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# WITHDRAWAL SHEET

## Ronald Reagan Library

**Collection:** MATLOCK, JACK F.: Files

**Archivist:** dlb/mjd

**File Folder:** Matlock Chron January 1984 [2 of 3] ~~OA 90887~~

**Date:** 8/30/96

*Box 3*

DOCUMENT NO. AND TYPE	SUBJECT/TITLE	DATE	RESTRICTION
1. <del>briefing paper</del>	re: suggested presentation (16pp) <i>R 11/26/02 NLSMO2-002 #1</i>	1/14/83	<del>P1 B1</del>
2. memo	from Robert McFarlane re: meeting with Suzanne Massie (1p) <i>R 11/13/02 ~ #2</i>	1/16/84	<del>P1 B1</del>
3. memo	from Matlock to McFarlane re: Massie's call on the President (1p) <i>R ~ #3</i>	1/13/84	<del>PT B1</del>
4. memo	from McFarlane to the President re: reaction to US-Soviet relations speech (1p)	n.d.	<del>PS open</del>
5. memo	from Charles Hill to McFarlane re: reaction to US-Soviet speech (3pp) <i>R 11/26/02 NLSMO2-002 #4</i>	1/17/84	<del>P1 B1</del>
6. memo	from Matlock to McFarlane re: report (1p)	1/11/84	<del>R1 B1</del> <del>PS</del>
7. report	(10pp) <i>PART. 4/25/03 MOZ-002 #5</i>	12/30/83	<del>P1 B1</del>
8. memo	from Matlock to McFarlane re: reaction to President's speech on US-Soviet relations (1p) <i>R 11/13/03 ~ #6</i>	1/20/84	<del>P1 B1</del>
9. memo	from McFarlane to the President re: reactions to speech (1p) <i>R ~ #7</i>	n.d.	<del>P1 B1</del>
10. memo	from Hill to McFarlane re: reactions to speech (2pp) <i>R 11/26/02 NLSMO2-002 #8</i>	1/19/84	<del>PT B1</del>
11. memo	from Matlock to McFarlane re: renewal of memo of cooperation (1p)	1/23/84	<del>R1 B1</del> <del>PS</del>

*CCB 12/4/00*

### RESTRICTION CODES

**Presidential Records Act - [44 U.S.C. 2204(a)]**

- P-1 National security classified information [(a)(1) of the PRA].
- P-2 Relating to appointment to Federal office [(a)(2) of the PRA].
- P-3 Release would violate a Federal statute [(a)(3) of the PRA].
- P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA].
- P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA].
- P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA].

C. Closed in accordance with restrictions contained in donor's deed of gift.

**Freedom of Information Act - [5 U.S.C. 552(b)]**

- F-1 National security classified information [(b)(1) of the FOIA].
- F-2 Release could disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA].
- F-3 Release would violate a Federal statute [(b)(3) of the FOIA].
- F-4 Release would disclose trade secrets or confidential commercial or financial information [(b)(4) of the FOIA].
- F-6 Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA].
- F-7 Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA].
- F-8 Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA].
- F-9 Release would disclose geological or geophysical information concerning wells [(b)(9) of the FOIA].



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12. memo	from Hill to McFarlane re: renewal of memo (3pp)	1/5/84	<del>R1</del> B1 <del>PS</del>
13. report	re: extension of the memorandum of cooperation between NBS and USSR Academy of Sciences (3pp)	n.d.	<del>R1</del> B1 <del>PS</del>
14. memo	from Edward Brady to Byron Morton, page 1 (1p, partial)	11/16/83	<del>PS</del> open
15. memo	page 5 of item # 14 (1p, partial)	11/16/83	<del>PS</del> open
16. memo	from Robert Kimmitt to Hill re: renewal of memo (1p)	n.d.	<del>R1</del> B1 <del>PS</del>

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Revised: 1/14/83

YOUR MEETING WITH GROMYKO IN STOCKHOLM,  
JANUARY 18, 1984

SUGGESTED PRESENTATION

I. Opening Statement

(As host, Gromyko will probably invite you to speak first.)

-- Our meeting comes at an important time. Hope you have had the opportunity to study the President's speech. President has restated his commitment to constructive and productive relationship with Soviet Union, and high-level dialogue in pursuit of it. That will be my approach in this meeting.

-- President has what I think you would call a "principled and consistent" policy for managing our difficult relationship. In speech he specified the objectives: reducing burden of armaments, reducing use and threat of force in international relations, increasing trust and confidence in our relationship.

-- The President and I think these are objectives our two countries should share. 1984 will be a year that shows whether or not this is true. It is an election year for us. As I told Ambassador Dobrynin, the President intends to play it straight in Soviet policy. He will base his decisions on what is good for the country, without regard to partisan politics.

-- We would like to make some real progress, and will do our part if you will. If you decide this is not the year for progress, we will be in a position to protect our interests. But we would prefer forward movement.

-- I value my exchanges with Ambassador Dobrynin and your exchanges with Ambassador Hartman in Moscow. President and I are pleased with your agreement to move forward with confidential private exchanges on thorny questions in this channel.

-- At same time, we recognize that the quality of our dialogue has not been what it should be, and we would like to improve it.

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DECL: OADR

DECLASSIFIED  
NLS 102-007-#1  
BY LOS, NARA, DATE 11/26/02



-- You and Art Hartman have had what I thought was a good exchange on the question of rhetoric in our relationship. I think it is worth reiterating his point that we do not inject rhetoric into our private exchanges. And you should consider the President's speech a significant effort to improve the atmosphere. We would like to see similar efforts on your part. Recent Soviet statements about the President and the U.S. have not helped.

-- However, I think we should both recognize that if our relations are bad, the reasons go far beyond rhetoric. We have different interests and values, and it will always be hard to manage relations well. We have differences not just over words, but over real issues, and these can knock the relationship off track at unexpected times.

-- In our view, dialogue between our two countries should have the objective of reducing the chances for confrontation and for resolving problems that can be solved. That is why, as I told Ambassador Dobrynin January 3, we agree that content will be the key to productive dialogue.

-- I should like to concentrate on content in this meeting. When I met with Ambassador Dobrynin January 3, I sketched out the issues I would like to discuss here in Stockholm: arms control (especially START, INF and MBFR), regional issues (especially the Middle East), and human rights. Of course each side should be free to raise any topic it chooses.

## II. Arms Control

-- I would now like to turn to arms control. Your decision to put formal arms control negotiations in abeyance has created an abnormal situation which is disquieting to us and to most of the rest of the world. We are ready to resume our negotiations at any time.

### START

-- It is time to make our dialogue on strategic arms reductions more constructive. The President believes that it is a matter of great importance that we move ahead with reducing the nuclear arsenals of both sides.

-- Thus far, however, the absence of a common conceptual structure or framework in START has impeded progress toward an agreement. The US and Soviet approaches to START have been so far apart on basics that after five rounds of talks, give-and-take negotiations on specifics have not yet really begun.



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-- We have carefully considered what might be done at this point. Alternative approaches may offer greater promise. The concept of trade-offs that Ambassador Rowny put forward in the last round provides a way to develop a foundation for progress towards a START agreement satisfactory to both nations.

-- In seeking a more stable strategic balance at levels lower than now exist, the US recognizes that there are important asymmetries between the strategic forces of our two countries, and that equality can be achieved without requiring forces to be mirror-images. Although our goal is to move toward a more stable balance and achieve substantial reductions in the nuclear arsenals of both our countries, we do not seek to restructure the forces of the Soviet Union.

-- As a means of seeking progress, we could explore various trade-offs of US and Soviet interests involving discrete elements of our respective strategic forces. The development of simple, less comprehensive steps, could generate progress towards a START agreement. We can, for instance, envisage a simple trade-off between constraints on air-launched cruise missile levels in exchange for reductions on ballistic missiles.

-- A better approach might be to work together to try to come up with a common structure which could contain the key elements of both the US and Soviet positions, including the concept of trade-offs.

-- We would welcome your ideas in this regard. We are prepared to discuss ideas for developing a common framework for reductions that would involve mutual acceptance of parts of the Soviet Union's current proposal and parts of our own proposal.

-- For our part, we would look for meaningful reductions in the number of Soviet and US ballistic missile warheads, and to reduce the asymmetry in the destructive power of our two strategic forces. Significant reductions in Soviet missile throw-weight are of particular importance to the United States.

-- In turn, we would be prepared to accept counterbalancing limits on US heavy bombers and air-launched cruise missiles about which the Soviet Union has expressed concern.

-- We are seeking a common framework that is simple, straightforward, and would explicitly recognize the concerns already expressed by both sides in the START negotiations -- one that would account for the Soviet Union's concerns over limiting US bombers and cruise missiles, while meeting our concerns about the large Soviet ICBM force. It would not have to make each other's forces identical or to achieve equality in every measure.

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-- The best solution would be for us to agree to continue serious START negotiations in Geneva this February and to explore mutually acceptable approaches that result in the reduction of both nation's strategic arsenals.

START: Contingency Points if Gromyko shows interest and responds constructively:

-- One approach would be agreement on a formula according to which the U.S. would agree to limit missiles and bombers together, as the Soviet Union has suggested, and your country would agree to sufficient limits on the ballistic missile capabilities that we consider especially threatening.

-- Such an arrangement might involve two parallel networks of limits and sublimits, one on delivery vehicles (as emphasized by the Soviet side), the other on warheads (as emphasized by the U.S.).

-- For delivery vehicles:

- o A single overall ceiling on the number of ballistic missiles and heavy bombers; and
- o Sublimits on the number of heavy ICBMs and heavy bombers equipped with air-launched cruise missiles (ALCMs), with some explicit trade-off between these two areas of relative advantage.

-- For warheads:

- o A single overall ceiling on ballistic missile warheads and air-launched cruise missiles; and
- o A series of sublimits on specific categories of warheads, particularly warheads on MIRVed missiles, similar to the sublimits the USSR has proposed for delivery vehicles with multiple warheads. These could be structured in a way that gives more favorable treatment to single-warhead missiles and air-launched cruise missiles.

-- This is a framework for negotiation which explicitly recognizes the concerns already expressed by both sides in the START negotiations. It accounts for the Soviet Union's expressed concerns over limiting U.S. bomber and cruise missiles, while meeting our concerns about the large Soviet ICBM force. But it does not require that we count each other's forces identically or that we achieve equality in every measure.

-- If agreement were reached on the principles of such an agreement, our two delegations in Geneva could then negotiate the actual levels of the various limits and sublimits, as well as other details of a final document.

-- We are prepared to continue confidential exploratory discussions of this idea through senior diplomatic channels, either in Washington or in Moscow.

INF

-- We regret the interruption of INF talks. Despite the impasse over treatment of LRINF missiles, we had been encouraged by the degree of convergence achieved last fall on key issues.

-- For example, in September we offered to explore limits on LRINF aircraft. President Andropov's interview one month later modified the Soviet position on aircraft. In subsequent discussions, Ambassadors Nitze and Kvitsinskiy were able to narrow considerably our differences over treatment of aircraft.

-- Second, our September initiative included an offer to discuss a specific commitment with regard to U.S. deployments in Europe. One month later, your government indicated a willingness in principle to freeze SS-20s in Asia. Thus, a degree of convergence was beginning to emerge on the geographic issue.

-- We believe INF negotiations should resume, but as in START, we would be interested in maintaining an INF dialogue with you through other channels.

-- For our part, we see a possibility of forward movement in such discussion. For instance, under a global ceiling of 420 LRINF warheads, we would be prepared to limit the actual level of U.S. deployments in Europe to two-thirds of that figure -- 280 warheads -- and to limit to 20 percent of that total -- about 56 warheads -- the number of warheads on deployed Pershing IIs.

-- I would welcome an expression of Soviet interest in exploratory discussions of this sort, which would not commit either side.

START/INF Merger (if Gromyko raises)

-- While we recognize the relationship between strategic and intermediate-range nuclear forces, we continue to believe that the most practical approach is to negotiate separately in START and INF.



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-- If the Soviet Union wishes to propose some formula that would relate the two fora more closely, we would of course be prepared to consider it in a constructive spirit.

-- But under no circumstances will we agree to limits on our intermediate-range systems such as the Pershing II and GLCM without reciprocal limits on Soviet INF systems like the SS-20.

#### MBFR

-- East should return to MBFR talks in Vienna.

-- West has proposed resumption and is prepared to hold plenary on any early date.

-- West gives high priority to MBFR.

-- We recognize that Eastern proposals of February and June, with subsequent clarifications, represent positive steps, particularly on subjects of verification and specification of reductions. We are studying ways to build on them.

-- West is prepared to continue dialogue on these as well as other points, which can be further developed to bring us closer to an agreement.

-- I should like to reiterate points made last fall to Dobrynin -- if there were progress on verification, there would be flexibility on our side on data issue.

-- A constructive Soviet response to this suggestion could open the way to genuine progress toward an agreement.

-- We are prepared simultaneously to resume a dialogue on MBFR issues in both bilateral channels and in the multilateral negotiating forum in Vienna.

#### CDE

-- CDE brought us to Stockholm, and this meeting is an important event in East-West relations at a time when we are not talking formally in other areas of arms control.

-- Our delegation chiefs worked well together during the preparatory meeting, and we agree with the point you have made in diplomatic channels that we should continue to remain in close touch and consult in businesslike fashion as the meeting proceeds.

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-- The NATO Allies will be presenting proposals for concrete confidence-building measures, to improve the notification and observation of military activities, and to provide for improved exchanges of information and communication and for improved verification.

-- Thus, we see the meeting as a real opportunity to reach agreement on steps that will modestly enhance the security of all our countries, based on the mandate worked out at Madrid. We do not see it as an occasion for competitive rhetoric, and we hope you will adopt the same practical approach.

#### Compliance

-- A practical approach also governs the way we will be handling the difficult issue of observance of existing treaties in the arms control field and elsewhere. This is not a new issue in our relations, but one which has been and will continue to be a matter of vital importance. Our most recent concerns have been raised repeatedly in diplomatic channels.

-- We have already explained to your Embassy in Washington the report the President will make in fulfillment of a commitment to the Congress. The President's report will be classified, and we are not planning an expanded public campaign to publicize it. The United States will also not alter the President's determination to seek effective arms control.

-- I must stress again, however, as we have stressed in raising specific compliance questions, that the very existence of the issue has a most corrosive effect on the whole arms control process. Soviet programs which stretch the terms of agreements to the breaking point, together with efforts to impede U.S. ability to monitor those programs, seriously undercut the confidence needed if we are to make further progress.

-- Our concerns are real, but our purpose in pursuing these questions is constructive. It is not our intention to embarrass the Soviet Union. We want resolve these issues in a way that strengthens the arms control process. Thus, we would like to continue to work with you in diplomatic channels and in the SCC to elucidate these questions and resolve them where it is possible to do so.

-- The President and I would therefore welcome further clarifications or, better yet, corrective action to remove our concerns.

-- I would ask you to interest yourself personally in these issues, and encourage your people to work with ours to get these questions resolved.



DABM (if Gromyko raises)

-- This is a research and development program similar to the one the Soviet side has had underway for some time.

-- Given the importance of the implications, it is not possible for us to allow you a unilateral advantage in such research and development.

-- But our program is not designed to reestablish American strategic superiority. Your side sometimes claims that this is our secret desire, but I hope you yourself realize that claim is without foundation.

-- You may be sure that our activities in this area are in strict compliance with our obligations under the ABM Treaty, which does not prohibit research for ABM systems. We have no intention or plans to alter either the Treaty or those obligations.

-- If our research turns up results which could affect the Treaty, we will consult with you as prescribed by the ABM Treaty, and we hope you will do the same if your program has such results.

-- In the meantime, our offer to reinforce our START and SCC delegations with experts knowledgeable in this field in order to discuss the issues involved remains on the table.

January 10 Soviet Proposal  
on Chemical Weapons in Europe (if Gromyko raises)

-- We have noted the proposal you made last week to eliminate chemical weapons from Europe. We and our Allies will want to discuss this proposal among ourselves before responding formally, but on the face of it we believe any proposal should be studied carefully.

-- There are some obvious problems. For example, chemical weapons can be easily transported, and a regional ban would not, in our view, be sufficient.

-- Our goal is to ban all chemical weapons everywhere, and we and our Allies have been negotiating at the Conference on Disarmament toward this end. Vice President Bush presented a major proposal in Geneva last February.

-- The most essential component of any such agreement -- the only sure means of providing adequate assurances -- is effective procedures for verification. Our efforts in Geneva have been aimed at reaching agreement on verification.



-- As a further stimulus to the Geneva negotiations, I will be instructing our negotiators to present a draft treaty for the complete and verifiable elimination of chemical weapons on a global basis, in the upcoming round of the Conference on Disarmament.

### III. Regional Issues

-- I would like to touch on a number of the issues which have figured on our agenda in this area, including southern Africa and Afghanistan, but I believe the situation in the Middle East is such that we should focus on it.

#### Middle East

(Note: The following points are cleared by NEA and EUR.)

-- Our exchanges on the Middle East have been useful, at least to me, and I think that given the dangerous potential for confrontation in the area now that both countries have troops in close proximity on the ground, we should continue to maintain a dialogue in order to eliminate unnecessary misunderstandings.

#### 1. Lebanon: U.S. and Soviet Roles

-- Agree With your statement to Hartman that Lebanon should not be object of conflict between our countries. That is why we should both encourage progress toward Lebanese reconciliation and complete withdrawal of foreign forces.

-- We have been using our influence to this end and have contributed to progress made; we will continue.

-- We recall your statement to Hartman that you have exerted "a restraining influence" on Syria. We remain very skeptical about Syria's intentions in Lebanon. Still far from clear that Syria has decided to cooperate on reconciliation and troop withdrawals.

-- Recognize Syria's interest in developments in Lebanon, and have made this clear in our dialogue, which Ambassador Rumsfeld is pursuing with Damascus.

-- At the same time, Israel must also have confidence that its interests are being addressed. Our relations are intended to provide Israelis with security and reassurance they need to participate in peace process. Constant attacks on our relationship with Israel do not help.

## 2. Lebanon: Current Situation

-- Security plan which Government of Lebanon hopes to implement would be positive developments; some problems remain. Reconciliation talks are accelerating. Success should lead to more stable Lebanese Government and reduction of sectarian violence.

-- We will be watching to see whether Jumblatt behaves more responsibly following his recent trip to Moscow.

-- Stronger Lebanese Government should be able to deal better with Syrian and Israeli security concerns and be in better position to negotiate withdrawal of all foreign forces.

## 3. Lebanon: MNF, Withdrawal of Foreign Forces

-- MNF has been important factor in encouraging progress in Lebanon; we do not desire a long term military presence, but significant progress toward internal settlement and withdrawal of foreign forces needed to allow departure of the MNF.

-- Similarly, Israel has made public commitment to withdraw its forces in May 17 agreement. We see no advantage to criticizing this agreement; rather, Lebanese should be put in position to redeem this Israeli commitment.

-- Although everyone understands that Syrian concerns must be taken into account in settlement, it would be extremely useful for Syria to match Israeli commitment with a commitment to withdraw its forces in Lebanon.

-- At a later phase, we believe an expanded UN peacekeeping or observer role may be useful to help the Government of Lebanon preserve stability and maintain its authority. Would appreciate your views on desirability of using an expanded UN presence.

## 5. Progress toward General Settlement

-- Looking beyond Lebanon, the Arab-Israeli conflict remains a serious threat to the stability of the region. We want to press ahead with the peace process on the basis of UNSC resolutions 242 and 338, the Camp David framework and President Reagan's September 1, 1982 proposals. Ambassador Rumsfeld is also pursuing this as well as Lebanon diplomacy.

-- Jordan's entry into peace negotiations, hopefully with representative Palestinian participation, is the essential next step in the broader peace process. We hope Arafat's move toward reconciliation with Egypt will lead to Arab and Palestinian willingness to support Hussein.



-- What is the Soviet view toward Palestinian support for peace talks between Jordan and Israel? We hope all interested parties will encourage this.

6. Iran-Iraq

-- Would like to reiterate some of the points Ambassador Hartman made to you December 15.

-- We are not trying to determine to whom Gulf states should sell oil, nor arrogating to ourselves right to order affairs in region.

-- Rather, our concern is over very real threat that prolonged conflict creates for right of free navigation in international waters and security of non-belligerent Gulf states.

-- We are aware that Soviet Union has also traditionally supported right of free navigation. Precisely because free navigation is threatened by continued Iran-Iraq conflict, is one reason world community should increase efforts to encourage negotiated settlement that protects territorial integrity and sovereignty of both Iran and Iraq.

-- This is context in which we are committed to continued freedom of navigation in international waters and would be obliged to act to protect that freedom if it were threatened.

-- Would appreciate Soviet views on current dangers in Gulf, and what international community can do to deal with them in practical terms. Is our assumption that the Soviet Union supports the right of freedom of navigation in the Gulf correct?

Southern Africa

(Note: The following points were cleared by AF and EUR.)

-- Has appeared to me to be an area where both countries could profit by progress toward peaceful resolution of current tensions.

-- Suspect our approaches will continue to differ in important respects, but would like to believe that events over past month have opened up fresh opportunities, and that you share our view that it would be a shame to let them pass unexplored.

-- Hope you have had a chance to examine the non-paper submitted by our Embassy in Moscow on Saturday. Here I would like briefly to touch on significant recent developments. Government of South Africa's December 15 offer to withdraw its forces from Angola, and now the end of forward military



operations there, were not steps taken to please us, but we encouraged them, and they were also responsive to concerns you and Government of Angola had pressed quite strongly. President Dos Santos' December 31 letter to UNSYG could also be an encouraging sign.

-- Believe it worthwhile for us to exchange views on these developments in more depth, and would be willing to make Assistant Secretary Crocker available for another round of discussions with an appropriate Soviet official. If you agree, timing and venue can be worked out in diplomatic channels.

#### Afghanistan

(Note: The following points were cleared by NEA and EUR.)

-- Would like also to touch briefly on Afghanistan.

-- Secretary General is considering renewal of indirect talks through his Personal Representative for some time in spring. Although these talks have not brought the results they deserved, we continue to support them as efforts to achieve a political solution to the problems in Afghanistan.

-- We continue to believe that the Afghanistan problem can only be resolved through political means: the use of force cannot succeed in imposing a solution.

-- You should also be aware that we continue to believe that any successful political solution must include four interrelated elements: return of your troop contingent to its homeland; reestablishment of Afghan independence and non-alignment under a government responsive to the will of Afghanistan's people; safe and honorable return of the refugees; and appropriate guarantees of the stability of the settlement.

-- It seems to us that despite your refusal to set a date for full return of your troop contingent and your apparent loss of interest last spring, some progress had been made concerning certain of these elements in the UN-sponsored talks. We will welcome any signs of renewed interest on your part in serious forward movement.

#### Central America and the Caribbean (if Gromyko raises)

-- Our purpose remains the one both I and Secretary Haig have consistently identified to you: to help the countries of the area resolve tensions on terms acceptable to them, without outside interference.

-- It was for that reason that the President agreed to accept the request of Grenada's neighbors to join in restoring democratic government there after the previous elected government had been eliminated. The purpose was limited, specific and worthwhile. Most of our troop contingent has already been withdrawn.

-- Grenada was not part of a pattern of U.S. policy. There still seems to be a pattern of Soviet policy in the region, however: a pattern of arms shipments to Cuba and Nicaragua far in excess of any reasonable defense need, used to support the export of revolution to their neighbors.

-- This pattern is not constructive either in regional or in bilateral terms, and we will protect our interests and help our friends in the region protect theirs. In particular, I must reiterate that continued massive arms shipments to Cuba are dangerous, and that the arrival of Cuban combat units or jet combat aircraft in Nicaragua would be unacceptable to us.

Korea (if Gromyko raises)

(Note: EA agrees in substance with the following points drafted in EUR.)

-- We are looking seriously at the North Korean proposal for tripartite talks and a North-South dialogue.

-- We share the ROKG's strong preference for direct talks between North and South or a larger forum in which both Korean parties would be represented equally, such as a quadripartite meeting.

-- But the main point is that the U.S. takes seriously its responsibility for the maintenance of peace on the peninsula, a responsibility we share with other outside powers including the Soviet Union. Peaceful reunification is a question that must be worked out primarily by the Koreans themselves, but we are willing to help facilitate a North-South dialogue and participate in efforts to reduce tension.

-- I would be interested in hearing your views on the recently announced North Korean proposal for talks including the South.

IV. Human Rights

-- There has been no change in the priority the President and I and all Americans attach to human rights: no set of issues in our relationship is more important.



-- In no other area has the Soviet approach so damaged the trust and confidence of Americans that is needed to have constructive relations with the Soviet Union; in no other area can constructive Soviet steps have such a positive impact on our relations. It was in that spirit that we appreciated your decision to permit the Pentecostalist families to emigrate last year.

-- Here as elsewhere the President and I are committed to a practical approach to resolving problems. We will not be silent when the Soviet approach is not in keeping with international commitments the Soviet Union has solemnly undertaken. But we strongly believe that specific issues can best be resolved through quiet diplomacy.

-- In this brief meeting I will mention only a few specific issues, (fuller background on each is in your briefing book):

1. Anatoliy Shcharanskiy's case is perhaps the best candidate for early resolution.

2. Andrey Sakharov remains in poor health in his exile, and together with scientists and scholars from all over the world I would urge you to make available to him the medical facilities of the Academy in Moscow.

3. The arrest and conviction of Iosif Begun seems to us an unjustified and wholly needless act of persecution against a man who cannot possibly harm the interests of a powerful state.

4. The level of Jewish emigration from the USSR was lower last year than at any time in recent history, and the number of anti-semitic statements and allusions appearing in Soviet media appears to be growing. We do not accept the claim Soviet spokesmen make that no more Jews wish to leave: the evidence is overwhelmingly to the contrary.

-- It would help our relations a great deal if steps were taken to reverse these regrettable trends. World Jewish Congress President Edgar Bronfman has informed me that he may be coming to Moscow to discuss these issues with responsible Soviet officials, and I hope this will be one means to resolve specific cases.

-- On a more traditional note, meetings between U.S. and Soviet foreign ministers have provided the occasion in the past to hand over various lists. You will recall that in our first meeting I gave you a short list of persons with a claim to American citizenship under our law who have long been denied exit permission, and that you undertook to have it reviewed.



~~SECRET/SENSITIVE~~

- 15 -

-- After our meeting I would like Ambassador Hartman to provide Minister Korniyenko with an updated version of that list and of two others: persons seeking reunification with members of their family in the United States, and binational divided spouses.

#### V. Bilateral Issues; Conclusion on Dialogue

-- I do not propose to spend much time on strictly bilateral issues in this relatively short meeting, but I think it would be unrealistic to dismiss the range of topics we have under discussion as unimportant. Let me note them briefly.

-- I was pleased that last week's discussions on the Hotline went so well and hope that we can continue to make prompt progress in a follow-on meeting this spring. We have presented various ideas for strengthening and expanding our communications in addition to the Hotline, and are interested in exploring not only these proposals but any ideas the Soviet Union might have in this field, formally or informally as you choose.

-- Similarly, we look forward to another round of bilateral consultations on nuclear non-proliferation matters in mid-February. This is surely an area where the interests of our two countries are often the same or are parallel.

-- Depiction of our Pacific maritime boundary is another such area. We are pleased you have responded positively to our proposal to resolve our technical differences on this issue, and we are looking forward to the talks you proposed for end of this month.

-- We continue to believe that trade can go forward as long as it is mutually beneficial, conducted on commercially sound terms, and not militarily related. Agribusiness is a good example of mutually beneficial, non-strategic trade.

-- We are of course willing to consider any ideas you may have about appropriate topics for bilateral discussion.

-- (If raised) We were encouraged by the limited progress that was achieved at last year's Consular Review Talks. We are considering the question of when to move forward with these talks.

-- I think we should pay particular attention to issues that can unexpectedly knock our relations off course. That is one reason why I sent Ambassador Hartman in to see you December 15 on the Middle East, and why I have devoted so much time to this topic here. The Middle East is perhaps the foremost current example of a situation that could get out of control if we are not very careful and in touch with each other.

~~SECRET/SENSITIVE~~



-- But there are also other issues that can hurt or help relations much more than their substance might suggest. The airliner tragedy is a clear example. The President and I were encouraged by progress we were making in relations last summer, before the plane was shot down, and of course that tragedy made it impossible to continue along same lines and at same pace.

-- Now, however, the airliner issue provides an opportunity for useful action which could help our relationship far beyond the civil aviation field. If you could join in implementing the technical steps available to avoid repetition of such terrible events, it would have a beneficial effect in other areas of our relations as well.

-- This could include placement of radio beacons and other fixed navigation aids in that area, and better communications links among the responsible civil aviation officials. We want to cooperate with you to the maximum extent possible within ICAO and welcome both multilateral and appropriate bilateral discussion with you on this topic.

-- Steps such as these would make it easier to move forward on issues like opening Consulates in Kiev and New York, and beginning negotiations on a new Cultural Agreement. The agreement in principle we made last summer to move forward here still stands. However, the timing must be right.

-- We would also like to apply this same practical approach to the other topics in our dialogue, and concentrate on content. It will be a hopeful sign if you take the same approach.

-- As the President announced once again in his speech, he believes strongly in the need for and potential benefits of dialogue between our two countries. And he is setting no artificial limits to the range of our communications: the way we talk should be determined by what we are talking about and by the progress we are making. If we are making sufficient progress, and there is adequate careful preparation, he is of course willing to envisage discussion at the highest level.

-- But there may be other ways to proceed short of that. If we are going to enrich the dialogue, this will mean contacts at different levels on specific subjects. But to make this work well, you and I will have to manage the process. This could mean more frequent meetings between us. What is your thinking on this

-- (If Gromyko seems interested, in addition to mentioning a possible trip by you to Moscow, you might mention a Weinberger-Ustinov or Vessey-Ogarkov meeting, stressing latter is and will remain private suggestion.)

2854m

Chron - Jan 84  
~~Mallock~~

932

CT

National Security Council  
The White House

64 JAN 14 P 3: 24

System # I

Package # 0288

	SEQUENCE TO	HAS SEEN	DISPOSITION
Bill Martin	<u>4</u>		
Bob Kimmitt	<u>1</u>	<u>K</u>	
John Poindexter	<u>2</u>	<u>J</u>	
Wilma Hall	<u>3</u>		
Bud McFarlane	<u>4</u>	<u>✓</u>	<u>A</u>
Bob Kimmitt			
NSC Secretariat			
Situation Room			

I = Information

A = Action

R = Retain

D = Dispatch

N = No further Action

cc: VP Meese Baker Deaver Other

COMMENTS

Should be seen by: 1/16/84 3:00 pm  
(Date/Time)



0288

# National Security Council The White House

System #

Package #

	SEQUENCE TO	HAS SEEN	DISPOSITION
Bill Martin		<i>WFM</i>	
Bob Kimmitt			
John Poindexter			
Wilma Hall			
Bud McFarlane			
Bob Kimmitt			
NSC Secretariat			
Situation Room			
<i>Jack MINTLOCK</i>	<i>2</i>		<i>[initials]</i>

I = Information

A = Action

R = Retain

D = Dispatch

N = No further Action

cc: VP Meese Baker Deaver Other

## COMMENTS

Should be seen by:

JACK - Bud has agreed to take Mr. Massie to <sup>(Date/Time)</sup> *The 9:30 on*  
*The 17th*. He needs to forward a short memo to the President  
 the day before describing the reason for her meeting in the standard Pres.  
 meeting memo, i.e. purpose, background, participants, mess, sequence  
 of events. This should be very short - no longer than a page.  
 Thanks, Bill

REF National Security Council  
The White House

04 JAN 1962 2:11 PM

System # \_\_\_\_\_

Package # 0288

	SEQUENCE TO	HAS SEEN	DISPOSITION
Bill Martin	_____	_____	_____
Bob Kimmitt	<u>1</u>	<u>K</u>	_____
John Poindexter	_____	_____	_____
Wilma Hall	_____	_____	_____
Bud McFarlane	_____	_____	_____
Bob Kimmitt	_____	_____	_____
NSC Secretariat	<u>2</u>	_____	<u>SHH</u>
Situation Room	_____	_____	_____
_____	_____	_____	_____

I = Information    A = Action    R = Retain    D = Dispatch    N = No further Action

cc: VP    Meese    Baker    Deaver    Other \_\_\_\_\_

COMMENTS

Should be seen by: \_\_\_\_\_

(Date/Time)

*Matlock for action/recommendation*



1984 JAN 16 PM 8:17

~~CONFIDENTIAL~~

THE WHITE HOUSE  
WASHINGTON

0288  
DECLASSIFIED  
NLS M02-002 #2  
BY CJS, NARA, DATE 11/13/03

January 16, 1984

CONFIDENTIAL

MEETING WITH MRS. SUZANNE MASSIE

DATE: January 17, 1984  
LOCATION: Oval Office  
TIME: 9:35 - 9:40 A.M.

FROM: ROBERT C. MCFARLANE *Rem*

I. PURPOSE: To introduce Mrs. Massie to you before her trip to Moscow, where she will be discussing unofficially and privately the possibilities for expanding cultural and information exchanges.

II. BACKGROUND: Mrs. Massie is a noted author of books about Russia. She and her husband co-authored Nicolas and Alexandra, about the last Tsar and his family, and she has written several others on her own. She was in Moscow in September and October (just after the KAL shoot-down) and found her Russian friends in the cultural and intellectual world fearful of the U.S. and eager to see an improvement of cultural ties and better communication. She offered to return to Moscow, if we wished, to convey our interest in improving contacts and to solicit private and unofficial suggestions as to how this can be done best. If the Soviets issue a visa for her, she will leave Thursday.

III. PARTICIPANTS:

The President  
The Vice President  
Robert C. McFarlane  
Meese, Baker and Deaver at their discretion

IV. PRESS PLAN:

None

V. SEQUENCE OF EVENTS:

Introduction  
Conversation for five minutes

Attachments:

Tab A Talking Points/card

cc: Vice President  
Edwin Meese  
James Baker  
Mike Deaver

Prepared by:  
Jack Matlock

CONFIDENTIAL

## TALKING POINTS

--Appreciate your undertaking this visit; hope it will help us find ways to improve contacts with Russian people.

--Please stress with your Russian contacts that they should take my speech yesterday as a serious and sincere effort to improve relations.

--Above all, we want the Russian people to understand that we want peace as much as they do. If there are problems, it is with their government, not with us.



## MEMORANDUM

## NATIONAL SECURITY COUNCIL

~~CONFIDENTIAL~~

January 13, 1984

ACTION

MEMORANDUM FOR ROBERT C. MCFARLANE

FROM: JACK MATLOCK *[Signature]*

SUBJECT: Suzanne Massie's Call on the President

In response to Mrs. Massie's request (TAB I), you have agreed that she will accompany you for five minutes of your meeting with the President at 9:30 A.M., January 17.

Mrs. Massie desires only to see the President briefly so she can tell her Soviet contacts that she has seen him and knows that he is sincere in his desire to improve relations. I believe it will be sufficient to introduce her as a renowned writer about Russia who will be travelling to the Soviet Union in a few days, and who has an interest in doing what she can to improve contacts in the cultural area.

The Soviet Embassy has not yet issued a visa for Mrs. Massie, but she is hoping to leave on her trip January 19 if it comes through. All other arrangements have been made or are in train.

RECOMMENDATION:

That Mrs. Massie accompany you for five minutes of your meeting with the President at 9:30 a.m., January 17, *and that you sign memo to President at Tab II*

Approve ✓Disapprove                     

## Attachment:

Tab I Letter from Mrs. Massie  
Tab II Memorandum for the President

~~CONFIDENTIAL~~

Declassify on: OADR

DECLASSIFIED

NLS M02-002 #3BY AS NARA, DATE 11/13/83

SUZANNE MASSIE  
60 WEST CLINTON AVENUE  
IRVINGTON, NEW YORK 10533

17/ annex for  
recommendation.  
I don't mind  
5 min at a 9:30  
January 8, 1984.  
sorry if you  
think it's worth -  
while.

Dear Mr. MacFarlane,

I regret, but fully understand that the pressure of your schedule did not permit us to meet when I was in Washington on Friday. I hope that a meeting with you will be possible at some future date before my departure.

M  
1-10-84

I am aware that Jack Matlock has fully informed you of our conversations and of my feeling that it is extremely important for me to see the President even if only for a short time before I leave on this mission. Nevertheless, I wish to explain to you directly my reasons for feeling so strongly about this.

It is my considered assessment, knowing the Russians as I do, that it is vital to the potential success of this initiative for me to be able to say that I have seen the President and that he has personally assured me of his interest in the resumption of dialogue between our two countries on the subject of cultural exchange. For Russians, personal contact is far more important than it is for us, a psychology that we often do not completely understand or share. For them, everything is decided at the top, and only at the top. If I say that I have spoken with the President's highest advisors but am forced to admit that I have not seen him personally, the results will not be the same. Not only will it diminish my credibility, but far more importantly I fear, it will reflect on his. As you are aware, an important part of the problem for them now is not only the question of issues and substance, but the matter of style and personality. They simply do not understand our President and do not trust him. Because of this they are deeply suspicious of his motives and all of his initiatives, however reasonable.



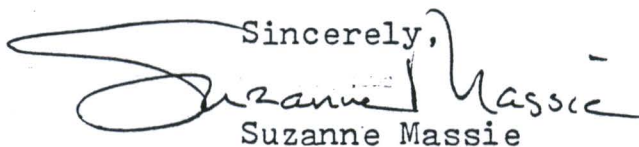
Mr. MacFarlane 2.

Given the state of communication between our countries at this time, this will not be an easy perception to dispel. My task of persuasion will be made much more difficult if I have to say that I have never actually met him. I know them. Their reaction may very well be, " We trust you, but if you have never met him, why do you trust him? How do you know this is a genuine gesture?" It will make it much easier for them to dismiss this initiative as " just another American ploy", rather than the sincere and genuine action I know it to be.

I hope you will give me the fullest support as I believe you understand that I would not presume on the President's time if I did not think a face to face meeting to be a necessary and perhaps vital ingredient in the success of this mission.

Thank you for your trust in me. I shall do my best to serve the interests of our nation and of peace.

Sincerely,

A handwritten signature in cursive script, reading "Suzanne Massie". The signature is written in dark ink and is positioned below the word "Sincerely,".

Suzanne Massie

## MEMORANDUM

## NATIONAL SECURITY COUNCIL

ACTION

January 18, 1984

MEMORANDUM FOR ROBERT C. MCFARLANE

FROM: PETER R. SOMMER *PR*

SUBJECT: International Reaction to the President's Speech

State has forwarded you an excellent summary of initial international reactions to the President's speech on U.S.-Soviet relations. While largely favorable and positive, the overall reaction is predictable. There is heavy emphasis on European reaction in State's summary (Tab A).

State's summary is concise and readable. Given the President's strong interest in U.S.-Soviet relations and all the time he spent on the speech, I thought you may wish to forward him a copy of State's summary.

RECOMMENDATION

That you sign the memo to the President at Tab I.

Approve \_\_\_\_\_ Disapprove \_\_\_\_\_

Tab I      Memo to the President  
Tab A      State Summary

*ML*  
John Lenczowski concurs and Jack Matlock is out of town.



MEMORANDUM

THE WHITE HOUSE  
WASHINGTON

0491

INFORMATION

MEMORANDUM FOR THE PRESIDENT

FROM: ROBERT C. MCFARLANE

SUBJECT: International Reaction to U.S.-Soviet Relations  
Speech

State has prepared an excellent summary of international reaction to your speech on U.S.-Soviet relations. While by and large very favorable and positive, overall international reaction (i.e., from the Soviets and certain Third World countries) has been highly predictable. We should get a better feel for Soviet reaction following George Shultz' private meeting with Gromyko. In the interim, I thought you might wish to review State's useful summary of international reactions (Tab A).

Tab A      State summary



United States Department of State

Washington, D.C. 20520

~~CONFIDENTIAL~~

January 17, 1984

MEMORANDUM FOR MR. ROBERT C. MCFARLANE  
THE WHITE HOUSESUBJECT: International Reaction to President's Speech  
On US-Soviet Relations

Initial response to the President's January 16 speech, with the predictable exception of negative Soviet bloc comments, was positive. Official reaction from our European allies was especially helpful, and much press coverage in non-aligned nations also welcomed the President's remarks, expressing interest and hope that improved atmospherics would lead to early progress on arms control and a reduction of international tensions.

The Soviets indirectly acknowledged the significance of the address by issuing a virtually simultaneous TASS rejoinder January 16 emphasizing the "propaganda nature" of the remarks. Citing the opinions of Western "political observers," perhaps to avoid the appearance of presenting considered official Soviet views, TASS stated that the speech was found to contain no new ideas and to provide "no indication of any positive changes in the Reagan Administration's approach to the solution of problems of limiting and reducing arms, first of all nuclear ones." The report claimed that the address was motivated by the Administration's desire "to dispel growing concern in the U.S. itself and in Western Europe over the militaristic policy pursued by the White House." Subsequent reports on Radio Moscow also followed this line.

The only official Soviet reaction to date is an informal remark by Deputy Foreign Minister Komplektov to our Chargé, when the latter delivered an advance text of the President's speech January 16, reflecting skepticism that the address would be followed by meaningful changes in the U.S. approach to the USSR. Komplektov did indicate, however, that a more authoritative response to the speech would be made shortly.

East European countries generally followed the Soviet lead in their responses, commenting through the press rather than with direct official statements. Poland and the GDR hewed the closest to the Soviet line. The Polish press claimed the speech had "little credibility" and was motivated by the upcoming Presidential election campaign. East Berlin radio, echoing TASS precisely, said the address was of a "propagandistic character" and contained no new ideas. On the other hand, initial Hungarian reports provided a factual account of the President's remarks, without commentary.

~~CONFIDENTIAL~~  
DECL:OADR

NLS

MO2-002 #4

BY

LOT

NARA DATE

11/26/02



~~CONFIDENTIAL~~

- 2 -

Among Soviet allies -- indeed among all commentaries -- the Cubans provided the sharpest assessment, calling the speech "demagoguery" and, perhaps a little nervously, stating that the President's remarks would have no effect on the Soviets and would increase existing problems between the U.S. and its European allies.

Official Western European reaction to the address was positive. British Foreign Minister Howe termed the speech "a very deliberate move" to improve East-West relations, and Swedish Prime Minister Palme called it "definitely a more conciliatory note than we have heard before." In a statement January 16, the West German government welcomed the President's remarks as "an expression of joint Western readiness for talks and cooperation with the Soviet Union," and expressed hope that the USSR would accept the offer of a serious dialogue. Foreign Minister Genscher also welcomed the speech as a message of goodwill to the Soviets on the eve of the CDE opening in Stockholm. However, SPD foreign policy spokesman Voigt, while approving the "conciliatory tone" of the speech, regretted the "lack of substance in terms of constructive proposals for arms control and economic cooperation between East and West."

Reports of the President's address which dominated West European newspapers and television the morning of January 17 were overwhelmingly favorable. Geneva's Le Journal de Genève claimed to see the speech as signalling a new beginning for détente. Although the French press used words such as "conciliatory," "positive" and "a turning point" in describing the address, several commentators -- noting Gromyko's harsh line against U.S. policy in his meeting with Cheysson in Stockholm January 16 -- believed the Soviets would reject the President's offer. Certain commentators, such as Le Figaro's Denis Legras, approved the President's expression of confidence in U.S. strength as the basis for improved relations; noting that the speech was aimed at Europeans, Legras called it "a profession of faith -- faith in U.S. power."

British and German press reaction was favorable, although caution was expressed about the actual possibilities for improving East-West relations. The Italian media welcomed the speech, several underlining the fact that Prime Minister Craxi had received an advance text with the President's thanks for Craxi's "good advice."

Press coverage in Asia was generally favorable, especially in Japan, with many commentators noting that the President's approach to Moscow was based on an upswing in U.S. power. In China Xinhua gave its readers a factual report of the speech under the headline, "Reagan Launches Peace Offensive Against

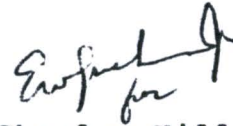
~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

- 3 -

USSR." Xinhua also reported the initial TASS treatment in a factual manner.

Most press treatment in non-aligned countries was factual in reporting and cautious in analysis. Many noted with approval a change in the Administration's rhetoric and hoped that a positive Soviet response might lead to concrete improvements in East-West relations. However, there was a great deal of skepticism -- in places such as India, Saudi Arabia, Mexico, and throughout Africa -- that superpower policies would change along with rhetoric. Several comments, echoing a senior Foreign Ministry official in Zimbabwe, expressed hope that reduced East-West tensions would lead both the U.S. and the USSR to stop treating Third World countries as surrogates of the superpowers.



Charles Hill  
Executive Secretary

~~CONFIDENTIAL~~



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WITHDRAWAL SHEET AT THE FRONT OF THIS FOLDER.

Central Intelligence Agency



Washington, D.C. 20505

DIRECTORATE OF INTELLIGENCE

30 December 1983

Soviet Thinking on the Possibility  
of Armed Confrontation with the United States

Summary

Contrary to the impression conveyed by Soviet propaganda, Moscow does not appear to anticipate a near-term military confrontation with the United States. With the major exception of the Middle East, there appears to be no region in which the Soviets are now apprehensive that action in support of clients could lead to Soviet-American armed collision. By playing up the "war danger," Moscow hopes to encourage resistance to INF deployment in Western Europe, deepen cleavages within the Atlantic alliance, and increase public pressure in the United States for a more conciliatory posture toward the USSR. [REDACTED]

E. O. 12958  
As Amended  
Sec. 6.1(c)

Soviet policymakers, however, almost certainly are very concerned that trends they foresee in long-term US military programs could in time erode the USSR's military gains of the past fifteen years, heighten US political leverage, and perhaps increase the chances of confrontation. [REDACTED]

This memorandum was prepared by [REDACTED]  
Office of Soviet Analysis. [REDACTED]

E. O. 12958  
As Amended  
Sec. 6.1(c)

~~WARNING NOTICE --  
Intelligence Sources or  
Methods Involved~~

CL BY [REDACTED]  
DECL OADR  
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~~SECRET~~  
~~NOFORN NOCONTRACT WMINTEL ORCON~~

DECLASSIFIED IN PART  
NLS M02-002 #5  
By AS, NARA, Date 4/25/03

→ Eric Matlock  
This is almost  
congruent to  
my analysis.  
What do  
you think?  
Bud  
1-10-84



Moscow's sense of pressure and challenge from the United States is probably magnified by difficult near-term policy dilemmas which US actions pose. The Kremlin must consider painful any increases in the rate of military spending; it must provide or deny additional assistance to client regimes under serious insurgent attack; and it must react to a sharp ideological offensive against communist rule at a time of growing public demoralization arising from stagnation in living standards in the USSR and Eastern Europe. Not surprisingly, Moscow is frustrated by and angry at the Reagan Administration. [REDACTED]

E. O. 12958  
As Amended  
Sec. 6.1(c)

1. Soviet rhetoric would suggest that Moscow believes the Reagan Administration has sharply increased the likelihood of armed confrontation between the United States and the USSR. Soviet spokesmen have accused the President and his advisers of "madness," "extremism" and "criminality" in the conduct of relations with the USSR. They have charged that the United States is pursuing a nuclear first strike capability and preparing to unleash nuclear war as a means of crushing communism. The Soviets maintain that the Reagan Administration is eager to apply military force in the Third World and has no intention of resolving its differences with Moscow through negotiation. [REDACTED]

2. Conversations by Westerners with Soviet citizens indicate that the "war danger" propaganda line is probably widely believed by the public at large, and that various elements of this line are accepted within the foreign policy advisory community. [REDACTED]

3. The question of whether Soviet leaders actually believe that war could break out, and whether they are basing policy on such a judgment, is critical. If the answer to this question were positive, then Moscow would have a strong incentive to pre-empt the United States and might be so hypersensitive to US moves that the chances of accidental conflict would be greatly increased. In our view, however, Soviet leaders do not believe their own war danger propaganda and are not likely to base policy on it. Rather, they have a fundamental and transparent policy interest in making it appear to the world public that the USSR is dedicated to preserving the

E. O. 12958  
As Amended  
Sec. 1.6(d)

positive elements of the bilateral relationship, that the United States has been intransigent and irresponsible, and that the Soviet side is rightfully angry. Their purpose is to:

- ° Encourage continuing resistance to INF deployment by the "peace movement" in Western Europe.
- ° Create support for a restructuring of arms control talks on a basis more acceptable to Moscow.
- ° Foster a long-term shift in Western Europe toward neutralism.
- ° Deepen suspicions in West European governments of the motives and competence of the Reagan Administration.
- ° Increase public pressure in the United States for concessions to the USSR in future arms control negotiations.
- ° Undercut the President's reelection prospects. [REDACTED]

4. [REDACTED] the Soviets have taken a deliberate policy decision to pull out all the stops to create an impression that the US-USSR dialogue has broken down and that the relationship is careening dangerously out of control. This interpretation is supported by [REDACTED]

[REDACTED] public remarks by such regime spokesmen as Georgiy Arbatov and Vadim Zagladin. Domestically, the propaganda line lays the ground for justifying higher military spending, greater consumer austerity, and tighter labor discipline. [REDACTED]

5. Apart from the basic Soviet interest in fostering the appearance that confrontation with the United States could erupt at any moment, there are other strong reasons for skepticism that Soviet policymakers either believe this proposition or base policy on it:

- ° Moscow's inflexibility in its INF tactics, its suspension of arms negotiations, and its reduction of contacts with the United States, are not moves the Kremlin would have taken if it genuinely feared confrontation. Rather, it would have tried to keep the dialogue open in order to keep closely in touch with US intentions and lessen the chances of miscalculation.



- ° Soviet policymakers almost certainly realize that the developments most disturbing to them--full US INF deployment, the broad US strategic buildup, and strengthening of US general purpose forces--could influence the military balance only gradually, would not affect the near-term US calculus of risks, and are still subject to substantial political uncertainty.
- ° Historically, Soviet policy has generally been driven by prudent calculation of interests and dogged pursuit of long-term objectives, even in the face of great adversity, rather than by sudden swells of fear or anger.
- ° However disturbed Soviet policymakers might be by the Reagan Administration, they also have a sense of the USSR's strengths and of potential domestic and international vulnerabilities of the United States. They typically take a longer view of Soviet prospects, and the perception from the Kremlin is by no means one of unrelieved gloom. [REDACTED]

6. These considerations imply that any anticipations of near-term confrontation that may exist in Moscow are likely to affect policy more at the margin than at the core. We believe this generalization is supported by how the Soviets probably assess the risk of conflict with the United States arising from two most likely quarters: nuclear-strategic rivalry, and competition in the Third World. [REDACTED]

#### The Nuclear-Strategic Rivalry

7. Despite their impassioned rhetoric about the "nuclear danger," we strongly believe that the Soviets are fundamentally concerned not about any hypothetical near-term US nuclear attack, but about possible five-to-ten year shifts in the strategic balance. In a TV interview on 5 December, the Chief of the General Staff, Marshal Ogarkov, pointed to the factors that would presumably now deter even the most hostile US administration from a deliberate first strike attempt--the large Soviet stockpile of nuclear weapons, diverse delivery systems, "repeatedly redundant systems of controlling them," and the vulnerability of the United States to retaliation. And, in a speech on 18 December, Minister of Defense Ustinov stated there was no need to "dramatize" the current tense situation. [REDACTED]

8. The Soviets probably do believe that US INF missiles, when fully deployed, would significantly affect their plans for conducting nuclear war. They think that the Pershing II is part

E.O. 12958  
As Amended  
Sec. 6.1(c)

of a broader US strategic plan to acquire forces to fight a limited nuclear war in the European theater, and that it would be able to strike critical strategic targets--particularly the Soviet command and control system--in the Western USSR, reducing Moscow's confidence in its launch-on-tactical warning option. They probably believe their public assertion that the range of the Pershing II is 2,500 km rather than the 1,800 km claimed by NATO, which would--as they assert--substantially increase the vulnerability to a sudden disabling nuclear attack of the Soviet leadership and strategic command and control facilities located in the Moscow region. But they apparently were willing to run the risk of passing up a possible INF deal involving no Pershing II deployments, in order to pursue their maximum objective of no US INF deployment at all. They are aware that full INF deployment is not scheduled to be completed until 1988, that it will be attended by heavy political opposition in Western Europe, and that it could be aborted or limited. Their likely near-term countermeasures to INF deployment are not provocative, and do not appear to be emotionally inspired. In Europe, in fact, there has been no serious Soviet threatening, and efforts to woo the democratic Left and maintain economic ties continue. [REDACTED]

9. As INF deployment is completed about the same time new US strategic systems are being fielded, the Soviets could see a greater possibility of confrontation with the United States. We do not believe the Soviets think that deployment will decisively alter the strategic balance, but they could think it would embolden the United States to take more risks and increase the chance of accidental war. With the sharp reduction in warning time accompanying deployment of the Pershing IIs, the Soviets could also well fear--as some spokesmen have obliquely implied--that they themselves might mistakenly trigger a nuclear exchange. [REDACTED]

#### Competition in the Third World

10. Despite the truculent mood in Moscow, we see no signs of any emerging general pattern of Soviet behavior risking armed confrontation with the United States in the Third World. Nor, by the same token, do we detect much fear that US actions in most parts of the Third World might precipitate an armed clash with Soviet forces that Moscow could not avoid. [REDACTED]

11. The single case today in which Moscow clearly does foresee a heightened threat of armed confrontation with the United States is Syria-Lebanon. The Soviets almost certainly are apprehensive that the proximity of US and Soviet combat units could spark a direct conflict. They may also fear that the

E.O. 12958  
As Amended  
Sec. 6.1(c)



recent US-Israeli security agreement could increase the risk of a US-Soviet clash in the event of renewed major hostilities between Israel and Syria. The Soviets have given no sign of interest in attempting actively to use their military resources in Syria and Lebanon to provoke Washington. And Moscow's public response to recent Syrian-US hostilities has been quite cautious. Yet, the Soviets have not been moved by fear of confrontation with the United States to qualify their support of Assad. Thus, in attempting to protect their equities in relations with Syria, they have assumed a posture toward a possible clash with the US that remains basically reactive. The Soviets have privately warned the United States not to attack the Syrians, have pledged to match with their support any US escalation of hostilities, and have asserted that they will use whatever means are needed to maintain their presence in Syria. They will feel under pressure to demonstrate that they and their client cannot be pushed around by the United States. Should US or Israeli military operations expand into Syria itself, the Soviets might be willing to provide much greater (and riskier) military support to Syria. [REDACTED]

E. O. 12958  
As Amended  
Sec. 6.1(c)

12. In attempting to make good on their threats, the Soviets might face choices that could lead directly to confrontation with the United States. But Moscow's capability to act militarily in the Lebanese-Syrian theater itself in ways that threatened armed confrontation with the United States is limited physically by severe constraints on the Soviet ability to project force rapidly into the region during hostilities, and would be influenced psychologically by considerable uncertainty about reactions that might be anticipated from the White House. The Soviets might agree to expand the number of Soviet advisers in Lebanon if the Syrians demanded this, but would strive hard to limit their combat exposure. They would probably prefer to ignore US-caused casualties among their advisers in Lebanon. At higher escalation levels, they might choose to increase their naval presence in the eastern Mediterranean if they had not already done so, dispatch some fighter aircraft to Syria, and deploy small numbers of airborne or naval infantry troops to rear areas in Syria--with the intention of showing the flag more and raising the deterrent tripwire. [REDACTED]

[REDACTED] would allow Soviet advisers with Syrian air defense units in Syria to participate in combat operations, and probably would authorize Soviet pilots already in Syria to fly combat missions within Syrian air space. They would try to use the SA-5s only in defense of Syrian territory, and even then might restrain themselves if US attacks on Syrian targets were not extensive. They would certainly attempt to defend SA-5 sites against US strikes. [REDACTED]

E. O. 12958  
As Amended  
Sec. 1.6(d)



### Soviet Concerns

13. Having asserted that the Soviets basically are not acting on the belief that war is likely to "break out" soon, we must add that in Moscow the Reagan Administration is nevertheless the least loved of any US administration since that of President Truman; that some Soviet officials may have talked themselves into believing their own war scare propaganda; and that the general level of frustration and anxiety surrounding relations with the United States is substantially higher than it was in the 1970s. [REDACTED]

14. Soviet officials have perceived a hardening of US policy beginning in the latter part of the Carter Administration. But US actions since President Reagan's election have heightened Soviet anxieties. The major foreign policy defeat represented by the initiation of INF deployment, the perceived unyielding current US posture in the START talks, the US action in Grenada, the deployment of marines in Lebanon, US aid to insurgencies against Soviet client regimes, the Reagan Administration's perceived political "exploitation" of the KAL shootdown, and in general the Administration's perceived unwillingness to acknowledge the legitimacy of the Soviet regime or to treat the Kremlin with the "superpower" deference it desires, appear to have combined to generate a sense of anger toward the United States among Soviet officials and a belligerent mood. [REDACTED]

15. Moscow, moreover, is probably genuinely concerned or uncertain about several developments that seem to have changed the terms of reference in bilateral relations and could potentially increase the likelihood of hostilities between the United States and the USSR or constrain opportunities for Soviet political gains abroad. These include:

- A possible adverse shift downstream in the overall military balance with the United States arising from the acceleration of US defense spending, support in America for a broad range of new strategic force programs, and increased momentum behind development of US general purpose forces.
- The perceived lower priority accorded by the Reagan Administration to arms control negotiations with Moscow, its unwillingness to accommodate Soviet interests in arms talks, and its apparent intention of developing weapons systems that Moscow may have thought were blocked simply by the fact that arms talks were ongoing.

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As Amended  
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--The end of the "Vietnam syndrome" and readiness of Washington to use force once again in the Third World, either by supporting insurgencies against Soviet client regimes--as in Nicaragua, or acting directly--as in Lebanon and Grenada. [REDACTED]

16. The immediate psychological and political impact of these developments--the enlivened sense of US pressure and "imperialist encirclement"--is probably greatly magnified by the difficult near-term policy dilemmas they pose for the Kremlin. In the defense area, US plans to deploy the Peacekeeper, R&D on the "Midgetman," development of the B1 and Stealth bomber, the beginning of deployment of Pershing IIs and GLCMs, development of precision guided munitions to attack armored forces, and announcement of a program to develop space-based defense systems confront Soviet leaders with a painful and possibly contentious choice of accelerating the growth of defense spending in the 1986-90 five-year plan. Decisions on the plan must be made over the next 12-18 months, and even the costs at the margin of slighting either investment or some improvement of living standards are clearly viewed by the Soviet leadership as very high indeed. [REDACTED]

17. Insurgencies against client regimes also create unpleasant near-term policy choices which probably reinforce a certain siege mentality on Moscow's part. Instead of being on the attack, the USSR has been placed on the defensive. It is constrained either to up the ante of military and economic aid, or pay the price of loss of political influence. Increases in Soviet assistance carry with it possible indirect costs in relations with third parties. Not least, the existence of insurgencies casts an unwanted propaganda spotlight on the repressiveness of allies of the USSR. [REDACTED]

18. While the Soviets have an obvious interest in portraying their own side as deeply offended by the militancy of the Reagan Administration's ideological offensive against communism, they probably do in fact find it quite unsettling. On a purely personal level, the top Soviet leadership undoubtedly does resent being challenged publicly by the President of the United States. More importantly, perhaps, Moscow is no longer inclined to treat the Administration's words as "rhetoric," but sees them as reflecting a serious policy aimed at actively exploiting political vulnerabilities across the board in the USSR and the Soviet bloc. The Soviets are well aware of public malaise generated by stagnating consumption and corruption, and of repressed nationalism throughout their empire; and they do not

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discount the power of ideas to weaken compliance or--as in Poland--spark actual resistance. [REDACTED]

### Prospects

19. The Soviets have a number of options for dealing with the situation as they perceive it. They are probably still counting on the Reagan Administration overreaching itself and

- ° Revitalizing the "peace movement" in Western Europe.
- ° Fanning anti-Americanism in the Middle East, Central America and elsewhere in the Third World.
- ° Losing support among American voters.

Their response to INF deployment provides evidence that they have not abandoned hope of capitalizing upon such developments. [REDACTED]

20. They could attempt to heighten the war of nerves by engaging in threatening military operations, conducting menacing military exercises or the like. Their approach here would have to be selective in order to avoid counteracting the attempt to depict the United States as the major threat to peace. So far they have not systematically engaged in such activities. To some extent their war scare propaganda has already backfired on them in Eastern Europe, where there has been considerable resistance to the emplacement of new Soviet missiles as a "countermeasure" to NATO INF deployment. [REDACTED]

21. They could also attempt through proxies to step up the pace of ongoing leftist insurgencies (for example, in Central America) or to provoke new armed conflicts that would, by forcing either US engagement or abstention, damage American interests. Pakistan's border with Afghanistan, or Zaire, perhaps, might be candidates for such attention. However, there are important obstacles or disincentives in most instances to pressing destabilization too hard and too openly, and thus the attractiveness of currently available options along such lines is arguable. [REDACTED]

22. If Soviet security concerns are basically long-term, as we believe, and are seriously felt, as is likely, we would expect that anxieties here would be expressed in an acceleration of the pace of military spending in the 1986-90 five-year plan. The current tense superpower environment will probably increase the pressures on the Politburo to accept "worst-case" threat assessments and stipulations of requirements from military



planners--despite the further strain this would place on an already taut economy. The extent of such a response, however, might not be visible to us for several years. [REDACTED]

E. O. 12958  
As Amended  
Sec. 6.1(c)

## MEMORANDUM

## NATIONAL SECURITY COUNCIL

~~CONFIDENTIAL~~

January 20, 1984

ACTION

MEMORANDUM FOR ROBERT C. MCFARLANE

FROM: JACK MATLOCK *JCM*SUBJECT: Further Foreign Reaction to President's Speech on  
U.S.-Soviet Relations

State has supplied additional foreign reactions to the President's January 16 speech in the memorandum at Tab A. It provides further evidence that the speech was welcomed almost universally by the Allies (with Greece a qualified and predictable exception), and by most of the neutral and non-aligned. All the foreign ministers with whom Shultz met in Stockholm expressed approval and often enthusiasm, except -- of course -- Gromyko.

I have attached a memorandum to the President at Tab I in case you feel he would be interested in these reactions.

*JL*  
Lenczowski, Kraemer and Sims concur.

RECOMMENDATION:

That you forward the memorandum at TAB A to the President if you feel he would be interested in further foreign reactions to his speech on U.S.-Soviet Relations.

Approve \_\_\_\_\_

Disapprove \_\_\_\_\_

## Attachments:

Tab I Memorandum from State

Tab A Memorandum to the President

~~CONFIDENTIAL~~

Declassify on: OADR

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NLS

MOZ-002 #6

BY

CIS, NARA, DATE 11/13/03



THE WHITE HOUSE  
WASHINGTON

~~CONFIDENTIAL~~

INFORMATION

MEMORANDUM FOR THE PRESIDENT

FROM: ROBERT C. MCFARLANE

State has prepared a summary of additional reactions abroad to your speech on U.S.-Soviet relations. They continue to be excellent among the Allies and many of the neutral and non-aligned countries, while those in the Soviet bloc have predictably followed the Soviet line. State's report is attached.

Attachment:

Tab A State Summary

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NLS M02002 #7

BY CIS NARA, DATE 11/13/03



8401734

United States Department of State

Washington, D.C. 20520<sup>0557</sup>

January 19, 1984

~~CONFIDENTIAL~~MEMORANDUM FOR MR. ROBERT C. MCFARLANE  
THE WHITE HOUSESUBJECT: Further Reaction to the President's  
Speech on US-Soviet Relations

The most notable element in second-day reaction to the President's speech was official commentary from the Soviets and West Europe. Press reports continued to be largely favorable.

Although the Soviets still have not made public a detailed analysis of the President's remarks, Foreign Minister Gromyko did allude to the speech in his address before the CDE in Stockholm January 18. Speaking of an improvement in East-West dialogue, Gromyko said that "what is needed is deeds and not verbal acrobatics, resort to which has particularly often been made lately in Washington. They clearly are a sign of short-term considerations, and people already know sufficiently well the worth of such tricks." He called for a substantive change of U.S. policy from "militarism and aggression" to "peace and international cooperation."

Also at the CDE, French Foreign Minister Cheysson told a press conference that the NATO allies are "singing the same song" and quoted from the President's speech as proof of the U.S. search for dialogue with the USSR. In a response to parliamentary questions January 16, Canadian Prime Minister Trudeau welcomed the "conciliatory" tone of the President's remarks and called upon the Soviets to respond in kind. Outgoing NATO Secretary-General Luns told Ambassador Abshire January 16 that the speech was "masterful," an evaluation seconded by Norway's Ambassador to NATO. Advisors to Italian Prime Minister Craxi and Portuguese Prime Minister Soares both told U.S. diplomats that the speech was well-received by the leadership of their countries.

Press coverage, especially in West Europe, continued to be overwhelmingly positive, with the exception of the committed leftist commentary ordinarily sympathetic to the Soviet position. As the CDE opened in Stockholm, the evening newspaper Expressen commented that the President's speech indicated that, following the successful start of Western INF deployments in Europe, the NATO governments now believe they can negotiate with the Soviets from a position of strength; tying this willingness to negotiate to the CDE, the paper added

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- 2 -

that, in contrast, the Soviets have "tried to play down the importance of the Stockholm meeting."

Spain's most popular evening television program (with an estimated audience of 14 million) gave extensive coverage to the President's remarks January 17, contrasting his moderate statements with the brusque reaction of the Soviets. Among press reaction in NATO countries, only the Greeks struck a discordant note. Athens newspapers gave the speech secondary play, and the pro-government Eleftheri Gnomi alleged that "Reagan has become pacifist because of the upcoming election and a need to change his image as a warmonger and war-lover."

Third-world and non-aligned press commentary in general continued to be favorable to the speech, if cautious about the chances for an early upturn in US-Soviet relations. Sao Paulo's O Estado de Sao Paulo was typical among moderate, balanced reports. The paper said the President's speech displayed "realism and optimism, firmness and pragmatism," adding that "his program aims at peace and security with negotiations but from a position of strength."



Charles Hill  
Executive Secretary

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NOV 16 1983

MEMORANDUM FOR Byron Morton  
Deputy Director, EUR/SOV  
Department of State

From: Edward L. Brady *Edward L. Brady*  
Associate Director for  
International Affairs

SUMMARY: The National Bureau of Standards recommends that, subject to overriding foreign policy objections, it be authorized to propose to the USSR Academy of Sciences that the current Memorandum on Cooperation (MoC) between the two institutions, now scheduled to terminate December 12, 1983, be renewed for an additional five-year period. NBS officials have critically reviewed the implementation of the MoC and have concluded that NBS has acquired technical information on work in progress in institutes of the Academy of Sciences that would be difficult, if not impossible, to obtain by other means. This information has been of significant benefit to the accomplishment of NBS scientific objectives. END SUMMARY

Background: The NBS/ASUSSR Memorandum on Cooperation, a copy of which is attached as Attachment A, derives from extended negotiations dating back to a proposal originally made in 1974 by the late President of the USSR Academy of Sciences, M. V. Keldysh. It was signed at Moscow by Academy Vice President Ye. P. Velikhov and NBS Director Ernest Ambler on December 13, 1978, with a period of validity of five years. It has the status of an implementing protocol of the intergovernmental Agreement on Cooperation in the Fields of Science and Technology, dated May 24, 1972. Despite the non-renewal, on foreign policy grounds, of this umbrella Agreement upon its termination in 1982, it was determined by a committee representing the Department of State and other agencies of the Executive Branch that activities under the MoC should continue because NBS acquisition of information under the program was considered beneficial to U.S. interests. The possibility of such continuation was allowed for in Paragraph 2 of Article 8 of the umbrella Agreement which states that "The termination of this Agreement shall not affect the validity of agreements made hereunder between agencies, organizations and enterprises of both countries." This, then, is the legal basis under which implementation of the MoC has continued to the present time.

History of Implementation of the MoC: During the past five years, the MoC has provided NBS with an operating flexibility and broad technical

scope hitherto unavailable in our interactions with leading institutions and scientists of the USSR and has effectively served to promote the acquisition of unpublished information from USSR research institutions and the achievement of mutually desired scientific objectives, through joint work in their own laboratories as well as in ours. Each side has appointed its own Coordinating Council to evaluate, monitor, and guide the joint activities and scientific progress under the MoC. The high-level significance that the Soviet side attaches to the MoC is demonstrated by the composition of its Coordinating Council, comprised of Academician Yu. A. Osip'yan, Director of the USSR Institute for Solid State Physics, as Chairman, plus eight other renowned Soviet scientists, many of whom are directors of leading research institutes and have Academy rank. The NBS Coordinating Council consists of the NBS Director, Ernest Ambler, as Chairman, plus senior members of the NBS staff.

As written, the MoC permits a broad program of scientific cooperation between NBS and research institutes of the ASUSSR and specifically mentions the fields of thermal physics and thermodynamics, materials science, spectroscopy, chemistry and chemical kinetics, and cryogenic science. However, other fields of science may be included by mutual agreement. Although the MoC provides for an annual quota of up to 14 man-months of long-term visits (2-6 months) by each side to the other, plus a quota of up to 6 man-months of short-term visits by senior scientists and program managers, we have not yet approached these upper limits in our cooperative activities. Rather, the program has progressed on a more modest and selective scale at an annual cost to NBS of about \$8-12K for transportation and subsistence. The Soviet side has preferred visits of longer duration (up to 3 months), whereas NBS scientists have concentrated on shorter visits (2 weeks to 1 month). The overall usage of the quota has been in favor of the Soviets by a ratio of about 2 Soviet visitors to 1 NBS, but the technical benefits are judged to have been generally equal.

NBS scientists who have participated in the program have without exception reported that Soviet willingness to cooperate at the working scientist level in an effort to make activities scientifically valid and productive is quite high. For example, NBS scientist Dr. Daniel Kelleher, who returned just last month from a two-week familiarization visit to Soviet laboratories, has reported that he encountered a number of forefront Soviet scientific programs that had not previously been known to him and that he had identified several areas where a joint effort would probably lead to significant, mutual scientific payoff. He further commented that non-renewal of the MoC would cut off a source of useful information for him. This observation is in accord with the general view of NBS that the full potential of benefit from the MoC has not yet been exploited.



This is not to say, however, that the program runs entirely smoothly. Bureaucratic and logistical problems on the Soviet side continue to interfere with gaining the maximum possible benefit from the cooperation. The recent one-month visit of NBS scientist Dr. J. Reader in the USSR is an example. Although considered by us to be a technical success, it nevertheless did not succeed in achieving the full benefits that were expected because of failure on the Soviet side to provide already agreed-upon arrangements and laboratory visits. NBS has sent a message of protest to the Soviets in which we request an explanation of this case before we proceed with processing of the applications of three Soviet scientists who have applied to visit NBS under the MoC.

At present, five applications for exchange visits are pending under the MoC--three from the Soviet side (involving three scientists), and two from the NBS side (involving six scientists). The Soviet proposals are in the fields of atomic and molecular spectroscopy, and the NBS proposals are in the fields of chemical thermodynamics and measurement methodology for non-ionizing electromagnetic radiation. We anticipate significant scientific benefit from both of the U.S. proposals, but we are particularly interested in the last-mentioned because of the wide difference between current U.S. and USSR exposure standards in this area.

Assessment of Scientific and Technical Benefits and Their Balance: All NBS participants say that the scientific benefit to their own programs has been significant. One NBS scientist has said that only by visiting and asking questions could he have learned all the details of the experimental techniques used by Soviet scientists in his field. Such details are ordinarily not published, or if they are published, they appear in USSR journals or reports that are difficult to obtain and difficult to read because of the language barrier. The NBS program of collaboration with the USSR in the compilation and evaluation of quantitative data on the physical and chemical properties of matter, which started several years before the establishment of the umbrella agreement for cooperation, has given NBS the benefit of several dozen man-years of high-quality scientific output. Similar benefits are characteristic of all of the cooperative interactions between NBS and USSR laboratories.

As a tangible product of the cooperation, joint publications in the archival technical literature have appeared or are in preparation in the fields of thermodynamic data analysis, crystal structure, molecular spectroscopy, and atomic spectroscopy. Several reprints of joint publications in the latter area are attached as Attachment B. These illustrate the contributions that joint research can make to NBS priority programs, in this case, the provision of data useful for diagnostic work in the DOE fusion energy efforts.

In some cases, the scale of benefits is decidedly tipped in favor of NBS. For example, NBS scientist Dr. K. Evenson reported that the Soviet effort he observed in Novosibirsk in the field of stabilized lasers, laser frequency measurements, and the scientific application of both of these is about seven times greater than that currently in progress at NBS and that their accomplishments probably surpass ours in several areas. NBS is currently employing some techniques that were originally suggested by the Novosibirsk group.

Dr. Kharlamov of the Soviet Academy spent most of his three-months' visit at NBS developing computer algorithms and programs for NBS data logging systems. He wrote and left with NBS a set of four useful computer programs that we now use in connection with data acquisition and processing in certain experimental areas connected with our diode laser spectrometer.

As a result of Dr. Givargizov's visit to NBS, we gained possession of a worthwhile collection of whisker crystal specimens that he brought with him from the USSR and that will benefit our future work.

Of course, NBS feels that it has not always received the full scope of technical benefit that it expected. However, these cases relate to only portions of the originally proposed programs, the remaining portions of which were achieved to our satisfaction.

Potential for Technology Loss to the United States: At the very beginning of implementation of the MoC, the Director of NBS established an internal NBS Coordinating Council to approve and monitor joint activities under the MoC to ensure that these activities provided technical benefits to NBS and the United States. The Director serves as the Chairman of this Council. In its appraisal of applications under the MoC, the Council pays particular attention to the questions of reciprocity, mutual benefit, scientific soundness, and any potential for significant technological loss to the United States. Subject areas are limited to those considered to be basic rather than applied research. In addition, before responding to the Soviet Academy, NBS routinely transmits Soviet applications to the State Department and to the Committee on Exchanges (COMEX) to obtain a thorough inter-agency appraisal of any potential technological loss. As a result of these evaluations and other internal considerations (such as whether the proposed program coincides with areas of current NBS interests), NBS has either rejected or modified several proposed Soviet visits. (No proposed visit by NBS scientists to the USSR has been rejected by the Soviet side.) While the Soviet visitors are in residence at NBS, care is taken to limit their access to the agreed areas only.



Cost Savings Achieved through Implementation of the MoC: As noted above, the budgetary outlay in the implementation of the MoC is quite modest in comparison with the technical benefits achieved. Technical benefits translate directly into cost savings through contributions to our own domestic objectives. One example of cost savings and avoidance of duplication of effort has already been mentioned--the joint production of a compilation of critically evaluated thermophysical data that will be a major publication of the U.S. National Standard Reference Data System that is overseen by NBS. This effort also includes exchanges of bibliographic references, which serves to strengthen the NBS knowledge of the availability of Soviet data in this field--data that might otherwise have been overlooked. During the past 2 years, the Soviet side has provided NBS with about 60,000 microfiche images containing such information, and NBS has provided the Soviet side with an equivalent number of references to U.S. literature.

NBS Recommendation: In recent months, NBS has received several inquiries from Soviet visitors and from officials in Moscow regarding NBS wishes to renew the agreement. At a reception in early 1983 at the Soviet Embassy in Washington, Academy Vice President Velikhov suggested that the Academy would be interested in an extension if NBS were.

In the judgment of NBS participants, the NBS/ASUSSR program of collaboration (1) has been of significant benefit to the technical objectives of NBS and (2) has provided a means of acquiring information on scientific programs within USSR laboratories that is not available from any other source. We recommend, therefore, that if there are no overriding objections on foreign policy grounds, authorization be given to NBS to propose to the USSR Academy of Sciences that the existing Memorandum on Cooperation be renewed for another five-year period.

Attachments

cc:  
L. Starbird

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# $3p^6 3d^8$ – $3p^5 3d^9$ transitions in Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII

Joseph Reader and Aleksandr Ryabtsev\*

National Bureau of Standards, Washington, D.C. 20234

Received September 29, 1980

The  $3p^6 3d^8$ – $3p^5 3d^9$  transitions in Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII have been newly measured by means of a low-inductance vacuum spark and a 10.7-m grazing-incidence spectrograph. The measurements have led to an improved analysis of this complex transition group in these ions. All levels of the combining configurations have been established. The energy parameters determined from least-squares fits to the observed levels are compared with Hartree–Fock calculations. The effective interaction  $\alpha L(L+1)$  for the  $3p^6 3d^8$  configuration decreases markedly with increasing ionization. The effective electrostatic interactions  $D^1(3p3d)$  and  $X^2(3p3d)$  for the  $3p^5 3d^9$  configuration are practically constant through the sequence.

Ions of the isoelectronic sequence Sr XIII–Mo XVII have the ground configuration  $3p^6 3d^8$ . The lowest excited configuration is  $3p^5 3d^9$ . In each ion the  $3p^6 3d^8$ – $3p^5 3d^9$  transitions form a complex group of lines that span a region of only about 18 Å. This region also contains complex spectra that are due to  $3p^6 3d^n$ – $3p^5 3d^{n+1}$  transitions of higher stages of ionization. The investigation of these transition groups thus requires selective excitation and high resolution. A photograph of this complex spectral region for Mo, as observed in spectra of the DITE Tokamak and a laser-produced plasma, has been given by Mansfield *et al.*<sup>1</sup>

The  $3p^6 3d^8$ – $3p^5 3d^9$  transitions in Y XIV, Zr XV, Nb XVI, and Mo XVII were investigated recently by Bogdanovichene *et al.*<sup>2</sup> They used a low-inductance vacuum spark together with 2- and 3-m grazing-incidence spectrographs to identify about 25 lines in each spectrum. From these identifications most of the energy levels of the two configurations were established. In a parallel investigation, Burkhalter *et al.*<sup>3</sup> used a low-inductance vacuum spark and a 2.2-m grazing-incidence spectrograph to identify 14 prominent  $3p^6 3d^8$ – $3p^5 3d^9$  transitions in Mo XVII.

In the present work we observed spectra of strontium, yttrium, zirconium, niobium, and molybdenum with a low-inductance vacuum spark and the 10.7-m grazing incidence spectrograph at the National Bureau of Standards (NBS). With these observations we were able to extend and partially revise the analyses of the ions Y XIV–Mo XVII as well as to provide the first spectral data for Sr XIII. About 40 lines have been identified in each spectrum. All levels of the  $3p^6 3d^8$  and  $3p^5 3d^9$  configurations have now been established for these ions.

## EXPERIMENT

The measurements were taken largely from spectrograms made in connection with recent investigations of several highly charged copperlike and zinlike ions.<sup>4–8</sup> These observations were made with the NBS 10.7-m spectrograph at an angle of incidence of 80°. The grating had 1200 lines/mm. At this angle of incidence the lowest wavelength that could be re-

corded was about 70 Å. As several important transitions for the present ions were expected to lie below 70 Å, new exposures were taken on the 10.7-m spectrograph at an angle of incidence of 85°. At this angle, spectra could be observed to about 33 Å. Wavelength-calibration procedures and further experimental details are given in Refs. 4–8.

The wavelengths, intensities, and classifications of the  $3p^6 3d^8$ – $3p^5 3d^9$  transitions of Sr XIII–Mo XVII obtained in the present work are given in Table 1. The uncertainty of the wavelengths is  $\pm 0.005$  Å. For perturbed lines the uncertainty is  $\pm 0.010$  Å. The intensities are visual estimates of photographic blackening. As noted in the table, many of the values represent new measurements for lines given originally in Refs. 2 and 3.

## ANALYSIS OF THE SPECTRA

To extend the analyses we first made least-squares fits for the most-reliably determined  $3p^6 3d^8$  and  $3p^5 3d^9$  levels.<sup>2</sup> The  $3p^6 3d^8$  levels included  $^3F_{2,3,4}$ ,  $^3P_{1,2}$ , and  $^1D_2$ . The  $3p^5 3d^9$  levels included  $^3F_{2,3,4}$ ,  $^3P_{1,2}$ ,  $^3D_{1,2,3}$ , and  $^1D_2$ . These levels were confirmed by additional combinations found in the present observations. The levels  $3p^6 3d^8$   $^3P_0$ ,  $^1G_4$ ,  $^1S_0$ , and  $3p^5 3d^9$   $^3P_0$ ,  $^1F_3$ , and  $^1P_1$ , which previously<sup>2</sup> were either doubtful or missing altogether in some ions, were thus excluded. Initial values for the parameters were taken from Hartree–Fock (HF) calculations made with the computer program of Froese-Fischer.<sup>9</sup> No effective interactions were included. These calculations proved to be satisfactory from the standpoint of regularity of parameter values and mean errors. The predicted level values were thus adopted as a basis for further analysis of the spectra.

### $3p^5 3d^9$ $^1P_1$

This level had been established by a single transition in each ion,  $^1D_2$ – $^1P_1$ . Our new low-wavelength data provided the  $^3P_2$ – $^1P_1$  combinations, confirming the previous identifications in Y, Zr, and Mo. For Nb XVI the previous  $^1D_2$ – $^1P_1$  identification (70.474 Å) was replaced by a line at 70.718 Å, resulting in a revised value for  $3p^5 3d^9$   $^1P_1$ .



$3p^6 3d^8 {}^1S_0$ 

This level was based on the single transition  ${}^1S_0-{}^1P_1$ . The identification was listed<sup>2</sup> as doubtful in Y and Zr and was absent in Nb and Mo. We have now replaced these identifications with those given in Table 1, which includes values for Nb and Mo as well. These lines were the most prominent unidentified lines in the expected region and, although there are no confirming transitions, there is little doubt that the identifications are correct. They are strongly supported by the least-squares calculations.

 $3p^6 3d^8 {}^1G_4$  and  $3p^5 3d^9 {}^1F_3$ 

The  ${}^1G_4-{}^1F_3$  transition is easily identified as an intense line on the low-wavelength side of the transition group.<sup>2,3</sup> It has the highest predicted line strength within the present array. In Ref. 2 these levels were connected to the main body of levels through the single transition  ${}^1G_4-{}^3D_3$ . We have now replaced the  ${}^1G_4-{}^3D_3$  identifications with those given in Table 1. This in turn revises the  ${}^1G_4$  and  ${}^1F_3$  level values. The new values are confirmed by the four additional combinations,  ${}^3F_3-{}^1F_3$ ,  ${}^3F_2-{}^1F_3$ ,  ${}^1D_2-{}^1F_3$ , and  ${}^1G_4-{}^3F_3$ . The line identified as  ${}^1G_4-{}^3D_3$  in Y XIV was previously identified as  ${}^3P_1-{}^3P_0$ .

Table 1. Observed  $3p^6 3d^8-3p^5 3d^9$  Transitions in Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII<sup>a</sup>

Transition	Sr XIII		Y XIV		Zr XV		Nb XVI		Mo XVII	
	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.
$3p^6 3d^8 {}^3F_3-3p^5 3d^9 {}^1F_3$			76.229	10	72.455	10	68.989	10	65.770	4
${}^3F_2-3p^5 3d^9 {}^1F_3$			76.506	1h	72.692	1h	69.174	2	65.891	1h
${}^3P_2-3p^5 3d^9 {}^1P_1$			77.268	25	73.239	15	69.540	15	66.100	3
${}^1D_2-3p^5 3d^9 {}^1P_1$	82.758	75	78.395 <sup>b</sup>	50p	74.395 <sup>b</sup>	40	70.718	40	67.302 <sup>c</sup>	15
${}^1D_2-3p^5 3d^9 {}^1F_3$			78.813	10	74.966	3	71.448	5	68.188	3h
${}^1G_4-3p^5 3d^9 {}^1F_3$	83.656	2000	79.338 <sup>b</sup>	3000	75.385 <sup>b</sup>	2000	71.759	1200	68.390 <sup>c</sup>	800
${}^3F_3-3p^5 3d^9 {}^3P_2$	85.311	120	80.714 <sup>b</sup>	150	76.509 <sup>b</sup>	70	72.656	100	69.088	30
${}^3F_2-3p^5 3d^9 {}^3P_2$			81.030 <sup>b</sup>	20	76.777	10	72.870	5		
${}^3P_2-3p^5 3d^9 {}^3P_2$			82.334	50	78.006 <sup>b</sup>	20	74.049	20	70.386 <sup>c</sup>	15
${}^3F_3-3p^5 3d^9 {}^3F_2$			82.628	5			74.132	2	70.367	3
${}^3F_2-3p^5 3d^9 {}^3F_2$	87.831	100	82.963 <sup>b</sup>	120	78.483 <sup>b</sup>	30	74.352	20	70.494	5
${}^3P_1-3p^5 3d^9 {}^3P_2$	88.151	200	83.397 <sup>b</sup>	140	79.046 <sup>b</sup>	70	75.060	70	71.359 <sup>c</sup>	30
${}^1D_2-3p^5 3d^9 {}^3P_2$			83.614	70	79.318	15			71.750	5
${}^1S_0-3p^5 3d^9 {}^1P_1$	88.631	70	83.970	50	79.689	30	75.754	20	72.092	20
${}^3F_2-3p^5 3d^9 {}^3D_1$	88.568	500	84.211 <sup>b</sup>	200	80.247 <sup>b</sup>	250	76.631 <sup>b</sup>	120	73.289 <sup>c</sup>	200
${}^3F_4-3p^5 3d^9 {}^3D_3$	88.754	800	84.266 <sup>b</sup>	400	80.176 <sup>b</sup>	400	76.442 <sup>b</sup>	300	72.990 <sup>c</sup>	300
${}^3P_2-3p^5 3d^9 {}^3F_2$			84.326	25	79.766	2h	75.590	20p	71.705	7
${}^3F_3-3p^5 3d^9 {}^3D_3$	89.797	200	85.372 <sup>b</sup>	160	81.350 <sup>b</sup>	250	77.685 <sup>b</sup>	120	74.306 <sup>c</sup>	200
${}^3P_2-3p^5 3d^9 {}^3D_1$			85.618 <sup>b</sup>	25			77.949 <sup>b</sup>	30	74.600	5
${}^1D_2-3p^5 3d^9 {}^3F_2$	90.618	150	85.673 <sup>b</sup>	150	81.140 <sup>b</sup>	200	76.980 <sup>b</sup>	120	73.122 <sup>c</sup>	150
${}^3P_0-3p^5 3d^9 {}^3D_1$	91.253	60	86.767 <sup>b</sup>	70	82.696 <sup>b</sup>	25	78.986 <sup>b</sup>	40	75.580	15
${}^3F_3-3p^5 3d^9 {}^3D_2$	91.481	500	87.009 <sup>b</sup>	400	82.948	300	79.241	500	75.840 <sup>b</sup>	150
${}^3P_2-3p^5 3d^9 {}^3D_3$	91.757	100	87.184 <sup>b</sup>	100	83.048 <sup>b</sup>	100	79.284 <sup>b</sup>	50p	75.816	15
${}^3F_4-3p^5 3d^9 {}^3F_3$	92.664	600	87.984 <sup>b</sup>	600	83.727 <sup>b</sup>	700	79.839 <sup>b</sup>	500	76.269 <sup>c</sup>	600
${}^3P_2-3p^5 3d^9 {}^3P_1$	92.734	150	88.186 <sup>b</sup>	140	84.061 <sup>b</sup>	100	80.298 <sup>b</sup>	150	76.863 <sup>b</sup>	200h
${}^1D_2-3p^5 3d^9 {}^3D_3$			88.623	5	84.534	2			77.396	5p
${}^3P_2-3p^5 3d^9 {}^3D_2$	93.517	150	88.893 <sup>b</sup>	150	84.708 <sup>b</sup>	100	80.890 <sup>b</sup>	80	77.410 <sup>b</sup>	20
${}^3P_1-3p^5 3d^9 {}^3P_0$	93.772	80	89.190 <sup>d,e</sup>	600	85.031 <sup>b</sup>	200	81.213 <sup>c</sup>	80	77.727	30
${}^3F_3-3p^5 3d^9 {}^3F_3$	93.800	100	89.190 <sup>d,e</sup>	600	85.011	70	81.202	100	77.706	20
${}^1G_4-3p^5 3d^9 {}^3D_3$	93.967	50	89.287 <sup>d</sup>	75	85.064	30	81.213 <sup>c</sup>	80	77.666 <sup>b</sup>	30
${}^3P_0-3p^5 3d^9 {}^3P_1$			89.408 <sup>d,e</sup>	150	85.236	20	81.412 <sup>d</sup>	20	77.898	15
${}^3P_1-3p^5 3d^9 {}^3P_1$			89.408 <sup>b,e</sup>	150	85.269 <sup>b</sup>	40	81.489	80	78.019 <sup>b</sup>	40
${}^1D_2-3p^5 3d^9 {}^3D_2$	94.955	50	90.389 <sup>b</sup>	120	86.256 <sup>b</sup>	70	82.495 <sup>b</sup>	50	79.062 <sup>b</sup>	100
${}^3F_4-3p^5 3d^9 {}^3F_4$	95.528	1500	90.871 <sup>b</sup>	1500	86.630 <sup>b</sup>	1500	82.749 <sup>b</sup>	1500	79.186 <sup>c</sup>	1500
${}^3F_3-3p^5 3d^9 {}^1D_2$			90.967	5			82.993	50bl	79.532	5
${}^3P_2-3p^5 3d^9 {}^3F_3$			91.177	5h			82.945	2	79.359	5
${}^3F_2-3p^5 3d^9 {}^1D_2$	95.998	400	91.371 <sup>b</sup>	600	87.147 <sup>b,g</sup>	600	83.275 <sup>b</sup>	600	79.711 <sup>c</sup>	700
${}^3F_3-3p^5 3d^9 {}^3F_4$	96.739	200/	92.160	40	88.006 <sup>b</sup>	20h	84.211 <sup>b</sup>	100	80.734	30
${}^1D_2-3p^5 3d^9 {}^3F_3$	97.450	100	92.749	25	88.486	20	84.619	40	81.080	20p
${}^3P_2-3p^5 3d^9 {}^1D_2$	97.766	400	93.031 <sup>b</sup>	400	88.732 <sup>b</sup>	300	84.823 <sup>b</sup>	150	81.261 <sup>b</sup>	100
${}^1G_4-3p^5 3d^9 {}^3F_3$			93.478	15	89.069	20	85.058	10	81.382	20
${}^3P_1-3p^5 3d^9 {}^1D_2$			94.390	10	90.080	10	86.154	30	82.556	20
${}^1D_2-3p^5 3d^9 {}^1D_2$	99.341	100	94.671 <sup>b</sup>	100	90.434 <sup>b</sup>	100	86.586 <sup>b</sup>	30	83.079 <sup>b</sup>	50

<sup>a</sup> Symbols: bl, blend of two lines; h, hazy; p, perturbed by close line.

<sup>b</sup> Present value for line given originally by Bogdanovichene *et al.*, Ref. 2.

<sup>c</sup> Present value for line given originally by Bogdanovichene *et al.*, Ref. 2, and by Burkhalter *et al.*, Ref. 3.

<sup>d</sup> Present value for line given originally by Bogdanovichene *et al.*, Ref. 2, revised classification.

<sup>e</sup> Doubly classified.

<sup>f</sup> Blended with 96.731 Å of Ti. (The Sr exposures were made with an anode of Sr and a cathode of Ti.)

<sup>g</sup> Blended with a line of Zr XII; see Ref. 7.



**Table 2. Energy Levels (in  $\text{cm}^{-1}$ ) of the  $3p^6 3d^8$  and  $3p^5 3d^9$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII**

Configuration	Term	<i>J</i>	Sr XIII <sup>a</sup>	Y XIV	Zr XV	Nb XVI	Mo XVII
$3p^6 3d^8$	$^3F$	4	0	0	0	0	0
		3	13 080	15 380	18 030	20 960	24 250
		2	18 000	20 230	22 560	24 890	27 030
	$^3P$	2	36 850	39 760	43 080	46 840	51 000
		0	51 230	55 230	59 470	63 830	68 350 <sup>a</sup>
		1	50 840	55 240	59 940	65 020 <sup>a</sup>	70 310
	$^1D$	2	53 040	58 380	64 280	70 790	77 960
	$^1G$	4	62 500	66 780 <sup>a</sup>	71 660 <sup>a</sup>	76 870 <sup>a</sup>	82 420 <sup>a</sup>
	$^1S$	0	133 120	143 060 <sup>a</sup>	153 590 <sup>a</sup>	164 790 <sup>a</sup>	176 700 <sup>a</sup>
$3p^5 3d^9$	$^3F$	4	1 046 800	1 100 460	1 154 330	1 208 470	1 262 860
	$^1D$	2	1 059 690	1 114 670	1 170 060	1 225 740	1 281 600
	$^3F$	3	1 079 180	1 136 550	1 194 370	1 252 520	1 311 160
	$^3D$	2	1 106 180	1 164 700	1 223 610	1 282 970	1 342 800
	$^3P$	1	1 115 200	1 173 720	1 232 700	1 292 180	1 352 050
	$^3P$	0	1 117 250	1 176 440 <sup>a</sup>	1 235 980 <sup>a</sup>	1 296 360 <sup>a</sup>	1 356 860 <sup>a</sup>
	$^3D$	3	1 126 700	1 186 740	1 247 240	1 308 200	1 370 010
	$^3D$	1	1 147 080	1 207 730	1 268 720	1 329 840	1 391 470
	$^3F$	2	1 156 570	1 225 610	1 296 720	1 369 820	1 445 570
	$^3P$	2	1 185 260	1 254 340	1 325 040	1 397 270 <sup>a</sup>	1 471 690
	$^1F$	3	1 257 880	1 327 220 <sup>a</sup>	1 398 200 <sup>a</sup>	1 470 450 <sup>a</sup>	1 544 660 <sup>a</sup>
	$^1P$	1	1 261 390	1 333 960	1 408 460	1 484 850 <sup>a</sup>	1 563 830

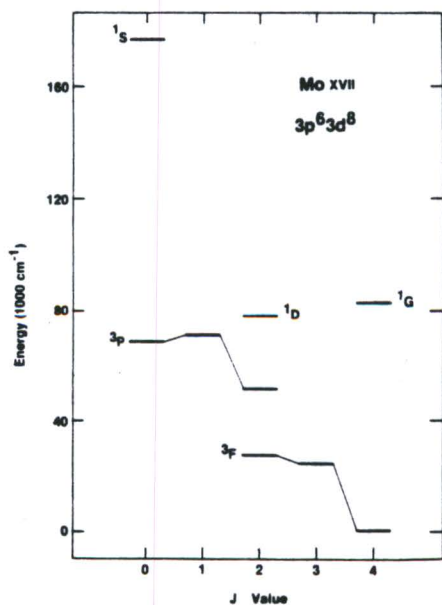
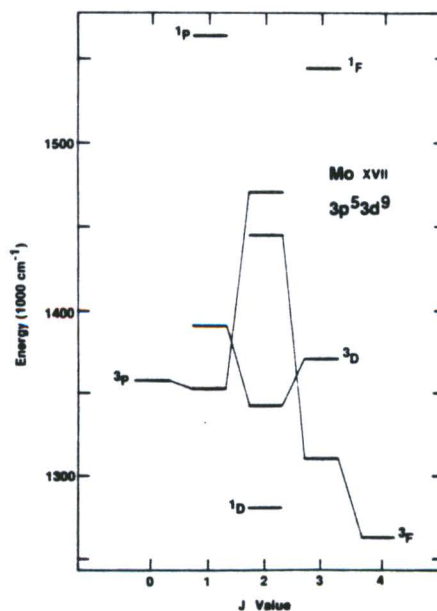
<sup>a</sup> New level; all levels for Sr XIII are new. **$3p^5 3d^9 \ ^3P_0$** 

This level makes only one combination within the present array,  $^3P_1-^3P_0$ . Although this transition is expected to be fairly strong, its identification is made difficult by the complexity of the spectrum in the expected region. Based on the present observations and calculations, we propose the new identifications for this transition given in Table 1. In Zr and Mo there is not much doubt about the assignments, because there is only one clear choice. In Y and Nb the proposed lines represent blends with other transitions of the same array. However, these identifications are well supported by iso-

electronic regularities. The evidence for a blend in Y is particularly strong because there is no other possible choice within a reasonable distance of the predicted position and, furthermore, the other member of the blend,  $^3F_3-^3F_3$ , appears to be anomalously strong compared with its appearance elsewhere in the sequence.

 **$3p^6 3d^8 \ ^3P_0$** 

This level can make three transitions, of which two,  $^3P_0-^3P_1$  and  $^3P_0-^3D_1$ , are expected to be reasonably strong and one,  $^3P_0-^1P_1$ , is expected to be weak. In Ref. 2, values for  $^3P_0$  were

Fig. 1. Structure of the  $3p^6 3d^8$  configuration of Mo XVII.Fig. 2. Structure of the  $3p^5 3d^9$  configuration of Mo XVII. Levels are grouped into LS terms.

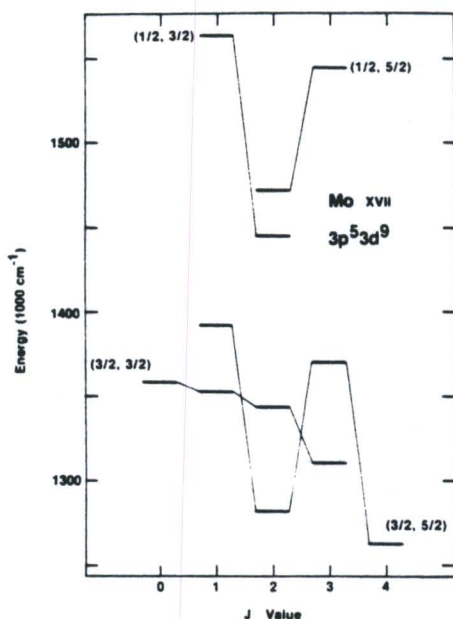


Fig. 3. Structure of the  $3p^5 3d^9$  configuration of Mo XVII. Levels are grouped into  $jj$  terms.

given for Y, Zr, and Nb based on the single transition  $^3P_0-^3D_1$ . No value was given for Mo. We have now observed the  $^3P_0-^3D_1$  as well as the  $^3P_0-^3P_1$  transition for the present ions, confirming the previous identifications and providing values for Mo. In Y the  $3p^6 3d^8$   $^3P_0$  and  $^3P_1$  levels are nearly coincident and the  $^3P_0-^3P_1$  and  $^3P_1-^3P_1$  transitions thus cannot be resolved. Our value for  $^3P_0-^3D_1$  in Mo replaces the identification for this transition given in Ref. 3.

#### Sr XIII

The spectra for this ion were relatively weak, but with the help of isoelectronic regularities the principal lines of the array and all of the levels could in fact be located. The presence of  $^3P_1-^3P_0$  as a fairly strong line in Sr further supports the proposed blend of  $^3P_1-^3P_0$  and  $^3F_3-^3F_3$  in Y.

Finally, we confirm the value for  $^3F_3-^3D_2$  of Mo XVII given in Ref. 2 (75.843 Å), compared with the value given in Ref. 3 (75.624 Å). The resulting levels are supported by several other combinations.

The values of the energy levels are given in Table 2. These values were determined by an optimization procedure<sup>10</sup> that minimizes the differences between the observed and calculated wave numbers. The uncertainty of the level values is about  $\pm 50 \text{ cm}^{-1}$ .

Table 3. Energy Parameters (in  $\text{cm}^{-1}$ ) and Mean Errors  $\Delta$  of Least-Squares Fits for the  $3p^6 3d^8$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII.<sup>a</sup>

Ion	Parameter	HF	Fitted	Fitted-HF
Sr XIII	$E_{av}$	36 440	34 031 $\pm$ 63	
	$F^2(3d3d)$	214 978	194 218 $\pm$ 513	0.903 $\pm$ 0.002
	$F^4(3d3d)$	136 981	115 570 $\pm$ 468	0.844 $\pm$ 0.003
	$\alpha(3d3d)$		203 $\pm$ 12	
	$\zeta_{3d}$	6 133	6 207 $\pm$ 74	1.012 $\pm$ 0.012
	$\Delta$		167	
Y XIV	$E_{av}$	39 578	37 009 $\pm$ 61	
	$F^2(3d3d)$	225 641	204 477 $\pm$ 496	0.906 $\pm$ 0.002
	$F^4(3d3d)$	143 929	123 560 $\pm$ 456	0.858 $\pm$ 0.003
	$\alpha(3d3d)$		171 $\pm$ 11	
	$\zeta_{3d}$	7 196	7 226 $\pm$ 70	1.004 $\pm$ 0.010
	$\Delta$		161	
Zr XV	$E_{av}$	42 883	40 323 $\pm$ 82	
	$F^2(3d3d)$	236 241	215 429 $\pm$ 678	0.912 $\pm$ 0.003
	$F^4(3d3d)$	150 838	131 717 $\pm$ 627	0.873 $\pm$ 0.004
	$\alpha(3d3d)$		156 $\pm$ 15	
	$\zeta_{3d}$	8 388	8 365 $\pm$ 92	0.997 $\pm$ 0.011
	$\Delta$		218	
Nb XVI	$E_{av}$	46 430	43 903 $\pm$ 103	
	$F^2(3d3d)$	246 787	226 602 $\pm$ 847	0.918 $\pm$ 0.003
	$F^4(3d3d)$	157 711	140 221 $\pm$ 789	0.889 $\pm$ 0.005
	$\alpha(3d3d)$		138 $\pm$ 19	
	$\zeta_{3d}$	9 717	9 641 $\pm$ 108	0.992 $\pm$ 0.011
	$\Delta$		272	
Mo XVII	$E_{av}$	50 238	47 735 $\pm$ 118	
	$F^2(3d3d)$	257 286	238 019 $\pm$ 975	0.925 $\pm$ 0.004
	$F^4(3d3d)$	164 554	149 180 $\pm$ 918	0.907 $\pm$ 0.006
	$\alpha(3d3d)$		123 $\pm$ 22	
	$\zeta_{3d}$	11 195	11 080 $\pm$ 117	0.990 $\pm$ 0.010
	$\Delta$		312	

<sup>a</sup> The value of  $E_{av}$  listed in the HF column is that obtained by diagonalizing the energy matrix with the HF parameters,  $^3F_4$  level set at zero.



**Table 4. Percentage Compositions for the  $3p^6 3d^8$  Levels of Sr XIII, Zr XV, and Mo XVII**

J	Term	Percentage Composition (LS)
0	$^3P$	96, 95, 93% $^3P$ + 4, 5, 7% $^1S$
	$^1S$	96, 95, 93% $^1S$ + 4, 5, 7% $^3P$
1	$^3P$	100, 100, 100% $^3P$
2	$^3F$	79, 69, 57% $^3F$ + 19, 27, 34% $^1D$ + 2, 4, 9% $^3P$
	$^3P$	47, 52, 55% $^3P$ + 37, 24, 12% $^1D$ + 16, 24, 33% $^3F$
	$^1D$	45, 50, 52% $^1D$ + 51, 43, 37% $^3P$ + 4, 7, 11% $^3F$
3	$^3F$	100, 100, 100% $^3F$
4	$^3F$	99, 99, 98% $^3F$ + 1, 1, 2% $^1G$
	$^1G$	99, 99, 98% $^1G$ + 1, 1, 2% $^3F$

The levels of the  $3p^6 3d^8$  configuration of Mo XVII are plotted in Fig. 1. Although a few distortions are evident, the levels can be designated fairly well in the *LS* scheme. The  $3p^5 3d^9$  levels of Mo XVII are plotted with *LS* designations in Fig. 2 and with *jj* designations in Fig. 3. Clearly, neither scheme is satisfactory. Although, as discussed below, the coupling is a little closer to *jj* than to *LS*, we have retained *LS* designations for the levels in order to facilitate comparison with Ref. 2, in which *LS* designations are used throughout.

### THEORETICAL INTERPRETATION

The results of fitting the theoretical energy parameters to the observed  $3p^6 3d^8$  level values by least-squares calculations are

**Table 5. Energy Parameters (in  $\text{cm}^{-1}$ ) and Mean Errors  $\Delta$  of Least-Squares Fits for the  $3p^5 3d^9$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII**

Ion	Parameter	HF	Fitted	Fitted-HF
Sr XIII	$E_{av}$	1 112 692	1 131 577 $\pm$ 46	
	$F^2(3p3d)$	202 415	193 004 $\pm$ 546	0.954 $\pm$ 0.003
	$G^1(3p3d)$	235 516	199 797 $\pm$ 237	0.848 $\pm$ 0.001
	$G^3(3p3d)$	150 323	141 352 $\pm$ 456	0.940 $\pm$ 0.003
	$D^1(3p3d)$		-13 736 $\pm$ 412	
	$X^2(3p3d)$		-6 063 $\pm$ 569	
	$\zeta_{3p}$	55 838	58 728 $\pm$ 87	1.052 $\pm$ 0.002
	$\zeta_{3d}$	6 096	5 984 $\pm$ 60	0.982 $\pm$ 0.010
	$\Delta$		148	
Y XIV	$E_{av}$	1 166 512	1 192 951 $\pm$ 60	
	$F^2(3p3d)$	210 891	201 963 $\pm$ 736	0.958 $\pm$ 0.003
	$G^1(3p3d)$	244 026	208 819 $\pm$ 312	0.856 $\pm$ 0.001
	$G^3(3p3d)$	156 264	147 262 $\pm$ 617	0.942 $\pm$ 0.004
	$D^1(3p3d)$		-13 522 $\pm$ 544	
	$X^2(3p3d)$		-5 883 $\pm$ 743	
	$\zeta_{3p}$	63 880	67 429 $\pm$ 110	1.056 $\pm$ 0.002
	$\zeta_{3d}$	7 152	7 004 $\pm$ 78	0.979 $\pm$ 0.011
	$\Delta$		193	
Zr XV	$E_{av}$	1 220 111	1 255 174 $\pm$ 83	
	$F^2(3p3d)$	219 314	210 733 $\pm$ 1056	0.961 $\pm$ 0.005
	$G^1(3p3d)$	252 433	218 008 $\pm$ 438	0.864 $\pm$ 0.002
	$G^3(3p3d)$	162 142	153 534 $\pm$ 889	0.947 $\pm$ 0.005
	$D^1(3p3d)$		-13 722 $\pm$ 764	
	$X^2(3p3d)$		-6 304 $\pm$ 1038	
	$\zeta_{3p}$	72 760	77 094 $\pm$ 148	1.060 $\pm$ 0.002
	$\zeta_{3d}$	8 335	8 162 $\pm$ 107	0.979 $\pm$ 0.013
	$\Delta$		267	
Nb XVI	$E_{av}$	1 274 595	1 318 169 $\pm$ 117	
	$F^2(3p3d)$	227 690	219 792 $\pm$ 1527	0.965 $\pm$ 0.007
	$G^1(3p3d)$	260 752	226 922 $\pm$ 622	0.870 $\pm$ 0.002
	$G^3(3p3d)$	167 965	159 526 $\pm$ 1295	0.950 $\pm$ 0.008
	$D^1(3p3d)$		-13 771 $\pm$ 1085	
	$X^2(3p3d)$		-7 039 $\pm$ 1469	
	$\zeta_{3p}$	82 533	87 640 $\pm$ 204	1.062 $\pm$ 0.002
	$\zeta_{3d}$	9 657	9 475 $\pm$ 148	0.981 $\pm$ 0.015
	$\Delta$		374	
Mo XVII	$E_{av}$	1 328 831	1 382 222 $\pm$ 132	
	$F^2(3p3d)$	236 026	228 252 $\pm$ 1772	0.967 $\pm$ 0.008
	$G^1(3p3d)$	268 994	235 911 $\pm$ 713	0.877 $\pm$ 0.003
	$G^3(3p3d)$	173 740	165 595 $\pm$ 1518	0.953 $\pm$ 0.009
	$D^1(3p3d)$		-14 052 $\pm$ 1242	
	$X^2(3p3d)$		-6 745 $\pm$ 1679	
	$\zeta_{3p}$	93 255	99 559 $\pm$ 226	1.068 $\pm$ 0.002
	$\zeta_{3d}$	11 125	10 918 $\pm$ 166	0.981 $\pm$ 0.015
	O		422	



**Table 6. Percentage Compositions for the  $3p^5 3d^9$  Levels of Sr XIII, Zr XV, and Mo XVII**

<i>J</i>	Term	Percentage <i>jj</i>	Percentage Composition ( <i>LS</i> )
0	$^3P$	100, 100, 100% (3/2,3/2)	100, 100, 100% $^3P$
1	$^3P$	81, 78, 75% (3/2,3/2)	84, 85, 86% $^3P$ + 16, 14, 12% $^3D$ + 0, 1, 2% $^1P$
	$^3D$	63, 66, 66% (3/2,5/2)	68, 65, 63% $^3D$ + 22, 27, 32% $^1P$ + 10, 8, 5% $^3P$
	$^1P$	80, 85, 89% (1/2,3/2)	78, 72, 66% $^1P$ + 16, 20, 25% $^3D$ + 6, 8, 9% $^3P$
2	$^1D$	70, 73, 77% (3/2,5/2)	75, 74, 73% $^1D$ + 17, 15, 14% $^3F$ + 8, 10, 12% $^3P$
	$^3D$	67, 72, 76% (3/2,3/2)	45, 49, 51% $^3D$ + 31, 31, 31% $^3P$ + 23, 20, 18% $^3F$
	$^3F$	93, 96, 98% (1/2,3/2)	59, 63, 66% $^3F$ + 19, 20, 20% $^1D$ + 12, 9, 7% $^3D$
	$^3P$	97, 98, 98% (1/2,5/2)	51, 51, 51% $^3P$ + 43, 42, 41% $^3D$ + 5, 6, 6% $^1D$
3	$^3F$	66, 63, 60% (3/2,3/2)	79, 72, 65% $^3F$ + 21, 27, 34% $^3D$
	$^3D$	66, 62, 58% (3/2,5/2)	75, 66, 57% $^3D$ + 17, 22, 28% $^3F$ + 8, 12, 15% $^1F$
	$^1F$	62, 67, 71% (1/2,5/2)	91, 88, 84% $^1F$ + 5, 7, 9% $^3D$ + 4, 5, 7% $^3F$
4	$^3F$	100, 100, 100% (3/2,5/2)	100, 100, 100% $^3F$

given in Table 3. The HF values of the parameters are also given here. The parameter  $\alpha$  for the effective electrostatic interaction  $\alpha L(L+1)$  is small but well defined. Its introduction into the calculation reduced the mean error of the fit considerably; for Y XIV, for example, the mean error decreased from 1300 to 161  $\text{cm}^{-1}$ . The present values of  $\alpha$  are consistent with the value of 108  $\text{cm}^{-1}$  obtained by Podobedova *et al.*<sup>11</sup> for the isoelectronic ion Ge VII. A value for  $\alpha$  of 48  $\text{cm}^{-1}$  was obtained by Meinders<sup>12</sup> for Cu IV, but this fit included two additional effective interactions, so a direct comparison may not be valid. Interestingly, for the present series of atoms,  $\alpha$  decreases significantly with increasing ionization.

The ratios of the fitted values of the parameters to the HF

**Table 7. Differences between Observed Level Values and Those Calculated with the Fitted Values of the Parameters for the  $3p^6 3d^8$  and  $3p^5 3d^9$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII (in  $\text{cm}^{-1}$ )**

Configuration	<i>J</i>	Term	Sr XIII	Y XIV	Zr XV	Nb XVI	Mo XVII
$3p^6 3d^8$	0	$^3P$	110	100	110	30	10
		$^1S$	-20	10	30	40	70
	1	$^3P$	-110	10	70	190	220
	2	$^3F$	220	220	210	180	-10
		$^3P$	80	-110	-220	-250	-230
		$^1D$	-80	-130	-180	-240	-290
	3	$^3F$	-90	30	150	270	420
	4	$^3F$	-130	-110	-160	-180	-150
		$^1G$	0	-10	-20	-20	-40
$3p^5 3d^9$	0	$^3P$	10	100	90	160	120
	1	$^3P$	-110	-240	-280	-410	-370
		$^3D$	100	-10	-60	-150	-220
		$^1P$	-30	0	30	70	120
	2	$^1D$	10	20	30	50	60
		$^3D$	80	150	230	310	340
		$^3F$	-70	-110	-170	-240	-290
		$^3P$	90	110	160	200	220
	3	$^3F$	100	120	200	250	330
		$^3D$	-190	-140	-220	-270	-360
		$^1F$	20	10	30	40	70
	4	$^3F$	-30	-40	-40	-20	0

values shown in Table 3 are generally close to unity. This is surprising because the HF calculation<sup>9</sup> does not include the effects of relativity. The ratios vary smoothly through the sequence.

The percentage compositions for the  $3p^6 3d^8$  configurations of Sr XIII, Zr XV, and Mo XIII are given in Table 4. As already noted, the coupling is close to *LS*, although the  $^3P_2$  and  $^1D_2$  states are strongly admixed.

The parameters for the  $3p^5 3d^9$  configurations are given in Table 5. The fitted-HF ratios are again close to unity and vary smoothly through the sequence. The parameters  $D^1(3p3d)$  and  $X^2(3p3d)$  for the direct and exchange effective electrostatic interactions<sup>13</sup> are well defined. Of the two, the direct interaction  $D^1(3p3d)$  is the more important. Its introduction into the calculation reduced the mean error for Y XIV from 2300 to 700  $\text{cm}^{-1}$ . Addition of  $X^2(3p3d)$  further reduced the mean error to 193  $\text{cm}^{-1}$ . [When  $X^2(3p3d)$  is added alone, the mean error is reduced only to 2200  $\text{cm}^{-1}$ .] These parameters are thus significant. Their values are nearly constant through the sequence.

The percentage compositions for the  $3p^5 3d^9$  configurations of Sr XIII, Zr XV, and Mo XVII are given in Table 6. As already mentioned, the major components in the *jj* scheme are generally higher than in the *LS* scheme. In the *jl* scheme the major component percentages were found to be a little lower on the average than in the *jj* scheme.

The differences between the observed level values and those calculated with the fitted values of the parameters are given in Table 7. The differences generally vary smoothly, although there are a few irregularities, such as for  $3p^6 3d^8 \ ^3F_2$  and  $^3P_2$ . In view of the uncertainties of the level values, we do not consider these irregularities to be significant.

A. Ryabtsev would like to thank W. C. Martin for generous hospitality in making possible his stay as a guest worker at NBS. This work was supported in part by the Office of Magnetic Fusion Energy of the U.S. Department of Energy.

\* Permanent address, USSR Academy of Sciences, Institute for Spectroscopy, Troitsk, Moscow Region 142092, USSR.



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# 3d-4p Transitions in the zinclike and copperlike ions Y X, XI; Zr XI, XII; Nb XII, XIII; and Mo XIII, XIV

Jean-François Wyart,\* Joseph Reader, and Aleksandr Ryabtsev†

National Bureau of Standards, Washington, D.C. 20234

Received December 16, 1980

Lines occurring as satellites on the long-wavelength side of the  $3d^{10}$ - $3d^9 4p$  resonance lines of Ni-like ions have been investigated with a low-inductance vacuum spark and a 10.7-m spectrograph for the elements Y, Zr, Nb, and Mo. The lines are interpreted as  $3d^{10} 4s$ - $3d^9 4s 4p$  and  $3d^{10} 4p$ - $3d^9 4p^2$  transitions in the Cu-like ions Y XI, Zr XII, Nb XIII, and Mo XIV and  $3d^{10} 4s^2$ - $3d^9 4s^2 4p$  transitions in the Zn-like ions Y X, Zr XI, Nb XII, and Mo XIII. The spectra of the Cu-like ions were interpreted by generalized least-squares fits for the energy levels of the sequence of four ions. Thirty-nine levels of  $3d^9 4s 4p$  were interpreted simultaneously with a root-mean-square deviation of  $122\text{ cm}^{-1}$ ; forty-four levels of  $3d^9 4p^2$  were interpreted in the same way with a root-mean-square deviation of  $200\text{ cm}^{-1}$ . Line identifications and energy levels were obtained for the  $3d^{10} 7p$  configuration of the Cu-like ions Y XI-Mo XIV.

The use of highly ionized molybdenum for plasma diagnosis in controlled-fusion research has stimulated spectroscopic investigations of this element in recent years. As a member of the Cu I isoelectronic sequence, Mo XIV has the ground configuration  $3d^{10} 4s$ . Its one-electron spectrum and those of the neighboring members of the sequence Y XI, Zr XII, and Nb XIII have already been well described.<sup>1-4</sup> In a recent description<sup>5</sup> of the spectra of Mo XIII-XVIII from laser-produced plasmas and low-inductance vacuum sparks, satellite lines occurring on the high-wavelength side of the  $3d^{10}$ - $3d^9 4p$  resonance transitions of the Ni-like ion Mo XV were interpreted as  $3d^{10} 4s$ - $3d^9 4s 4p$  transitions of Mo XIV and  $3d^{10} 4s^2$ - $3d^9 4s^2 4p$  transitions of Mo XIII. Unfortunately, three prominent lines near the middle of the satellite group remained unexplained.

In the present work we photographed spectra of Y, Zr, Nb, and Mo on the 10.7-m grazing-incidence spectrograph at the National Bureau of Standards (NBS) and theoretically interpreted the corresponding satellite line groups in each of these spectra. The unexplained lines in Mo were interpreted as  $3d^{10} 4p$ - $3d^9 4p^2$  transitions of Mo XIV.

## EXPERIMENT

The experimental material for this work was the same as used for a recent study of  $3p^6 3d^8$ - $3p^6 3d^9$  transitions of Y XIV, Zr XV, Nb XVI, and Mo XVII.<sup>6</sup> Briefly, the 10.7-m grazing-incidence spectrograph at NBS was used at angles of incidence of  $80^\circ$  and  $85^\circ$  to record spectra from a low-inductance vacuum spark between metallic electrodes. The grating had 1200 lines/mm. The plate factor was about  $0.12\text{ Å/mm}$  at the  $85^\circ$  angle of incidence.

## LINE IDENTIFICATIONS AND THEORETICAL INTERPRETATION

### $3d^{10} 4s$ - $3d^9 4s 4p$ Transitions

As was seen in Mo XIV,<sup>5</sup> the strongest satellite lines are due to  $3d^{10} 4s$ - $3d^9 4s 4p$  transitions. We thus interpreted these transitions first. The  $3d^9 4s 4p$  configuration contains 23 levels, of which eleven have  $J = 1/2$  or  $3/2$  and can therefore combine with  $3d^{10} 4s\ ^2S_{1/2}$ . Our line identifications were made with the help of theoretical calculations of the  $3d^9 4s 4p$ -level structures and  $3d^{10} 4s$ - $3d^9 4s 4p$  line strengths in the four ions that were investigated. Initial energy parameters for the  $3d^9 4s 4p$  configurations were obtained by Hartree-Fock (HF) calculations.<sup>7</sup> After identifying the strongest and most reliable transitions in each ion, we repeated the calculations with values of the parameters determined from least-squares fits to the observed energy levels. New line identifications were then carried out. In this way, 10 of the 11 possible transitions in each ion could be identified. Only the transition  $3d^{10} 4s\ ^2S_{1/2}$ - $3d^9(2D)4s 4p(^1P)\ ^2D_{3/2}$ , which is calculated to be 400 times weaker than the strongest transition of the array, could not be identified. The low calculated line strength for this transition results from the fact that the upper level corresponds to a fairly pure  $^2D_{3/2}$  state. The previous<sup>5</sup> identification of this transition in Mo XIV is probably spurious.

The wavelengths and classifications of the identified  $3d^{10} 4s$ - $3d^9 4s 4p$  transitions are given in Table 1. The uncertainty of the wavelengths is  $\pm 0.005\text{ Å}$ . The intensities are visual estimates of photographic plate blackening. The line identifications are well supported by the calculated line strengths, which predict the observed trends well. Because



Table 1. Lines Classified as  $3d^{10}4s-3d^94s4p$  and  $3d^{10}4p-3d^94p^2$  Transitions in Y XI, Zr XII, Nb XIII, and Mo XIV<sup>a</sup>

Classification	Code	Y XI		Zr XII		Nb XIII		Mo XIV	
		$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.
$4s^2S_{1/2}-(2D, 1P) 2P_{1/2}^*$	A	73.639	15	64.466	20	57.001	15	50.788	10
$4p^2P_{3/2}^*-(2D, 1S) 2D_{5/2}$	a	73.908	2	64.794	1w	57.393	2	51.20	1
$4p^2P_{1/2}^*-(2D, 3P) 4P_{3/2}$	b	74.175?	1			57.187	1		
$4p^2P_{1/2}^*-(2D, 3P) 2P_{1/2}$	c	74.391	5	65.059	2	57.468	2	51.158	1
$4s^2S_{1/2}-(2D, 1P) 2P_{3/2}^*$	B	74.456	30	65.200	50	57.662	30	51.398	20
$4p^2P_{1/2}^*-(2D, 1D) 2D_{3/2}$	d	74.896	8	65.466	5	57.797	3	51.434	1
$4p^2P_{3/2}^*-(2D, 1D) 2F_{5/2}$	e	74.954	2p	65.540	3	57.884	2	51.531	1
$4p^2P_{3/2}^*-(2D, 3P) 4P_{1/2}$	f			65.609	1				
$4p^2P_{3/2}^*-(2D, 3P) 4P_{3/2}$	g	75.209	10						
$4p^2P_{1/2}^*-(2D, 3P) 4F_{3/2}$	h	75.233	15	65.760	10	58.053	10	51.666	5
$4p^2P_{3/2}^*-(2D, 3P) 2P_{3/2}$	i	75.307	25	65.896	10	58.241	15	51.894	8
$4p^2P_{1/2}^*-(2D, 1D) 2P_{1/2}$	j			65.816?	1				
$4p^2P_{3/2}^*-(2D, 3P) 2P_{1/2}$	k	75.438	10	66.029	5	58.362	5	52.00	2u
$4p^2P_{3/2}^*-(2D, 3P) 2D_{5/2}$	l	75.521	35	66.080	20	58.386	20	52.013	10u
$4p^2P_{1/2}^*-(2D, 3P) 2D_{3/2}$	m	75.584	25	66.115	10	58.407	10	52.019	8u
$4p^2P_{1/2}^*-(2D, 3P) 4D_{1/2}$	n	75.945	2	66.327	2				
$4s^2S_{1/2}-(2D, 3P) 4D_{3/2}^*$	C	76.274	25	66.597	8	58.728	10	52.225	5
$4p^2P_{1/2}^*-(2D, 1D) 2P_{3/2}$	o	76.283?	2u	66.687?	3	58.888*	5	52.415*	2
$4p^2P_{3/2}^*-(2D, 3P) 4F_{5/2}$	p					58.909	3		
$4p^2P_{1/2}^*-(2D, 1D) 2S_{1/2}$	q	76.331	10	66.717	5p	58.888*	5	52.415*	2
$4p^2P_{3/2}^*-(2D, 1D) 2P_{1/2}$	r	76.434?	15l	66.792?	5				
$4p^2P_{1/2}^*-(2D, 3P) 4D_{3/2}$	s	76.584?	15						
$4s^2S_{1/2}-(2D, 3P) 4D_{1/2}^*$	D	76.66	1	66.928	3	59.016	5w	52.473	5
$4s^2S_{1/2}-(2D, 3P) 2P_{1/2}^*$	E	76.843	40	67.121	30	59.214	20	52.687	10
$4s^2S_{1/2}-(2D, 3P) 2P_{3/2}^*$	F	76.920	50	67.201	50	59.285	40	52.750	20
$4s^2S_{1/2}-(2D, 3P) 2D_{3/2}^*$	G	77.340	35	67.569	30	59.612	20	53.044	10
$4p^2P_{3/2}^*-(2D, 1D) 2P_{3/2}$	t					59.826	2		
$4p^2P_{3/2}^*-(2D, 1D) 2S_{1/2}$	u	77.436	5l						
$4s^2S_{1/2}-(2D, 3P) 4P_{1/2}^*$	H	77.667	5	67.768	5	59.722	5	53.095	3
$4s^2S_{1/2}-(2D, 3P) 4F_{3/2}^*$	I	77.910	5u	68.022	2	59.971	5	53.335	3
$4s^2S_{1/2}-(2D, 3P) 4P_{3/2}^*$	J	78.424	25	68.476	15	60.383	10	53.725	5

<sup>a</sup> Levels are designated in LS coupling. The parent terms for  $3d^9$  and for the coupled external electrons  $4s4p$  or  $4p^2$  are given in parentheses. A code has been attributed to the transitions to facilitate correspondence with Fig. 1. Capital letters denote  $3d^{10}4s-3d^94s4p$  transitions; lower-case letters denote  $3d^{10}4p-3d^94p^2$  transitions. Symbols: u, unresolved; w, wide; l, shaded to longer wavelengths; p, perturbed by close line; \*, doubly classified. Lines for which a question mark is given have observed intensities much larger than expected; they may be blended with lines of other ionization stages. Not all the transitions are shown in Fig. 1.

the transitions may be written as  $[3d^{10}(1S)]4s-[3d^94p(L,S)]4s$ , the intensities are proportional to the amount of  $[3d^94p(1P)]4s^2P_{1/2}^*$  state in the upper level. For the line marked D in Fig. 1, this is calculated as 4.9% for Mo, 3.9% for Nb, 2.5% for Zr, and 0.9% for Y. Therefore the low intensity found for this transition in Y XI is theoretically justified. Tracings of a portion of the satellite spectra observed in each element are shown in Fig. 1.

The least-squares calculation for the  $3d^94s4p$  levels involves fitting the ten observed levels with the eight Slater parameters for the  $3d^94s4p$  configuration:  $A$ ,  $F^2(3d4p)$ ,  $G^1(3d4p)$ ,  $G^3(3d4p)$ ,  $G^1(4s4p)$ ,  $G^2(3d4s)$ ,  $\zeta_{3d}$ , and  $\zeta_{4p}$ . As  $G^3(3d4p)$  has a constant contribution to the terms having  $J = 1/2, 3/2$  levels ( $2^4P, 2^4D, 4F$ ), its value could be fixed at the HF value, leaving seven parameters to be varied.

By optimizing the remaining seven parameters, we could obtain good agreement between calculated and observed energies. Also, the resultant scaling factors for the HF parameters of the four ions were found to be quite similar. Nevertheless, their variation along the sequence was not completely regular. The irregularities are undoubtedly due to small perturbations that may be expected for such high

configurations. For example, the  $3d^{10}7p$  configuration overlaps  $3d^94s4p$  and, as the relative position of the two configurations varies along the sequence, different repulsion effects may be expected. As the ratio of observed levels to free parameters is small, the parameter values are thus sensitive to such small perturbations.

In order to reduce the number of free parameters and improve their reliability, we adopted a generalized least-squares (GLS) procedure in which the four observed spectra were treated simultaneously. In this procedure the HF values of the integrals were entered explicitly into the energy matrices as coefficients of the angular factors and the scaling factors for the HF parameters considered as free parameters. The scaling factors  $SF(Z)$  were constrained to be linearly dependent on  $Z$ :  $SF(Z) = SF_{av} + a(Z - Z_{av})$ . (For the present ions,  $Z_{av} = 40.5$ .) However, with this constraint, the coefficient  $a$  of the linear term in the GLS procedure was undefined for all parameters except  $G^1(4s4p)$  and  $\zeta_{3d}$ . We thus set  $a = 0$  except for these two parameters, leaving 13 parameters to account for the 40 observed levels. The resultant root-mean-square deviation of this fit,  $122 \text{ cm}^{-1}$ , is comparable with the uncertainty of the energy-level values, which is about



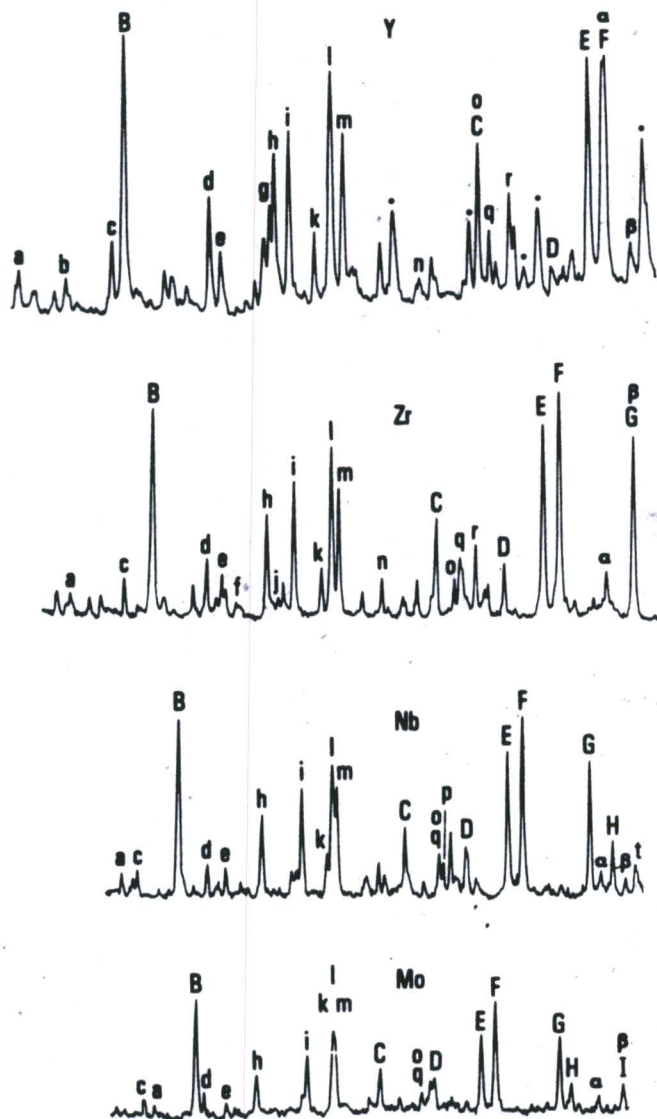


Fig. 1. Comparison of the spectra of Y XI, Zr XII, Nb XIII, and Mo XIV showing isoelectronic regularities in the region of the strongest  $3d^{10}4s-3d^9 4s 4p$  transitions (capital letters),  $3d^{10}4s-3d^9 4p$  transitions (lower-case letters), and  $3d^{10}4s-3d^9 4p$  transitions (Greek letters). Complete designations are given in Tables 1 and 7. Lines marked with dots pertain to higher ionization stages in Y; two of them have been classified as Y XIV.<sup>6</sup>

$140\text{ cm}^{-1}$ . Compared with the independent calculations, the GLS process does not produce changes in any of the line identifications. Only nine lines have deviations  $\Delta\sigma = \sigma_{\text{exp}} - \sigma_{\text{calc}}$  larger than the experimental uncertainty.

The  $3d^9 4s 4p$  energy levels are listed in Table 2. The levels are designated in the  $3d^9(2D)4s 4p(1,3P^\circ)$  SLJ scheme, which proved to be the best of the several possible schemes.

The fitted values of the scaling factors and parameter values are given in Tables 3 and 4, respectively. In Table 5 we list the HF values of the parameters.

### $3d^{10}4p-3d^9 4p^2$ Transitions

With the strongest satellite lines accounted for by the  $3d^{10}4s-3d^9 4s 4p$  transitions, we then tried to correlate the remaining lines with the group expected to be next in strength,

$3d^{10}4p-3d^9 4p^2$ . When we did this, application of the GLS procedures used for the  $3d^9 4s 4p$  configurations proved to be important.

The  $3d^9 4p^2$  configuration is expected to lie below the ionization limit in the present ions. It has a total of 28 levels, of which 21 have  $J = 1/2, 3/2, 5/2$  and can combine with  $4p^2 P_{1/2,3/2}^\circ$ . Because of strong electrostatic interactions within the  $n = 4$  shell, the  $3d^9 4p^2$  configuration is expected to be perturbed by the  $3d^9 4s^2$ ,  $3d^9 4s 4d$ , and  $3d^9 4d^2$  configurations, which do not radiate to the  $3d^{10}n!$  levels. They show their presence mainly by perturbing the  $3d^9 4p^2$  levels. The  $3d^9 4s^2$  and  $3d^9 4d^2$  configurations are expected to be far enough from  $3d^9 4p^2$  that their perturbations can be treated by effective electrostatic interactions. However,  $3d^9 4s 4d$  is close to  $3d^9 4p^2$  and must be specifically included in the energy matrix. Our matrix thus included the 18 ordinary electrostatic and spin-orbit parameters for these two interacting configurations plus a correction of the type  $\alpha L(L+1)$  for the terms of the subconfiguration  $4p^2$  and a similar one for the final terms of  $3d^9 4p^2$ .

From an initial set of scaled HF parameters, predicted wavelengths and line strengths for the  $3d^{10}4p-3d^9 4p^2$  transitions could be calculated. This led to the identification of several strong lines of this array and also made it evident that the levels of  $3d^9 4s 4d$  and about 10 levels of  $3d^9 4p^2$  would not be observable with the present data. Ensuing least-squares calculations were made by fixing the internal  $3d^9 4s 4d$  parameters at their HF values. The position of the  $3d^9 4s 4d$  configuration relative to  $3d^9 4p^2$  was fixed in such a way that the separation between their lowest levels would equal the value of  $E(3d^{10}4d) - 2E(3d^{10}4p)$  as given by the known levels of the one-electron system. Thus all  $3d^9 4s 4d$  parameters were fixed except the  $3d^9 4s 4d-3d^9 4p^2$  configuration interaction integral  $R^1(4p 4p, 4s 4d)$ . Again, a GLS procedure was used for fitting the  $3d^9 4p^2$  parameters and  $R^1(4p 4p, 4s 4d)$ . The scaling factors of  $F^2(3d 4p)$ ,  $G^1(3d 4p)$ ,  $G^3(3d 4p)$ ,  $\zeta_{3d}$ , and  $R^1(4p 4p, 4s 4d)$  were assumed to be constant along the sequence. Scaling factors for  $F^2(4p 4p)$  and  $\zeta_{4p}$  were left unconstrained.

By reducing the number of free parameters to 17, and carrying out successive line identifications and least-squares calculations, we could obtain values for 44  $3d^9 4p^2$  energy levels in the four ions. The fitted and HF values of the parameters for the  $3d^9 4p^2$  configurations are given in Tables 4 and 5, respectively. Table 5 also includes the HF values for  $3d^9 4s 4d$ . In the least-squares fits to the observed levels, the  $\alpha L(L+1)$  correction for the final terms of  $3d^9 4p^2$  remained undefined and was dropped. The fitted values of  $\alpha$  for the terms of  $4p^2$  are given in Table 4. The final root-mean-square deviation of the calculated values was  $200\text{ cm}^{-1}$ .

The identified  $3d^{10}4p-3d^9 4p^2$  transitions are given in Table 1. The  $3d^9 4p^2$  energy levels are given in Table 6. For designating the levels, no entirely satisfactory coupling scheme could be found. We have adopted the  $(3d^9 S_1 L_1, 4p^2 S_2 L_2)$  SLJ scheme, although it is not appreciably better than the  $(3d^9 S_1 L_1 J_1, 4p^2 S_2 L_2 J_2)$  J scheme. The lack of a pure coupling scheme results from the presence of electrostatic and spin-orbit terms of comparable magnitude in the Hamiltonian. The labeling of levels is further complicated by the changing importance of these interactions along the sequence. For example, the ratio  $F^2(4p 4p)/\zeta_{4p}$  decreases from 5.5 in Y XI to 3.5 in Mo XIV. Therefore significant changes occur



Table 2. Experimental Energy Levels of the  $3d^9 4s 4p$  Configurations of Y XI, Zr XII, Nb XIII, and Mo XIV<sup>a</sup>

<i>J</i>	Designation	Y XI			Zr XII			Nb XIII			Mo XIV		
		<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent
1/2	( <sup>2</sup> D, <sup>3</sup> P) <sup>4</sup> P°	1 287 540	-20	81	1 475 630	-120	77	1 674 440	50	73	1 883 400	-50	68
	( <sup>2</sup> D, <sup>3</sup> P) <sup>2</sup> P°	1 301 350	50	90	1 489 840	10	85	1 688 800	60	82	1 898 000	0	79
	( <sup>2</sup> D, <sup>3</sup> P) <sup>4</sup> D°	1 304 450	* <sup>b</sup>	79	1 494 150	90	71	1 694 450	20	63	1 905 750	140	56
	( <sup>2</sup> D, <sup>1</sup> P) <sup>2</sup> P°	1 357 980	-90	98	1 551 210	260	97	1 754 350	-170	97	1 968 960	130	96
3/2	( <sup>2</sup> D, <sup>3</sup> P) <sup>4</sup> P°	1 275 120	70	64	1 460 370	-80	58	1 656 110	230	52	1 861 340	90	46
	( <sup>2</sup> D, <sup>3</sup> P) <sup>4</sup> F°	1 283 530	60	86	1 470 100	-200	85	1 667 480	-10	84	1 874 940	-60	84
	( <sup>2</sup> D, <sup>3</sup> P) <sup>2</sup> D°	1 292 990	-30	54	1 479 960	-100	53	1 677 520	50	52	1 885 220	-50	50
	( <sup>2</sup> D, <sup>3</sup> P) <sup>2</sup> P°	1 300 060	150	59	1 488 080	-40	58	1 686 760	20	57	1 895 720	-60	57
	( <sup>2</sup> D, <sup>3</sup> P) <sup>4</sup> D°	1 311 070	50	52	1 501 560	20	52	1 702 750	-60	52	1 914 770	-90	51
	( <sup>2</sup> D, <sup>1</sup> P) <sup>2</sup> P°	1 343 080	-80	92	1 533 750	160	91	1 734 240	-180	90	1 945 620	-50	89
	( <sup>2</sup> D, <sup>1</sup> P) <sup>2</sup> D°	[1 372 610]		96	[1 566 430]		96	[1 770 900]		95	[1 986 080]		94

<sup>a</sup> The deviations  $\Delta E = E_{\text{exp}} - E_{\text{th}}$  are taken from the generalized least-squares treatment of the whole sequence. The percentage of the leading *LS* component is given. Predicted energies for the (<sup>2</sup>D, <sup>1</sup>P) <sup>2</sup>D<sub>3/2</sub> levels are given in brackets.

<sup>b</sup> \*Level value based on eyepiece measurement; not used in least-squares fit.

Table 3. Fitted Scaling Factors for the Hartree-Fock Integrals

Parameter	Y XI	Zr XII	Nb XIII	Mo XIV	Footnotes
<i>F</i> <sup>2</sup> (4 <i>p</i> 4 <i>p</i> )	0.772 ± 0.014	0.769 ± 0.013	0.733 ± 0.013	0.720 ± 0.013	<sup>a</sup>
<i>F</i> <sup>2</sup> (3 <i>d</i> 4 <i>p</i> )	0.987 ± 0.007	0.987	0.987	0.987	<sup>a,1</sup>
	0.992 ± 0.006	0.992	0.992	0.992	<sup>b,1</sup>
<i>G</i> <sup>1</sup> (3 <i>d</i> 4 <i>p</i> )	0.983 ± 0.008	0.983	0.983	0.983	<sup>a,1</sup>
	0.981 ± 0.007	0.981	0.981	0.981	<sup>b,1</sup>
<i>G</i> <sup>3</sup> (3 <i>d</i> 4 <i>p</i> )	0.983	0.983	0.983	0.983	<sup>a,2</sup>
<i>G</i> <sup>2</sup> (3 <i>d</i> 4 <i>s</i> )	1.012 ± 0.018	1.012	1.012	1.012	<sup>b,1</sup>
<i>G</i> <sup>1</sup> (4 <i>s</i> 4 <i>p</i> )	0.786 ± 0.001	0.789 ± 0.001	0.791	0.794	<sup>b,3</sup>
$\zeta_{3d}$	1.049 ± 0.012	1.049	1.049	1.049	<sup>a,1</sup>
	1.028 ± 0.006	1.024 ± 0.006	1.021	1.018	<sup>b,3</sup>
$\zeta_{4p}$	1.090 ± 0.012	1.088 ± 0.008	1.094 ± 0.007	1.095 ± 0.007	<sup>a</sup>
	1.125 ± 0.005	1.125	1.125	1.125	<sup>b,1</sup>
<i>R</i> <sup>1</sup> (4 <i>p</i> 4 <i>p</i> , 4 <i>s</i> 4 <i>d</i> )	0.956 ± 0.066	0.956	0.956	0.956	<sup>a,1</sup>

<sup>a</sup> GLS fit of  $3d^9 4p^2 + 3d^9 4s 4d$ .

<sup>b</sup> GLS fit of  $3d^9 4s 4p$ .

<sup>1</sup> An equal value has been assumed for the four elements.

<sup>2</sup> The same scaling factor has been assumed for *G*<sup>3</sup>(3*d*4*p*) and *G*<sup>1</sup>(3*d*4*p*).

<sup>3</sup> The scaling factors are constrained to be linearly dependent on the atomic number.

in the eigenvectors, as is seen in Table 6, and also in some of the calculated line strengths. Our names for levels having leading percentages of less than 50% are assigned mainly for use with the classified line list.

#### Identification of the $3d^{10} 7p \ ^2P^\circ$ Term

Comparison of the spectra in Fig. 1 shows that in Y XI line *F* is weaker relative to the other  $3d^{10} 4s-3d^9 4s 4p$  transitions and is split into two components. The two components (76.920 and 76.928 Å) both have the excitation character of Y XI. If these lines are taken as transitions to the ground state, they would involve upper levels with effective quantum numbers  $n^* = 6.0737$  and  $n^* = 6.0725$ , respectively. As the known members of the  $3d^{10} np \ ^2P^\circ_{3/2}$  series have effective quantum numbers  $n^*(4p) = 3.0245$ ,  $n^*(5p) = 4.0546$ , and  $n^*(6p) = 5.0667$ , there is little doubt that one of these lines is  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{3/2}$ . If we identify a line at 77.058 Å as  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{1/2}$ , we obtain a value of  $\delta n^* = n^*(j = 3/2) - n^*(j = 1/2)$  of 0.0196 if 76.920 Å is identified as  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{3/2}$  and 0.0184

if 76.928 Å is used for this transition. Because of the regularity of  $\delta n^*$  for the lower members of the *np* series (0.0192 for 4*p*, 0.0188 for 5*p*, and 0.0187 for 6*p*), we consider 76.928 Å as the best choice for  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{3/2}$ . The reduced intensity of *F* in Y XI is undoubtedly caused by mixing between the  $3d^9(2D)4s 4p(^3P) \ ^2P^\circ_{3/2}$  and  $3d^{10} 7p \ ^2P^\circ_{3/2}$  states, which makes unambiguous identification of the two lines difficult.

In Mo XIV Curtis *et al.*<sup>8</sup> classified lines at  $53.19 \pm 0.05$  Å and  $53.30 \pm 0.05$  Å as  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{3/2}$  and  $4s \ ^2S_{1/2}-7p \ ^2P^\circ_{1/2}$  transitions, respectively. These wavelengths agree with our present values for these lines,  $53.221 \pm 0.005$  Å and  $53.335 \pm 0.005$  Å. However, it is clear from isoelectronic considerations that most of the intensity of the 53.335-Å line is due to the  $3d^{10} 4s \ ^2S_{1/2}-3d^9(2D)4s 4p(^3P) \ ^4F^\circ_{3/2}$  transition. Our new value for the  $7p \ ^2P^\circ_{3/2}$  level, 1 878 940 cm<sup>-1</sup>, is confirmed by observation of the  $4d \ ^2D_{5/2}-7p \ ^2P^\circ_{3/2}$  transition at 87.717 Å.

Our wavelengths for the  $4s-7p$  transitions in Y XI, Zr XII, Nb XIII, and Mo XIV are given in Table 7. The lines are noted

**Table 4. Fitted Parameter Values (in  $\text{cm}^{-1}$ ) for the  $3d^9 4s 4p$  and  $3d^9 4p^2$  Configurations of Y XI, Zr XII, Nb XIII, and Mo XIV**

Configuration	Parameter	Y XI	Zr XII	Nb XIII	Mo XIV
$3d^9 4s 4p$	A	1 339 595	1 529 988	1 730 788	1 241 997
	$G^2(3d 4s)$	19 422	20 452	21 479	22 501
	$F^2(3d 4p)$	53 883	57 598	61 268	64 899
	$G^1(3d 4p)$	17 428	18 610	19 779	20 935
	$G^3(3d 4p)$	17 362 <sup>a</sup>	18 605 <sup>a</sup>	19 832 <sup>a</sup>	21 046 <sup>a</sup>
	$G^1(4s 4p)$	93 059	98 402	103 703	108 974
	$\zeta_{3d}$	6 959	8 103	9 376	10 787
	$\zeta_{4p}$	13 128	15 770	18 741	22 068
$3d^9 4p^2$	A	1 565 492	1 774 993	1 994 607	2 225 502
	$F^2(3d 4p)$	53 462	57 155	60 803	64 413
	$G^1(3d 4p)$	17 404	18 590	19 763	20 924
	$G^3(3d 4p)$	17 013	18 236	19 444	20 639
	$F^2(4p 4p)$	69 351	72 864	73 041	75 265
	$\alpha(4p 4p)$	-1 017	-1 017	-1 017	-1 017
	$\zeta_{3d}$	7 107	8 302	9 638	11 125
	$\zeta_{4p}$	12 684	15 214	18 184	21 435
Configuration Interaction	$R^1(4p 4p, 4s 4d)$	105 857	112 338	118 640	124 790

<sup>a</sup> Fixed at HF value.**Table 5. Hartree-Fock Integrals (in  $\text{cm}^{-1}$ ) for the configurations  $3d^9 4s 4p$ ,  $3d^9 4p^2$ , and  $3d^9 4s 4d$  of Y XI, Zr XII, Nb XIII, and Mo XIV**

Configuration	Integral	Y XI	Zr XII	Nb XIII	Mo XIV
$3d^9 4s 4p$	$E_{av}$	1 326 636	1 519 359	1 724 419	1 937 001
	$G^2(3d 4s)$	19 184	20 202	21 216	22 226
	$F^2(3d 4p)$	54 307	58 052	61 751	65 410
	$G^1(3d 4p)$	17 764	18 969	20 160	21 339
	$G^3(3d 4p)$	17 362	18 605	19 832	21 046
	$G^1(4s 4p)$	118 392	124 758	131 028	137 217
	$\zeta_{3d}$	6 770	7 909	9 183	10 600
	$\zeta_{4p}$	11 668	14 015	16 657	19 613
$3d^9 4p^2$	$E_{av}$	1 525 782	1 733 589	1 953 431	2 181 418
	$F^2(3d 4p)$	54 193	57 937	61 635	65 294
	$G^1(3d 4p)$	17 698	18 904	20 097	21 277
	$G^3(3d 4p)$	17 300	18 544	19 772	20 987
	$F^2(4p 4p)$	89 810	94 775	99 675	104 519
	$\zeta_{3d}$	6 772	7 911	9 184	10 601
	$\zeta_{4p}$	11 640	13 985	16 624	19 579
$3d^9 4s 4d$	$E_{av}$	1 643 121	1 862 502	2 093 871	2 332 554
	$F^2(3d 4d)$	46 395	50 995	55 546	60 053
	$F^4(3d 4d)$	21 681	24 038	26 379	28 705
	$G^0(3d 4d)$	15 728	17 215	18 673	20 105
	$G^2(3d 4d)$	18 298	20 210	22 099	23 966
	$G^4(3d 4d)$	13 497	15 457	16 954	18 438
	$G^2(3d 4s)$	19 224	20 230	21 234	22 235
	$G^2(4s 4d)$	80 820	86 671	92 274	97 663
	$\zeta_{3d}$	6 780	7 920	9 193	10 610
	$\zeta_{4d}$	1 147	1 435	1 766	2 146
Configuration Interaction	$R^1(4p 4p, 4s 4d)$	110 744	117 524	124 116	130 550

as  $\alpha$  and  $\beta$  in Fig. 1. The  $7p$  energy levels are given in Table 8.

### $3d-4p$ Transitions in Zn-like and Ni-like Ions

The remaining satellite lines are the  $3d^{10} 4s^2-3d^9 4s^2 4p$  transitions in the Zn-like ions. Our identifications for the

$3d^9 4s^2 4p \ ^1P_1^o$  and  $^3D_1^o$  levels of Y XI, Zr XII, and Nb XIII are given in Table 9. Our new measurements for these transitions in Mo XIV are also given here. The  $3d^{10} 4s^2 \ ^1S_0-3d^9 4s^2 4p \ ^3P_1^o$  transition, expected to be weak, has not been observed.

Our measurements for the  $3d^{10}-3d^9 4p$  resonance lines of the Ni-like ions Y XII, Zr XIII, Nb XIV, and Mo XV are given in



Table 6. Experimental Levels of  $3d^34p^2$  <sup>a</sup>

<i>J</i>	Designation	Y XI			Zr XII			Nb XIII			Mo XIV		
		<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent	<i>E</i> (cm <sup>-1</sup> )	$\Delta E$	Per-cent
1/2	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>S</i>	1 499 890	150	57	1 704 070	-160	57	1 918 750	180	59	2 143 950	40	59
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>D</i>	1 506 550	-160	79	1 712 880	0	79	[1 929 750]		81	[2 157 680]		81
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>P</i>	1 516 750?		62	1 724 700?		62	[1 942 150]		62	[2 171 190]		62
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>2</sup> <i>P</i>	1 534 050	100	86	1 742 110	160	86	1 960 760	-10	87	2 190 700	80	88
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>P</i>	[1 541 140]		83	1 751 810	-30	81	[1 973 850]		80	[2 207 330]		78
3/2	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>D</i>	1 495 570?		69	1 699 310	70	67	[1 913 240]		64	[2 137 880]		62
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>P</i>	1 500 720?		66	1 704 740?		65	1 918 760?		64	2 143 940?		63
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>2</sup> <i>D</i>	1 512 840	-60	42 <sup>b</sup>	1 717 720	-20	46	1 932 740	70	49	2 158 460	270	51
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>F</i>	1 519 020	50	36 <sup>c</sup>	1 725 880	40	40	1 943 180	-320	44	2 171 600	-500	46
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>D</i>	1 524 990	-40	56	1 732 710	-20	55	1 950 830	-30	55	2 180 320	0	54
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>2</sup> <i>P</i>	1 536 320	-120	24 <sup>d</sup>	1 745 170	-150	57	1 964 340	-170	61	2 194 630	-120	62
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>P</i>	1 538 060	270	31 <sup>e</sup>	[1 747 680]		46	1 969 260	160	45	[2 202 130]		43
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>S</i> ) <sup>2</sup> <i>D</i>	[1 577 960]		86	[1 790 120]		84	[2 011 970]		82	[2 246 300]		80
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>D</i>	[1 484 890]		52	[1 685 980]		48	[1 896 670]		45	[2 117 650]		42
5/2	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>2</sup> <i>F</i>	[1 503 800]		53	[1 707 860]		53	[1 922 230]		51	[2 147 280]		50
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>P</i>	[1 506 180]		38	[1 710 790]		41	[1 925 540]		43	[2 151 050]		45
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>4</sup> <i>F</i>	[1 520 030]		28/ <sup>f</sup>	1 727 180	150	32	1 944 890	110	35	[2 173 560]		39
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>F</i>	[1 522 800]		23 <sup>g</sup>	[1 730 340]		25 <sup>h</sup>	[1 948 520]		28	[2 177 840]		31
	( <sup>2</sup> <i>D</i> , <sup>3</sup> <i>P</i> ) <sup>2</sup> <i>D</i>	1 532 560	-50	54	1 740 950	-40	53	1 960 070	140	52	2 190 210	110	51
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>D</i> ) <sup>2</sup> <i>F</i>	1 542 590	-100	58	1 753 410	-20	56	1 974 930	60	51	2 208 210	380	47
	( <sup>2</sup> <i>D</i> , <sup>1</sup> <i>S</i> ) <sup>2</sup> <i>D</i>	1 561 470	40	83	1 770 980	110	80	1 989 710	-100	76	2 220 830	-160	71

<sup>a</sup> The deviations  $\Delta E = E_{\text{exp}} - E_{\text{th}}$  are taken from the generalized least-squares treatment of the whole sequence. Predicted energies for unknown levels are given in brackets. The designations are given in *LS* coupling with parent term of  $4p^2$  in parentheses. The percentages of the leading eigenvector components are also given.

<sup>b</sup> Leading component, (<sup>3</sup>*P*) <sup>4</sup>*F*, 49%.

<sup>c</sup> Leading component, (<sup>3</sup>*P*) <sup>2</sup>*D*, 40%.

<sup>d</sup> Leading component, (<sup>1</sup>*D*) <sup>2</sup>*P*, 26%.

<sup>e</sup> Leading component, (<sup>3</sup>*P*) <sup>2</sup>*P*, 47%.

<sup>f</sup> Leading component, (<sup>3</sup>*P*) <sup>4</sup>*P*, 30%.

<sup>g</sup> Leading component, (<sup>3</sup>*P*) <sup>4</sup>*F*, 29%.

<sup>h</sup> Leading component, (<sup>3</sup>*P*) <sup>4</sup>*F*, 26%.

Table 7.  $3d^{10}4s-3d^{10}7p$  Transitions in Y XI, Zr XII, Nb XIII, and Mo XIV

Transition	Code	Y XI	Zr XII	Nb XIII	Mo XIV
$3d^{10}4s^2S_{1/2}-3d^{10}7p^2P_{3/2}^o$	$\alpha$	76.931	67.440	59.666	53.228
$3d^{10}4s^2S_{1/2}-3d^{10}7p^2P_{1/2}^o$	$\beta$	77.064	67.576 <sup>a</sup>	57.793	53.341 <sup>b</sup>

<sup>a</sup> Blended with  $3d^{10}4s^2S_{1/2}-3d^94s4p$  (<sup>2</sup>*D*, <sup>3</sup>*P*) <sup>2</sup>*D*<sub>3/2</sub>.

<sup>b</sup> Blended with  $3d^{10}4s^2S_{1/2}-3d^94s4p$  (<sup>2</sup>*D*, <sup>3</sup>*P*) <sup>4</sup>*F*<sub>3/2</sub>.

Table 8. Energy Levels (in cm<sup>-1</sup>) of the  $3d^{10}7p$  Configurations of Y XI, Zr XII, Nb XIII, and Mo XIV<sup>a</sup>

Designation	Y XI	Zr XII	Nb XIII	Mo XIV
$3d^{10}7p^2P_{1/2}^o$	1 297 620	(1 479 820)	1 672 440	(1 874 730)
$3d^{10}7p^2P_{3/2}^o$	1 299 870	1 482 800	1 676 000	1 878 710

<sup>a</sup> The values in parentheses are derived from blended lines.

Table 9.  $3d-4p$  Transitions in Ni-like and Zn-like Ions

Transition	$\lambda(\text{\AA})$ Int.		$\lambda(\text{\AA})$ Int.		$\lambda(\text{\AA})$ Int.		$\lambda(\text{\AA})$ Int.	
	Y XII		Zr XIII		Nb XIV		Mo XV	
$3d^{10}1S_0-3d^94p^3D_1^o$	72.103	80	63.234	100	55.963	100	49.914	100
	72.734	100	63.828	150	56.523	150	50.448	150
	73.588	5	64.538	5	57.119	5	50.956	5
$3d^{10}4s^21S_0-3d^94s^24p^3D_1^o$	Y XI		Zr XII		Nb XIII		Mo XIV	
	78.706	10	68.562	5	60.332	10	53.551	10
	79.338 <sup>a</sup>	100	69.161	15	60.902	20	54.101	20

<sup>a</sup> Blended with  $3p^63d^81G_4-3p^53d^91F_3$  transition of Y XIV.

Table 9. For some lines they differ significantly from the earlier values of Alexander *et al.*<sup>9</sup> Our assignment of the line at 73.588 Å as  $3d^{10}1S_0-3d^94p\ ^3P_1$  in Y XII represents a revised line identification from that given in Ref. 9.

J.-F. Wyart wishes to acknowledge the support of his stay at NBS by a NATO grant. A. Ryabtsev would like to thank W. C. Martin for generous hospitality in making possible his stay as a guest worker at NBS. This work was supported in part by the Office of Magnetic Fusion Energy of the U.S. Department of Energy.

\* NBS Guest Worker, on leave from Laboratoire Aime Cotton, CNRS, France.

† NBS Guest Worker; permanent address, USSR Academy of Sciences, Institute for Spectroscopy, Troitsk, Moscow Region, 142092, USSR.

*Note added in proof:* Recent measurements in second and third orders have indicated systematic shifts in our wavelenths for Zr XII and Nb XIII. The improved values for Zr XII (in Å) are as follows (intensities are in parentheses):

64.488 (20)	65.775 (10)	66.341 (2)	67.130 (30)
64.814 (1w)	65.910 (10)	66.608 (8)	67.209(50)
65.080 (2)	65.832 (1)	66.699 (3)	67.576 (30)
65.218 (50)	65.044 (5)	66.727 (5p)	67.774 (5)
65.484 (5)	66.094 (20)	66.803 (5)	68.028 (2)
65.557 (3)	66.129 (10)	66.938 (3)	68.479 (15)

The improved values for Nb XIII are:

58.367 (8)	58.893 (5)	59.295 (40)	59.984 (5)
58.391 (20)	58.917 (3)	59.623 (20)	60.397 (10)
58.413 (10)	59.024 (5w)	59.836 (2)	
58.735 (10)	59.223 (20)	59.733 (5)	

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# Spectra of the cobaltlike ions Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Aleksandr N. Ryabtsev\* and Joseph Reader

National Bureau of Standards, Washington, D.C. 20234

Received December 19, 1981

Spectra of the cobaltlike ions Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI have been observed by means of a low-inductance vacuum spark and a 10.7-m grazing-incidence spectrograph in the region 40–95 Å. For Y XIII, Zr XIV, Nb XV, and Mo XVI more than 40 transitions of the type  $3d^9-3d^84p$  were identified in each ion. For Sr XII about 20 such transitions were identified. The identifications were made with the aid of Hartree-Fock and least-squares parametric calculations. New wavelengths were obtained for the  $3p^63d^9-3p^53d^{10}$  transitions in these ions. The previous analysis of Mo XVI was partially revised and extended.

The spectra of atoms of highly ionized molybdenum have been of increased interest lately because of their use in connection with tokamak fusion research. Spectra of the cobaltlike ion Mo XVI have been observed in the TFR tokamak in France<sup>1</sup> as well as in the DITE tokamak in England.<sup>2</sup> Current studies also indicate the likely use of niobium and zirconium in future reactors. It is thus important to obtain well-established line identifications for highly ionized atoms of these elements. In the present paper we report line identifications and energy levels for the isoelectronic sequence of cobaltlike ions Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI.

Ions of the Co I isoelectronic sequence have the ground configuration  $3p^63d^9$ . The first excited configuration is  $3p^53d^{10}$ , which gives rise to three strong resonance transitions at relatively long wavelengths (70 Å in Mo XVI). The next excited odd configuration is  $3p^63d^84p$ , which gives rise to a complex group of resonance lines at somewhat shorter wavelengths (45 Å in Mo XVI).

The  $3p^63d^9-3p^53d^{10}$  transitions of Sr XII, Y XIII, Zr XIV, and Mo XVI were first observed by Edlén,<sup>3</sup> although no wavelength measurements were reported. Edlén's preliminary wavelengths for these ions can be inferred from the data in Table 27 of his review monograph<sup>4</sup>; for Sr XII, Y XIII, and Zr XIV, the wavelengths may also be inferred from the level values given in *Atomic Energy Levels*.<sup>5</sup> In 1971, Alexander *et al.*<sup>6</sup> reported measurements for the  $3p^63d^9-3p^53d^{10}$  transitions of Y XIII–Mo XVI. New wavelengths for these transitions in Mo XVI were given in 1980 by Burkhalter *et al.*<sup>7</sup> Wavelengths for the same transitions in Sr XII were given recently by Acquista and Reader.<sup>8</sup>

The  $3d^9-3d^84p$  transitions of Sr XII and Y XIII were first observed by Edlén. The transition groups are indicated on the spectrograms in Fig. 2 of Ref. 3 and in Fig. 49 of Ref. 4. No wavelengths were given. Alexander *et al.*<sup>6</sup> published wavelengths with no identifications for about 25 lines of this group in each of the ions from Y XIII to Mo XVI. Mansfield *et al.*<sup>2</sup> used a laser-produced plasma to observe this group in Mo XVI. They reported identifications for 25 lines. These identifications were revised and extended to a total of 38 lines by

Burkhalter *et al.*<sup>7</sup> Our present work further revises these identifications and extends the number to 43.

## EXPERIMENT

The measurements were taken from spectrograms made in connection with a recent investigation<sup>9</sup> of the spectra of the ironlike ions Sr XIII–Mo XVII. The spectra were made on the 10.7-m grazing-incidence spectrograph at the National Bureau of Standards (NBS). The grating had 1200 lines/mm. The angle of incidence used for Y, Zr, Nb, and Mo was 85°. This resulted in a plate factor of 0.12 Å/mm at 60 Å. The spectrum of Sr was photographed at an angle of incidence of 80°. The plate factor was 0.17 Å/mm. The spectra were excited by means of a low-inductance vacuum spark operating at a capacitance of 14 μF and a voltage of 10 kV.

One set of plates was measured with the aid of a semiautomatic comparator at the Institute for Spectroscopy in Moscow.<sup>10</sup> Wavelengths were calculated by using a computer code that provided an approximation of the plate-correction curve by a cubic polynomial. Secondary standards of wavelength were obtained by measurements of lines in the second order relative to impurity lines of oxygen and fluorine as well as lines of Y–Mo in various stages of ionization.<sup>9,11–14</sup> A second set of plates was measured at NBS. For this set all lines were measured in the second order. Averages of the wavelengths from the two sets were used for the finally adopted values.

Intensities for the observed lines of Y–Mo were derived in Moscow from densitometer recordings of the spectrograms by use of an estimated characteristic curve to represent the response of the photographic plate. For Sr XII the intensities were visually estimated from the photographic blackening. The intensity of the  $3d^9\ ^2D_{5/2}-3d^8(^3F)4p\ ^2F_{7/2}$  transition in each spectrum was given a value of 1000.

The wavelengths, intensities, and classifications of the  $3d^9-3d^84p$  transitions are given in Table 1. The uncertainty of the wavelengths is estimated as  $\pm 0.005$  Å. The present values for the  $3p^63d^9-3p^53d^{10}$  transitions are given in Table



Table 1.  $3d^9-3d^84p$  Transitions in Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Transition	Sr XII		Y XIII		Zr XIV			Nb XV		Mo XVI	
	$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.	Int. <sup>a</sup>	$\lambda$ (Å)	Int.	$\lambda$ (Å)	Int.
$^2D_{5/2}-(^1S) ^2P_{3/2}$			60.662	20	53.847	90	116	48.138	80	43.324 <sup>b</sup>	60
$^2D_{3/2}-(^1S) ^2P_{3/2}$			61.303	10	54.437	20	33	48.685	30	43.837 <sup>b</sup>	30
$^2D_{3/2}-(^1S) ^2P_{1/2}$			62.111	30	55.190	100	130	49.399	160	44.509 <sup>b</sup>	100
$^2D_{5/2}-(^1G) ^2G_{7/2}$			63.408	90	56.141	170	177	50.091	120	45.000 <sup>b</sup>	220
$^2D_{5/2}-(^3P) ^2D_{3/2}$			63.964	30	56.585	110	104	50.451	110	45.290 <sup>b</sup>	60
$^2D_{5/2}-(^1D) ^2F_{7/2}$			64.012	60	56.597	110	44	50.435	80	45.250	30
$^2D_{5/2}-(^3P) ^2D_{5/2}$			64.112	10	56.706	10	14				
$^2D_{3/2}-(^3P) ^2P_{1/2}$			64.272	200	56.879	260	664	50.732	250	45.553 <sup>b</sup>	300
$^2D_{5/2}-(^3P) ^2P_{3/2}$	73.329	50	64.279	250	56.854	270	459	50.678	170	45.483 <sup>b</sup>	220
$^2D_{5/2}-(^3P) ^4D_{5/2}$			64.469	90	56.986	220	226	50.770	240	45.545	250
$^2D_{5/2}-(^1D) ^2P_{3/2}$	73.679	150	64.555	200	57.083	290	628	50.877	400	45.659 <sup>b</sup>	300
$^2D_{3/2}-(^1G) ^2F_{5/2}$	73.631	250	64.569	600	57.138	700	1177	50.958	850	45.756 <sup>b</sup>	700
$^2D_{3/2}-(^3P) ^2S_{1/2}$			64.646	40	57.230	380 <sup>c</sup>	200	51.055	280 <sup>c</sup>	45.867	150
$^2D_{3/2}-(^3P) ^2D_{3/2}$			64.677	40	57.230	380 <sup>c</sup>	92	51.055	280 <sup>c</sup>	45.853 <sup>b</sup>	170
$^2D_{5/2}-(^3P) ^4D_{7/2}$	73.772	500	64.691	600	57.241	800	659	51.038	650	45.809 <sup>b</sup>	500
$^2D_{3/2}-(^3P) ^2D_{5/2}$	73.932	50	64.825	200	57.360	320	340	51.155	450	45.938 <sup>b</sup>	500
$^2D_{5/2}-(^3P) ^4D_{3/2}$			64.851	10			17				
$^2D_{5/2}-(^1D) ^2D_{5/2}$	74.074	150	64.906	250	57.393	290	269	51.147	200	45.887 <sup>d</sup>	200
$^2D_{3/2}-(^3P) ^2P_{3/2}$	74.129	100	65.003	250	57.513	450	453	51.286	700 <sup>c</sup>	46.043 <sup>b</sup>	1000 <sup>c</sup>
$^2D_{5/2}-(^1G) ^2F_{7/2}$	74.208	500	65.013	700	57.494	1000	1337	51.257	1300	46.024 <sup>b</sup>	1600
$^2D_{5/2}-(^1D) ^2D_{3/2}$			65.047	150	57.526	450	700	51.286	700 <sup>c</sup>	46.043 <sup>b</sup>	1000 <sup>c</sup>
$^2D_{3/2}-(^3P) ^4D_{5/2}$	74.405	100	65.194	60	57.647	180	177	51.380	220	46.113 <sup>b</sup>	300
$^2D_{3/2}-(^1D) ^2P_{3/2}$			65.278	20	57.748	40	136	51.490	140	46.229 <sup>b</sup>	220
$^2D_{5/2}-(^1D) ^2F_{5/2}$			65.304	90	57.715	260	242	51.419	400	46.131 <sup>b</sup>	600
$^2D_{5/2}-(^3F) ^2D_{3/2}$			65.500	40	57.851	90	120	51.516	50	46.197	110
$^2D_{5/2}-(^3F) ^2F_{5/2}$	74.855	500	65.522	600	57.905	800	929	51.592	700	46.291 <sup>b</sup>	650
$^2D_{3/2}-(^3P) ^4D_{3/2}$	74.795	50	65.584	250	58.036	900 <sup>c</sup>	671	51.763	900 <sup>c</sup>	46.478 <sup>b</sup>	1000 <sup>c</sup>
$^2D_{3/2}-(^1D) ^2D_{5/2}$			65.641	100	58.064	380	254	51.763	900 <sup>c</sup>	46.463 <sup>b</sup>	440
$^2D_{3/2}-(^1D) ^2P_{1/2}$			65.667	30			2				
$^2D_{3/2}-(^3P) ^4D_{1/2}$					58.095	190	91	51.828	140	46.573 <sup>d</sup>	750 <sup>c</sup>
$^2D_{5/2}-(^3F) ^2G_{7/2}$			65.710	120	58.036	900 <sup>c</sup>	155	51.682	300	46.352 <sup>b</sup>	450
$^2D_{3/2}-(^1D) ^2D_{3/2}$	75.056	250	65.785	400	58.201	500	637	51.908	400	46.623 <sup>b</sup>	250
$^2D_{5/2}-(^3P) ^4P_{5/2}$	75.127	500	65.823	650	58.209	1000	706	51.889	700	46.573 <sup>d</sup>	750 <sup>c</sup>
$^2D_{5/2}-(^3F) ^4F_{7/2}$	75.294	250	65.847	350	58.134	500	199	51.745	350	46.378 <sup>b</sup>	260
$^2D_{5/2}-(^3P) ^4P_{3/2}$			65.939	10	58.284	70	19	51.935	80	46.592 <sup>d</sup>	80
$^2D_{5/2}-(^3F) ^4F_{5/2}$	75.427	250	65.970	150	58.247	350	158	51.849	250	46.478 <sup>b</sup>	1000 <sup>c</sup>
$^2D_{3/2}-(^1D) ^2F_{5/2}$	75.400	100	66.046	40	58.395	60	77	52.045	90	46.712 <sup>b</sup>	130
$^2D_{3/2}-(^3F) ^2D_{3/2}$	75.687	500	66.247	250	58.534	300	255	52.145	150	46.781 <sup>b</sup>	120
$^2D_{3/2}-(^3F) ^2F_{5/2}$			66.271	100	58.588	180	197	52.228	1200 <sup>c</sup>	46.877	150
$^2D_{5/2}-(^3F) ^2D_{5/2}$	75.876	1000	66.390	1000	58.645	1000	1000	52.228	1200 <sup>c</sup>	46.841 <sup>b</sup>	900
$^2D_{5/2}-(^3F) ^2F_{7/2}$	75.955	1000	66.449	1000	58.688	1000	491	52.258	1000	46.859	1000
$^2D_{3/2}-(^3P) ^4P_{1/2}$					58.844	35	3				
$^2D_{3/2}-(^3P) ^4P_{5/2}$			66.580	40	58.902	120	114	52.527	100	47.165 <sup>b</sup>	170
$^2D_{3/2}-(^3P) ^4P_{3/2}$			66.696	40	58.978	130	69	52.573	120	47.186 <sup>d</sup>	140
$^2D_{3/2}-(^3F) ^4F_{5/2}$	76.262	50	66.728	100	58.939	160	67	52.486	140	47.068 <sup>b</sup>	90
$^2D_{5/2}-(^3F) ^4F_{3/2}$			66.845	10	59.040	40	23				
$^2D_{5/2}-(^3F) ^4G_{5/2}$			66.914	70	59.126	190	55	52.676	190	47.262 <sup>d</sup>	180
$^2D_{5/2}-(^3F) ^4G_{7/2}$			67.074	10	59.237	40	8	52.750	80	47.302	20
$^2D_{5/2}-(^3F) ^4D_{5/2}$			67.234	20	59.360	50	12	52.846	110	47.382	30
$^2D_{3/2}-(^3F) ^4D_{3/2}$			67.335	20	59.482	15	14				
$^2D_{3/2}-(^3F) ^4F_{3/2}$			67.627	110	59.790	210	74	53.309	160	47.871 <sup>d</sup>	150
$^2D_{3/2}-(^3F) ^4G_{5/2}$			67.692	10	59.836	30	5				
$^2D_{5/2}-(^3F) ^4D_{7/2}$			67.973	15	60.038	90	11	53.471	130	47.959 <sup>d</sup>	90

<sup>a</sup> Calculated from fitted values of energy parameters.<sup>b</sup> Present value for line given by Burkhalter *et al.*, Ref. 7.<sup>c</sup> Doubly classified.<sup>d</sup> Present value for line given by Burkhalter *et al.*, Ref. 7, revised classification.

2. along with the values previously reported. The present values for Sr XII are not compared with those of Ref. 8 because the measurements were taken from the same exposures and thus differ only slightly.

## SPECTRUM ANALYSIS

The observations were interpreted by comparing the observed spectra with calculated wavelengths and intensities of the five



**Table 2.**  $3p^63d^9-3p^53d^{10}$  Transitions in Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Transition		Sr XII		Y XIII		Zr XIV		Nb XV		Mo XVI		
		$\lambda$ (Å) <sup>a</sup>		$\lambda$ (Å) <sup>a</sup>	$\lambda$ (Å) <sup>b</sup>	$\lambda$ (Å) <sup>a</sup>	$\lambda$ (Å) <sup>b</sup>	$\lambda$ (Å) <sup>a</sup>	$\lambda$ (Å) <sup>b</sup>	$\lambda$ (Å) <sup>a</sup>	$\lambda$ (Å) <sup>b</sup>	$\lambda$ (Å) <sup>c</sup>
$3p^63d^9$ $2D_{3/2}-3p^53d^{10}$	$2P_{1/2}$	86.413		81.610	81.604	77.249	77.245	73.273	73.315	69.596	69.580	69.589
	$2D_{5/2}$	92.029		87.394	87.382	83.196	83.181	79.374	79.357	75.869	75.861	75.863
	$2P_{3/2}$	93.288		88.731	88.716	84.612	84.602	80.871	80.845	77.456	77.450	77.450

<sup>a</sup> This work.<sup>b</sup> Alexander *et al.*, Ref. 6.<sup>c</sup> Burkhalter *et al.*, Ref. 7.**Table 3.** Energy Levels (in cm<sup>-1</sup>) of Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI<sup>a</sup>

Configuration	Term	J	Sr XII	Y XIII	Zr XIV	Nb XV	Mo XVI
$3p^63d^9$	$2D$	5/2	0	0	0	0	0
		3/2	14 660	17 230	20 140	23 380	27 020
$3p^53d^{10}$	$2P$	3/2	1 086 610	1 144 240	1 201 990	1 259 890	1 318 070
		1/2	1 171 890	1 242 570	1 314 660	1 388 140	1 463 880
$3p^63d^84p$	$(^3F)^4D$	7/2	(1 287 050)	1 471 170	1 665 610	1 870 170	2 085 110
		9/2	(1 294 130)	(1 478 120)	(1 672 850)	(1 877 670)	(2 092 710)
		5/2	(1 300 810)	1 487 340	1 684 640	1 892 290	2 110 510
	$(^3F)^4G$	7/2	(1 304 500)	1 490 890	1 688 130	1 895 730	2 114 080
		5/2	(1 308 000)	1 494 480	1 691 340	1 898 400	2 115 860
		11/2	(1 307 760)	(1 495 300)	(1 693 740)	(1 903 070)	(2 123 170)
	$(^3F)^4F$	3/2	(1 309 240)	1 495 960	1 692 640	1 899 240	2 115 970
		3/2	(1 314 560)	1 502 340	1 701 320	(1 910 980)	(2 131 480)
		9/2	(1 314 230)	(1 502 500)	(1 701 410)	(1 911 100)	(2 131 540)
	$(^3F)^2F$	7/2	1 316 570	1 504 910	1 703 930	1 913 580	2 134 060
		1/2	(1 316 930)	(1 505 990)	(1 706 010)	(1 916 450)	(2 137 580)
		5/2	1 317 940	1 506 250	1 705 180	1 914 680	2 134 880
	$(^3F)^2G$	9/2	(1 324 150)	(1 513 830)	(1 715 100)	(1 927 290)	(2 150 740)
		5/2	1 325 860	1 515 840	1 716 820	1 928 660	2 151 610
		3/2	(1 327 960)	1 516 560	1 715 720	1 925 490	2 146 290
	$(^3F)^4F$	7/2	1 328 130	1 518 670	1 720 160	1 932 550	2 156 190
		5/2	1 331 080	1 519 200	1 717 920	1 927 180	2 147 240
		1/2	(1 332 740)	(1 520 560)	1 719 550	(1 928 850)	(2 148 770)
	$(^3F)^2G$	7/2	(1 331 850)	1 521 840	1 723 070	1 934 910	2 157 400
		5/2	1 335 920	1 526 200	1 726 970	1 938 290	2 160 260
		3/2	1 335 890	1 526 720	1 728 560	1 941 120	2 164 640
	$(^1D)^2F$	5/2	1 340 920	1 531 320	1 732 640	1 944 800	2 167 770
		3/2	1 347 000	1 537 340	1 738 330	1 949 870	2 171 880
		7/2	1 347 560	1 538 150	1 739 310	1 950 950	2 172 780
	$(^1D)^2P$	1/2	(1 348 800)	1 540 060	(1 742 530)	(1 955 360)	(2 179 420)
		9/2	(1 352 680)	(1 540 680)	(1 740 350)	(1 950 390)	(2 170 640)
		5/2	1 350 000	1 540 680	1 742 380	1 955 150	2 179 270
	$(^3P)^4D$	1/2	(1 351 070)	(1 541 330)	1 741 460	1 952 840	2 174 190
		3/2	1 351 650	1 542 000	1 743 210	1 955 260	2 178 580
		7/2	1 355 530	1 545 810	1 747 000	1 959 320	2 182 980
	$(^1D)^2P$	3/2	1 357 240	1 549 100	1 751 820	1 965 510	2 190 160
		5/2	1 358 660	1 551 120	1 754 830	1 969 660	2 195 620
		3/2	1 363 690	1 555 670	1 758 880	1 973 240	2 198 620
	$(^3P)^2D$	5/2	1 367 250	1 559 800	1 763 500	1 978 220	2 203 870
		11/2	(1 368 780)	(1 560 220)	(1 763 660)	(1 978 120)	(2 203 340)
		7/2	(1 368 940)	1 562 210	1 766 880	1 982 750	2 209 940
	$(^3P)^2D$	3/2	(1 370 640)	1 563 380	1 767 250	1 982 120	2 207 940
		1/2	(1 371 270)	1 564 120	1 767 480	1 982 050	2 207 240
		5/2	1 372 780	1 565 960	1 770 290	1 985 780	2 212 530
	$(^3P)^4S$	3/2	(1 375 020)	(1 568 520)	(1 772 530)	(1 987 640)	(2 213 610)
		1/2	(1 378 010)	1 573 120	1 778 260	1 994 520	2 222 270
		7/2	(1 383 560)	1 577 090	1 781 230	1 996 370	2 222 220
	$(^1G)^2G$	9/2	(1 385 820)	(1 579 410)	(1 783 860)	(1 999 340)	(2 225 390)
		1/2	(1 429 980)	1 627 250	1 832 060	2 047 710	2 273 760
		3/2	(1 447 620)	1 648 480	1 857 120	2 077 400	2 308 200

<sup>a</sup> Values for unobserved levels, given in parentheses, are those calculated with the fitted values of the energy parameters.

ions. The calculations were made with a set of computer codes developed by the Institute of Physics of the Lithuanian Academy of Sciences.<sup>15,16</sup> The radial integrals were first computed by a Hartree-Fock (HF) calculation and then scaled by factors obtained by extrapolation along the Co I isoelectronic sequence.<sup>17,18</sup>

Although the observed spectra are complex and blended in some regions, the predicted isoelectronic trends yielded un-

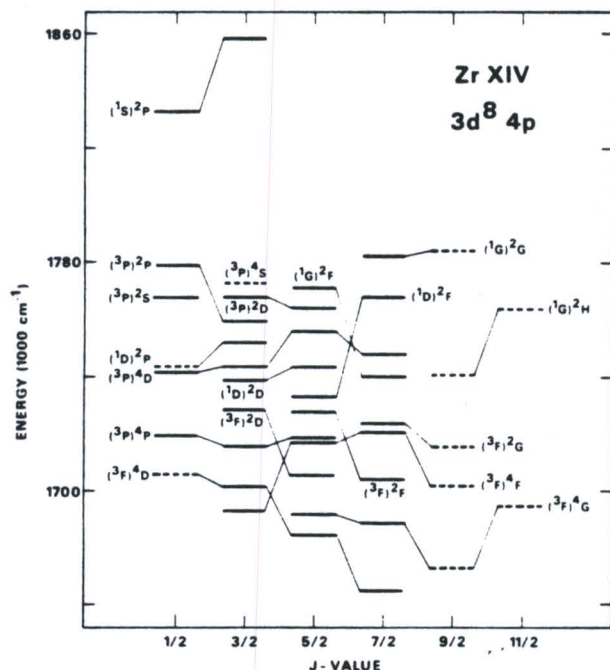


Fig. 1. Structure of the  $3d^8 4p$  configuration of Zr XIV. The calculated positions of unobserved levels are shown as dashed lines.

Table 4. Spin-Orbit Parameters  $\zeta_{3d}$  (in  $\text{cm}^{-1}$ ) for the  $3p^6 3d^9$  Configurations of Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Ion	HF	Obs.	Obs./HF
Sr XII	5 836	5 864	1.005
Y XIII	6 863	6 892	1.004
Zr XIV	8 016	8 056	1.005
Nb XV	9 304	9 352	1.005
Mo XVI	10 737	10 808	1.007

Table 5. Energy Parameters (in  $\text{cm}^{-1}$ ) for the  $3p^5 3d^{10}$  Configurations of Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Ion	Parameter	HF	Obs.	Obs./HF
Sr XII	$E_{av}$	1 100 410	1 115 040	
	$\zeta_{3p}$	54 326	56 853	1.0465
Y XIII	$E_{av}$	1 155 130	1 177 020	
	$\zeta_{3p}$	62 188	65 553	1.0541
Zr XIV	$E_{av}$	1 209 140	1 239 550	
	$\zeta_{3p}$	70 877	75 113	1.0598
Nb XV	$E_{av}$	1 264 360	1 302 640	
	$\zeta_{3p}$	80 448	85 500	1.0628
Mo XVI	$E_{av}$	1 317 920	1 366 670	
	$\zeta_{3p}$	90 958	97 207	1.0687

Table 6. Energy Parameters and Mean Errors  $\Delta$  (in  $\text{cm}^{-1}$ ) for the  $3d^8 4p$  Configurations of Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI

Ion	Parameter	HF	Fitted	Fitted/HF
Sr XII	$E_{av}$	1 356 870	1 340 470 $\pm$ 130	
	$F^2(3d3d)$	214 010	192 820 $\pm$ 910	0.901 $\pm$ 0.004
	$F^4(3d3d)$	136 318	116 630 $\pm$ 3480	0.856 $\pm$ 0.026
	$\alpha_1(3d3d)$		107 $\pm$ 40	
	$F^2(3d4p)$	55 593	54 830 $\pm$ 930	0.986 $\pm$ 0.017
	$G^1(3d4p)$	18 218	17 740 $\pm$ 340	0.974 $\pm$ 0.019
	$G^3(3d4p)$	17 886	20 560 $\pm$ 2040	1.150 $\pm$ 0.114
	$\alpha(3d4p)$		69 $\pm$ 56	
	$\zeta_{3d}$	6 088	6 180 $\pm$ 90	1.015 $\pm$ 0.015
	$\zeta_{4p}$	11 329	12 540 $\pm$ 230	1.107 $\pm$ 0.020
	$\Delta$		200	
Y XIII	$E_{av}$	1 551 260	1 530 440 $\pm$ 70	
	$F^2(3d3d)$	224 667	204 370 $\pm$ 610	0.910 $\pm$ 0.003
	$F^4(3d3d)$	143 263	130 100 $\pm$ 520	0.908 $\pm$ 0.004
	$\alpha_1(3d3d)$		71 $\pm$ 24	
	$F^2(3d4p)$	59 275	60 220 $\pm$ 530	1.016 $\pm$ 0.009
	$G^1(3d4p)$	19 399	19 210 $\pm$ 230	0.990 $\pm$ 0.012
	$G^3(3d4p)$	19 106	20 800 $\pm$ 1090	1.089 $\pm$ 0.057
	$\alpha(3d4p)$		32 $\pm$ 22	
	$\zeta_{3d}$	7 144	7 180 $\pm$ 70	1.005 $\pm$ 0.010
	$\zeta_{4p}$	13 586	15 150 $\pm$ 120	1.115 $\pm$ 0.009
	$\Delta$		240	
Zr XIV	$E_{av}$	1 755 480	1 731 230 $\pm$ 60	
	$F^2(3d3d)$	235 264	214 890 $\pm$ 580	0.913 $\pm$ 0.002
	$F^4(3d3d)$	150 169	136 350 $\pm$ 480	0.908 $\pm$ 0.003
	$\alpha_1(3d3d)$		76 $\pm$ 24	
	$F^2(3d4p)$	62 917	63 970 $\pm$ 450	1.017 $\pm$ 0.007
	$G^1(3d4p)$	20 569	20 360 $\pm$ 220	0.990 $\pm$ 0.011
	$G^3(3d4p)$	20 312	22 150 $\pm$ 1170	1.090 $\pm$ 0.058
	$\alpha(3d4p)$		34 $\pm$ 23	
	$\zeta_{3d}$	8 328	8 410 $\pm$ 70	1.010 $\pm$ 0.008
	$\zeta_{4p}$	16 127	17 910 $\pm$ 110	1.111 $\pm$ 0.007
	$\Delta$		240	
Nb XV	$E_{av}$	1 972 210	1 942 790 $\pm$ 70	
	$F^2(3d3d)$	245 805	226 020 $\pm$ 740	0.920 $\pm$ 0.003
	$F^4(3d3d)$	157 039	143 220 $\pm$ 610	0.912 $\pm$ 0.004
	$\alpha_1(3d3d)$		66 $\pm$ 28	
	$F^2(3d4p)$	66 526	67 860 $\pm$ 640	1.020 $\pm$ 0.010
	$G^1(3d4p)$	21 729	21 630 $\pm$ 260	0.995 $\pm$ 0.012
	$G^3(3d4p)$	21 507	22 950 $\pm$ 1490	1.067 $\pm$ 0.069
	$\alpha(3d4p)$		45 $\pm$ 27	
	$\zeta_{3d}$	9 650	9 690 $\pm$ 70	1.004 $\pm$ 0.007
	$\zeta_{4p}$	18 974	21 120 $\pm$ 130	1.113 $\pm$ 0.007
	$\Delta$		270	
Mo XVI	$E_{av}$	2 198 910	2 165 110 $\pm$ 80	
	$F^2(3d3d)$	256 302	235 430 $\pm$ 760	0.919 $\pm$ 0.003
	$F^4(3d3d)$	163 880	149 560 $\pm$ 650	0.913 $\pm$ 0.004
	$\alpha_1(3d3d)$		51 $\pm$ 27	
	$F^2(3d4p)$	70 106	71 150 $\pm$ 660	1.015 $\pm$ 0.009
	$G^1(3d4p)$	22 879	22 810 $\pm$ 250	0.997 $\pm$ 0.011
	$G^3(3d4p)$	22 692	23 710 $\pm$ 1550	1.045 $\pm$ 0.068
	$\alpha(3d4p)$		51 $\pm$ 27	
	$\zeta_{3d}$	11 119	11 180 $\pm$ 70	1.005 $\pm$ 0.006
	$\zeta_{4p}$	22 150	24 690 $\pm$ 130	1.115 $\pm$ 0.006
	$\Delta$		270	

ambiguous classifications for all the identified lines. The identifications were greatly facilitated by the fact that the  $3d^9$ - $3d^8 4p$  group is well isolated from lines of other ionization



stages. The identifications are supported by repetition of the  $3d^9\ ^2D$  fine-structure interval in the measurements. Nearly all  $3d^84p$  levels with  $J = 3/2$  or  $J = 5/2$  have observed transitions to both of the  $3d^9\ ^2D$  levels.

In general, the observed intensities compare well with the calculated values. As an example, the calculated values for Zr XIV are shown following the observed intensities in Table 1. The scale for the calculated values was obtained by setting the intensity of the  $3d^9\ ^2D_{5/2}-3d^8(^3F)4p\ ^2D_{5/2}$  transition equal to its observed value.

The energy levels derived from the wavelength measurements are given in Table 3. The uncertainty of the values of the  $3d^84p$  levels relative to the ground term is approximately

$\pm 200\text{ cm}^{-1}$ . The relative values within  $3d^84p$  are uncertain by about  $\pm 100\text{ cm}^{-1}$ . The  $3d^9\ ^2D$  intervals were derived from all observed pairs, with double weight given to the  $3p^63d^9\ ^2D_{5/2,3/2}-3p^63d^{10}\ ^2P_{3/2}$  pair because of its longer wavelength.

The structure of the  $3d^84p$  configuration of Zr XIV is shown in Fig. 1. Although the levels are designated in the  $LS$ -coupling scheme, the coupling is far from pure. In Table 3 we have given common designations to levels that derive from specific spectral lines that can be traced through the isoelectronic sequence. However, because the coupling changes along the sequence, for some levels it is not possible to adopt an  $LS$  name that corresponds to the major eigenvector com-

Table 7. Percentage Compositions for the  $3d^84p$  Configurations of Sr XII, Zr XIV, and Mo XVI

$J$	Term	Percent $J_1J_2$	Percentage Composition ( $LS$ )
1/2	$(^3F)^4D$	73, 62, 48% ( $^3F_2, 3/2$ )	74, 62, 48% ( $^3F$ ) $^4D$ + 19, 25, 30% ( $^3P$ ) $^4D$ + 6, 8, 11% ( $^1D$ ) $^2P$
	$(^3P)^4P$	62, 66, 72% ( $^3P_1, 1/2$ )	86, 86, 84% ( $^3P$ ) $^4P$ + 5, 4, 2% ( $^1D$ ) $^2P$ + 2, 3, 5% ( $^3P$ ) $^4D$
	$(^3P)^4D$	61, 51, 51% ( $^3P_0, 1/2$ )	69, 48, 50% ( $^3P$ ) $^4D$ + 12, 31, 26% ( $^3F$ ) $^4D$ + 11, 0, 12% ( $^1D$ ) $^2P$
	$(^1D)^2P$	42, 47, 32% ( $^1D_2, 3/2$ )	42, 47, 32% ( $^1D$ ) $^2P$ + 32, 19, 31% ( $^3P$ ) $^2P$ + 11, 2, 17% ( $^3F$ ) $^4D$
	$(^3P)^2S$	66, 66, 68% ( $^3P_1, 3/2$ )	57, 61, 61% ( $^3P$ ) $^2S$ + 27, 22, 19% ( $^3P$ ) $^2P$ + 6, 7, 8% ( $^3P$ ) $^4D$
	$(^3P)^2P$	60, 53, 47% ( $^3P_2, 3/2$ )	33, 33, 34% ( $^3P$ ) $^2P$ + 32, 24, 19% ( $^3P$ ) $^2S$ + 30, 35, 38% ( $^1D$ ) $^2P$
	$(^1S)^2P$	93, 91, 88% ( $^1S_0, 1/2$ )	93, 91, 88% ( $^1S$ ) $^2P$ + 3, 3, 4% ( $^1D$ ) $^2P$ + 2, 3, 4% ( $^3P$ ) $^4D$
3/2	$(^3F)^4F$	60, 55, 42% ( $^3F_2, 1/2$ )	27, 26, 20% ( $^3F$ ) $^4F$ + 37, 14, 6% ( $^3F$ ) $^4D$ + 10, 21, 26% ( $^1D$ ) $^2D$
	$(^3F)^4D$	35, 39, 31% ( $^3F_3, 3/2$ )	40, 54, 50% ( $^3F$ ) $^4D$ + 13, 20, 24% ( $^3P$ ) $^4D$ + 7, 10, 13% ( $^3P$ ) $^4P$
	$(^3P)^4P$	38, 38, 30% ( $^3P_2, 1/2$ )	39, 40, 33% ( $^3P$ ) $^4P$ + 33, 25, 19% ( $^3F$ ) $^4F$ + 14, 9, 7% ( $^1D$ ) $^2P$
	$(^3F)^2D$	34, 35, 23% ( $^3F_2, 3/2$ )	37, 27, 16% ( $^3F$ ) $^2D$ + 31, 41, 40% ( $^3F$ ) $^4F$ + 23, 15, 14% ( $^3P$ ) $^4P$
	$(^1D)^2D$	31, 13, 2% ( $^1D_2, 1/2$ )	31, 20, 11% ( $^1D$ ) $^2D$ + 29, 22, 15% ( $^3F$ ) $^2D$ + 12, 22, 28% ( $^3P$ ) $^2P$
	$(^3P)^4D$	66, 37, 17% ( $^3P_1, 1/2$ )	50, 29, 14% ( $^3P$ ) $^4D$ + 6, 20, 36% ( $^3F$ ) $^2D$ + 6, 15, 21% ( $^1D$ ) $^2D$
	$(^1D)^2P$	75, 57, 35% ( $^1D_2, 3/2$ )	61, 53, 38% ( $^1D$ ) $^2P$ + 19, 11, 5% ( $^1D$ ) $^2D$ + 3, 9, 17% ( $^3P$ ) $^2P$
	$(^3P)^2P$	48, 34, 17% ( $^3P_2, 3/2$ )	65, 52, 37% ( $^3P$ ) $^2P$ + 10, 16, 17% ( $^1D$ ) $^2D$ + 10, 13, 15% ( $^3P$ ) $^4D$
	$(^3P)^2D$	50, 45, 33% ( $^3P_0, 3/2$ )	78, 74, 69% ( $^3P$ ) $^2D$ + 12, 12, 9% ( $^3P$ ) $^4D$ + 3, 4, 5% ( $^1S$ ) $^2P$
	$(^3P)^4S$	47, 47, 47% ( $^3P_1, 3/2$ )	87, 82, 75% ( $^3P$ ) $^4S$ + 4, 5, 8% ( $^3P$ ) $^2P$ + 3, 4, 3% ( $^3P$ ) $^4P$
	$(^1S)^2P$	95, 93, 91% ( $^1S_0, 3/2$ )	95, 93, 91% ( $^1S$ ) $^2P$ + 2, 2, 2% ( $^1D$ ) $^2P$ + 1, 2, 2% ( $^3P$ ) $^2D$
5/2	$(^3F)^4D$	59, 60, 56% ( $^3F_3, 1/2$ )	72, 66, 60% ( $^3F$ ) $^4D$ + 17, 19, 18% ( $^3F$ ) $^4F$ + 7, 8, 9% ( $^3P$ ) $^4D$
	$(^3F)^4G$	62, 55, 43% ( $^3F_2, 1/2$ )	64, 56, 46% ( $^3F$ ) $^4G$ + 11, 15, 19% ( $^1D$ ) $^2F$ + 9, 9, 12% ( $^3F$ ) $^4F$
	$(^3F)^2D$	30, 29, 25% ( $^3F_4, 3/2$ )	48, 46, 41% ( $^3F$ ) $^2D$ + 18, 22, 26% ( $^3F$ ) $^4G$ + 16, 11, 7% ( $^3F$ ) $^4F$
	$(^3F)^4F$	65, 69, 66% ( $^3F_3, 3/2$ )	37, 35, 33% ( $^3F$ ) $^4F$ + 21, 19, 16% ( $^3F$ ) $^2F$ + 14, 19, 19% ( $^3F$ ) $^4D$
	$(^3P)^4P$	28, 31, 29% ( $^3P_2, 1/2$ )	31, 27, 20% ( $^3P$ ) $^4P$ + 22, 29, 32% ( $^3F$ ) $^2D$ + 14, 11, 10% ( $^1D$ ) $^2F$
	$(^3F)^2F$	48, 33, 21% ( $^3F_2, 3/2$ )	54, 43, 36% ( $^3F$ ) $^2F$ + 15, 17, 15% ( $^1D$ ) $^2F$ + 6, 13, 18% ( $^1D$ ) $^2D$
	$(^1D)^2F$	31, 31, 34% ( $^1D_2, 1/2$ )	35, 26, 22% ( $^1D$ ) $^2F$ + 45, 38, 28% ( $^3P$ ) $^4P$ + 8, 11, 13% ( $^3F$ ) $^4G$
	$(^1D)^2D$	9, 17, 25% ( $^3P_2, 3/2$ )	36, 21, 9% ( $^1D$ ) $^2D$ + 29, 29, 24% ( $^3P$ ) $^2D$ + 11, 18, 26% ( $^3F$ ) $^2F$
	$(^3P)^4D$	32, 33, 28% ( $^1D_2, 3/2$ )	24, 17, 14% ( $^3P$ ) $^4D$ + 23, 27, 24% ( $^1D$ ) $^2D$ + 14, 22, 30% ( $^1G$ ) $^2F$
	$(^3P)^2D$	55, 56, 57% ( $^3P_1, 3/2$ )	46, 40, 36% ( $^3P$ ) $^2D$ + 36, 38, 40% ( $^3P$ ) $^4D$ + 13, 16, 18% ( $^1G$ ) $^2F$
	$(^1G)^2F$	63, 53, 43% ( $^1G_4, 3/2$ )	63, 53, 43% ( $^1G$ ) $^2F$ + 7, 11, 16% ( $^1D$ ) $^2D$ + 10, 11, 11% ( $^1D$ ) $^2F$
7/2	$(^3F)^4D$	87, 89, 91% ( $^3F_4, 1/2$ )	77, 73, 69% ( $^3F$ ) $^4D$ + 13, 15, 16% ( $^3F$ ) $^4F$ + 5, 6, 8% ( $^3F$ ) $^2F$
	$(^3F)^4G$	87, 89, 91% ( $^3F_3, 1/2$ )	68, 66, 65% ( $^3F$ ) $^4G$ + 13, 14, 15% ( $^3F$ ) $^2G$ + 14, 12, 12% ( $^3F$ ) $^4F$
	$(^3F)^2F$	67, 74, 79% ( $^3F_4, 3/2$ )	53, 57, 59% ( $^3F$ ) $^2F$ + 25, 20, 15% ( $^3F$ ) $^4F$ + 12, 15, 18% ( $^3F$ ) $^4D$
	$(^3F)^4F$	79, 86, 90% ( $^3F_3, 3/2$ )	47, 52, 53% ( $^3F$ ) $^4F$ + 36, 28, 22% ( $^3F$ ) $^2F$ + 6, 9, 14% ( $^3F$ ) $^2G$
	$(^3F)^2G$	68, 61, 50% ( $^3F_2, 3/2$ )	64, 52, 36% ( $^3F$ ) $^2G$ + 20, 28, 37% ( $^1D$ ) $^2F$ + 12, 13, 12% ( $^3F$ ) $^4G$
	$(^1G)^2F$	29, 49, 69% ( $^1G_4, 1/2$ )	32, 50, 64% ( $^1G$ ) $^2F$ + 32, 14, 2% ( $^1D$ ) $^2F$ + 13, 15, 14% ( $^3F$ ) $^2G$
	$(^3P)^4D$	44, 51, 56% ( $^3P_2, 3/2$ )	44, 51, 56% ( $^3P$ ) $^4D$ + 43, 26, 8% ( $^1G$ ) $^2F$ + 1, 5, 14% ( $^3F$ ) $^2G$
	$(^1D)^2F$	43, 47, 48% ( $^1D_2, 3/2$ )	43, 48, 48% ( $^1D$ ) $^2F$ + 35, 33, 30% ( $^3P$ ) $^4D$ + 10, 4, 1% ( $^1G$ ) $^2F$
	$(^1G)^2G$	86, 88, 88% ( $^1G_4, 3/2$ )	88, 83, 77% ( $^1G$ ) $^2G$ + 11, 14, 17% ( $^1G$ ) $^2F$ + 1, 2, 3% ( $^1D$ ) $^2F$
9/2	$(^3F)^4G$	97, 98, 98% ( $^3F_4, 1/2$ )	42, 40, 37% ( $^3F$ ) $^4G$ + 33, 36, 37% ( $^3F$ ) $^2G$ + 24, 23, 23% ( $^3F$ ) $^4F$
	$(^3F)^4F$	97, 98, 98% ( $^3F_4, 3/2$ )	71, 71, 70% ( $^3F$ ) $^4F$ + 23, 25, 26% ( $^3F$ ) $^2G$ + 5, 3, 2% ( $^3F$ ) $^4G$
	$(^3F)^2G$	96, 98, 99% ( $^3F_3, 3/2$ )	43, 37, 34% ( $^3F$ ) $^2G$ + 53, 57, 60% ( $^3F$ ) $^4G$ + 4, 5, 6% ( $^3F$ ) $^4F$
	$(^1G)^2H$	92, 93, 94% ( $^1G_4, 1/2$ )	92, 90, 87% ( $^1G$ ) $^2H$ + 7, 9, 10% ( $^1G$ ) $^2G$ + 1, 1, 2% ( $^3F$ ) $^2G$
	$(^1G)^2G$	92, 93, 94% ( $^1G_4, 3/2$ )	92, 90, 88% ( $^1G$ ) $^2G$ + 7, 8, 10% ( $^1G$ ) $^2H$ + 1, 1, 1% ( $^3F$ ) $^4F$
11/2	$(^3F)^4G$	99, 99, 98% ( $^3F_4, 3/2$ )	99, 99, 98% ( $^3F$ ) $^4G$ + 1, 1, 2% ( $^1G$ ) $^2H$
	$(^1G)^2H$	99, 99, 98% ( $^1G_4, 3/2$ )	99, 99, 98% ( $^1G$ ) $^2H$ + 1, 1, 2% ( $^3F$ ) $^4G$



**Table 8. Percentage Composition of the Levels Designated as  $3d^8(^1D)4p\ ^2P_{1/2}$  and  $3d^8(^3P)4p\ ^4D_{1/2}$  in Sr XII, Y XIII, Zr XIV, Nb XV, and Mo XVI**

Level Designation	Percentage Composition
$(^1D)^2P_{1/2}$	42, 19, 47, 40, 32% $(^1D)^2P$ + 31, 36, 19, 28, 31% $(^3P)^2P$ + 11, 23, 2, 10, 17% $(^3F)^4D$ + 1, 13, 13, 3, 1% $(^3P)^4D$ + 5, 2, 11, 10, 11% $(^3P)^2S$ + 3, 4, 1, 2, 2% $(^1S)^2P$ + 7, 3, 7, 7, 6% $(^3P)^4P$
$(^3P)^4D_{1/2}$	69, 53, 48, 54, 50% $(^3P)^4D$ + 11, 30, 0, 5, 12% $(^1D)^2P$ + 12, 5, 31, 28, 26% $(^3F)^4D$ + 3, 7, 0, 2, 5% $(^3P)^2S$ + 2, 4, 0, 0, 0% $(^3P)^4P$ + 2, 1, 17, 8, 4% $(^3P)^2P$ + 1, 0, 4, 3, 3% $(^1S)^2P$

ponent in every ion. Because of this and the inherently impure coupling within the individual ions, for many levels the *LS* name is useful only as a convenient means of referring to the level.

In Table 4 we compare the observed values of the spin-orbit parameter  $\zeta_{3d}$  for the  $3d^9$  configuration with those calculated with the HF program of Froese-Fischer.<sup>19</sup> In Table 5 we give a similar comparison for the  $3p^53d^{10}$  configuration.

In Table 6 the values of the energy parameters obtained at NBS from least-squares fits to the observed  $3d^84p$  levels are compared with the HF values. The least-squares calculations include the parameters  $\alpha_1(3d3d)$  and  $\alpha(3d4p)$  for effective electrostatic interactions within the  $3d^8$  core and between the  $3d^8$  core and the  $4p$  electron. The former has matrix elements  $\alpha_1 L_1(L_1 + 1)$ , where  $L_1$  is the total orbital angular momentum of the  $3d^8$  core; the latter has matrix elements  $\alpha L(L + 1)$ , where  $L$  is the total orbital angular momentum.

The percentage compositions for Sr XII, Zr XIV, and Mo XVI calculated with the fitted values of the parameters are given in Table 7. As was already mentioned, the average purities in the *LS* scheme are low. The purities in both the  $J_{1j}$  and the  $J_{1l}$  schemes are similarly low. The values of unobserved  $3d^84p$  levels calculated with the fitted parameter values are given in parentheses in Table 3. Inasmuch as none of the levels with  $J = 9/2$  or  $J = 11/2$  has an allowed transition to the  $3d^9$  ground configuration, the values for these levels are all necessarily calculated. Most of the other unobserved levels are  $J = 1/2$  levels whose transitions to  $3d^9\ ^2D_{3/2}$  are calculated to be very weak. For Sr XII no  $J = 1/2$  levels were observed.

## DISCUSSION

Our  $3d^9$ – $3d^84p$  line identifications for Sr XII–Nb XV are entirely new. Our wavelengths for Mo XVI are higher than those of Burkhalter *et al.*<sup>7</sup> by about 0.007 Å on the average. Considering that the wavelength uncertainty of Burkhalter *et al.*<sup>7</sup> was  $\pm 0.010$  Å and that our present uncertainty is  $\pm 0.005$  Å, the wavelengths are in satisfactory agreement. Five of the Mo XVI lines in Table 1 were not observed by Burkhalter *et al.*<sup>7</sup> Three of the lines listed by them were not observed by us. The identifications of seven lines have been changed.

As is seen in Table 6, the effective parameters  $\alpha_1(3d3d)$  and  $\alpha(3d4p)$  are small and poorly defined. The effective parameter for the core  $\alpha_1(3d3d)$  decreases though the sequence. This is the same trend as that found for the  $3d^8$  configuration of the Fe I sequence.<sup>9</sup> In the Co sequence  $\alpha_1(3d3d)$  has its maximum value<sup>17,18</sup> at about Kr X. This may be the consequence of a perturbation of the  $3p^63d^84p$  configuration by  $3p^53d^{10}$ , which is nearly coincident in energy in this ion. In Sr XII the  $3p^63d^8(^1D)4p\ ^2P_{3/2}$  level appears to be perturbed by  $3p^53d^{10}\ ^2P_{3/2}$ , and we therefore omitted it from the least-squares fit.

A point of some interest is the crossing of the  $(^3F)^2F_{5/2}$  and  $(^3P)^4P_{5/2}$  levels between Zr XIV and Nb XV. Although these levels have the same *J* value, there is no evidence of a perturbation caused by their closeness in energy. A more complicated crossing occurs for the  $(^3P)^4D_{1/2}$  and  $(^1D)^2P_{1/2}$  levels. The  $(^3P)^4D_{1/2}$  level is calculated to lie above  $(^1D)^2P_{1/2}$  in Sr XII and Y XIII but below it in Zr XIV, Nb XV, and Mo XVI. However, the eigenvectors of these two levels do not change smoothly through the sequence. The percentage compositions for these two levels in all five ions are given in Table 8, where abrupt changes in composition are evident. In Y XIII–Mo XVI a transition to  $3d^9$  is observed from the lower of these two levels but not from the upper. Thus, in spite of the crossing, it is always the lower of the two levels that is observed.

## ACKNOWLEDGMENTS

A. N. Ryabtsev is grateful to the Atomic Spectroscopy Group of NBS, especially to W. C. Martin, V. Kaufman, and N. Acquista, for hospitality and invaluable assistance in using the NBS 10.7-m grazing-incidence spectrograph. Thanks are also due to V. Viktorov for help with the computer calculations in Moscow. This work was supported in part by the Office of Magnetic Fusion Energy of the U.S. Department of Energy.

\* Permanent address, USSR Academy of Sciences, Institute for Spectroscopy, Troitsk, Moscow Region 142092, USSR.

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# Revised $3p^63d^8\ ^1S_0$ level of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII

Joseph Reader and Aleksandr Ryabtsev\*

National Bureau of Standards, Washington, D.C. 20234

Received March 12, 1983

Following an observation by Wyart *et al.* [Phys. Scr. **26**, 141 (1982)], we have revised the position of the  $3p^63d^8\ ^1S_0$  level in Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII and have redetermined the  $3p^63d^8$  energy parameters in these ions.

Recently, Reader and Ryabtsev<sup>1</sup> analyzed the  $3p^63d^8$ – $3p^53d^9$  transitions in the isoelectronic ions Sr XIII–Mo XVII. In this analysis the  $3p^63d^8\ ^1S_0$  level was established by the single transition  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$ . Subsequently,  $3p^63d^8$ – $3p^63d^84p$  transitions were analyzed in Sr XII–Mo XVI by Ryabtsev and Reader<sup>2</sup> and in Y XIII–Ag XXI by Wyart *et al.*<sup>3</sup> In their report Wyart *et al.*<sup>3</sup> noted that the parameters for the  $3p^63d^8$  core of the  $3p^63d^84p$  configuration differed in some important respects from those of the  $3p^63d^8$  configuration of the next ion. They concluded that the differences were due to an incorrect  $3p^63d^8\ ^1S_0$  level, for the ions Sr XIII–Nb XVI in Ref. 1. Further, they proposed new identifications for the  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$  transitions in Y XIII–Nb XVI.

We have reviewed our spectra in this regard and have found transitions of the type  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$  that support the proposed identifications of Wyart *et al.*<sup>3</sup> A  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$  transition was present in our original array for Mo XVII, but it was not included in Ref. 1 because of its apparent absence in the isoelectronic spectra. On the basis of revised calculations for the  $3p^63d^8$  configuration we have also revised the  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$  identification in Sr XIII. The lines identified as  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$  Y XIV–Nb XVI in Ref. 1 are actually  $3p^63d^7$ – $3p^53d^8$  transitions of the next higher stage of ionization, that is, of man-ganeselike ions.<sup>4</sup>

In Table 1 we give the  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$  and  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$  transitions in the ions Sr XIII–Mo XVII. The revised positions of the  $3p^63d^8\ ^1S_0$  level in these ions are given in Table 2. The revision of  $3p^63d^8\ ^1S_0$  in Mo XVII is due to our inclusion of the  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$  transition in the array, which produces a slightly different average value for the  $3p^63d^8\ ^1S_0$  level.

The revised energy parameters for the  $3p^63d^8$  configuration are given in Table 3. The ratios of the fitted value of  $F^4(3d3d)$  to the Hartree–Fock (HF) value, which previously<sup>1</sup> varied from 0.844 for Sr XIII to 0.907 for Mo XVII, are now nearly constant through the sequence. The values of  $\alpha(3d3d)$ , which previously<sup>1</sup> varied from 203 cm<sup>–1</sup> for Sr XIII to 123 cm<sup>–1</sup> for Mo XVII, are also now nearly constant through the sequence. The differences between the observed level values and those calculated with the revised energy parameters are given in Table 4. The percentage compositions obtained with the revised parameters do not differ significantly from those of Ref. 1 and are therefore not given here.

## ACKNOWLEDGMENT

This work was supported in part by the Office of Magnetic Fusion Energy of the U.S. Department of Energy.

Table 1.  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$  and  $3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$  Transitions in the Ions Sr XIII–Mo XVII<sup>a</sup>

Transition	Sr XIII		Y XIV		Zr XV		Nb XVI		Mo XVII	
	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.	$\lambda(\text{\AA})$	Int.
$3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^1P_1$	88.915	30	84.180	40	79.830	20	75.828	15	72.092	20
$3p^63d^8\ ^1S_0$ – $3p^53d^9\ ^3D_1$	–	–	94.186	10	89.853	15	85.938 <sup>b</sup>	60	82.317	10

<sup>a</sup> Intensities are visual estimates of photographic blackening.

<sup>b</sup> Blended with  $4p\ ^2P_{3/2}$ – $6s\ ^2S_{1/2}$  transition of Nb XIII.

Table 2.  $3p^63d^8\ ^1S_0$  Levels of Sr XIII–Mo XVII (in cm<sup>–1</sup>)

Configuration	Term	<i>J</i>	Sr XIII	Y XIV	Zr XV	Nb XVI	Mo XVII
$3p^63d^8$	$^1S$	0	136 720	146 020	155 800	166 070	176 680



**Table 3. Energy Parameters (in  $\text{cm}^{-1}$ ) and Mean Errors  $\Delta$  of Least-Squares Fits for the  $3p^63d^8$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII<sup>a</sup>**

Ion	Parameter	HF	Fitted	Fitted/HF
Sr XIII	$E_{av}$	36 440	34 047 $\pm$ 110	
	$F^2(3d3d)$	214 978	195 749 $\pm$ 886	0.911 $\pm$ 0.004
	$F^4(3d3d)$	136 981	123 012 $\pm$ 814	0.898 $\pm$ 0.006
	$\alpha(3d3d)$		121 $\pm$ 20	
	$\zeta_{3d}$	6 133	6 103 $\pm$ 124	0.995 $\pm$ 0.020
	$\Delta$		292	
Y XIV	$E_{av}$	39 578	37 084 $\pm$ 114	
	$F^2(3d3d)$	225 641	206 447 $\pm$ 928	0.915 $\pm$ 0.004
	$F^4(3d3d)$	143 929	129 622 $\pm$ 856	0.901 $\pm$ 0.006
	$\alpha(3d3d)$		124 $\pm$ 21	
	$\zeta_{3d}$	7 196	7 127 $\pm$ 129	0.990 $\pm$ 0.018
	$\Delta$		304	
Zr XV	$E_{av}$	42 883	40 376 $\pm$ 121	
	$F^2(3d3d)$	236 241	216 969 $\pm$ 987	0.918 $\pm$ 0.004
	$F^4(3d3d)$	150 838	136 286 $\pm$ 913	0.904 $\pm$ 0.006
	$\alpha(3d3d)$		120 $\pm$ 22	
	$\zeta_{3d}$	8 388	8 284 $\pm$ 134	0.988 $\pm$ 0.016
	$\Delta$		320	
Nb XVI	$E_{av}$	46 430	43 937 $\pm$ 125	
	$F^2(3d3d)$	246 787	227 526 $\pm$ 1027	0.922 $\pm$ 0.004
	$F^4(3d3d)$	157 711	142 891 $\pm$ 957	0.906 $\pm$ 0.006
	$\alpha(3d3d)$		118 $\pm$ 23	
	$\zeta_{3d}$	9 717	9 596 $\pm$ 132	0.988 $\pm$ 0.014
	$\Delta$		330	
Mo XVII	$E_{av}$	50 238	47 730 $\pm$ 118	
	$F^2(3d3d)$	257 286	238 000 $\pm$ 971	0.925 $\pm$ 0.004
	$F^4(3d3d)$	164 554	149 128 $\pm$ 914	0.906 $\pm$ 0.006
	$\alpha(3d3d)$		123 $\pm$ 22	
	$\zeta_{3d}$	11 195	11 081 $\pm$ 116	0.990 $\pm$ 0.010
	$\Delta$		311	

<sup>a</sup> The value for  $E_{av}$  listed in the HF column is that obtained by diagonalizing the energy matrix with the HF parameters,  $^3F_4$  level set at zero.

**Table 4. Differences Observed Minus Calculated (in  $\text{cm}^{-1}$ ) between Observed Level Values and Those Calculated with the Fitted Values of the Parameters for the  $3p^63d^8$  Configurations of Sr XIII, Y XIV, Zr XV, Nb XVI, and Mo XVII**

Configuration	J	Term	Sr XIII	Y XIV	Zr XV	Nb XVI	Mo XVII
$3p^63d^8$	0	$^3P$	170	110	80	0	20
		$^1S$	80	80	70	70	70
	1	$^3P$	130	200	210	260	220
		$^3F$	210	160	120	90	0
	2	$^3P$	-270	-310	-310	-270	-230
		$^1D$	-360	-330	-330	-330	-290
	3	$^3F$	170	250	340	380	420
		$^3F$	-100	-110	-150	-180	-140
	4	$^1G$	-60	-50	-40	-50	-30

\* Permanent address, Institute for Spectroscopy, USSR Academy of Sciences, Troitsk, Moscow Region 142092, USSR.

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M E M O R A N D U M  
On Cooperation Between the US National Bureau of Standards  
and  
the USSR Academy of Sciences

In accordance with the US-USSR Agreement on Cooperation in the Fields of Science and Technology, dated July 8, 1977, the US National Bureau of Standards and the USSR Academy of Sciences, referred to below as the Sides, desiring to facilitate the expansion of scientific cooperation for mutual benefit to the two Sides, have agreed as follows:

Article 1

Scientific cooperation may be conducted in the fields of thermal physics and thermodynamics, materials science, spectroscopy, chemistry and chemical kinetics, and cryogenic science. Other fields may be additionally included by mutual agreement.

This cooperation will be carried out pursuant to, and within the framework of, the US-USSR Agreement on Cooperation in the Fields of Science and Technology.

Article 2

Such cooperation may be implemented by exchange of scientists, exchange of scientific and technical information and documentation, joint meetings and seminars, joint research projects, and by other means as may be mutually agreed.

Article 3

Each Side shall designate a coordinator for determining the scientific directions of the cooperation and for ensuring the scientific usefulness of this cooperation.

Article 4

The Sides agree to exchange up to five scientists annually from each Side, with a total length of stay of up to 14 man-months, for carrying out joint research, and also to exchange up to 10 leading specialists from each Side representing the scientific disciplines listed in Article 1 of this Memorandum, for a total length of stay of up to 6 man-months.

Article 5

The selection of scientists described in Article 4 rests with the sending Side, and all visits will be undertaken subject to acceptance by the receiving Side. In addition, each Side may suggest scientists it would like to receive from the other Side within Article 4, and each Side, insofar as possible, will take into account these desires of the other Side.



## Article 6

Exchange of scientists and other activities under this Memorandum will be conducted on a receiving-side-pays basis, which means:

1. The receiving Side will assume the expenses for receiving scientists and will pay:

a) per diem in the amount of 12 rubles in the USSR and, correspondingly, the equivalent in dollars in the US for each day of the visit;

b) lodging in a hotel or the provision of an apartment;

c) travel expenses within the country in accordance with the program of visits;

d) emergency medical care, including emergency dental care;

e) expenses for automobile transportation for meeting and seeing off;

2. Expenses for transportation to and from the main destination, which as a rule will be Washington or Moscow, will be borne by the sending Side.

3. Each Side will provide scientists of the other Side the opportunity to conduct scientific research work in laboratories and libraries without cost.

4. Expenses for procuring materials, apparatus, literature, photocopies, and microfilm, which are essential for the completion of the agreed plan of work by scientists of the other Side will be borne by the receiving Side.

5. The receiving Side will not pay expenses for the stay of members of the family of visiting scientists in the receiving country.

## Article 7

Nominations of scientists for exchange visits will be submitted to the receiving Side no later than four months before the proposed date for starting the visit. For each scientist nominated, the sending Side will provide the following information: the full name of the scientist, date and place of birth, education and academic degrees, place of work, scientific speciality, a list of the main scientific works and publications, the proposed program of scientific work with a suggested list of the scientific establishments or laboratories to be visited and the scientists to be met, knowledge of foreign languages, topics of lectures that could be delivered by the scientist, proposed date of arrival, and the length of stay.

### Article 8

The Receiving Side will respond to this nomination no later than three months after its receipt. If the nomination is acceptable, the receiving Side will inform the sending Side of a possible date of arrival of the scientist in the country and will give its agreement to the program or will propose alternatives to the program.

After receiving the consent of the receiving Side to accept a given scientist, the sending Side shall inform the receiving Side by telegram or telex, two weeks or more in advance, of the exact date of the arrival of the scientist in the country.

### Article 9

The receiving Side will facilitate the timely receipt of visas by the scientists of the other Side traveling in accordance with this Memorandum.

### Article 10

The National Bureau of Standards authorizes its Office of International Relations, and the USSR Academy of Sciences authorizes its Foreign Relations Department, to conduct administrative affairs in connection with this cooperation.

### Article 11


This Memorandum shall enter into force upon signature by both Sides and shall remain in force for five years. Additions and modifications may be made to it, and its period of validity extended, by mutual agreement of the Sides, and with the concurrence of the Executive Agents designated in Article VII of the US-USSR Agreement on Cooperation in the Fields of Science and Technology.

DONE at Moscow this 13th day of December, 1978, in duplicate, in the English and Russian languages, both equally authentic.

For the US National Bureau  
of Standards

  
\_\_\_\_\_  
Director

For the USSR Academy  
of Sciences

  
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