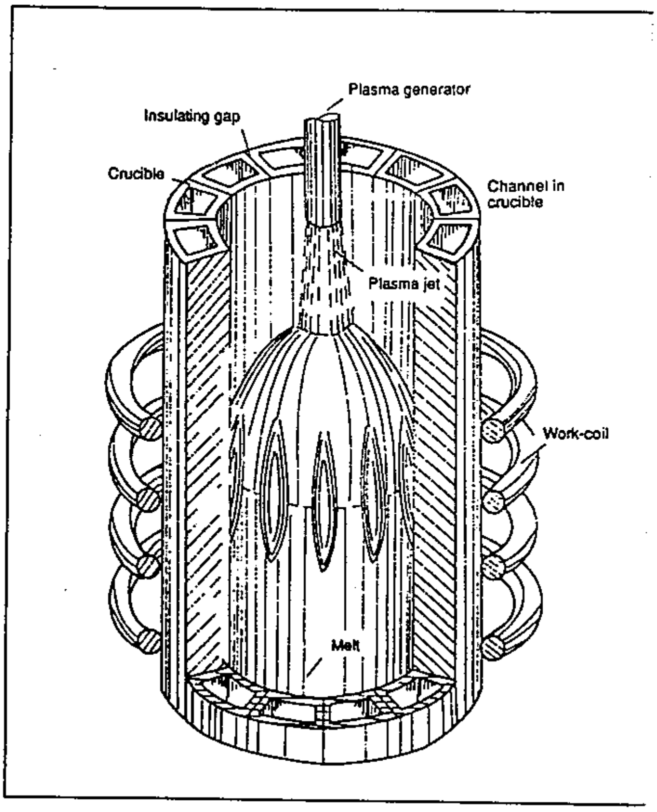


Figure 13 Schematic of a cold crucible induction furnace with additional plasma heating

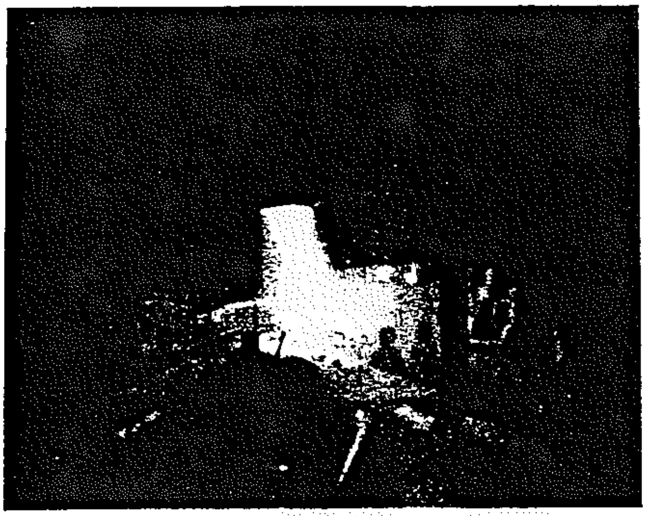
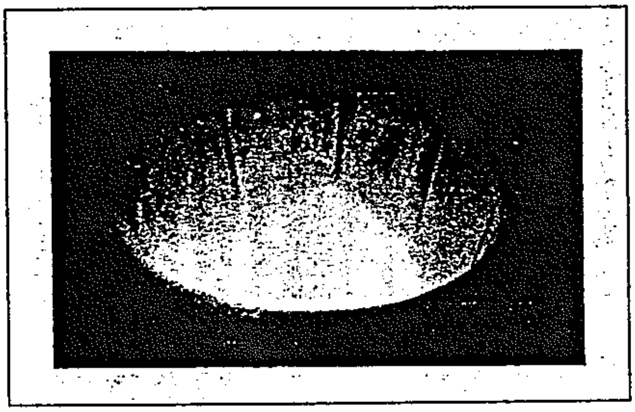


Figure 14 Vacuum induction plasma melting in a cold crucible



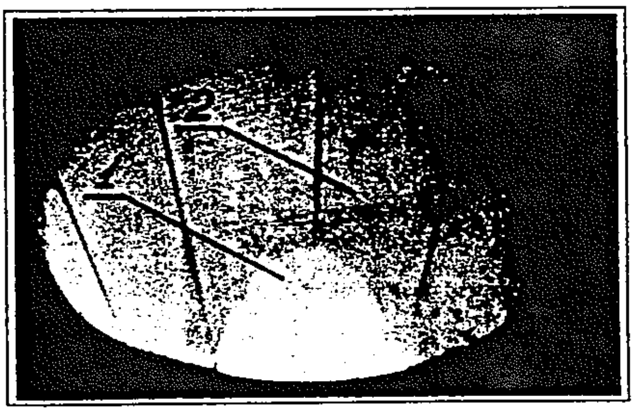


Figure 15 Electromagnetic repulsion of the melt from the crucible wall: (1) zirconium melt, (2) cold crucible

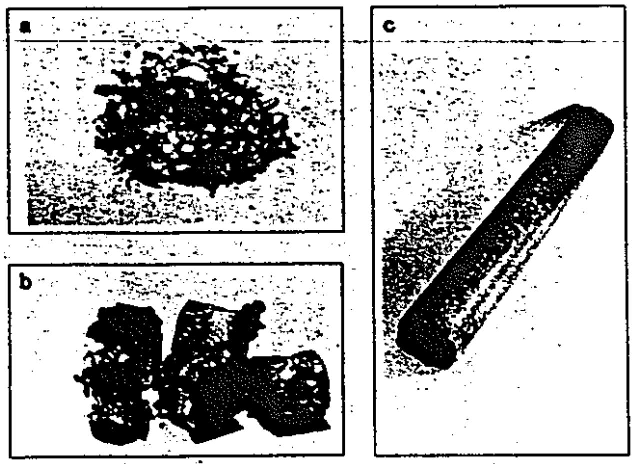


Figure 16 Charging material for cold crucible melting: (a) electromagnetic chromium, (2) zirconium sponge, (3) compressed chromium chips

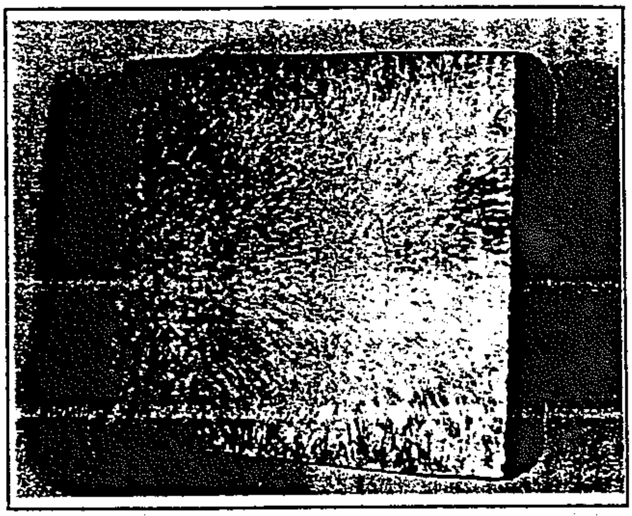


Figure 17 Primary structure of an ingot solidified in a cold crucible. Note: non-metallic inclusions are transported to the ingot surface

In some cases a rectangular ingot is advantageous when further processing of the metal is required e.g., rolling. VNIIETO has developed a cold crucible furnace with a rectangular cross section to produce rectangular ingots. (Note Figure 11) At present, chamberless cold crucible induction furnaces are being tested in the Soviet Union. The crucible with the induction coil is sealed vacuum tight with non-conductive insulating composite material as shown in Figure 12. The application of an additional plasma heat sources extends substantially the technological capabilities of the cold crucible induction furnace technology with respect to superheating and further refining of molten alloy, especially for large melts.(Note Figures 13 and 14). The combination of plasma and induction heating provides the following possibilities:

- faster dissolution of alloying elements in the melts
- better removal of non-metallic inclusions
- easier temperature adjustment
- better removal of undesired residuals with higher vapor pressures.

Due to high flux density of thermal losses in the contact zone melt/crucible(100 W/cm^3 to 400 W/cm^3) it is important to reduce the contact area. This can be achieved by forcing the top part of the melt away from the crucible wall with electromagnetic forces.[5] (Note Figure 15) Of course, the hydrodynamics instability of the miniscus causes non-stationary distortion of its surfaces, mainly in the shape of vertical folds. Dimensions of these fold are usually of the same order of the depth of the current penetration into the molten metal. Accordingly, their presence indicates the absorption of the field energy by the miniscus.

Table 1 shows the technical data of some cold crucible induction furnaces running in the Soviet Union. The furnaces are used to melt various metals and alloys. In Table 2, the specific consumption of electric power and overall efficiency during melting of some alloys are listed.[2]

Table 1 Basic Technical Data of Some Cold Crucible Induction Furnaces

Parameter	Furnace Type			
	ISV	IKVX*	ITVX	INVX
Cold Crucible Capacity, l	230	670	20	20
Cold Crucible Diameter, mm	200/500	650	250	250
Permissible Temperature of the Melt, °C	2600	2600	2500	2500
Melt Chamber Pressure, Pa	0.133	0.133	0.133	0.133
Converter Power, kW	1500	2000	1000	1000
Coil Current Frequency, Hz	2400	2400	2400	2400
Coil Voltage, V	800	800	800	800
Plasma Generator, pc/kW	-	-	2/250	1/250
Furnace Dimensions				
Area, sq.m.	11 x 6	10.6 x 8.3	10 x 5	10 x 9.5
Height, m	13.5	10	8	6.5
Total Weight, t	70	85	50	70

* Crucible for Metallothermic Reduction

Table 2 Specific Consumption and Overall Efficiency of Cold Crucibles

	Super-alloys	Cr	Ti	Gd	Y	La	Ni
Power Consumption for Melting-Down, kwh/kg	2.1	3.2	2.3	1.1	2.2	1.2	5.0
Average Efficiency, %	16	12	18	8	7	5	7

Metallurgical Potential of Cold Induction Furnaces

Vacuum induction furnace with water cooled segment metallic crucibles open up new possibilities to produce clean metals and alloys. The special features of cold crucible melting are summarized as follows:

- no chance of oxide contamination by ceramic lining material
- possibility to melt reactive and refractory metals and alloys
- intensive magnetic agitation results in a homogeneous melt with respect to temperature and as well as chemistry
- melting of any charge material, eg. chips, sponge, powder, etc. (Note Figure 16)
- high degree of cleaning non-metallic inclusions, undissociated inclusions are transported to the skull and entrapped (Note Figure 17)
- possibility to control the shape of the solidification from and ingot structure, if solidified in the crucible
- possibility to produce ingots with ingot withdrawal system
- possibility for bottom tapping (a special interest for investment casing and powder production)
- possibility for metallothermic reduction of chemically active and refractory metals
- applications using additional plasma heat sources provides increased metallurgical potential.

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